



Cervical spinal manipulation for neck pain - effect on muscle recruitment patterns, spinal kinematics, pain and disability in participants in KwaZulu-Natal

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DECLARATION

I, Laura Maié O'Connor, do declare that this thesis is representative of my own work in both conception and execution (except where acknowledgements indicate to the contrary). This work has not been submitted to any other institution except in the form of manuscripts for publication purposes.

Date: 25 August 2025

Laura Maié O'Connor

DEDICATION

This work is dedicated to my wonderful family. First, to my beautiful Mom – this world has not been the same since you left, but you left behind a strong desire in me to always strive to do better, to never sit idle and to reach for the stars. You always encouraged us to be strong, independent women, and I wish you could be here to share this accomplishment with me – you would be so proud. To my darling Dad, thank you for always being there for me. I have so much to thank you for. This journey has been long, and you would be so proud to know that it is done! I wish you could be here to celebrate with me.

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“Life isn’t about waiting for the storm to pass; it’s about learning to dance in the rain”

- Vivian Greene

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ABSTRACT

Background

Neck pain is a common disabling condition that can become chronic, leading to economic and personal burdens. A small pool of research highlights variations in motor control in neck pain, where alterations in spinal kinematic and/or muscle activation patterns, have been found during head, neck and unilateral arm tasks. Bilateral arm tasks have not been assessed, despite their common use in occupational settings and daily life. Few studies have simultaneously assessed spinal kinematics and muscle recruitment patterns in those with neck pain. The combined assessment allows a more holistic view of how neck pain may impact motor control which can lead to more effective interventions to target these processes.

A common treatment for neck pain is spinal manipulative therapy (SMT). Although well utilised, the specific mechanism through which it exerts its reported clinical effects are not well understood. Mechanistic studies suggest that it activates neurophysiological processes which in addition to inducing pain relief activate reflexogenic, spinal and supraspinal structures involved in motor control. Little is known regarding the effect of SMT on spinal kinematics and muscle recruitment patterns and if changes in these motor variable correlate with pain and disability in those with neck pain. Thus, this study aimed to determine the effect of cervical SMT on pain, disability, cervicothoracic spinal kinematic and muscle activation patterns while performing a cervical range of motion (ROM), a unilateral and bilateral arm task when comparing to a control intervention.

Methods

Prior to the implementation of a randomised, controlled trial (RCT), a case controlled cross-sectional study was undertaken to determine the presence of cervicothoracic spinal kinematic and muscle activation patterns in adults with chronic, non-specific neck pain (n=20) compared to age and sex matched controls (n=20). Pain and disability measures and were obtained from those with neck pain; with health status

being collected from all the participants. Spinal kinematics were obtained via motion capture and surface electromyography was utilised to obtain muscle recruitment patterns from six pairs of cervicothoracic muscles. Data were collected during seated cervical ROM, a seated unilateral and standing bilateral upper limb lifting task. Statistical analysis was performed with a p -value less than 0.05.

A randomised, controlled trial (RCT) was then utilised to collect data from adults with chronic, non-specific neck pain ($n=39$), who were allocated to receive either cervical SMT or a control intervention. Four treatments were administered over 2 weeks with a one week follow up. Pain, disability and health status were measured. The same methodology as utilised in the case-controlled study was employed to obtain cervicothoracic spinal kinematics muscle recruitment patterns from six pairs of cervicothoracic muscles. Participants undertook 3 tasks: cervical range of motion, a unilateral and bilateral upper limb lifting task. Measurements were taken at baseline, the fourth visit and at a one-week follow-up. Statistical analysis was performed with a p -value less than 0.05.

Results

When comparing those with neck pain to those without, during cervical ROM the participants with neck pain took longer to complete right lateral flexion ($p = 0.018$, $r = 0.35$), no differences between the groups were found for peak displacement, peak and mean velocity and jerk ($p > 0.05$). Those with neck pain had reduced left posterior cervical muscle activation time during cervical extension ($p = 0.026$, $r = 0.34$), peak activation during left and right away lateral flexion ($p = 0.030$, $r = 0.32$; $p = 0.047$, $r = 0.29$) and in the left anterior scalene during right rotation ($p = 0.049$, $r = 0.29$). Increased activation time was found in right lateral flexion in the left paraspinal muscle during the away and return phase ($p = 0.042$, $r = 0.27$; $p = 0.026$, $r = 0.34$), for rotation in the left paraspinal on right rotation during the away and return phase ($p = 0.042$, $p = 0.002$), for peak and mean activation in the away and return phases ($p < 0.05$, medium effect sizes).

The unilateral arm task resulted in those with neck pain having less peak displacement in upper thoracic spine rotation ($p = 0.017$, $r = 0.35$), greater displacement in lateral

flexion ($p = 0.006$, $r = 0.40$) and rotation ($p = 0.038$, $r = 0.31$) in the lower thoracic spine. During lifting and lowering those with neck pain had a greater lower thoracic spine rotation range ($p = 0.036$; $p = 0.004$). Muscle activation showed a greater percentage activation time in the right upper trapezius (UT) and left paraspinal at T4 ($p = 0.039$, $r = 0.30$; $p = 0.039$, $r = 0.30$) and lower peak activation in the left paraspinal at T4 ($p = 0.032$, $r = 0.32$) in lifting. During lowering the left paraspinal muscle at T4 had a greater activation time percentage ($p = 0.005$, $r = 0.34$), lower peak ($p = 0.019$, $r = 0.42$) and mean ($p = 0.044$, $r = 0.24$) activation in those with neck pain. The bilateral task showed greater cervical lateral flexion velocity ($p = 0.024$, $r = 0.34$) in those without neck pain, and an increased rotation range in the upper and lower thoracic spines ($p = 0.024$, $r = 0.34$; $p = 0.016$, $r = 0.37$) in those with neck pain while lifting. During lowering, those without neck pain had increased average velocity in cervical lateral flexion ($p = 0.012$, $r = 0.34$) and rotation ($p = 0.022$, $r = 0.35$). No significant differences between the groups were found for muscle activation patterns in the bilateral arm task.

When comparing the effect of cervical SMT to a control group, those receiving SMT had greater pain reduction by visit four ($p = 0.010$; $\eta^2 = 0.22$), with no between group difference by the one-week follow up. The SMT had improved disability by one-week follow when compared to the control ($p = 0.006$, $\eta^2 = 0.24$). At the fourth visit, the SMT group had an improvement in pain ($p = 0.010$, $\eta^2 = 0.22$), with no difference between the groups at the one week follow up ($p = 0.340$, $\eta^2 = 0.03$). Greater improvements in disability occurred at the one week within the SMT group ($p = 0.006$, $\eta^2 = 0.24$). No between group differences were found for the global impression of change scale or level of satisfaction ($p > 0.05$) between the groups, except for the SMT group reporting improved emotions ($p = 0.001$) and quality of life ($p = 0.025$). For cervical ROM assessment after one treatment, increased velocity in left rotation ($p = 0.040$, $\eta^2 = 0.119$) and jerk in flexion ($p < 0.05$), right ($p = 0.023$, $\eta^2 = 0.148$) and left ($p = 0.025$, $\eta^2 = 0.144$) lateral flexion and left rotation ($p = 0.043$; $\eta^2 = 0.115$) was found in the SMT group. The control group had greater activation in the left posterior cervical (PC) ($p = 0.012$, $\eta^2 = 0.180$) in flexion, left anterior scalene (AS) ($p = 0.007$, $\eta^2 = 0.215$), left sternocleidomastoid (SCM) ($p = 0.019$, $\eta^2 = 0.164$) in extension and the left paraspinal at T9 (LT9) during right lateral flexion ($p = 0.049$, $\eta^2 = 0.116$). Less activation occurred

in the control group for peak ($p = 0.041$, $\eta^2 = 0.128$) and mean ($p = 0.045$, $\eta^2 = 0.123$) activation in the LAS and the left LUT ($p = 0.008$, $\eta^2 = 0.192$) in right lateral flexion; peak ($p = 0.029$, $\eta^2 = 0.145$) and mean ($p = 0.025$, $\eta^2 = 0.151$) activation in the right AS and in the LT9 for away time percentage ($p = 0.019$, $\eta^2 = 0.145$) in left lateral flexion and the right PC ($p = 0.024$, $\eta^2 = 0.146$), LT4 ($p = 0.021$, $\eta^2 = 0.147$) and right SCM ($p = 0.038$, $\eta^2 = 0.127$) for right rotation. After three treatments the SMT group had increased return peak jerk in flexion ($p = 0.034$, $\eta^2 = 0.146$) and return peak ($p = 0.028$) and away average jerk ($p = 0.008$, $\eta^2 = 0.191$, $\eta^2 = 0.175$) in left rotation. Muscle activation was less in the control group in the right AS during flexion ($p = 0.024$) and greater for right PC for peak ($p = 0.034$, $\eta^2 = 0.149$) and mean activation ($p = 0.002$, $\eta^2 = 0.179$) and LUT ($p = 0.015$, $\eta^2 = 0.187$) in extension, left AS in away ($p = 0.048$, $\eta^2 = 0.142$) and return ($p = 0.042$, $\eta^2 = 0.042$) right lateral flexion and in the LPC away ($p = 0.029$, $\eta^2 = 0.159$) and mean ($p = 0.029$, $\eta^2 = 0.134$) activation in left lateral flexion. The intervention group had greater activation in the left paraspinal at T4 during the return phase of flexion ($p = 0.035$, $\eta^2 = 0.149$).

When assessing the effect of the interventions on the unilateral arm task there were no differences between the groups for spinal kinematics following one treatment ($p > 0.05$), with greater peak ($p = 0.038$, $\eta^2 = 0.13$) and mean ($p = 0.031$, $\eta^2 = 0.14$) muscle activity in the right paraspinal muscle in the intervention group during the lowering phase. At the fourth visit the intervention group had a greater upper thoracic spine rotation range ($p = 0.021$, $\eta^2 = 0.17$) during lifting, and increased flexion/extension range in the lower thoracic spine ($p = 0.037$, $\eta^2 = 0.141$) during lowering. The right upper trapezius muscles had greater mean activity in the intervention group ($p = 0.026$, $\eta^2 = 0.141$) during lifting. In the bilateral arm task, greater flexion/extension jerk occurred in the lower thoracic spine ($p = 0.038$, $\eta^2 = 0.13$) during lowering in the control group, with the intervention group having greater jerk in lateral flexion ($p = 0.014$, $\eta^2 = 0.13$) and rotation ($p = 0.019$, $\eta^2 = 0.17$) and greater rotation range ($p = 0.041$, $\eta^2 = 0.13$) and velocity ($p = 0.006$, $\eta^2 = 0.22$) in the lower thoracic spine. The intervention group had less peak activity in the right PC muscle during lifting ($p = 0.049$, $\eta^2 = 0.119$), with greater peak activation in the right paraspinal T4 ($p = 0.026$, $\eta^2 = 0.151$) and activation time percentage in the right SCM during lifting ($p = 0.029$, $\eta^2 = 0.148$) and lowering ($p = 0.015$, $\eta^2 = 0.186$). At the fourth visit, the intervention group had greater

upper thoracic spine flexion/extension jerk ($p = 0.045$, $\eta^2 = 0.14$) during lowering, with lower left PC peak muscle activation during lifting ($p = 0.029$, $\eta^2 = 0.16$) and mean activation during lowering ($p = 0.006$, $\eta^2 = 0.237$). Mean activation of the left ($p = 0.039$, $\eta^2 = 0.154$) and right ($p = 0.034$, $\eta^2 = 0.157$) SCMs during the lowering phase was greater in the intervention group. No differences were found between those receiving SMT and the control for perceived global impression of change categories ($p=0.500$) or level of satisfaction ($p > 0.05$), except that the SMT group reported improved emotions ($p = 0.001$) and quality of life ($p = 0.025$).

Conclusion

People with neck pain presented with an altered pattern of motor control reflected by changes in cervicothoracic spinal kinematic and muscle recruitment patterns. This presentation was influenced by the activity, which was undertaken, often involving the thoracic spine more than the cervical spine. When treated with cervical SMT there was a decrease in pain and disability with increased rotation velocity and jerk in flexion, lateral flexion and left rotation immediately after one treatment and in the short term when performing cervical ROM. This was associated with increased activation patterns of cervicothoracic muscles during lateral flexion and rotation after one treatment with lower activation levels occurring after three treatments. In the upper limb tasks, the intervention effects were few and variable. This study showed that cervical SMT had a more favourable impact on muscle recruitment patterns than spinal kinematics. Highlighting the potential role of cervical SMT to bring about changes in motor control.

Keywords: spinal manipulation, neck pain, cervical spine, motion capture, surface electromyography, muscle recruitment, range of motion, functional task

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LIST OF ABBREVIATIONS

ACC:	Anterior cingulate cortex
ADL:	Activities of daily living
AD:	Anterior deltoid
AMI:	Arthrogenic muscle inhibition
ARV:	Average rectified value
AS:	Anterior Scalene muscles
Ave:	Average
CG:	Control group
CI:	Confidence interval
cm:	Centimetres
CDC:	Chiropractic day clinic
CNS:	Central nervous system
CPG:	Clinical practice guidelines
CS:	Central sensitisation
CSM:	Cervical spinal manipulation
DLPT:	Dorsolateral pontine tegmentum
DN:	Dry needling
DOF:	Degrees of freedom
EG:	Experimental group
EMG:	Electromyography

ES:	Erector spinae muscles
FE:	Flexion-extension
GRADE:	Grading recommendations, assessment, development and evaluation approach
GROC:	Global impression of change scale
Grp:	Group
GTO:	Golgi tendon organ
HARM:	Harmony of movement
HPA:	Hypothalamic-pituitary-adrenal axis
FRP:	Flexion relaxation phenomena
HVLA:	High-velocity, low-amplitude
Hz:	Hertz
ICC:	Intra-class correlation coefficient
ICR:	Instantaneous centre of rotation
IMU:	Inertial measurement unit
IREC:	Institutional research ethics committee
Kg:	Kilograms
L:	Left
LBP:	Low back pain
LF:	Lateral flexion
Mdn:	Median

M:	Mean
m:	Meters
MD:	Mean difference
MDC:	Minimal detectable change
MCID:	Minimally clinically important difference
mm:	Millimeters
MP:	Megapixel
ms:	millisecond
m/s:	Velocity
m/s^2 :	Acceleration
m/s^3 :	Jerk
mV:	Microvolts
MA:	Muscle activity
MD:	Mean difference
MEP:	Motor evoked potential
MFMA:	Mechanical force and manually assisted spinal manipulation therapy
MTM:	Multiple thoracic manipulation
MVC:	Maximum voluntary contraction
MVIC:	Maximum voluntary isometric contraction
n:	Sample number
N:	Newton

NDI:	Neck disability index
NP:	Neck pain
NPAD:	Neck pain and disability scale
NRM:	Nucleus raphe magnus
NPRS:	Numerical pain rating scale
OEMS:	Optoelectronic measurement systems
p :	Probability value of statistical significance
PA:	Posterior-anterior
PAG:	Periaqueductal gray
PC:	Posterior Cervical muscles
PGIC:	Patients global impression of change scale
P-P:	Pre to post
P-4:	Pre to fourth visit
PROM:	Patient reported outcome measures
PPT:	Pressure pain threshold
Q1:	First quartile
Q2:	Median
Q3:	Third quartile
R:	Right
r :	Correlation coefficient
RCT:	Randomized Clinical Trial

RMS:	Root mean square
RoB 2:	Risk of bias 2 tool
ROM:	Range of motion
Rot:	Rotation
s:	Second
SCM:	Sternocleidomastoid muscles
SD:	Standard deviation
SE:	Standard error
SEM:	Standard error of measurement
sEMG:	Surface electromyography
SEP:	Somatosensory evoked potentials
STM:	Single thoracic manipulation
SMT:	Spinal manipulative therapy
SNAGS:	Sustain apophyseal natural glide
SO:	Suboccipital
T4:	Thoracic vertebrae 4
T9:	Thoracic vertebrae 9
TB:	Triceps brachii
TMS:	Transcranial magnetic stimulation
UT:	Upper trapezius muscle
VAS:	Visual analog scale

WAD: Whiplash associated disorder

WE: Wrist extensors

WF: Wrist flexors

YLD: Years lived with disability

Symbols:

α : Alpha

γ : Gamma

d : Cohen's D

$^{\circ}$: Degrees

$^{\circ}/s$: Velocity

$^{\circ}/s^3$: Jerk

$\int_{env}$: Integral envelope

$M\Omega$: Milliohms

mV: Millivolts

%: Percentage

η^2 : Partial eta squared

LIST OF DEFINITIONS

Acceleration: The second derivative of a position vector.

Allodynia: Pain from a stimulus which normally does not result in pain and is a clinical term (IASP Task Force on Taxonomy 1994).

Arthrogenic muscle

Inhibition: A clinical impairment resulting from joint injury that results in a reflexive inhibition of joint musculature (Lepley and Lepley 2022; Norte, Rush and Sherman 2022)

Central activation

failure: Failure of central motor drive from an inability to recruit all motor units and/or a reduced motor firing rate, resulting in less than maximum muscle activation (Kent-Braun and Le Blanc 1996). Diminished (less than normal) voluntary activation of a muscle (Norte, Rush and Sherman 2022)

Central

sensitization: When there is increased nociceptive firing resulting in increased neural signalling in the central nervous system (Woolf, 2011)(Yam *et al.* 2018)

Cervical range of

Motion: In this thesis this refers to the motions of flexion, extension, left and right lateral flexion and rotation of the cervical spine

Corticospinal

excitability: The integrity of the corticospinal tract and its excitability measured for example by motor-evoked potential amplitude

(Groppa *et al.* 2012). Excitability of the motor neurons located in the motor cortex that communicate directly with the peripheral muscles (Norte, Rush and Sherman 2022).

Effect measure: The statistical construct that compares outcome data between two or more groups.

EMG amplitude: The time varying standard deviation of the EMG signal associated with the transmission of action potentials along the muscle fiber membrane (Besomi *et al.* 2020).

Excitability: The excitability of the alpha motor neuron associated with a given motor neuron pool from a muscle/group of muscles, can be measured by the H reflex showing the proportion of the entire motor neuron pool able to be recruited (Palmieri, Ingersoll and Hoffman 2004)

Facilitation: The enhancement or reinforcement of a reflex or other nervous activity by the arrival of excitatory impulses at the reflex centre {Stedman, 2000 #115}.

Hyperalgesia: Increased pain from a stimulus that normally would result in pain and is a clinical term (IASP Task Force on Taxonomy 1994).

Inhibition: The limitation or depression of reflex activity (Venes 2017).

Jerk: The third derivative of a position vector, and the time derivative of acceleration.

Joint manipulation: A manual procedure that involves a directed thrust to move a joint past normal physiological range of motion (ROM) without exceeding the anatomical limit. It is commonly associated with an audible ‘crack’ or cavitation {Bergmann, 2010 #40;Bergmann, 2010 #40;Hawk, 2017 #154}. In this dissertation, “joint manipulation” is referred to as spinal manipulation.

Kinematics: The motion of objects in space assessed using their position vector and its derivatives (Franov *et al.* 2022).

Kinaesthesia: Position and motion of the limbs and trunk (Proske and Gandevia 2009)

Muscle activation: The number of muscle fibers that are activated and their respective firing rates (Besomi *et al.* 2020).

Muscle inhibition: The inability to fully activate a muscle due to on-going reflex inhibition (Venes 2017).

Muscle recruitment

patterns: The manner in which the nervous system recruit's muscles to execute a task.

Motor control: The interaction of the nervous system with various components of the body, such as the sensorimotor system (Riemann and Lephart 2002), and the environment to result in directed movement (Juras and Latash 2021), occurring in line with the principles of biomechanics and the laws of physics (Mulla and Keir 2023).

Neuromuscular

control: The aspects surrounding nervous system control over muscle activation and the factors contributing to task performance (Riemann and Lephart 2002).

Nociceptive: Stimulus-response process involving the stimulation of pain sensitive nociceptors and the transmission of impulses along the peripheral nerves to the CNS (Venes 2017).

Noxious stimulus: A stimulus that results in damage or the threat of damage (IASP Task Force on Taxonomy 1994).

Sensorimotor

integration: The process of incorporating sensations from the body and the external environment to alter movement (Wolpert, Goodbody and Husain 1998), with this occurring in the spinal cord, thalamus, basal ganglia, cerebellum and other areas of the cerebral cortex (Asan, McIntosh and Carmel 2022).

Surface

electromyography: An electrical, non-invasive, accurate method of measuring muscle excitation and activation through the placement of electrodes over the muscle being assessed (Sousa and Tavares 2012).

Spinal manipulative

therapy: A type of specialised manual therapy that is non-invasive, performed by the hands, with the aim to treatment musculoskeletal pain and disability (Gyer *et al.* 2019). For the purpose of this thesis when reference is made to spinal manipulative therapy it is referring to the technique of high velocity, low amplitude (HVLA) manipulation.

Spinal-reflexive

excitability: Monosynaptic reflex activity in the spinal cord, reflecting an estimate of the alpha motor neuron excitability when presynaptic inhibition and intrinsic excitability of the alpha motor neurons remain constant (Palmieri, Ingersoll and Hoffman 2004).

Peripheral

sensitisation: When there is a decrease in primary afferent nociceptor stimulation threshold and an increase in their firing rate due to increased sensitivity (Yam *et al.* 2018)

Velocity: The first derivative of a position vector.

Wind-up: When a neuron is exposed to a repetitive stimulus with constant intensity, it results in progressive, frequency-dependent facilitation (Herrero, Laird and Lopez-Garcia 2000)

PRESENTATIONS ASSOCIATED WITH THIS THESIS

2023: Durban University of Technology, Faculty of Health Sciences Research Day
(oral presentation)

Topic: The test-retest reliability of a motion capture system to assess cervical range of motion in neck pain and healthy participants

O'Connor, L, Pillay, J.D., Murphy, B.

2024: Chiropractic Association of South Africa Annual Congress (poster presentation)

Topic: Muscle recruitment patterns in people with and without neck pain during active cervical range of motion

O'Connor, L, Pillay, J.D., Murphy, B.

2024: Chiropractic Association of South Africa Annual Congress (poster presentation)

Topic: A comparison of cervical spine kinematics in neck pain sufferers and healthy controls

O'Connor, L, Pillay, J.D., Murphy, B.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND TO THIS CHAPTER

Neck pain is a multidimensional, global challenge (Hoy *et al.* 2014; Kazeminasab *et al.* 2022) leading to years lived with disability (Safiri *et al.* 2020). It can result in negative personal and economic consequences (Haldeman, Carroll and Cassidy 2010). The musculoskeletal manifestations of neck pain include changes to muscle recruitment (Falla *et al.* 2004a; Falla, Jull and Hodges 2004a; Falla *et al.* 2004b), gait patterns (Falla *et al.* 2017; Burton *et al.* 2023), proprioception (Peng *et al.* 2021; Qu *et al.* 2022) and spinal kinematics (Franov *et al.* 2022), resulting in a decline in sensorimotor task performance (Harman *et al.* 2021). Treatments addressing these may lead to improved outcomes.

Spinal manipulation, a common treatment for neck pain (Whalen *et al.* 2019), has been found to affect neurophysiological function by altering spinal reflexes (Herzog *et al.* 1995; Herzog, Scheele and Conway 1999; Symons *et al.* 2000; Gorrell, Conway and Herzog 2019), motor neuron excitability (Dishman and Bulbulian 2000; Dishman, Ball and Burke 2002; Dishman, Dougherty and Burke 2005; Bicalho *et al.* 2010), muscle strength (Keller and Colloca 2000; Cleland *et al.* 2004; Koppenhaver *et al.* 2011) and cortical drive (Haavik *et al.* 2017; Haavik *et al.* 2018). The effect that this treatment has on altering spinal kinematics and muscle activation patterns in neck pain has been understudied. Thus, this is the focus of this thesis.

In light of this, this chapter aims to provide the background to the research problem under investigation together with a statement of the problem justifying this project. The significance of the study will be highlighted together with the study aims and objectives, ending with the thesis scope and chapter overview.

1.2 INTRODUCTION TO THE STUDY

Neck pain is common, disabling and has a negative impact on daily life (Andelic *et al.* 2012; Hoy *et al.* 2014; Kazeminasab *et al.* 2022). It is estimated that more than 30% of people will succumb to neck pain annually (Cohen, 2015), with 67% of people suffering from neck pain at some point in their life (Côté, Cassidy, Carroll, and Kristman, 2004). During the initial 6 weeks neck pain sufferers may have a decrease in pain (45%) and disability (43%) (Hush *et al.* 2011), with about 50% of sufferers continuing to experience pain or re-occurrence (Vos *et al.* 2008; Vasseljen *et al.* 2013; Cohen 2015). Developing countries are afflicted by comparable, and in some cases, higher rates than developed countries (Safiri *et al.* 2020), highlighting that no population is immune to neck pain.

Neck pain is a major burden, not only to the person who is suffering from it but the negative effects impact social, work and life participation and the economy due to work absenteeism (Hoy, Protani and Buchbinder, 2010). The recent rises in neck pain prevalence further adds to this impact (Martin *et al.* 2008). It has been reported that spinal pain sufferers have almost doubled the healthcare expenditure when compared to those without spinal pain (Martin *et al.* 2008; Davis *et al.* 2012). Despite the high disability associated with neck pain it has not received the same attention as other leading causes of disability (Cohen 2015).

Neck pain can be classified into three main types neuropathic, other underlying cause or non-specific. Neuropathic pain occurs when the primary lesion is in the neural tissues or structures, often resulting in sensory changes such as hyperesthesia, hyperalgesia, allodynia, or paresthesia (El-Tallawy *et al.* 2021). The patient may complain of burning, shooting, electric pain, numbness, pins or needles (Bates *et al.* 2019). The second type is where there is an underlying cause such as cancer or referred pain from organic diseases like cardiomyopathy or vascular diseases and may present with red flags (Cohen 2015). The third type is the most common and referred to as mechanical neck pain (Bogduk 2003) or non-specific neck pain (Binder 2007), which is the focus of this thesis. This type of neck pain arises from the structures in or around the spine, such as the facet joints, intervertebral discs, muscles or ligaments

(Cohen 2015). Differentiation between these types occurs via a comprehensive case history, physical and orthopaedic examination (Blanpied *et al.* 2017; Fandim *et al.* 2021). The examination should record pain intensity together with a psychological, quality of life and work impact assessment together with a physical functioning assessment (Fandim *et al.* 2021).

The examination should include an assessment of physical function to assess motor control (Riemann and Lephart 2002), spinal kinematics (Franov *et al.* 2022) and functional joint stability (Panjabi 1992). Neuromuscular disturbances have been found in neck pain particularly affecting the anterior cervical flexor muscles, with the deep anterior cervical flexor muscles showing insufficient activation (Falla, Jull and Hodges 2004a) and the superficial neck flexor muscles showing increased fatigability and over activity during various tasks (Falla *et al.* 2003; Falla *et al.* 2004a). Other muscles such as the upper trapezius have also been shown to exhibit increased activation in neck pain (Szeto, Straker and O'Sullivan 2005, 2009; Leonard *et al.* 2010). These impairments reflect altered neuronal control and muscle fibre changes that may initiate or sustain neck pain (Falla and Farina 2007).

Neuromuscular impairments in neck pain extend beyond the cervical region affecting the cervicothoracic (Tsang, Szeto and Lee 2013b) and/or neck-shoulder region (Sheard *et al.* 2012). Assessment of functional upper limb task in those with neck pain have shown changes to neuromuscular control in the cervicothoracic musculature – these studies primarily focused on unilateral upper limb arm lifting (Zakharova-Luneva *et al.* 2012; Tsang *et al.* 2018) or computer related typing tasks (Szeto, Straker and O'Sullivan 2009). Bilateral arm tasks are frequently utilised in the occupational settings and are associated with neck-shoulder complaints (Shin and Yoo 2015), yet few studies assess neuromuscular control during bilateral arm tasks in those with neck pain.

Spinal kinematic assessment in neck pain has predominantly focused on cervical range of motion (ROM), where reduced peak displacement has been reported as a feature of neck pain (Stenneberg *et al.* 2017; Hesby *et al.* 2019). The sensorimotor component of movement relies on afferent input, efferent output and central integration

to allow for effective motion and joint stability (Riemann and Lephart 2002). In the presence of pain or when there is dysfunction in the muscle/s or joint/s impaired mechanoreceptors feedback occurs, for example from muscle spindles, negatively impacting this 'loop', leading to poor motor output (Kantak, Johnson and Zarzycki 2022). This can be seen via measuring kinematics (Winter 2009; Balasubramanian *et al.* 2015), such as velocity, acceleration and jerk (first, second and third derivatives, respectively) - time derivatives of the position vector and frequently referred to as the qualitative aspects of motion (Qu *et al.* 2022). There has been less emphasis placed on these outcomes in the neck pain literature (Franov *et al.* 2022).

During cervical ROM reduced movement velocity (Salehi *et al.* 2021), acceleration (Tsang, Szeto and Lee 2013a) and smoothness (Sjölander *et al.* 2008; Yang, Su and Guo 2014; Salehi *et al.* 2021), have been reported although the literature is conflicted (Snodgrass *et al.* 2014; Franov *et al.* 2022). Few studies have assessed spinal kinematics in tasks other than cervical ROM in neck pain (Moghaddas *et al.* 2019). Tasks assessed included virtual reality environments (Sarig Bahat, Weiss and Laufer 2010; Sarig Bahat *et al.* 2014; Sarig Bahat *et al.* 2015), putting on a seatbelt (Moghaddas *et al.* 2019), unilateral arm lifting (Grip *et al.* 2008; Tsang, Szeto and Lee 2014; Moghaddas, Edwards and Snodgrass 2022) and typing tasks (Szeto, Straker and O'Sullivan 2005; Xie *et al.* 2018). Like the studies assessing neuromuscular alterations in neck pain there is a paucity of studies assessing spinal kinematics during bilateral arm tasks.

It is recommended to combine the investigation of muscle activation and kinematics, when assessing the impact of motor control disturbance, to enable a more comprehensive picture of the affected structures, control mechanisms and movement efficiency (Kotov-Smolenskiy *et al.* 2021), blending biomechanics and neuroscience (Mulla and Keir 2023). Yet, in neck pain, only a few studies have applied these methodologies. Tsang *et al.* (2014), found that during a seated lifting task neck pain participants had decreased cervical velocity and acceleration, with prolonged co-activation of cervical and thoracic muscles during the performance of a single arm lifting task when compared to healthy controls. Both groups achieved the same task, highlighting that when experiencing neck pain, motor control is altered (Tsang, Szeto

and Lee 2014). Patients with neck pain often report difficulty executing daily activities (Andelic *et al.* 2012; Coronado *et al.* 2012; Harman *et al.* 2021), many of these activities are components of commonly used self-reported disability scales like the Neck Disability Index (Vernon and Mior 1991; Howell 2011). Thus, assessing and understanding the neurophysiological impact of neck pain can assist clinicians in selecting appropriate treatments and designing rehabilitation programmes (Harman *et al.* 2021).

When treating neck pain, the goal is to reduce pain and disability (Fandim *et al.* 2021) and improve daily living (Chimenti, Frey-Law and Sluka 2018; Weigl, Letzel and Angst 2021). Clinical practice guidelines recommend a variety of treatments depending on the chronicity of the pain and presentation of the neck pain, with spinal manipulation consistently being recommended as a treatment (Bussi res *et al.* 2016; Blanpied *et al.* 2017; Bier *et al.* 2018; Verhagen 2021). Spinal manipulative therapy (SMT), in the form of high velocity, low amplitude (HVLA) thrust procedures, is frequently utilised by manual therapists (Wirth *et al.* 2019), like chiropractors and physiotherapists (Pickar and Bolton 2012). SMT has been shown to reduce neck and low back pain and improve self-reported disability (Bronfort *et al.* 2004; Paige *et al.* 2017; Gevers-Montoro *et al.* 2021a), yet the mechanisms underlying the effectiveness of this technique are poorly understood (Pickar 2002; Potter, McCarthy and Oldham 2005; Bialosky *et al.* 2018; Gyer *et al.* 2019; Gevers-Montoro *et al.* 2021b).

Current literature has shifted away from biomechanical explanations and suggests that neurophysiological mechanisms are responsible for its beneficial effect (Pickar 2002; Bialosky *et al.* 2009; Gyer *et al.* 2019; Haavik *et al.* 2021). These effects include muscle-reflexogenic responses (Herzog *et al.* 1995; Herzog, Scheele and Conway 1999; Gorrell *et al.* 2022; Currie *et al.* 2023), somatosensory changes (Pickar and Bolton 2012) and sensorimotor integration (Haavik and Murphy 2012), altered motor neuron excitability (Robinault *et al.* 2021) and sympathetic activity (Kovanur Sampath *et al.* 2015; Araujo *et al.* 2019). Many studies assessing the effect of SMT are conducted on healthy populations (Kovanur Sampath *et al.* 2015) or animals (Lima, Martins and Reed 2020), with a need for more research in symptomatic populations (Wirth *et al.* 2019).

Pickar and colleagues (2012) using impulse loads, with similar force time profiles to HVLA-SMT, found that muscle spindles, Golgi tendon organs (GTO) and high threshold mechanoreceptors afferents discharged following the intervention (Pickar and Bolton 2012). This barrage of sensory information to the spinal cord is purported to result in a 'cascade' of neurophysiological responses such as reflexogenic effects (Pickar 2002; Reed *et al.* 2014) and alterations in motoneuron excitability (Pickar 2002). A reduction in muscle hypertonicity has been observed following SMT (Pickar *et al.* 2007; Reed *et al.* 2013; Hamilton, Garden and Brown 2022) and in those with low back pain where modulation of muscular control occurred during flexion-extension motion cycles resulting in reduced fatigability (Lalanne, Lafond and Descarreaux 2009; Bicalho *et al.* 2010; Harvey and Descarreaux 2013). In neck pain when feedforward responses were assessed by examining flexion relaxation phenomena cervical spinal manipulation combined with exercise showed improved ratios when compared to an exercise only group (Murphy, Taylor and Marshall 2010).

Cervical SMT has been found to alter electromyographic amplitude and fatigue resistance during isometric deltoid contractions in neck pain participants (de Camargo *et al.* 2011) and result in excitatory effects in an upper limb muscle (Dunning and Rushton 2009). Other authors have reported no change in resting muscle activity following SMT (King, Docrat and Abdul-Rasheed 2022). These trials allude to possible benefits of SMT in altering muscle control in the cervical spine. Supraspinal effects of SMT have been shown in subclinical neck pain populations where changes in somatosensory cortical processing were observed in the prefrontal cortex, altering sensorimotor integration and CNS responses to motor tasks (Haavik-Taylor and Murphy 2007; Haavik and Murphy 2012; Lelic *et al.* 2016; Haavik *et al.* 2017). Supporting this work, increased recruitment of motor units (Niazi *et al.* 2020) and alterations to the descending drive (Niazi *et al.* 2015) following SMT suggest changes to motor function, yet further studies are needed (Robinault *et al.* 2021), especially in symptomatic populations (Wirth *et al.* 2019).

Assessing the effect of a physiotherapy treatment, which included SMT, for neck pain in a longitudinal study, Meisingset *et al.* (2016) found evidence supporting changes in neck flexibility, peak velocity and motion control trajectory during cervical ROM, with

decreased pain and disability being associated with increases in cervical ROM and peak velocity (Meisingset *et al.* 2016). This study alludes to the positive effects of treatment on the neurophysiological process, but the lack of a control group and standardisation of treatment limit the generalisability of these conclusions. In contrast no differences were found between those receiving cervical SMT or a control intervention on cervical ROM and movement harmony (Serra-Añó *et al.* 2023), nor when cervical ROM velocity was assessed between those receiving cervical mobilisation or a control (Lascurain-Aguirrebeña *et al.* 2018a) in neck pain populations. Both these studies utilised a randomised controlled trial design with a singular session. It has been recommended that multiple sessions may yield different results (Snodgrass *et al.* 2014). Most mechanistic studies assessing the effects of SMT focus on immediate changes, lacking follow-up assessments (Gyer *et al.* 2019).

It has been recommended that longitudinal studies are needed to determine if the neurophysiological effects observed following SMT are maintained at follow-up and to establish if they correlate with clinical outcomes (Coronado *et al.* 2012; Lehman 2012; Cardinale *et al.* 2015; Currie *et al.* 2016; Young *et al.* 2019). In light of this, this thesis aimed to add to this body of literature by determining the effect of cervical spinal manipulation on selected cervicothoracic muscle recruitment patterns and spinal kinematics during the performance of three tasks: cervical ROM, a single and bilateral arm lifting task, to determine if the neurophysiological effects associated with SMT impact these parameters and are correlated with changes in pain, in chronic neck pain sufferers.

1.3 STATEMENT OF THE PROBLEM

The problem under investigation is that neck pain is frequently experienced and often debilitating. Ensuring adequate treatment timeously will reduce its burden. Spinal manipulation is often used to treat neck pain, with many guidelines recommending it as a treatment. The mechanism through which SMT brings about its effects is not conclusive. An area that has been highlighted as deficient in neck pain sufferers, but which has not received much attention, is the effect that SMT has on motor control, specifically spinal kinematics. This coupled with an assessment of muscle recruitment

patterns, particularly during the performance of motor tasks, may shed new light on the mechanism through which SMT brings about its effect.

1.4 RATIONALE OF THE STUDY

Neck pain has been ranked fourth highest for disability, as measured by years of healthy life lost due to disability, and 21st for overall burden (Hoy et al. 2014). It has a large public health impact (Vassilaki and Hurwitz 2014) and is of concern under the United Nations Sustainable Development Goal three which addresses the need for healthy lives and promotion of well-being for all ages (United Nations 2015). Scientists see the number one research priority for neck pain as the need to establish treatment effectiveness and cost-effectiveness (Silva *et al.* 2019). Mechanistic studies investigating the underlying mechanism of action of SMT are needed to understand, when and in what types of neck pain presentations, the application of SMT is appropriate to maximize its therapeutic efficacy (Chimenti, Frey-Law and Sluka 2018; Young *et al.* 2024). Clarifying its specific effects will assist in further validating this treatment, reduce scepticism around its use (Bialosky, George and Bishop 2008), assist clinicians in identifying patients who are more likely to have favourable outcomes (Gevers-Montoro *et al.* 2021a), and reducing expenditure.

The increasing prevalence of non-communicable diseases and injuries, together with ageing populations, have contributed to a growing demand for rehabilitation worldwide (Gimigliano and Negrini 2017). Two of the top non-communicable diseases, which are ranked high for disease burden (Hoy *et al.* 2014; Safiri *et al.* 2020), are neck and back pain both of which are commonly treated using SMT (Masaracchio *et al.* 2019; Chaibi, Stavem and Russell 2021) (Gross *et al.* 2015; Beliveau *et al.* 2017; Coulter *et al.* 2018). In addition to SMT relieving pain (Savva, Giakas and Efstathiou 2014; Gevers-Montoro et al. 2021a), it affects motor control by altering muscle activity (Clark et al. 2011; Fryer and Pearce 2012; Hegarty et al. 2021) and modulating muscle recruitment (Bicalho et al. 2010; Harvey and Descarreaux 2013). These effects could result in improved rehabilitation outcomes and decreased morbidity. Yet further research is needed to delineate these effect (Gyer *et al.* 2019) and to inform a mechanistic approach to treatment. This approach requires two criteria: one, that the mechanism causing the

clinical problem is identified, and second, that the biological effects that a treatment induces are understood (Bialosky *et al.* 2018). In terms of SMT, the neurophysiological effects of SMT have been found to affect peripheral, spinal cord and supraspinal structures (Gevers-Montoro *et al.* 2021a), but there has been a call for more studies using longitudinal designs (Coronado *et al.* 2012; Lehman 2012; Cardinale *et al.* 2015; Currie *et al.* 2016; Young *et al.* 2019), with multiple treatments (Snodgrass *et al.* 2014) and on symptomatic populations (Wirth *et al.* 2019), to further understand the clinical implications of the observed neurophysiological effects.

1.5 SIGNIFICANCE OF THE STUDY

It is proposed that when experiencing musculoskeletal pain muscle activity can reorganise within and between the muscles as an attempt to “protect” the tissues and the patient from further pain or injury (Hodges 2011; Hodges and Tucker 2011). These changes can occur at various levels of the motor system (Hodges 2011) and have been found to occur in neck pain (Falla *et al.* 2004a; Falla and Farina 2007; Tsang, Szeto and Lee 2014; Falla *et al.* 2017). The effect of treatments such as SMT on ‘normalising’ this redistribution of muscle function has received inadequate attention in neck pain (Tsang, Szeto and Lee 2013a). Neck pain negatively affects sensorimotor integration leading to modifications in the kinaesthetic sense of the upper limb, with patients often reporting feelings of clumsiness, which negatively impacts their quality of life (Harman *et al.* 2021). These changes contribute to a patient’s symptoms and the recurrence of neck pain (Falla *et al.* 2004a), possibly adding to the poor prognosis (Hush *et al.* 2011; Walton *et al.* 2013). Identifying and addressing motor control alterations may lead to the identification of more effective rehabilitation strategies to improve outcomes.

Many different healthcare professionals provide SMT as a treatment for back and neck pain with chiropractors, osteopaths, and physiotherapists being the predominant providers (Hurwitz 2012). This modality of treatment results in decreasing pain and disability yet the mechanisms through which it brings about these effects are not well understood (Pickar 2002; Haavik and Murphy 2012; Gyer *et al.* 2019; Gevers-Montoro *et al.* 2021b). Theoretical models exist to explain these effects (Pickar 2002; Pickar

and Bolton 2012; Bialosky *et al.* 2018; Haavik *et al.* 2021) yet the mechanisms through which SMT normalises motor function are unclear (Chimenti, Frey-Law and Sluka 2018). Addressing deficits in this system is important (Hodges and Smeets 2015), especially in spinal care and pain management (Gliedt *et al.* 2017).

Studies assessing alterations in motor control in neck pain patients compared to healthy controls have been done in diverse settings (Stenneberg *et al.* 2017; Moghaddas *et al.* 2019; Franov *et al.* 2022), with no studies from Africa. South Africa is a developing country, with a multiracial and culturally diverse population (Samodien *et al.* 2021). The country is afflicted by huge disparity between the high-income earners and those living in poverty (Mayosi and Benatar 2014). The public health care system is dysfunctional and services approximately 84% of the population (Mayosi and Benatar 2014). There is a high burden of disease with an increase in non-communicable diseases (Samodien *et al.* 2021) and multi-morbidity (Modjadji 2021). There is a deficit of information on the prevalence and burden of neck pain in the country (Basson, Olivier and Rushton 2019), but a global assessment found that between 2005 and 2015 low back and neck pain were the single largest causes of disability, with little change to their rates over the 10-year period (Safiri *et al.* 2020).

The development and impact of neck pain, varies between and within population groups, due to social, economic, cultural and environmental influences (Mukhtar, Ibrahim and Mohammed 2023), necessitating the need for studies in diverse geographical locations. This thesis will help to address this by first determining if the motor control variability in neck pain observed in other parts of the world occurs in a South African population and then determining the effect that SMT has on spinal kinematics and muscle recruitment patterns. This will contribute to the theoretical understanding of this commonly utilised treatment.

1.6 RESEARCH AIMS, OBJECTIVES, NULL (H_0) AND ALTERNATE (H_A) HYPOTHESES

1.6.1 Aim of the study

This thesis aimed to establish the effect of cervical spinal manipulation, compared to a control intervention, on cervical and thoracic spinal kinematics, selected muscle recruitment patterns, pain and disability, when performing three functional tasks: cervical ROM, a unilateral and bilateral upper limb tasks, in participants with chronic non-specific neck pain.

1.6.2 Independent and dependant variables

Independent variable:

- cervical spinal manipulation
- control intervention

Dependant variables:

1) Primary outcomes:

- Spinal kinematic variables: angular displacement (degrees), peak and mean velocity (m/s) and jerk (m/s^2).
- Muscle recruitment patterns obtained from the sternocleidomastoid (SCM), anterior scalene (AS), upper trapezius (UT), posterior cervical (PC) and thoracic (T4 and T9) paraspinal muscles bilaterally and measured in terms of peak and mean activation (normalised microvolts) and activation time percentage (percentage).

2) Secondary outcomes:

- Pain intensity - a score out of 10.
- Self-rated disability - recorded as a percentage.
- Global impression of change following treatment – rated out of seven.
- Level of satisfaction with the treatment received – Likert scale.

1.6.3 Thesis objectives and hypotheses (Ha)

1.6.3.1 Objective one

To conduct a systematic review and meta-analysis of the empirical literature on the effect of spinal manipulation on muscle recruitment patterns and spinal kinematics in patients with non-specific neck pain.

1.6.3.2 Objective two

To determine the test-retest reliability of the procedures utilised to obtain cervical spinal kinematics (angular displacement, peak and mean velocity and jerk) using motion capture while performing cervical ROM in participants with and without neck pain.

HA: It was hypothesised that the test-retest reliability of the spinal kinematic outcomes (angular displacement, peak and mean velocity and jerk) obtained during cervical ROM would be greater than ICC 0.5.

1.6.3.3 Objective three

To compare cervical spinal kinematics (angular displacement, peak and mean velocity and jerk) and muscle recruitment patterns (peak and mean activation and activation time percentage) of selected muscle in the cervicothoracic spine in participants with and without neck pain whilst performing cervical ROM.

Ho: There will be no difference ($p < 0.05$) between those with and without neck pain for the primary outcomes assessed during cervical ROM.

HA: There will be a significant ($p < 0.05$) difference between those with and without neck pain for the primary outcomes assessed during cervical ROM.

1.6.3.4 Objective four

To compare cervical and thoracic spinal kinematics (angular displacement, peak and mean velocity and jerk) and muscle recruitment patterns (peak and mean activation

and activation time percentage) in participants with and without neck pain during a unilateral and bilateral arm lifting task.

Ho: There will be no difference ($p < 0.05$) between those with and without neck pain for the primary outcomes assessed during a unilateral and bilateral arm lifting task.

HA: There will be a significant ($p < 0.05$) difference between those with and without neck pain for the primary outcomes assessed during a unilateral and bilateral arm lifting task.

1.6.3.5 Objective five

To determine the effect of cervical SMT, in the form of HVLA-thrust manipulation, on patient reported outcomes (pain intensity, disability, perceived treatment effect and level of satisfaction), cervical spinal kinematic (angular displacement, peak and mean velocity and jerk) and muscle recruitment patterns (peak and mean activation and activation time percentage) of selected muscle in the cervicothoracic spine compared a control intervention while performing cervical ROM.

Ho: There will be no difference ($p < 0.05$) between the groups receiving either cervical SMT or the control intervention for the primary and secondary outcomes assessed during cervical ROM.

HA: It was hypothesised that those receiving cervical SMT would have significantly greater improvements ($p < 0.05$) in the primary and secondary outcomes when compared to the control intervention during cervical ROM.

1.6.3.6 Objective six

To determine the effect of cervical SMT, in the form of HVLA-thrust manipulation, on patient reported outcomes (pain intensity, disability, perceived treatment effect and level of satisfaction), cervical spinal kinematic (angular displacement, peak and mean velocity and jerk) and muscle recruitment patterns (peak and mean activation and

activation time percentage) of selected muscle in the cervicothoracic spine compared a control intervention while performing a unilateral and bilateral upper limb task.

Ho: There will be no difference ($p < 0.05$) between the groups receiving either cervical SMT or the control intervention for the primary and secondary outcomes assessed during a unilateral and bilateral upper limb task.

Ha: It was hypothesised that those receiving cervical SMT would have significantly greater improvements ($p < 0.05$) in primary and secondary outcomes when compared to the control intervention during a unilateral and bilateral upper limb task.

1.7 SCOPE OF THE THESIS

This thesis consists of several studies:

The first study undertook a systematic review and meta-analysis of the literature to establish the level of evidence available to support the use of SMT in inducing changes in spinal kinematics and muscle recruitment patterns in people with neck pain. Selected databases, that were accessible, were systematically searched for articles in English or that were able to be translated into English. Specific criteria for article selection were utilised. The Cochrane Risk of Bias 2 tool and Grading of Recommendations, Assessment, Development and Evaluation criteria were utilised to assess and grade the evidence. Where applicable meta-analysis was performed.

The second study assessed the test, and retest reliability of the OptiTrack motion capture system together with the STT-system software in obtaining a reliable assessment of cervical spine kinematics during cervical ROM in those with and without neck pain. Patient reported outcomes (PROMs) were obtained from those with neck pain, with the RAND 36-Item Health Survey 1.0 (SF-36) being utilised in both groups to obtain the health status of the participants. Participants were tested and re-tested 20 minutes later, while performing cervical ROM, a single and double arm lifting task.

The third and fourth studies were case-controlled, cross-sectional studies where participants with neck pain, were age and sex matched to participants without neck

pain. PROMs were obtained from those with neck pain and health status was assessed in both groups using the SF-36 form. Spinal kinematic and muscle recruitment patterns were obtained during cervical ROM, a single and double arm lifting task with the aim to compare the groups in a South African setting.

The fifth and sixth studies consisted of an RCT, undertaken to assess the effect of cervical SMT compared to a control in participants with non-specific neck pain, during cervical ROM, a single and double arm lifting task. Participants were recruited and assessed for PROMs, spinal kinematics and muscle recruitment patterns. Four treatments were administered over 2 weeks, with a one-week follow-up.

To undertake this study a biomechanics laboratory was developed at the Durban University of Technology's Chiropractic Clinic. It consisted of eight Prime-13 motion capture cameras from OptiTrack™ and a Biopac™ BioNomadix system with surface electromyographic (sEMG) capabilities to measure 12 muscles simultaneously.

1.8 ASSUMPTIONS AND DELIMITATIONS OF THE THESIS

1.8.1 Thesis assumptions

A few assumptions were made in this thesis:

- It was assumed that the participants with neck pain were truthful and honest in describing their pain and its duration to gain entry into the study. They were required to have chronic pain lasting more than three months. Before being invited to attend a consultation they were asked the duration of their neck pain to determine their eligibility for inclusion.
- PROMs were utilised to characterise the participants' neck pain and their response to the treatments in the RCT. It was assumed that they would provide honest responses.
- Statistical assumptions limited the use of certain tests, for example when the data were not normally distributed the use of student t-tests was not possible requiring the use of Mann Whitney U test.

- The study of human movement is complex and limited by the ability to monitor only certain joints and muscles due to the availability of laboratory equipment and time. It is theorized that the execution of tasks takes place by the central nervous system (CNS) which has pre-coded the combination of joint angles (uncontrolled manifold) that are needed for an end-effector position (Latash *et al.* 2010). It then selects the appropriate muscle synergy (Bizzi and Ajemian 2020). Due to the nature of the tasks investigated in this study, being closely related to activities of daily living, it was assumed that the muscles were grouped for the tasks, using less variety in the task execution (Latash *et al.* 2010).

1.8.2 Thesis delimitations

Several delimitations were noted:

- A standardised set up was utilised in the laboratory and was not adjusted to the anthropometric characteristics of the participants. This was done as many work and home place environments are designed to a standard, and the literature regarding the causal relationship between ergonomics and back pain has been questioned (Andersen *et al.* 2011). The table height was fixed at 70cm, which is within the recommended height range of 68 – 72cm.
- Amongst the multitude of outcome measures that could be included, this thesis focused on the kinematics of angular displacement, velocity of motion and jerk. For surface EMG the data analysis was limited to timing duration of task, peak and mean amplitude and percentage of muscle activation, as these measures were able to be standardized between the heterogeneous participants.
- The cervicothoracic region consists of many muscles that that would be involved in the tasks that were assessed in this study. Only six pairs of muscles could be assessed due to limitations in the surface EMG equipment available at the research site, thus those muscles deemed to be most relevant to neck pain, and that have been studied previously in the literature (Tsang, Szeto and Lee 2014; Tsang *et al.* 2018), were selected for inclusion in this thesis.

- Based on the study hypotheses the RCTs utilised in this thesis as a means to assess the effect of cervical spinal manipulation on muscle recruitment patterns and spinal kinematics were aimed not at determining 'what works' but rather 'how it works' (Deaton and Cartwright 2018), to add to the mechanistic understanding of this commonly utilised treatment modality. Thus the focus on pain and disability were secondary outcomes in this thesis, contrasting to most manual therapy RCTs, where more emphasis is placed on the outcomes that are relevant to the patient (Moustgaard *et al.* 2014), such as pain.
- Due to financial and time constraints the case controlled and RCT trials used the following people: one person took the participants' case histories, administered the PROMs, and performed the physical and orthopaedic examinations and treatments (where necessary); with the aid of two research assistants, who were blinded to participant group allocation, who collected the objective outcomes measures. They alternated taking the measures depending on their availability. They both underwent training to ensure that the data collection occurred in a similar manner.

1.9 STRUCTURE OF THE THESIS

Chapter one provides the introduction to the research, the background to the research and highlights the need for the study. It also provides the study aims and objectives, with an overview of the flow of the dissertation.

Chapter two details the current literature regarding spinal manipulation for the management of neck pain and the theories supporting its effects. It also discusses the measurements used to determine the impact of cervical spinal manipulation on spinal kinematics, muscle recruitment patterns and patient reported outcomes.

Chapters three to eight are presented in manuscript format. These manuscripts have not been submitted to a journal.

Chapter three presents a systematic review and meta-analysis of the effect of spinal manipulative therapy on muscle activity and spinal kinematics in patients with non-specific neck pain.

Chapter four presents the test-retest reliability of the motion capture system and sEMG procedures utilised in this research to analyse cervical ROM and two functional tasks.

Chapter five investigates the differences between people with and without non-specific neck pain in terms of cervicothoracic spinal kinematics and muscle recruitment patterns while performing cervical ROM.

Chapter six studied the differences between people with and without non-specific neck pain in terms of cervicothoracic spinal kinematics and muscle recruitment patterns while performing two upper limb functional tasks.

The data used for chapter five and six were collected at the same time but presented as separate chapters to allow each chapter to focus on specific outcomes.

Chapter seven assesses the effect of cervical spine manipulation when compared to a control intervention in the treatment of non-specific neck pain in terms of patient reported outcome measures, cervical spinal kinematics and muscle recruitment patterns during execution of cervical ROM.

Chapter eight investigates the effect of cervical spine manipulation when compared to a control intervention in the treatment of non-specific neck pain in terms of cervicothoracic spinal kinematics, muscle recruitment patterns and patient reported outcome measures during the performance of a unilateral and bilateral upper limb task.

Similarly to chapters five and six, the data for chapter seven and eight were collected at the same time but presented as separate chapters allowing a more focused discussion on the tasks investigated.

Chapter nine reflects on the main findings of the thesis through an overall synthesis and presentation of the thesis limitations, recommendations and conclusions.

1.10 CONCLUSION

This chapter contextualises the high prevalence and negative impact of neck pain and highlights that besides pain, it results in motor control deficits. The presentation of

these deficits is altered depending on the task performed, with bilateral arm tasks being understudied. Commonly used treatment for neck pain, in the form of SMT, has been shown to impact neurophysiological pathways and result in changes which occur locally and in the central nervous system. The effect that these neurophysiological effects impact the motor control deficits seen in neck pain is not well understood and requires further investigation. In light of this, the rationale, aim, objectives and scope of this thesis were presented.

CHAPTER TWO

LITERATURE REVIEW OF SPINAL MANIPULATION FOR THE MANAGEMENT OF NECK PAIN AND MECHANISMS OF ITS IMPACT ON MOTOR CONTROL

2.1 BACKGROUND TO THIS CHAPTER

This chapter contextualises the literature related to neck pain, its epidemiology, diagnosis and treatment. This is followed by a review of the role of motor control in neck pain specifically looking at spinal kinematics and muscle activity, and the measurement thereof. Regarding neck pain treatment, emphasis will be placed on spinal manipulative therapy (SMT), specifically the high-velocity, low amplitude (HVLA) thrust technique and its effect on motor control. The research and theoretical underpinnings for the use of this treatment will be explored and presented.

2.2 SEARCH STRATEGY

Empirical literature to support the writing of this chapter was sourced using the following electronic databases: PubMed (MEDLINE; 1966 to present), Scopus (1970 onwards), CINAHL (EBSCOhost CINAHL Complete database, 1937 to present) and the Web of Science (Core collection, 1990 to present) and the academic search engines of Google Scholar and Summon (Ex Libris. ©2020, Ex Libris Ltd).

Medical subject headings (MeSH) and the search terms utilised included: neck pain, cervicalgia, cervical spine, epidemiology, diagnosis, clinical practice guideline, treatment, proprioception, sensorimotor, systematic review, literature review, clinical predication rule, musculoskeletal pain, low back pain, spinal pain, pain, upper quadrant, non-specific neck pain, mechanical neck pain, manipulation, spinal manipulation, chiropractic manipulation, orthopaedic musculoskeletal manipulations, osteopathic, spinal adjustment, chiropractic, chiropractic adjustment, cervical manipulation, high-velocity low-amplitude, manual therapy, thrust, kinesiology, kinematic, motor control, biomechanical, head movement, spinal movement, motor pattern, movement co-ordination, range of motion, motor variability, muscle activity,

muscle recruitment, muscle recruitment pattern, muscle pattern, myoelectric, neuromuscular function, spinal reflex, muscle function, electromyograph/y, electromyogram, neural responses, reflex responses, neurophysiology.

2.3 NECK PAIN

Neck pain is defined as pain perceived in the area from the nuchal line, along the neck margins to an imaginary line horizontally through the T1 spinous process (Bogduk 2011; Fandim *et al.* 2021). It is a multifactorial disease (Kazeminasab *et al.* 2022) and together with low back pain, is a leading cause of disability, specifically in the age group 20 to 44 years of age (GBD 2015 DALYs and HALE Collaborators 2016). Most people can expect to experience neck pain at some point in their lifetime (Haldeman *et al.* 2008). The global incidence rate for neck pain is 16.2% (Kim *et al.* 2018). Similar prevalence rates have been reported in the general population, workers, and following motor vehicle accidents (Haldeman *et al.* 2008). Its course can be described as multi-episodic, with periods of recovery between episodes (Guzman *et al.* 2009). It is estimated that between 50 to 85% of people who have experienced neck pain, will have another episode within 1 to 5 years of the first (Haldeman *et al.* 2008; Hogg-Johnson *et al.* 2009).

A normal healthy functioning cervical spine allows for the performance of several activities of daily living (ADL) and is necessary for maintaining a good quality of life (Tan, Riew and Traynelis 2017). It is responsible for protecting the spinal cord and supporting the head which weighs approximately 4.5 kg (Yoganandan *et al.* 2009), allows for great mobility – especially when compared to other areas of the spine (Scheer *et al.* 2013). It also acts as a conduit for blood vessels to and from the brain (Okereke, Mmerem and Balasubramanian 2021) and allows the maintenance of a horizontal gaze (Scheer *et al.* 2013), highlighting the importance of this region in daily life.

2.3.1 Epidemiology of neck pain

Data from the Global Burden of Disease study, between 1990 and 2017, reported that the global prevalence, incidence and years lived with disability (YLD) from neck pain

has remained unchanged since 2010 (Safiri *et al.* 2020; Shin *et al.* 2022). Point prevalence, annual incidence and YLD per 100 000 populations have been found to be highest in the Nordic countries, with lower rates seen in African countries. The UK, Sweden and Kuwait showed the greatest increase in the number of prevalence and incident cases, with lower rates being found in Taiwan, New Zealand and Qatar/Cape Verde, respectively (Safiri *et al.* 2020). Using the Sociodemographic Index, both high (Li, Zhang and Shu 2023), middle and low index countries (Safiri *et al.* 2020; Shin *et al.* 2022) were found to have a high burden of neck pain. Highlighting that across the socioeconomic spectrum neck pain is a problem. In Southern Sub-Saharan Africa, there were small increases in the prevalence (0.33%; 0.16-0.55) and incidence (0.25; 0.07, 0.48) of neck pain with YLD decreasing slightly (−0.37; −1.79, 1.06) from 1990 to 2019, given the constant burden, it has been recommended that future studies investigate neck pain in Sub-Saharan Africa (Shin *et al.* 2022).

2.3.2 Risk factors for the development and progression of neck pain

The Bone and Joint Decade 2000–2010 Task Force on Neck Pain and Its Associated Disorders presented a model to explain the determinants of neck pain in workers (Côté *et al.* 2008). Although specifically developed for workers, due to the high prevalence of neck pain in this population (Carroll *et al.* 2009; Ehsani, Mosallanezhad and Vahedi 2017), the model provides an overview of some of the factors which contribute to the development of neck pain and identifies factors that can be modified (Côté *et al.* 2008). The model proposes that there are factors inherent in the individual, such as their demographic and genetic make-up, these factors then interact with other attributes of the person such as their general health, comorbidities, psychological factors, health behaviours and occupational environment. The person with this unique mix of factors then enters the work environment and is subject other influences like stress, work and employer demands, and strain from the environment resulting from for example poor ergonomics, which act as modifiers for the presence of neck pain (Côté *et al.* 2008).

The model emphasises that the individual's experience of pain/disease is modulated by various biological inputs arising from nociception, endocrinological and immunological function, to the perception of past pain experiences, together with the

social, cultural and psychological context (Jinks, Ong and O'Neill 2010; Dahlgren and Whitehead 2021; Masters 2023). These factors do not have a unidirectional effect but work with or against other factors in the development of neck pain (Côté *et al.* 2008). These factors influence the varied prevalence rates seen in different settings (Safiri *et al.* 2020).

Risk factors for neck pain can be divided into non-modifiable, those inherent in the person, and modifiable, those that can be altered due to lifestyle, culture and occupation (Hogg-Johnson *et al.* 2009):

Non-modifiable risk factors:

Females are at a greater risk of developing neck pain than their male counterparts (Shin *et al.* 2022) (Safiri *et al.* 2020; Li, Zhang and Shu 2023); age, where neck pain can occur at any age (Kazeminasab *et al.* 2022) the peak prevalence is between 45 to 54 age showing a decrease with increased age (Safiri *et al.* 2020). There are several diseases that are associated with neck pain such as those related to genetic variation and autoimmune diseases like rheumatoid arthritis, ankylosing spondylitis and systemic lupus erythematosus (Cohen 2015; Kazeminasab *et al.* 2022). Neuromusculoskeletal diseases such as cervical spondylosis, fibromyalgia, cervical radiculopathy, and whiplash-associated disorders commonly result in neck pain (Kazeminasab *et al.* 2022). In addition, pain in another spinal area such as the low back has been associated with an increased risk for neck pain (Blanpied *et al.* 2017).

Modifiable risk factors:

Factors related to the working environment such as the ability to adjust one's sitting position (Paksaichol *et al.*, 2014), working in sustained or awkward positions (Luime *et al.*, 2004), working on a computer, high workload (Kazeminasab *et al.* 2022), sedentary positions and repetitive work (Haldeman *et al.* 2008) with long study time in students (Kazeminasab *et al.* 2022) being factors associated with the development of neck pain. Upper limb tasks such as heavy, bilateral lifting (Skovlund *et al.* 2022) and sustained upper limb positions (Veiersted and Westgaard 1993; Szeto, Straker and O'Sullivan 2005) have been associated with neck pain. Altered neuromuscular

function in terms of reduced cervical extensor muscle endurance (Shahidi, Curran-Everett and Maluf 2015), sustained upper trapezius muscle activity (Hanvold *et al.* 2013), lower isokinetic neck/shoulder lifting strength and static endurance of the neck muscles (Hamberg-van Reenen *et al.* 2006) have been found as a risk factor for neck pain.

In addition, psychological factors like worrisome attitude, poor quality of life rating (Blanpied *et al.* 2017), anxiety and depression (Kim *et al.* 2018), family and work related issues and poor coping strategies have also been linked to the development of neck pain (Haldeman *et al.* 2008; Kazeminasab *et al.* 2022). Psychological factors, as part of a multi-causal matrix, not only play a significant role in chronic pain but can influence the development of chronicity in spinal pain syndromes (Linton 2000). Tools have been developed to assist clinicians in identifying patients who present with psychological factors that may be drivers for continued pain such as the central sensitisation index (Mayer *et al.* 2012) and fear avoidance beliefs questionnaire (Lee, Chiu and Lam 2006).

2.3.3 Pathophysiology of neck pain

Neck pain can arise from several structures in and around the cervical spine including the zygapophyseal joints, the intervertebral disc, the vertebral artery, the dura mater and the muscles (Bogduk 2003; Bogduk 2011). It is important to differentiate neck pain of an unspecified cause from neck pain resulting from myelopathy or radiculopathy (Evans 2014). Other causes of neck pain include spinal malignancy, arthritis, muscle and neurologic diseases with the exact neurobiological mechanisms underlying neck pain being ill recognised (Al-Khazali *et al.* 2023).

Pain is defined by the International Association for the Study of Pain (IASP) as an unpleasant sensory and emotional experience that is associated with, or resembles an association with, actual or potential tissue damage (Raja *et al.* 2020). It is further emphasised that pain is always a personal experience, and not merely the activation of sensory receptors (IASP Task Force on Taxonomy 1994). The initiation, maintenance and perception of pain is influenced by the biological, psychological and movement systems. Pain can be classified into three types (nociceptive, nociplastic

and neuropathic) on how nociceptive activation occurs, how the nociceptive pathway in the CNS adapts to the pain and if there is direct damage to the nociceptive system (Chimenti, Frey-Law and Sluka 2018; Yam *et al.* 2018). Patients can present with a combination of pain types (Chimenti, Frey-Law and Sluka 2018).

Acute pain occurs as a normal biological response from the tissues of the body reacting to a harmful stimulus, is short-lived and is initiated by the stimulation of A δ fibres, it is helpful, normal and protective (Delaney, Clauw and Waljee 2020). This initiates an inflammatory reaction and normally lasts 7 to 30 days (Kent *et al.* 2017). Whereas chronic pain is activated through the C-fibres (Yam *et al.* 2018) and is seen as pathological, with little benefit to the person (Delaney, Clauw and Waljee 2020).

Chronic pain is pain that extends beyond the normal healing time (Yam *et al.* 2018). Despite the physiological tissue response times, various definitions for acute and chronic pain exist. Acute pain has been defined as pain lasting less than three months, and chronic pain being pain persisting longer than three months (Masters 2023). Alternatively, the categories of acute (up to 6 weeks), subacute (6 to 12 weeks) and chronic (>12 weeks) have been used (Blanpied *et al.* 2017; Ishaq *et al.* 2023). The conversion of acute to chronic pain and the differentiation of acute from chronic pain is challenging (Kent *et al.* 2017). Acute and chronic pain can coexist making the diagnosis more difficult (Delaney, Clauw and Waljee 2020).

2.3.3.1 The pain matrix

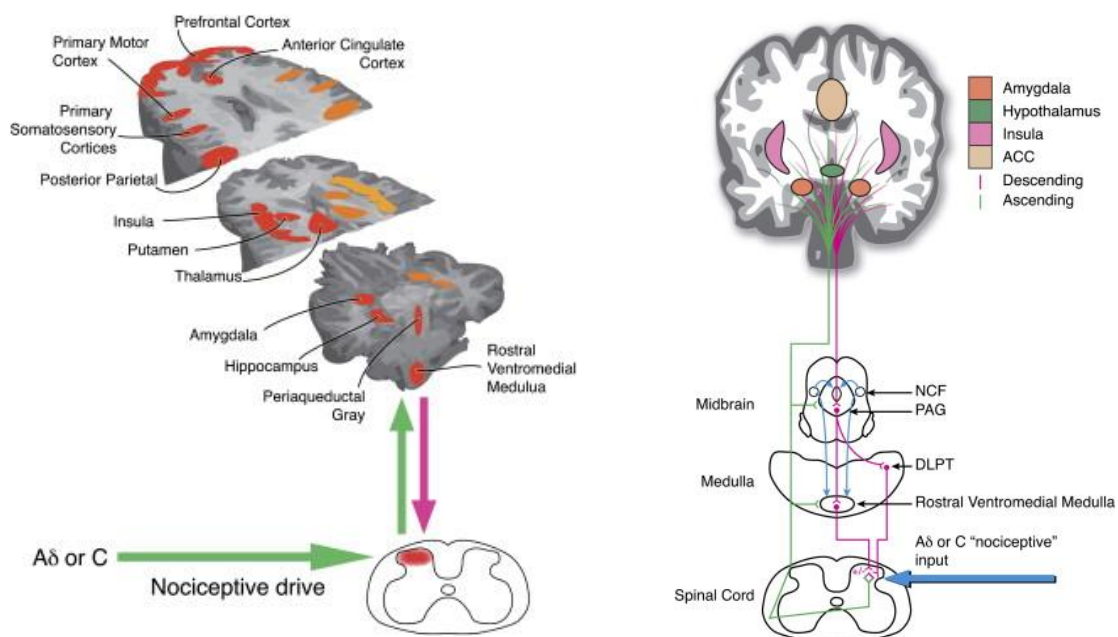
The pain matrix is a complex network of neurons that are involved in the central processing of pain (Tracey and Mantyh 2007; Tobimatsu 2021) and depending on the type of pain, can modulate the pain experience (Tracey and Mantyh 2007). It is activated by a peripheral noxious stimulus that activates primary afferent neurons (myelinated (A δ)) and unmyelinated C fibres carrying mechanical, chemical or thermal stimuli to the dorsal horn of the spinal cord through the trigeminal and dorsal root ganglion for synaptic transmission and modulation (Stein *et al.* 2009; Yam *et al.* 2018). When these signals arrive at the dorsal horn, the primary neuron synapses with the secondary order neuron from the spinothalamic (lateral) and the spinoreticular (medial) tracts, relaying afferent projections to higher centres of the brain including the

thalamus, brainstem nuclei such as periaqueductal gray (PAG) and nucleus raphe magnus (NRM). These centres are involved in descending endogenous pain modulation (Eller-Smith, Nicol and Christianson 2018). Tertiary neurons then project to the primary and secondary somatosensory cortex where the information is processed in terms of location, duration and intensity, or to the limbic system – anterior cingulate cortex (ACC) and insula – which are involved in affective and emotional components of pain (Marchand 2008; Yam *et al.* 2018), as seen in **Figure 2.1**. The pain matrix is not prescriptive as regions of the brain may play more or less of a role depending on the individual context (Tracey and Mantyh 2007).

Modulation of nociceptive pain occurs via the descending pain inhibitory system which mostly occurs at the dorsal horn (Tracey and Mantyh 2007). It is suggested that hyperactivation of the frontal lobe, ACC, insula, amygdala, hypothalamus, PAG, nucleus cuneiformis, and rostral ventromedial medulla, which regulate descending inhibition can influence chronic pain states. The lowering of transmission thresholds at the dorsal horn, together with decreased descending inhibitory transmission, exacerbates the chronic state (Eller-Smith, Nicol and Christianson 2018) (Puntillo *et al.* 2021).

The effects of spinal manipulation have been postulated to work via descending inhibition, whereby the PAG region area of the midbrain is activated which results in stimulation of the noradrenergic descending system resulting in reduction of the nociceptive afferent barrage occurring at the spinal cord resulting in mechanical hypoalgesia (Savva, Giakas and Efstathiou 2014).

A noxious stimulus can lead to peripheral and central sensitisation occurring when the neuronal threshold for firing decreases and results in an increased neuronal response (Schaible, Ebersberger and Natura 2011; Harte, Harris and Clauw 2018). In acute pain, this dissipates with the underlying cause, whereas when the noxious stimuli persist, and the hyperexcitability in the neurons increase in frequency and spontaneity, it activates wide dynamic range neurons, which normally do not transmit noxious stimulus to contribute to the noxious activity leading to chronic pain and ‘wind-up’ (Izzo *et al.* 2015; Yam *et al.* 2018).



Central pain processing

Descending pain inhibition

(NCF - nucleus cuneiformis; PAG - periaqueductal gray; DLPT - dorsolateral pontine tegmentum; ACC - anterior cingulate cortex; +/- indicates both pro- and anti- nociceptive influences, respectively)

Figure 2.1: Central pain processing and descending pain inhibition (Tracey and Mantyh 2007)

Wind-up occurs when there is an imbalance between the inhibitory and excitatory neurotransmitters resulting in persistent activation of the primary-order neurons and activation of nitric oxide synthase (Yam *et al.* 2018). This results in a vicious cycle of neurotransmitter release furthering CNS inflammation (Puntillo *et al.* 2021). Supra-spinal centres respond by sending descending signals to modulate the persistent incoming signals but due to the wind-up are ineffective. The wind-up is maintained via positive feedback and can occur even in the absence of a peripheral input (Herrero, Laird and Lopez-Garcia 2000; Puntillo *et al.* 2021). Glial cells have also been implicated in perpetuating the pain matrix (Ji, Berta and Nedergaard 2013).

In a chronic pain state neuro-immune and neuro-inflammatory changes occur which can perpetuate and amplify pain (Puntillo *et al.* 2021). There is debate as to whether the development of a chronic pain state occurs due to a 'top-down' - where changes

in the CNS are already present irrespective of noxious stimulus input; or ‘bottom-up’ - where excessive peripheral noxious stimulus induces sensitisation; amplification process (Eller-Smith, Nicol and Christianson 2018). Dysregulation in the hypothalamic-pituitary-adrenal (HPA) axis can accentuate the pain response as there is an inability to regulate stress. Structures from the limbic such as the hippocampus, amygdala, and prefrontal cortex, help following a stressful experience to resetting the HPA axis. The inhibition or activation from these areas affects the stress response (Eller-Smith, Nicol and Christianson 2018).

Chronic pain can affect the proprioceptive representation of the body in the somatosensory cortex where the ‘pain’ results in distortion which in turn may affect motor control as the body map becomes distorted (Moseley 2007). Thus, it is important to identify key features of the pain types in acute and chronic pain to differentiate and determine the correct management strategy (Bonezzi *et al.* 2020). Using tools like the central sensitisation inventory can assist clinicians in this process (Mayer *et al.* 2012).

2.3.4 Classification of neck pain

The Bone and Joint Decade 2000–2010 Task Force on Neck Pain and Its Associated Disorders proposed a classification of neck pain based on 4 grades (Haldeman *et al.* 2008) and it’s the most frequently used classification (Ishaq *et al.* 2023):

- Grade I: No signs or symptoms of major structural pathology with no or minor interference with activities of daily living; most likely will respond to minimal intervention such as reassurance and pain control; does not require intensive investigations or ongoing treatment.
- Grade II: No signs or symptoms of major structural pathology, with major interference with activities of daily living; requires pain relief and early activation/intervention aimed at preventing long-term disability.
- Grade III: No signs or symptoms of major structural pathology, but neurological signs are present such as decreased deep tendon reflexes, weakness, and/or sensory deficits; might require investigation and, occasionally more invasive treatments.

- Grade IV: Signs or symptoms of major structural pathology, such as fracture, myelopathy, neoplasm, or systemic disease; requires prompt investigation and treatment.

An alternative classification system is via the mechanisms involved in neck pain: mechanical, neuropathic, or secondary to another cause, differentiation between these is necessary as it influences management and red flags, **Table 2.1**, must be excluded (Cohen 2015; Cohen and Hooten 2017). Mechanical pain, often referred to as non-specific, is the most common cause of neck pain (Binder 2007). It refers to pain that arises from the spine or its supporting structures like the muscles and ligaments (Cohen 2015) and is often related to poor posture occupational or sporting neck strain (Binder 2007). Whiplash associated disorder is a component of non-specific neck pain as long as there is no dislocation, fracture or neurological symptoms (Binder 2007). Neuropathic pain refers to pain arising from a lesion or disease occurring in the somatosensory nervous system such as trigeminal neuralgia or central post stroke pain (Finnerup, Kuner and Jensen 2021). Whereas pain resulting from secondary causes arises due to other mechanisms such as cancer or organ-referred pain (Oliva-Pascual-Vaca *et al.* 2019).

In some cases, the tissue causing the patient's neck pain is unknown (Blanpied *et al.* 2017). The use of advanced testing and imaging techniques is only recommended for patients with neurological or suspected pathological involvement and should not be used routinely in uncomplicated neck pain (Blanpied *et al.* 2017; Cohen and Hooten 2017). No specific imaging modality is considered the 'gold standard' for spinal pain diagnosis, due to a lack of a clear correlation between symptoms and imaging findings, which are often present in asymptomatic individuals (Izzo *et al.* 2015).

2.3.5 Patient reported outcome measures to quantify neck pain and rule out fear avoidance, kinesiophobia and central sensitisation

Patient reported outcomes measures (PROMs) are recommended to enable evaluation, prognosis, diagnosis and to allow ongoing evaluation of pain, disability, psychosocial and daily functioning in neck pain (Blanpied *et al.* 2017; Basson, Olivier and Rushton 2019). There are numerous tools that practitioners and researchers may

utilise with no specific measures being recommended (Gross *et al.* 2015; Fandim *et al.* 2021). A recent review (Ramirez *et al.* 2023) reported that the most common measurement tools utilised in manual therapy for neck pain are the neck disability index (NDI), visual analogue (VAS) or numerical pain rating (NPRS) scale and the Short Form-36 to ascertain general health status.

Table 2.1: Red flags for neck pain (Bier *et al.* 2018)

- Elderly
- History of trauma
- Corticosteroid use
- Osteoporosis
- Cerebrovascular symptoms or signs
- Neurologic symptoms e.g. neurologic signs extending to the arms and/or legs, loss of sensation or muscle strength, bowel and bladder dysfunction
- Symptoms and signs of infection (such as fever, night sweats) or risk factors for infection like underlying chronic diseases, immunosuppression, intravenous drug abuse, infective disease exposure
- History of malignancy
- Failure to improve with 1 month of treatment.
- Unexplained weight loss
- Dysphagia, headache, vomiting
- Systemic disease (herpes zoster, ankylosing spondylitis, inflammatory arthritis, rheumatic arthritis)

Neck disability Index

This is the most widely utilised tool (Vernon 2008; Juul *et al.* 2015). It allows a self-rated level of disability (Vernon 2008) through 10 items (pain intensity, personal care, lifting, work, headaches, concentration, sleeping, driving, reading, and recreation), each with 6-points. The 6-points are scaled from no disability (scored as 0) to complete disability (scored as 5). Each response is summed to a total out of 50 (range 0-50), which can be converted to a percentage and scored out of 100%. The higher the score

the higher the self-perceived disability (Vernon and Mior 1991; Young *et al.* 2009). It has shown excellent reliability and acceptable validity (Vernon and Mior 1991; Young *et al.* 2019; Pontes-Silva *et al.* 2021). Minimal detectable change (MDC) scores were 6.9, with minimal clinically important differences (MCID) of 5.5 in patients with mechanical NP (Young *et al.* 2019). Another tool is the Neck OutcOme Score which was developed based on the Reflective model (classic test theory) and the International Classification of Functioning, Disability and Health framework allowing disability from neck pain to be related to impairment, activity limitations, and participation restrictions (Juul *et al.* 2015; Juul *et al.* 2016). When tested against the NDI and the Short form-36 it was found to be valid, with good to excellent test-retest reliability and responsiveness to longitudinal changes greater than 3 months in physiotherapy practices (Juul *et al.* 2016).

Visual Analogue and Numerical Pain Rating Scale

When assessing pain intensity there are two popular measures – the Visual analogue (VAS) and Numerical pain rating scale (NPRS). Both are self-reported and require the patient to rate their pain from zero being no pain to 10 being the worst pain imaginable. The difference is that in the VAS there are no markers, it is just a straight line, whereas with the NPRS every centimetre is a unit resulting in an 11-point scale which can also be converted into categorical data measures: 0-no pain, 1-3 mild, 4-6 moderate and 7-10 severe pain (Karcioglu *et al.* 2018) (Young *et al.* 2019). Two reviews have had similar conclusions recommending both scales as valid and reliable for use in adults, but the NPRS was found to be more user friendly with better sensitivity (Williamson and Hoggart 2005; Karcioglu *et al.* 2018). The MDC for the NPRS has been reported to be 5.5 with an MCID of 1.5, determined using the Global Rating of Change (CROC), in patients with neck pain (Young *et al.* 2019).

Short Form-36 Health Survey

The Short form-36 (Medical Outcomes Trust, Boston, MA) is a generic health survey covering eight scales: physical function, social function, limitations in the role because of physical health, limitation in role because of mental health, vitality, bodily pain, and general health. It is made up two summary measures: physical and mental health. It

can be used to assess the burden of disease in both general and specific populations, evaluate health benefits from interventions and for health screening (Ware 2000). It has been found to have good construct validity and a suitable measure of self-reported general health in patients with nonspecific chronic neck pain (de Vries *et al.* 2015).

Fear avoidance behaviours and kinesiophobia

Kinesiophobia refers to an irrational, debilitating fear of moving resulting from a deep-seated feeling that the motion will result in harm or re-injury (Kori, Miller and Todd 1990). It is common in people who suffer from musculoskeletal pain (Perrot *et al.* 2018) and should be considered to be in both acute and chronic pain (McNeil *et al.* 2018). The presence of kinesiophobia has been associated with future disability and lack of complete return to work in patients with neck pain (Waddell *et al.* 1993; Lee, Chiu and Lam 2006). The Fear Avoidance Beliefs Questionnaire (FAB) consists of 16 items assessing beliefs regarding pain and its effect on work and physical activity. It can be used successfully for determining work-related disability in chronic pain patients (Waddell *et al.*, 1993). It has been found to be valid and reliable, with a medium level of responsiveness in people with neck pain (Lee, Chiu and Lam 2006). The Tampa Scale of Kinesiophobia (TSK) is a 17-item tool, with items 4, 8, 12 and 16 being reversed, assessing pain-related fear of re-injury (Woby *et al.*, 2005). It tallies to a score between 17 to 68 with higher scores indicating more severe kinesiophobia (Pool *et al.* 2009). A recent systematic review reported that the TSK-13 and 17 were valid, reliable, and responsive in people with musculoskeletal pain (Dupuis *et al.* 2023).

Central sensitisation

Central sensitisation (CS) occurs when there is hypersensitivity in the CNS (Latremoliere and Woolf 2009; Volcheck *et al.* 2023). This has been implicated in several chronic conditions where the aetiology is vague, but patients suffer widespread pain, together with fatigue, sleeping disorders, paraesthesia and cognitive difficulties (Yunus 2007). There is often overlap with other disorders like fibromyalgia, irritable bowel syndrome, restless leg syndrome and temporomandibular joint disorder (Maixner *et al.* 2016). A self-report inventory was developed to assist clinicians in identifying key symptoms found in central sensitisation syndrome to help distinguish

between different types of chronic pain patients (Mayer *et al.* 2012). The scale consists of 25 questions and was found to have good psychometric properties, clinical usefulness and construct validity to help identify those patients who may have CS impairment (Mayer *et al.* 2012). A score of greater than 40 out of 100 alludes to CS (Neblett *et al.* 2013). There is no gold standard for assessing CS, thus a tool like this should be utilised together with a clinical examination (Nijs and Huysmans 2022).

2.3.6 Prognosis and burden of neck pain

Neck pain prognosis is multifactorial (Haldeman *et al.* 2008) with the clinical course being variable and mostly unfavourable (Blanpied *et al.* 2017). Many people experience neck pain in an episodic fashion, with periods of pain and remission (Guzman *et al.* 2009). The Bone and Joint task team for neck pain reported that between 50% and 85% of those who experience initial neck pain will report neck pain again within 1 to 5 years (Haldeman *et al.* 2008).

Suffering from chronic musculoskeletal conditions, like neck pain, can be associated with declined mental health and reduced quality of life (Björnsdóttir, Jónsson and Valdimarsdóttir 2014) and has been associated with poor sleep quality and insomnia (Baker *et al.* 2017). A qualitative study into the burden of neck pain found that besides the pain experienced, patients reported a burden due to impaired mobility, feelings of fatigue or poor concentration, physical complaints, negative psychological aspects/consequences, limitations of activities of daily living, negative impacts on social participation and financial consequences. Care-givers found it difficult to treat/diagnose neck pain, there were divergent opinions regarding neck pain provision, and they struggled to understand the social environment of the patient, and how people dealt with their neck pain (van Randeraad-van der Zee *et al.* 2016). Several of these items linked to the commonly used Neck Disability Index (NDI) (van Randeraad-van der Zee *et al.* 2016).

In addition to the personal burden, neck pain impacts families and healthcare systems. In 2016, among the 154 conditions, low back and neck pain had the highest amount of health care spending estimated at \$134.5 billion (95% CI, \$122.4-\$146.9 billion), of which 57.2% (95% CI, 52.2%-61.2%) was paid by private insurance, 33.7% (95% CI,

30.0%-38.4%) by public insurance, and 9.2% (95% CI, 8.3%-10.4%) by out-of-pocket payments (Dieleman *et al.* 2020). Despite the high burden of neck pain, it is relatively understudied (Safiri *et al.* 2020).

2.4 THE MOTOR SYSTEM

Motor control refers to the nervous system's ability to engage with the body and the environment resulting in purposeful, coordinated movement (Latash *et al.* 2010; Juras and Latash 2021). Human movement is complex (Abd *et al.* 2021) and it involves the disciplines of neurophysiology, biomechanics (Mulla and Keir 2023), behavioural and cognitive sciences (Cano-de-la-Cuerda *et al.* 2015; Kantak, Johnson and Zarzycki 2022).

2.4.1 Neurophysiology of motor control

An important mechanism in motor control is the sensorimotor system, consisting of the somatosensory, visual and vestibular systems that converge in the CNS, where the information is integrated and then an efferent output response occurs (Riemann and Lephart 2002), **Figure 2.2**. The somatosensory system transmits afferent signals along the dorsal root of the spinal nerve, along the large Ia fibres from the muscle spindles (responsible for spinal cord reflexes) and medium A-beta fibres transmitting mechanoreceptors information from the skin and joints (Johnson *et al.* 2010). These signals are also transmitted alongside the small C non-myelinated and A-delta myelinated fibres which carry nociceptive and thermal stimuli (Johnson *et al.* 2010).

The muscle spindles with their specialised intrafusal and extrafusal fibres respond to 'ramp-and-hold' stretches of the muscle, discharging relative to the size and degree of the stretch, that detect changes in muscle length and velocity (Proske and Gandevia 2012; Santuz and Akay 2023). These specialised nerve endings send afferent information via the myelinated sensory Ia nerves to the CNS. Muscles are regulated by beta innervation from alpha motor neurons, which send efferent output to both intrafusal and extrafusal fibres resulting in a motor response, and via gamma motor neuron innervation to the intrafusal component which matches muscle spindle gain to the level of muscle contraction, so that they maintain their sensitivity to respond to

unexpected perturbations in the muscle (Liu, Thornell and Pedrosa-Domellöf 2003; Santuz and Akay 2023). Muscle spindles are often highly concentrated in areas where fine motor skill is required, such as the hand and head (Boyd-Clark, Briggs and Galea 2002).

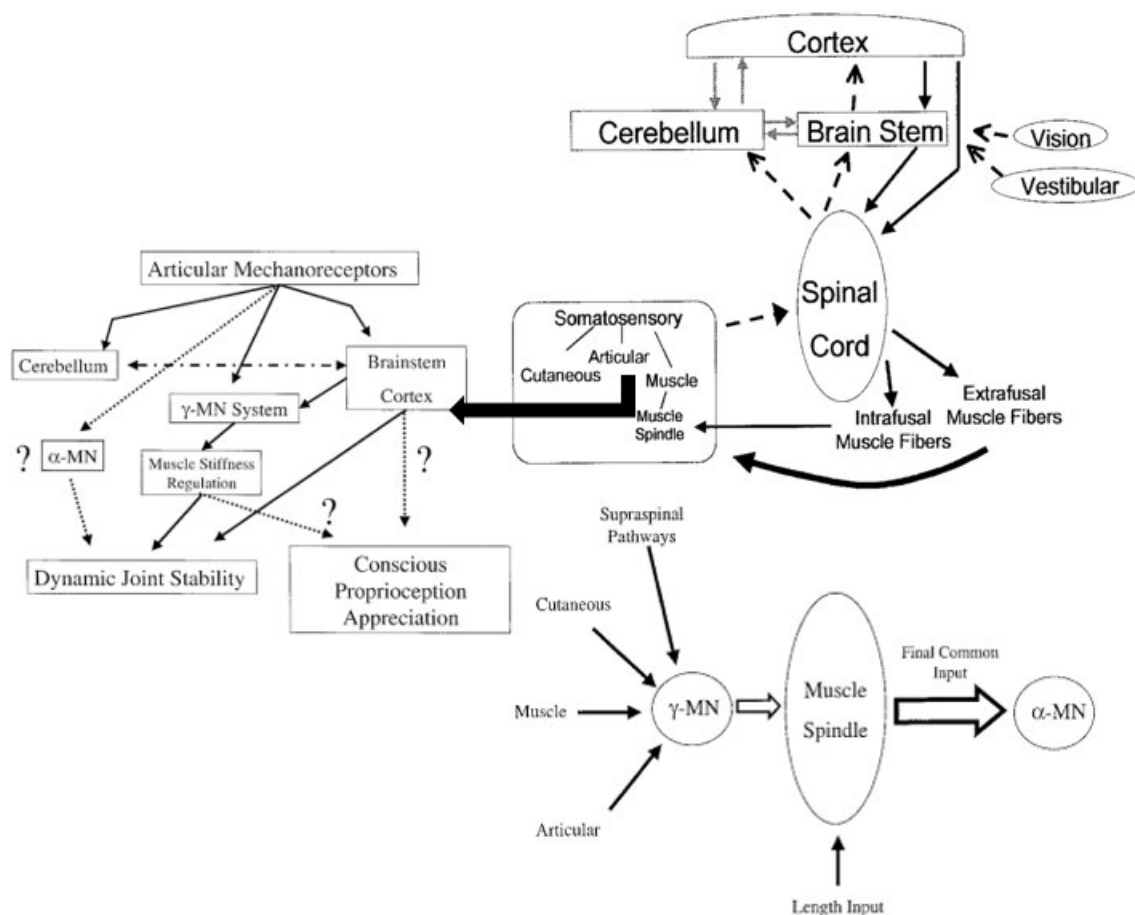


Figure 2.2: Sensorimotor control system (Riemann and Lephart 2002)

There is also a high concentration of muscle spindles in the sub-occipital region (Treleaven 2008). Muscle spindles play an intimate role in sensorimotor control through their multi-synaptic connections with the spinal and brainstem interneurons, combining with descending commands (Li *et al.* 2015; Loeb and Tsianos 2015). The gamma motor system works with the α motor neuron, whereby the alpha motor neuron provides the drive or activation, the gamma motor system executes careful control over movement dynamics and postural control, facilitating accurate and stable

movement (Li *et al.* 2015). Neural recruitment leads to muscle activation where muscle force, length and work are regulated, and force-velocity and force-length relationships modulated (Nordin *et al.* 2017).

The Golgi tendon organs (GTOs), located in the musculotendinous junction of skeletal muscles, are responsible for detecting a sense of effort, and responding to changes in muscle load (Jami 1992). They are innervated by Ib afferents and are highly sensitive to contraction of the related motor units, responding rapidly (Davies, Petit and Scott 1995; Oliver *et al.* 2021). Their physiological similarities to Ia afferents have presented a challenge in understanding the central pathways and their physiological role in motor control (Oliver *et al.* 2021). Both muscle spindles and Golgi tendon organ afferents have been shown to be affected by spinal manipulation (Pickar 2002).

Mechanoreceptors including Wyke receptors I, II and III, Ruffini and Pacinian corpuscles, together with Golgi tendon organs have been found in human cervical facet joints (McLain 1994). These receptors were thought to have a major role in motion detection, however recent literature shows that they become active when a joint is approximating its limits (Proske and Gandevia 2009), having a joint angle activation point, (Burgess and Clark 1969) where the receptors fire (Proske 2023). Any force that results in joint capsule stretching, as spinal manipulation is proposed to do (Evans 2002), can facilitate these receptors (Proske 2023).

The cutaneous receptors play an important part in kinaesthesia, with slow adapting Type II receptors with Ruffini endings being activated on skin stretching, resulting in position and motion sensation feedback to the CNS (Collins *et al.* 2005). This information is thought to be subservient to that acquired from muscle spindles (Proske and Gandevia 2009) but is still considered important especially when considering manual therapies which are typically applied on the skin (Ge, Roth and Sansone 2017; Geri *et al.* 2019).

Once the afferent input arises at the spinal cord, the neuron bifurcates meeting an interneuronal network to allow the execution of the efferent functions. Reflex output involves excitation of the alpha and gamma motor neurons (Davidoff and Hackman 1991; Riemann and Lephart 2002). The higher centres involved in motor control

include the brain stem and cerebral cortex, with input from the cerebellum and basal ganglia assisting with coordinated motor control (Riemann and Lephart 2002). When afferent input is asymmetrical or mismatched it can result in alterations in perceived body orientation (Karnath *et al.* 2002). The intricacies of the cervical spine make it vulnerable to various disorders and complications (Scheer *et al.* 2013). Assessing the impact of neck pain on visual, vestibular and mechanoreceptor systems, it was found that neck pain sufferers had poor joint-position sense (Hesby *et al.* 2019; Särkilahti *et al.* 2024a), oculomotor function and increased postural sway (Särkilahti *et al.* 2024b) with increased number of errors (Hesby *et al.* 2019; Franov *et al.* 2022) and decreased accuracy (Sarig Bahat *et al.* 2015) during head tracking tasks, compared to healthy controls. These disturbances together with altered proprioception lead to changes in neural plasticity, muscle recruitment and cervical kinematics (Qu *et al.* 2022).

Once the afferent input from all sources is integrated, the composite efferent output occurs (Riemann and Lephart 2002; Proske and Gandevia 2012) via the ventral root of the spinal nerve, resulting in muscle activation and force production (Riemann and Lephart 2002). This allows for compensations of head and body posture during neck pain, to allow spinal alignment, pelvic tilt and maintenance of horizontal gaze (Scheer *et al.* 2013). Thus, to assess the efferent system of sensorimotor control one can assess movement, by measuring and quantifying its kinematics (Winter 2009; Schwarz *et al.* 2019).

2.4.2 Biomechanics and motor control

Biomechanics is the application of mechanical principles to living creatures allowing an understanding of how the bony and soft tissue structures of the body, both individually and together, contribute to mobility and stability (Izzo *et al.* 2013). It is a part of the puzzle that leads to the understanding of human movement together with motor control and muscle activation (Motti Ader *et al.* 2020).

Panjabi (1992) proposed a model to explain how the spine ensures stability. It consisted of three subsystems: the active referring to the muscles, the passive joint structures which included the bony anatomy, ligaments, fascia, tendons and joint capsule; and the CNS which was considered the master controller. The cervical spine

is highly mobile, and its bony anatomy provides stability anteriorly via the vertebral bodies and discs and posteriorly through articulating facet joints on either side of the spine, which share 64% of weight (Louis 1985; Pal and Sherk 1988). This structural support is enhanced by the ligaments, fascia, tendons and joint capsules which have a rich supply of mechanoreceptors which feed proprioceptive information regarding load, kinaesthesia and postural control to the CNS for modulation (Panjabi 1992a; McLain 1994; Macefield 2021). This afferent information results in an efferent response directed at the muscles, where the muscles can then compensate, either locally or distal to the site (Riemann and Lephart 2002), for deficits in the passive structures to bring about stability (Panjabi 1992). In other words, the sensorimotor system ensures that movement occurs with stability (Riemann and Lephart 2002).

For example, when a muscle contracts in a voluntary movement, the agonists move the spine, and antagonists eccentrically engage (Cheng, Lin and Wang 2008; Latash 2023). In the cervical spine the neck extensors, whether acting as antagonists or agonists, have been reported to be more active than the cervical flexors during sagittal neck motions. In flexion motion, the cervical antagonists act against gravity preventing the head from falling, whereas in the return motion, they act as agonists to erect the head against gravity, with the antagonists (cervical flexors) only contracting slightly to support the movement (Cheng, Lin and Wang 2008).

This co-activation highlights the functional role of cervical muscles (Lecompte *et al.* 2007) and its role in bringing about spinal stiffness and stability (Lecompte *et al.* 2007; Cheng, Lin and Wang 2008). Muscles can increase stability by increasing muscle co-contraction, this strategy is more likely adapted in novel tasks, unpredictable conditions or where neuromuscular impairment is present; and/or by organizing multi-muscle synergies allowing for co-variation of muscle activation levels which highlight the flexibility of muscle synergies (Latash 2010).

2.4.3 Selected theories of motor control

An individual wanting to perform a particular task has several movement strategies available to allow for the execution of that task (Bernshteĭn 1967). For each movement, there are an infinite number of feasible solutions across the muscles to complete the

task (Sohn, McKay and Ting 2013; Cohn *et al.* 2018), referred to as the principle of abundance (Gelfand and Latash 1998). The CNS favourably selects the combinations of muscle synergies that will execute the task (Abd *et al.* 2021). Feedforward and feedback information provide the necessary details, informing the body about the task. The feedforward mechanism involves planning *a priori*, whereas the feedback mechanism occurs following sensory detection, allowing for modifications (Riemann and Lephart 2002; Seidler, Noll and Thiers 2004). The mechanism of moving not only involves the targeted muscles and joints but requires numerous regulatory challenges such as postural stability, antagonistic muscle inhibition and neuronal modulating. A simple movement is a global event (Bizzi and Ajemian 2020).

The seminal work by Bernstein (1967) presented a model consisting of four levels:

- Level one - level of tonus describes the neural and muscular system communication which takes place at the spinal cord. It is responsible for the preparation of the 'movement apparatus' by changing the excitability of sensory and motor cells, based on signals from higher structures.
- Level two - The level of Synergies regulates the degrees of freedom of the motor components and coordinates movement, grouping muscles in synergies based on proprioceptive information from the body. This occurs in the mid-brain and is a background controlling mechanism, as no information is received here from the visual and vestibular components of the sensorimotor system.
- Level three - the Level of Space, is where purposeful movement occurs due to combining visual, vestibular optical, acoustical, and cutaneous receptors with past experiences that provide a 'space field' within which body movements can occur. This field acts upon the level of synergies, not dictating how a movement should be produced but rather informing the level of synergies that a certain goal-directed movement is needed. Thus, it does not control movement sequence.
- Level four - the highest ranking, is the Level of Action, this is where movement sequence is controlled and organised to respond to a behavioural problem. The response can occur via an array of different elements to achieve the same goal,

allowing flexibility in how the task is completed (Bernshtein 1967; Profeta and Turvey 2018).

To further explain this model equilibrium-point hypothesis was proposed where central control signals alter the activation threshold of alpha-motoneurons based on muscle length afferent signals (the tonic stretch reflex) resulting in muscle tension and velocity changes (Feldman and Latash 2005; Juras and Latash 2021), both voluntary and involuntary (Latash *et al.* 2010). This allows changes to postural stabilisation due to changing muscle activation thresholds (Feldman and Latash 2005) and relies on neurophysiological and physical principles (Feldman and Latash 2005). In terms of movement, the nervous system sets a joint space domain, known as the uncontrolled manifold, this contains combinations of joint angles, with their equilibrium points, that will allow for a specific task. From this, the task relevant joint directions that will result in the best stabilisation are recruited for the spatial task over those combinations that are more likely to result in instability (Latash *et al.* 2010).

The Feasibility theory of motor control proposes that the motor command for a certain task is sent from the motor cortex to the spinal cord inter-neuron and alpha-motor neuron pool. The drive produced here, results in a multi-dimensional muscle activation pattern that elicits the muscle force to match the mechanical obligations of the task (Cohn *et al.* 2018). The muscle activation pattern is selected from the 'feasibility activation space', similar to the uncontrolled manifold (Mulla and Keir 2023), where a given task can be executed by a large number of valid muscle activation patterns (Cohn *et al.* 2018; Mulla and Keir 2023). At sub-maximal tasks, such as those of daily living, the variability of the feasibility space is greater as muscles have numerous ways to co-contract with little postural compensation (Mulla and Keir 2023). During motor learning - an optimal solution, or one which is 'good enough' will be selected to allow task execution (Loeb 2012). However, optimality theory puts forward that not every solution is feasible and the same, with some solutions being preferred (Mulla and Keir 2023).

2.4.4 Theories of how pain influences the motor system

People in pain or expecting pain alter the way that they move (Hodges and Smeets 2015; Kantak, Johnson and Zarzycki 2022). These changes may persist past healing and can result in kinetic and kinematic changes that may be associated with re-injury or continued disability (Kantak, Johnson and Zarzycki 2022). There is a multi-faceted relationship between pain and movement (Hodges and Smeets 2015) involving numerous systems (Kantak, Johnson and Zarzycki 2022). Selecting specific interventions is important to assist patients with reducing the motor responses that are exacerbated by pain and/or to improve function and minimising motor effects (Chimenti, Frey-Law and Sluka 2018).

One traditional view of pain and the motor system suggests that a vicious cycle occurs where muscle dysfunction results in hypertonicity which causes pain, reinforcing the dysfunction (Travell, Rinzler and Herman 1942; Roland 1986; Johansson and Sojka 1991). It proposes that hypertonicity results in metabolites which increase muscle spindle sensitivity from group III and IV afferents (nociceptive muscle afferents) activating gamma motoneurons which project to surrounding muscle. The change in gamma-motoneuron firing influences the sensitivity to stretch, resulting in discharges of primary and secondary spindle afferents, resulting in increased muscle stiffness and accumulation of metabolites, further exacerbating the increased secondary spindle afferent activity, this loops back to the gamma system, further perpetuating the stiffness (Roland 1986; Johansson and Sojka 1991). Certain treatments like the use of muscle relaxants align with this model (Merkle, Sluka and Frey-Law 2020), but the variability of muscle responses to pain provides little support for this theory (Lund *et al.* 1991). For example, some studies show muscle inhibition as opposed to facilitation during pain (Verbunt *et al.* 2005). In conditions where muscle hypertonicity is a characteristic, EMG studies show little change in muscle tension (Simons and Mense 1998).

Lund and Colleagues (Lund *et al.* 1991) presented the pain adaption theory where they proposed that muscle responses were protective rather than a cause of pain. Activation of nociceptive muscle afferents facilitates inhibitory pathways when the

muscle acts as an agonist, and when acting as an antagonist excitatory pathways are facilitated – occurring as a reflexive adaption. This reduces the maximum voluntary contraction (MVC) and affects range, velocity and force. This was seen in experimentally induced jaw pain where smaller and slower jaw movements occurred possibly due to a functional adaptation (Sohn *et al.* 2000). This theory disputes the tonically hyperactive muscle state induced by pain in the vicious cycle hypothesis. Although there is support for this theory (Arendt-Nielsen *et al.* 1996; Zedka *et al.* 1999; Sohn *et al.* 2000) it fails to explain changes observed in automatic functions like postural control (Hodges 2011), the diversity of motor adaptations (Hodges and Smeets 2015), the timing of muscle activity and load sharing (van Dieën, Selen and Cholewicki 2003) that are seen in pain.

The contemporary theory of motor adaption in pain proposes that the motor system responds to pain in a varied manner aiming to protect the threatened or painful area (Merkle, Sluka and Frey-Law 2020). This motor response can result in either small modification which could be reorganisation of muscle activity in and between muscles, to gross adaptations like avoidance of movement (Hodges and Smeets 2015; Merkle, Sluka and Frey-Law 2020). These alterations in movement can be both a ‘cause’ and an ‘effect’ of the injury, nociceptive input, pain or the threat of pain, especially when the alterations persist long-term. They result from a range of mechanisms across the sensorimotor system resulting in either positive or negative outcomes for the pain sufferer, which are individualised (Hodges and Smeets 2015), **Figure 2.3**. This model differs from other models in that the muscle response does not follow inhibition or facilitation but allows for a re-organisation within the muscle where some motor units will be de-recruited and others recruited, maintaining force output (Tucker *et al.* 2009). This redistribution in the motor system can occur within and between muscles, impacting movement (Merkle, Sluka and Frey-Law 2020).

In support of this theory, participants who were subjected to experimental pain showed movement adaptations when there was a reduction in the pain experience, irrespective of whether the pain increased or decreased during the new motion strategy. Showing that motor changes do not only occur to protect the tissues from threat, but that movement itself is associated with pain reduction (Bergin *et al.* 2021). When acute

experimentally induced pain was elicited in the spine, muscles were found to act to stabilise the spine, but no specific pattern of muscle activation was observed between individuals (Hodges *et al.* 2013), supporting the contemporary theory of motor adaption in pain.

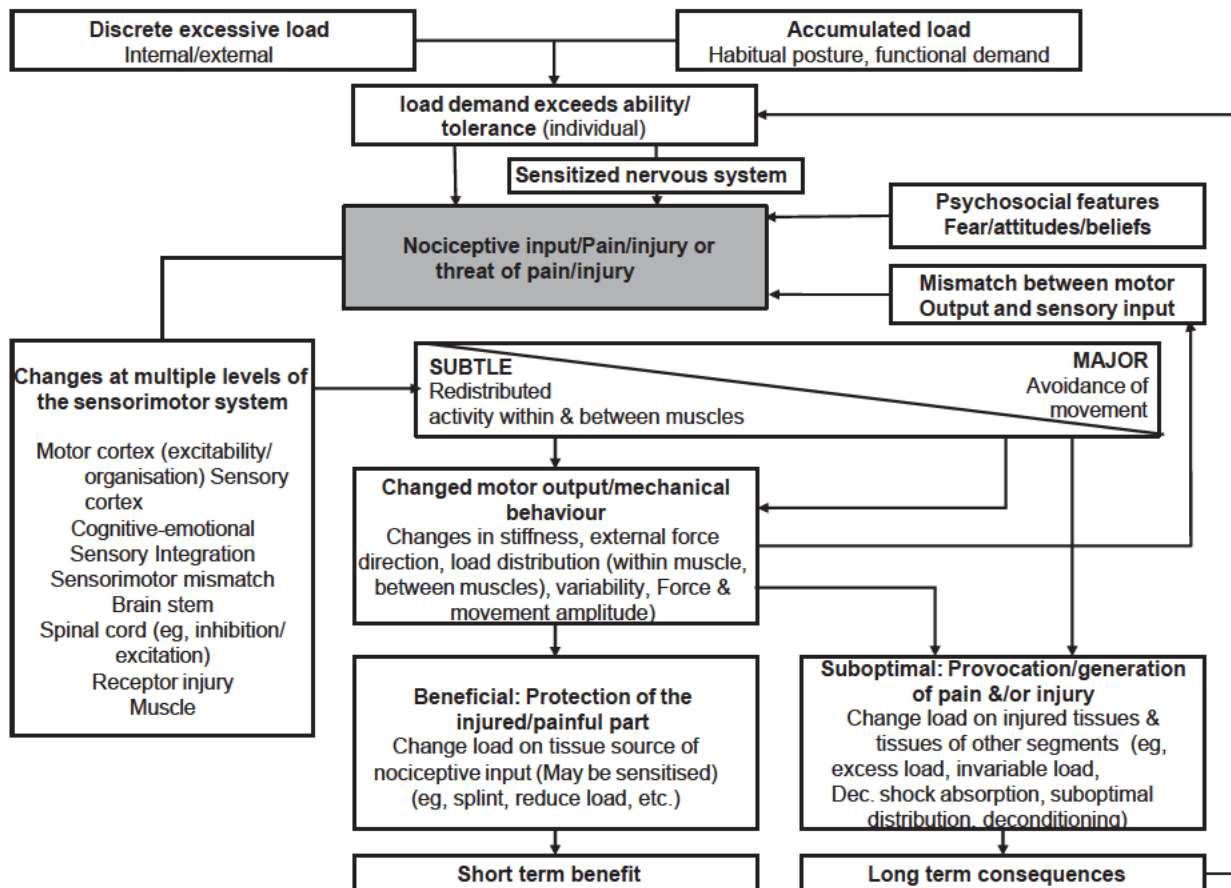


Figure 2.3: Contemporary theory of motor adaption in pain (Hodges and Smeets 2015)

Kantak and Colleagues (Kantak, Johnson and Zarzycki 2022) utilised the contemporary theory of motor adaption in pain to map out the aspects of how pain influences the different stages of motor control. They broke it into the feedforward and feedback loops, **Figure 2.4**. The red arrow shows how the feedback from the somatosensory systems and the knowledge of the result of the action impact subsequent actions. Whereas the blue arrow refers to 'online' feedback which is ongoing. Sensory input allows for the identification of important task and environment

changes, whereas goal selection, action, and planning of actions predominantly rely on feedforward mechanisms prior to task execution. At each stage, pain-related deficits can occur which can negatively impact the quality of the motor response (Kantak, Johnson and Zarzycki 2022).

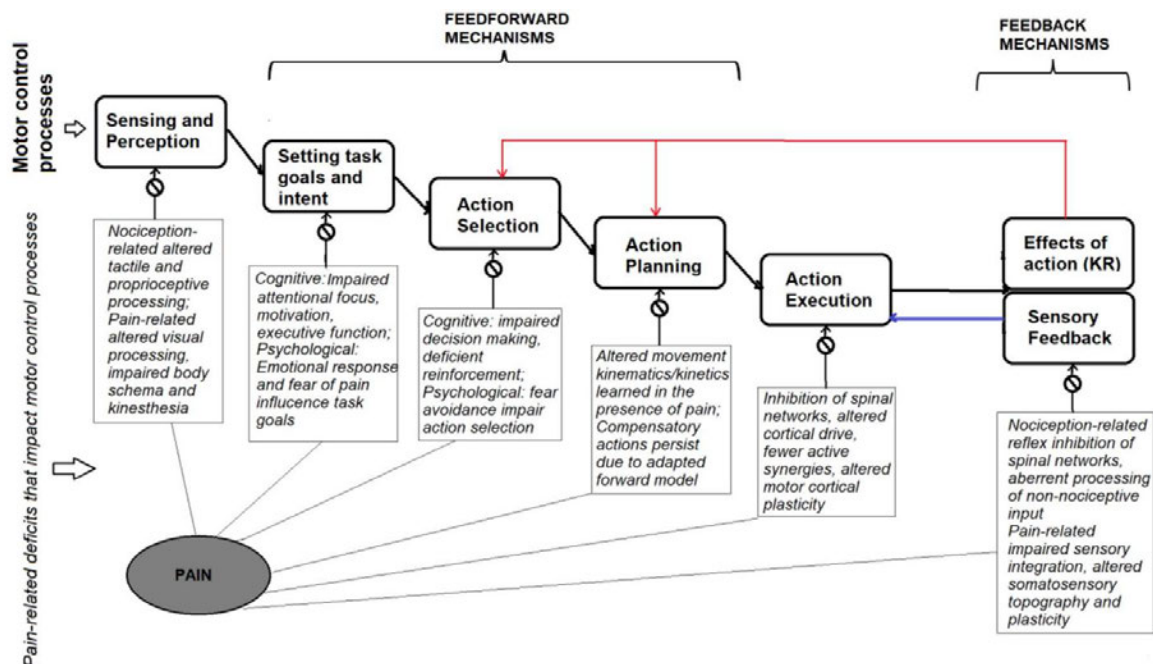


Figure 2.4: A contemporary model of motor control and the effects of pain on each of the processes (Kantak, Johnson and Zarzycki 2022)

2.5 NECK PAIN AND MOTOR CONTROL

2.5.1 Neck pain and spinal kinematics

In the clinical environment, one of the most frequently assessed kinematic outcomes is cervical ROM, which is often decreased in patients with neck pain (Snodgrass *et al.* 2014; Blanpied *et al.* 2017). When assessing the cervical spine for maximum ROM, consideration should be given to the various components of the cervical spine. Although muscles are responsible for moving the spine - kinematics, the bony anatomy of the cervical vertebrae dictates its movement capability (Bogduk and Mercer 2000).

The cervical spine is divided into two regions - the upper cervical spine consisting of the atlas, axis and the C2-3 articulation, and the lower cervical spine made up of C3-seven vertebrae (Swartz, Floyd and Cendoma 2005), with each region having unique motion characteristics as detailed in **Table 2.2**. Some joints reach their maximum range prior to the cervical spine reaching its full range. These joints then respond by either inducing flexion or extension motions until the full ROM is reached (Bogduk and Mercer 2000; Swartz, Floyd and Cendoma 2005). Execution of the motion from either flexion to extension or extension to flexion can result in a collective difference in the range of 10-30° (Bogduk and Mercer 2000). Over repeated measures, variations in segment specific ROM can be as much as five degrees, thus multiple assessments are required to obtain a mean with a range of variance (Bogduk and Mercer 2000). When assessing the motion of a functional spinal unit in the cervical spine, the motion occurs along an arc, with the instantaneous centre of rotation (ICR) occurring in the superior aspect of the lower vertebrae. Abnormal ICR has been correlated with neck pain, with the symptomatic segment not necessarily occurring at the level of the ICR (Amevo, Aprill and Bogduk 1992).

The global physiological ROM of the cervical spine has been reported as approximately 90° of flexion, 70° of extension, 20° to 45° of lateral bending, and up to 90° of rotation on each side (Swartz, Floyd and Cendoma 2005; Tan, Riew and Traynelis 2017). These values are higher than those reported in a recent systematic review where pooled data for normal adult populations during active cervical ROM were obtained using The Cervical Range of Motion Measuring device (CROM)(Thoomes-de Graaf *et al.* 2020) and are presented in **Table 2.3**. The authors recommend that 'normal ROM' should be considered within the 'normal range'. Validity and reliability studies performed testing the cervical ROM on participants with (Fletcher and Bandy 2008) and without neck pain (Fletcher and Bandy 2008; Audette *et al.* 2010) found good to excellent reliability, with low standard error (SE) measurement and low minimal detectable change (MDC) scores, as reported in Table 2.3. Only one study has attempted to determine minimum clinically important differences (MCID) in neck pain, comparing changes in the neck disability index (NDI) from baseline to 4 months, measured using a bubble inclinometer (Jørgensen *et al.* 2017), **Table 2.3**. No

important sex differences have been reported for cervical ROM, but with increasing age, there is a decrease ROM (Chen *et al.* 1999).

Table 2.2: Typical kinematics of the cervical spine (Bogduk and Mercer 2000)

Cervical spinal area	Motion characteristics
Atlanto-occipital	• Flexion and extension, with little to no rotation and lateral flexion.
Atlantoaxial joint (C1-2)	• Primarily responsible for rotation, with rotation of C1-2 and the head occurring as one motion. • Motion is restrained by the joint capsule and the alar ligament. • Several muscles attach to the atlas but only the longus cervicis facilitates flexion, with no antagonistic muscle. • Rotation occurs due to splenius capitis and sternocleidomastoid muscles acting on the head, transmitting the torque inferiorly. • Splenius cervicis attaching to the atlas supplement this action. • Lateral flexion motion is limited by the contralateral alar ligament and the impact of the lateral mass on the odontoid process. • Motions of flexion and extension are passive and paradoxical i.e. when the head flexes the atlas extends.
C2-3	• Coupling of lateral flexion during axial rotation of the neck – opposite to that seen in the lower cervical spine.
C3 to C7	• Flexion and extension are the main motions. • Flexion is controlled by the posterior longitudinal and interspinous ligaments, ligamentum flavum and facet joint capsule. • Extension is limited by the anterior longitudinal ligament and the annulus fibrosis together with impaction of the spinous processes. • Coupled motions occur for rotation and lateral flexion, where horizontal rotation motion occurs with ipsilateral lateral flexion. • Rotation is limited by the joint capsule and annulus fibrosis and orientation of the facet joints.

Reviews have found that people with neck pain present with decreased active cervical ROM (Snodgrass *et al.* 2014; Hesby *et al.* 2019), especially in full-cycle flexion-extension and total rotation, and half-cycle extension motion (Snodgrass *et al.* 2014). These results support observations from clinical practice (Childs *et al.* 2008; Snodgrass *et al.* 2014; Blanpied *et al.* 2017; Verhagen 2021). Yet several trials failed to find a relationship between neck pain and reduced cervical ROM (Tsang, Szeto and Lee 2013a; Lascurain-Aguirrebeña *et al.* 2018b). There is also scant evidence

discerning the role that restricted cervical ROM has on neck pain outcomes (Snodgrass *et al.* 2014).

Table 2.3: Normative data, minimal detectable change and minimally clinically important difference for active CROM, in adults with neck pain (Thoomes-de Graaf *et al.* 2020)

Age range	20-29 n(SD)	30-39 n(SD)	40-49 n(SD)	50-59 n(SD)	MDC (Fletcher and Bandy 2008)	MCID (Jørgensen <i>et al.</i> 2017)
Flex	58.4 (10.4)	55.4 (9.2)	56.2 (9.4)	50.8 (9.3)	9.6°	6.0°
Ext	76.8 (11.1)	69.7 (10.5)	67.0 (10.4)	63.0 (10.8)	7.0°	4.0°
LLF	45.0 (7.0)	42.1 (7.5)	39.8 (8.0)	36.6 (7.2)	9.1°	5.0°
RLF	44.7 (6.4)	41.9 (7.6)	39.5 (9.0)	36.8 (7.3)	5.9°	3.0°
LRot	74.6 (7.4)	74.5 (8.8)	72.7 (9.0)	67.1 (8.9)	6.7°	5.0°
RRot	75.2 (6.6)	75.3 (8.0)	73.8 (9.4)	67.2 (8.1)	7.6°	10.0°

(Minimal detectable change – MDC; minimally clinically important difference – MCID; Flex – flexion; Ext – extension; LRot – left rotation; RRot – right rotation; LLF – left lateral flexion; RLF – right lateral flexion)

Similarly, conflicting evidence is available for cervical ROM variability, with some studies indicating a reduction (Sjölander *et al.* 2008; Meisingset *et al.* 2015; Cattrysse *et al.* 2020) and others showing greater variation (Vogt *et al.* 2007). The reduced variability would be supported by the vicious cycle theory (Travell, Rinzler and Herman 1942; Roland 1986; Johansson and Sojka 1991), where muscle hypertonicity reduces movement, whereas the increase in variability would likely be explained by the contemporary theory of motor adaption in pain, where greater variability in the motor system occurs (Hodges and Smeets 2015). These findings warrant further research to determine the effect of neck pain on ROM, its clinical relevance, and its correlation with changes in neck pain symptomatology (Stenneberg *et al.* 2017).

Looking beyond displacement to time derivatives of the position vector like velocity (1st derivative), acceleration (2nd derivative) or jerk (3rd derivative), allows additional insight into the quality of the motion (Franov *et al.* 2022)(Qu *et al.* 2022)(Godfrey *et al.* 2008). For example, in seated cervical ROM no difference in angular displacement

was found between those with neck pain and those without, yet differences in velocity and acceleration in all ROMs were found. This highlights that in neck pain, the way the spine moved was more important than how much it moved (Tsang, Szeto and Lee 2013a). Factors that can influence velocity and acceleration include the magnitude and direction of the applied force (Lu and Chang 2012), development of skilled movement (Nagasaki 1989), the more proficient one is at a task, the more that task can be done with increased speed, and pain (Hodges and Smeets 2015). As discussed previously, movement in pain can be modified by other factors like fear avoidance behaviours (Lundberg and Archer 2022).

The studies assessing spinal kinematics in neck pain can be divided into those that assess head specific tasks (Vogt *et al.* 2007; Sjölander *et al.* 2008; Woodhouse and Vasseljen 2008; Descarreaux, Passmore and Cantin 2010; Sarig Bahat, Weiss and Laufer 2010; Guo *et al.* 2012; Tsang, Szeto and Lee 2013a; Vikne *et al.* 2013a; Yang, Su and Guo 2014; Waeyaert *et al.* 2016; Lascurain-Aguirrebeña *et al.* 2018b; Alsultan *et al.* 2019; Salehi *et al.* 2021) and those that are functional in nature (Constand and MacDermid 2013; Tsang, Szeto and Lee 2014; Falla *et al.* 2017; Xie *et al.* 2018; Alsultan *et al.* 2019; Moghaddas, Edwards and Snodgrass 2022).

2.5.1.1 Spinal kinematics in neck pain during cervical ROM

Several case controlled trials have investigated spinal kinematics during cervical motion in people with neck pain, compared to health controls, and in some cases, people with whiplash associated disorder - a summary of these studies can be found in **Appendix A**. Trials assessing spinal kinematics in people with and without neck pain during head-neck motion reported decreases in velocity during a virtual reality game (Sarig Bahat, Weiss and Laufer 2010; Sarig Bahat *et al.* 2015) and seated cervical ROM (Rutledge *et al.* 2013; Tsang, Szeto and Lee 2013a). This was supported by a review where it was reported that neck pain sufferers move more slowly than healthy controls (Hesby *et al.* 2019). However, there is disagreement in the literature regarding neck pain and its impact on velocity as not all studies during cervical motion support reduced velocity in neck pain (Lascurain-Aguirrebeña *et al.* 2018b; Lemmers *et al.* 2018).

Acceleration allows the spontaneity of motion to be assessed (Baydal-Bertomeu *et al.* 2011). Like velocity, the case-control literature is ambiguous as to whether neck pain decreases acceleration. During cervical ROM, in the seated position, decreased cervical acceleration was found in all directions in those with neck pain (Tsang, Szeto and Lee 2013a), whereas in a similar task but only assessing rotation and lateral flexion range, no differences in acceleration were seen between those with and without neck pain (Lemmers *et al.* 2018). When assessing a rapid head aiming task where participants were challenged to perform cervical motion as quickly and precisely as possible, the neck pain participants had increased deceleration phase duration with no differences in the acceleration phase. This finding depended on the task, as the task difficulty increased, the motor changes became more apparent (Descarreaux, Passmore and Cantin 2010).

It is known that as task difficulty increases the rate of success will decrease and this is relative to the skill of the performer (Pollock *et al.* 2014). The motor system with its muscle synergies (Singh *et al.* 2018) aims to maintain movement even when compromised. It does this through re-organising the motor response to allow task execution (Kantak, Johnson and Zarzycki 2022; Mulla and Keir 2023), however, as highlighted the motor control loss may - only be apparent when the system is stressed past its coping level (Guadagnoli and Lee 2004).

Besides the speed and spontaneity of motion, motion smoothness is necessary to allow motion in a continual fashion without jerkiness (Balasubramanian *et al.* 2015). Jerk, the third derivative of position over time, indicates the change in acceleration (Sjölander *et al.* 2008). Several trials show that neck pain sufferers have reduced movement smoothness when compared to healthy controls (Sjölander *et al.* 2008; Sarig Bahat, Weiss and Laufer 2010; Yang, Su and Guo 2014; Waeyaert *et al.* 2016), however, a recent review highlighted that the evidence is limited (Franov *et al.* 2022). During a virtual reality game, increased velocity peaks (Sarig Bahat, Weiss and Laufer 2010) and asymmetrical patterns were found in acceleration-deceleration when compared to healthy controls (Sarig Bahat *et al.* 2015).

Similarly, when assessing cervical motions with spectral entropy, movement smoothness was reduced in those with neck pain (Yang, Su and Guo 2014). Two studies assessing jerk during cervical rotation range found an increase in those with neck pain compared to healthy controls (Sjölander *et al.* 2008; Waeyaert *et al.* 2016). In the one trial where they assessed movement jerk and the type of pain experienced, it was found that those with symmetrical pain had less smoothness of motion (Waeyaert *et al.* 2016). Other factors that can influence jerk are fatigue and expertise – the more adapted one is to a particular movement pattern the more likely it will be done with motion smoothness (Zhang *et al.* 2019).

Tsang *et al.* (2013) extended beyond cervical spine kinematics and included an assessment of cervicothoracic kinematics in those with and without neck pain. They found that the thoracic spine contributes towards cervical spine ROM, particularly the upper thoracic spine (Tsang, Szeto and Lee 2013b), potentially explaining how therapeutic interventions applied to the thoracic spine result in improvements in neck pain (Masaracchio *et al.* 2019). When assessing cervicothoracic kinematics Tsang and colleagues (2013) found that during seated cervical flexion and extension, motion velocity was decreased, and during right lateral flexion acceleration decreased in the upper thoracic spine ($p < 0.05$).

In contrast, for the lower thoracic spine during cervical flexion and extension, velocity and acceleration decreased with acceleration decreasing only in left lateral flexion ($p < 0.05$). Their study also revealed that for angular displacement in the sagittal and coronal planes ($p < 0.001$), and for velocity and acceleration measures in the cervical and upper thoracic spines ($p < 0.05$), less cervicothoracic co-ordination occurred (Tsang, Szeto and Lee 2013a). This novel study highlights the role of the spine as a kinematic chain (Karandikar and Vargas 2011).

These trials highlight that an assessment of neck kinematics is needed to determine movement impairment in neck pain and to understand the role of kinematics in neck pain. This can then inform intervention strategies which can be tailor made to address the deficiencies and improve movement function, coordination (Tsang, Szeto and Lee 2013a) and restore movement variability (Alsultan *et al.* 2019).

2.5.1.2 Spinal kinematics in neck pain during functional tasks

Few studies have compared spinal kinematics in those with neck pain to asymptomatic populations during functional tasks execution (Moghaddas *et al.* 2019). A summary of these studies can be found in **Appendix B**. A common activity associated with neck pain is smartphone and computer work (Hagen *et al.* 2011). In a study to determine if neck pain sufferers had altered kinematics when texting and using a computer, it was found that during bilateral and unilateral smartphone texting tasks neck pain sufferers had greater angular displacement in cervical lateral flexion, with a trend of increased angular displacement ranges and a higher frequency of postural changes. The latter was also the case during the computer typing task (Xie *et al.* 2018).

Postural deviations in neck pain were also found during a one-hour computer typing task where in addition to lateral flexion, sustained neck flexion and rotation were found in neck pain participants, with no differences being found for thoracic posture and movements between the groups (Szeto, Straker and O'Sullivan 2005). Sustained neck flexion has been associated with a reduction in neck stiffness, delayed cervical erector spinae reflexive responses and increased angular velocity measures making the spine more vulnerable to instability and injury (Mousavi-Khatir *et al.* 2018). In contrast during a reading task, no differences were found between those with and without neck pain when assessing neck flexion angle (Constand and MacDermid 2013).

Forward or overhead reaching is an activity of daily living that requires arm and trunk coordination moving the body's centre of mass forward to the edge of the base of support (Duncan *et al.* 1990). It is also an item on several disability indices that are used to measure disability associated with neck pain (Vernon 2008; Dyrek *et al.* 2023). During a standing overhead reaching task, forward and to each side, it was found that neck pain sufferers displayed more flexed postures of their head and neck with higher velocity peaks, suggesting reduced movement smoothness, when compared to healthy controls (Moghaddas, Edwards and Snodgrass 2022). This finding contrasts with Constand (2013) who reported no differences between neck pain and controls in a one arm standing lifting task (Constand and MacDermid 2013). The main difference between these trials is that in Constand and MacDermid's (2013) study a metronome

was utilised to standardise the participant's arm motion, whereas, in the Moghaddas *et al* (2022) study, the participants executed the motion at their own pace.

When a seated one arm lifting task was assessed, no differences were found between those with and those without neck pain for cervical or thoracic displacements in all three movement planes. However, those with neck pain displayed a reduced velocity and acceleration in cervical flexion and extension during the task (Tsang, Szeto and Lee 2014). When the effect of neck pain on catching a ball was assessed, it was found that the centre of rotation was displaced in those with neck pain and that their movements were slower and with more restricted upper body motion, implying an altered movement strategy, possibly to bring stability to the cervical spine (Grip *et al.* 2008). These studies highlight the complexity of movement strategy selection (Latash *et al.* 2010) and how in pain the CNS maintains movement (Hodges and Tucker 2011).

Other functional activities that have been assessed include gait. In a review and meta-analysis (Burton *et al.* 2023), it was reported that chronic neck pain negatively impacts gait health, particularly gait speed, irrespective of whether it occurs at the person's preferred or fast speed, with large effect sizes. In addition, cadence was decreased particularly when the participants took part in dual tasks such as walking and head nodding or rotation. During gait neck pain, participants had reduced trunk rotation indicating a 'stiffer' spinal posture (Falla *et al.* 2017). The findings were less clear when immersive virtual reality environments were utilised to determine the impact of neck pain. Results from a review suggest alterations in peak and mean velocities, time to peak percentage, number of velocity peaks and movement accuracy with inconsistent results for ROM and movement response time (Luc *et al.* 2022). It has been recommended that more research should be conducted to further understand the effect of neck pain on spinal kinematics during functional tasks (Moghaddas *et al.* 2019).

2.5.2 Neck pain and altered muscle activation patterns

Falla and colleagues (2003) in a series of studies found that in neck pain there was increased fatigability of the sternocleidomastoid (SCM) and anterior scalene (AS) muscles when assessed during isometric contractions (Falla *et al.* 2003), and that

these muscles required greater activation to produce the same maximum voluntary contraction (MVC) force as those who had no neck pain (Falla *et al.* 2004a). On further investigation, they found that following an arm raising task, neck pain sufferers had delayed muscle onset timing of the deep cervical flexors and contralateral SCM and AS, findings which were not observed in healthy controls (Falla, Jull and Hodges 2004a).

To further assess the role of the deep cervical flexor muscle in neck pain, they assessed the activation of this group of muscles during the performance of the craniocervical flexion exercise and found that their activation level was lower than that seen in healthy controls (Falla, Jull and Hodges 2004b). These and other studies from this group (Falla, Jull and Hodges 2004a; Falla *et al.* 2004b; Falla and Farina 2005; Falla *et al.* 2007) highlight altered muscle activation patterns in neck pain. Lund *et al.* (1991) proposed that in chronic pain there is a reduction in muscle output when it acts as an agonist and an increased output when it acts as an antagonist, often affecting MVC, velocity and range (Lund *et al.* 1991). This, together with changes in feedforward control could potentially leave the cervical spine vulnerable to perturbations and injury (Falla, Jull and Hodges 2004a). A summary of these studies and those below can be found in **Appendix C**.

The flexion relaxation phenomenon refers to a myoelectrical silent point that occurs in the erector spinae muscles in full forward spinal flexion (Floyd and Silver 1955; Gouteron *et al.* 2022). In a portion of non-specific low back pain patients, these muscles fail to enter this latent phase (Gouteron *et al.* 2022), with suggestions that it is a biomarker for chronic low back pain (Moissenet *et al.* 2021). Investigating this phenomenon in chronic neck pain, a similar pattern was observed in the cervical extensor muscles where the muscles failed to enter a silent phase in full flexion (Murphy, Marshall and Taylor 2010; Maroufi, Ahmadi and Mousavi Khatir 2013; Pinheiro, dos Santos and Chaves 2016), suggesting a similar pattern to that observed in low back pain patients (Gouteron *et al.* 2024). This finding suggests that in chronic neck pain, there is reorganisation between the agonist, synergists and antagonist, as an adaptive motor control strategy to allow movement execution when in pain (Maroufi, Ahmadi and Mousavi Khatir 2013; Merkle, Sluka and Frey-Law 2020).

Several trials have assessed muscle activity during occupational tasks. Szeto and colleagues in two trials reported increased right UT muscle activity during resting and a computer task. Those with high discomfort display higher levels of UT muscle activity (Szeto, Straker and O'Sullivan 2005, 2009). Similar results were found for prolonged writing tasks, where increased UT muscle activity was observed in neck pain sufferers (Leonard *et al.* 2010). In addition, increased muscle stiffness has been reported in the UT muscle in neck pain, with no conclusive data for other muscles of the head and neck (Opara and Kozinc 2023). Occupational work such as working at a computer has been associated with neck (Côté *et al.* 2008). Office workers have reported a strong association between UT muscle tenderness and perceived neck pain (Brandt *et al.* 2014). Yet in instrumental musicians who have a high prevalence of neck pain (Gómez-Rodríguez *et al.* 2020), there were conflicting findings of increased UT muscle tension being associated with neck pain (Overton, Du Plessis and Sole 2018).

Falla and colleagues, in two trials involving the performance of a one arm task found that when dotting on a piece of paper, neck pain participants had increased SCM, AS and UT muscle activation compared to healthy controls (Falla, Bilenkij and Jull 2004); and during arm raising and lowering there was an increase in average conduction velocity of the UT muscle when compared to those without neck pain. When the arm task was repeatedly executed, the conduction velocity decreased more rapidly than in healthy controls, suggesting morphological changes to the UT (Falla and Farina 2005). Fatty infiltration has been found in muscles in people who suffer from chronic spinal pain (Lund *et al.* 2023; Wesselink *et al.* 2023), and is a feature of whiplash, however in chronic non-specific neck pain, disuse atrophy characterises the morphological changes of muscles of the head and neck (De Pauw *et al.* 2016). Disuse atrophy has been associated with a decrease in muscle fibre conduction velocity (Sirago *et al.* 2023). Atrophy leads to reduced strength, which was found in neck flexion, extension and lateral flexion when compared to healthy controls in those with chronic neck pain in a recent review (Miranda *et al.* 2019).

When assessing muscle imbalances in the cervical flexor and extensor muscles during cervical ROM in half cycles in neck pain, it was found that there was a general increase in both flexor and extensor muscle activity and that the flexor to extensor muscle ratios

showed an increase in flexor activity (Nobe *et al.* 2022). This study supports the work of Falla and colleagues where increased activity was observed in the cervical flexors in neck pain (Falla *et al.* 2003; Falla *et al.* 2004a; Falla, Jull and Hodges 2004a; Falla and Farina 2007), but it adds to the understanding that motor changes in neck pain are complex (Kantak, Johnson and Zarzycki 2022) and a holistic view of the involved mechanisms is an important consideration for clinical practice (Chimenti, Frey-Law and Sluka 2018).

Human motion is complex, and it is necessary to break the motion into discrete portions for analysis as there is a nonlinear relationship between myoelectric activity and movement kinematics (Kotov-Smolenskiy *et al.* 2021). For example, when assessing cervical ROM, one could consider the flexion phase as moving the head from neutral to maximum flexion and then back to neutral, however, this movement pattern consists of a flexion phase from neutral to maximum flexion, then an extension phase from maximal flexion back to the neutral starting point. The role of the muscles change during this cycle, from acting as agonists (cervical flexors working as concentric during the flexion phase) to becoming antagonistic (cervical flexors acting eccentrically in the extension phase) muscles, plus the change in the centre of gravity brings about biomechanical alterations (Cheng, Lin and Wang 2008). These factors should be considered when utilising EMG (Kotov-Smolenskiy *et al.* 2021)

2.5.3 Studies assessing the presence of spinal kinematic and muscle activation patterns in neck pain

Muscles are responsible for moving the spine through a ROM and thus the degree of displacement will modulate muscle activation level (Lascurain-Aguirrebeña *et al.* 2018b). To holistically assess motor control, one needs to examine the nervous system and how it controls posture and movement through motor, sensory, and integrative processes (van Dieën *et al.* 2019). Several trials, as detailed in **Appendix D**, have assessed both kinematics and muscle activity in neck pain.

During standing cervical ROM Lascurain-Aguirrebeña *et al.* (2018) found that those with neck pain had conjunct motion during flexion with left rotation, whereas the asymptomatic controls deviated to the right. They observed no differences in velocity

measures across groups during cervical ROM; however, the asymptomatic participants moved at a motion rate matching those with neck pain to control speed. Although not significant, the UT muscle had more activity in those with neck pain than the healthy controls, in line with other studies reporting increased UT activity in neck pain (Szeto, Straker and O'Sullivan 2005, 2009; Leonard *et al.* 2010). When assessing muscle activation patterns, the only ROM where differences between those with and without neck pain occurred was in sagittal motion. During flexion and extension, the right scalene muscle was less active in those with neck pain, but in those without neck pain there was increased activity in extension (Lascurain-Aguirrebeña *et al.* 2018b). This conflicts with the work by Falla and colleagues where increased scalene muscle activity during flexion and extension was reported (Falla, Bilenkij and Jull 2004; Jull and Falla 2016). In addition, muscle activity showed large variations within the groups, which has been previously reported (Voerman, Vollenbroek-Hutten and Hermens 2007).

Conjunct motion during prone cervical extension was assessed in those with unilateral neck pain and it was found that during early extension there was a deviation in rotation to the painful side and lateral flexion away from the painful side, differing from those without neck pain. It was also noted that there was greater displacement and delayed paraspinal muscle onset on the painful side, in those with neck pain (Park *et al.* 2017). Supporting the work of Lascurain-Aguirrebeña *et al.* (2018) (Lascurain-Aguirrebeña *et al.* 2018b) and the contemporary theory of motor adaption in pain (Hodges and Smeets 2015; Merkle, Sluka and Frey-Law 2020).

Contrary to Lascurain-Aguirrebeña *et al.* (2018), Vikne *et al.* (2013a) in people with whiplash associated disorder (WAD), reported reduced velocity and peak displacement measures when assessing the sub-phases of sagittal cervical ROM. In addition, they found that those with neck pain had reduced acceleration and movement smoothness with differences in the agonist and antagonist muscle activation patterns. When controlling for movement displacement, only velocity and acceleration differences persisted (Vikne *et al.* 2013a). In an different trial using asymptomatic participants, it was found that movement speed influenced movement smoothness, with slower motions resulting in decreased movement smoothness (Vikne *et al.*

2013b). Although tested in asymptomatic populations this study highlights the relationship between displacement, speed and smoothness of motion.

Tsang et al (2014) assessed cervical and thoracic kinematics and muscle activation patterns during a right sided, one arm lifting task. They reported that thoracic motion occurred during the task, with the neck pain group having slightly greater degrees of thoracic extension and left side flexion compared to those without neck pain, although this was not significant. No differences between the groups were found for cervical displacement in all ROMs, cervical and thoracic regional displacement, velocity and acceleration time curves ($p > 0.05$). Neck pain participants displayed lower velocity and acceleration profiles during cervical flexion ($p = 0.048$; $p = 0.024$) and extension ($p = 0.033$; $p=0.008$) movements with more participants activating almost all their muscles, except for right cervical erector spinae (CES) and left thoracic erector spinae at T9 (TES9). Higher time percentage activation for all muscles, except the right CES, occurred with the right TES4 having greater percentage activation during all phases of the task compared to those without neck pain. The greatest differences were seen during the lifting phase (Tsang, Szeto and Lee 2014). Exacerbation of motor control deficits have been shown when adding task difficulty or load (Descarreaux, Passmore and Cantin 2010; Pollock *et al.* 2014).

These trials highlight motor control issues in neck pain. The majority of studies were cross-sectional in nature and thus failed to show cause and effect (Tsang, Szeto and Lee 2014; Wang and Cheng 2020). These trials have mostly been conducted in North America, Europe and Asia, with a lack of emphasis on South African populations (Basson, Olivier and Rushton 2019). No trials were found in the published literature that assessed motor control deficiencies in neck pain in populations from Africa.

2.5.4 Measuring spinal kinematics and muscle recruitment patterns

Biomechanical assessment of human movement is measured by physiological means such as electromyography to measure muscle activity and accelerometers, gyroscopes, force transducers, electromagnetic and motion capture tracking systems to measure kinematics and kinetics (Madeleine *et al.* 2011).

2.5.4.1 Spinal kinematic assessment tools

There are various instruments used to measure cervical ROM. The Cervical ROM device is one of the most utilised tools for measuring active ROM (Thoomes-de Graaf *et al.* 2020), although it is considered an objective measure, its interpretation is via the clinician (Gajdosik and Bohannon 1987; Thoomes-de Graaf *et al.* 2020). Other devices include tape measures, eye-balling (Sukari *et al.* 2021), inclinometers (Jørgensen *et al.* 2014) and goniometers (Audette *et al.* 2010; Farooq *et al.* 2016; Wolan-Nieroda *et al.* 2020), to more sophisticated devices like electromagnetic (Jordan *et al.* 2000; Jordan *et al.* 2004), radiographic (Chen *et al.* 1999; Park *et al.* 2014), inertial sensors (Raya *et al.* 2018; Palmieri *et al.* 2023) and optical motion capture systems (Evans *et al.* 2013; Inokuchi *et al.* 2015; Song *et al.* 2018; Feng *et al.* 2019).

Differences in cervical ROM have been found depending on the device utilised to obtain the measures (Thoomes-de Graaf *et al.* 2020). Motion capture has the added advantage of detecting three-dimensional motion and allows for continuous monitoring of spinal movement (Papi, Bull and McGregor 2018). This in turn allows quantitative assessment of kinematics such as angular displacement, acceleration and velocity, which can further enhance understanding of mechanisms involved in the development and continuation of spinal pain (Papi, Bull and McGregor 2018). Most patients feel that restricted ROM is relevant to their neck pain and that its improvement is an important goal of the treatment (Thoomes-de Graaf *et al.* 2020), with patients altering their lifestyles to prevent impairment from painful neck ROM (Langenfeld *et al.* 2018).

Motion capture technologies can use either optical or non-optical systems (Yunus *et al.* 2021). Optical systems utilise cameras which detect markers, with some systems offering marker-less capturing, whereas non-optical systems measure motion based on the relative position of different body segments (Fleron *et al.* 2019) through pressure sensors, force plates or via inertial sensors (Yunus *et al.* 2021). In the literature on neck pain and kinematics, two systems are predominately utilised:

- Electromagnetic measurement systems

These systems utilise an electromagnetic field, where magnetic waves from the transponder to the base station determine the x, y and z axis position and orientation (Urbanczyk *et al.* 2021). The benefits include the ability to capture from a large volume and no requirement for line of sight (Franz *et al.* 2014). They are sensitive to magnetic material which could distort the recording and the distance between the transponder and base station deteriorates the signal over the distance (Franz *et al.* 2014). They are suitable for indoor use (van der Kruk and Reijne 2018) and have been found to have high accuracy and low error margin (Romero *et al.* 2017; Roggio *et al.* 2021). When compared to optoelectronic measurement systems (OEMS) they were found to be less accurate and performed poorly (van der Kruk and Reijne 2018) due to the superior precision, speed, and consistency of the OEMS systems (Franz *et al.* 2014).

- OEMS systems

These systems use stereophotogrammetry - which is the construction of 3-dimensional (3-D) coordinates of an object, by using photographic images from 2 or more different positions, then collating the x, y and z points (Nagymáté and Kiss 2018). These systems can use either infra-red light or reflective markers (Lim *et al.* 2015). The emitted/reflected light is detected by several cameras and used to estimate the 3D position of a marker. The same object is seen from different angles and the coordinates are synthesised (van der Kruk and Reijne 2018; Guduru and Domeika 2019).

The accuracy of the measurement depends on the experimental set-up, where at least 2 cameras must see each reflector, and the markers must be applied accurately to the anatomical area with consideration (Franz *et al.* 2014). Palpation and placement errors of a few millimetres may result in angular errors of approximately 2 degrees (de Groot 1997). Using experienced practitioners to place markers, results in better test–retest reliability than when intermediate or novice practitioners are utilised (Sinclair, Hebron and Taylor 2014). Drawbacks to a marker used technology are that the markers may become occluded, there is noise detection, and the proximity between markers may influence the quality (Lim *et al.* 2015). Skin motion can create an error in the measurement of a few degrees or millimetres and is unavoidable (Valevicius *et al.*

2018). More recently marker-less systems have been investigated and have shown promising results (Lahkar *et al.* 2022).

OEMSs are more accurate than the other systems (van der Kruk and Reijne 2018) and are considered the gold standard (Nagymáté and Kiss 2018; Roggio *et al.* 2021). The quality of the camera system and the software used with it can alter the accuracy of a system (Topley and Richards 2020). Consideration should be given to camera resolution, sample frequency and camera calibration (Chin *et al.* 2015). Calibration of the cameras allows for the configuration and reconstruction of the model of human movement (Lim *et al.* 2015).

Cameras should be placed around the testing site allowing various angles to be captured (Rahimian and Kearney 2015; Haratian 2022). In most cases, the camera configuration is made by the researcher/operator and tested to ensure minimal marker occlusion, which can be time consuming (Aissaoui *et al.* 2018). Sampling rates of 120Hz are recommended as at lower rates time intervals increase and resolution is lost resulting in less accurate results (Fallahtafti, Wurdeman and Yentes 2021).

A comparison of 10 commonly utilised OEMS systems such as Vicon®, OptiTrack® and Qualisys®, found that these systems, when compared to those from 20 years ago, have improved their accuracy, with much smaller errors. They also found that the error rate between different laboratories and systems was small, indicating that data could be shared across laboratories (Topley and Richards 2020). Modern day systems have the added benefit of software where marker replacement/switching, filling gaps, and signal filtering can be applied to improve the quality of the data captured (Topley and Richards 2020). The main drawback to these systems is that the equipment is expensive, often not portable, requires technical expertise and there is a lengthy calibration process (Al-Amri *et al.* 2018).

More recently the use of inertial measurement unit sensory systems (IMUs) consisting of accelerometer, gyroscope and magnetic sensors (Sabatini 2011) are being utilised to attain data on acceleration, velocity and direction (van der Kruk and Reijne 2018). They are lightweight, comfortable to wear (Roggio *et al.* 2021), portable and relatively inexpensive compared to other systems (Al-Amri *et al.* 2018). When assessing spinal

joint angles, moments, and reaction forces between IMUs and OEMS, they were found to be similar except for overestimation of joint moments and underestimation of joint reaction forces by 20.9% and 15.7% (Sibson *et al.* 2024). Due to lacking an absolute reference position, they can be less accurate (Lugrís *et al.* 2023).

Figure 2.5 shows the processes involved in obtaining data from motion capture, starting with camera calibration and setting the capture volume right through the pipeline to processing and cleaning the capture making it ready to be exported for analysis.

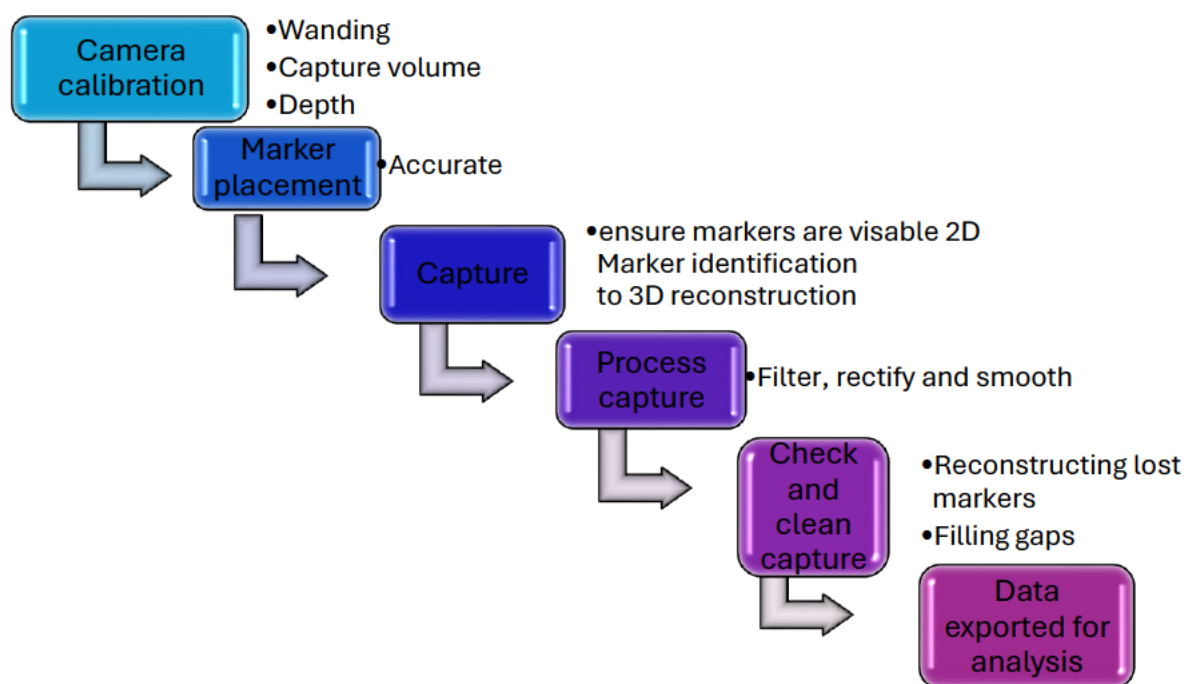


Figure 2.5: Motion Capture Pipeline

2.5.4.2 Measuring muscle recruitment patterns with electromyography

The physiological measurement of muscle activity is done via EMG using two methods: intra-muscular needles and surface electrodes placed on the skin (Farina, Fosci and Merletti 2002). EMG allows quantification of muscle activation during a movement or task and enriches the clinical evaluation by providing information on functional impairment and adaptations (Campanini *et al.* 2020). Signals received from

the central nervous system converge on the alpha motor neuron resulting in an action potential, constituting neural drive to the muscle. At the neuromuscular junction, the action potential is converted into a muscle fibre action potential (Farina and Negro 2012). This is followed by depolarisation of the outer muscle-fibre membrane at the innervation zone which travels outwards towards the tendon regions. This gives rise to an electrical field that can be detected by EMG (Merlo, Campanini and Merlo 2010).

There are two main types of EMG: Intra-muscular EMG, otherwise known as needle or fine wire, the first requires the insertion of a needle into the muscle. This needle can then detect a single motor unit action potential (MUAP) (Zieliński and Gawda 2024). One of the considerations when using EMG is cross talk. This is when the signal from the intended muscle is altered by the signal from the surrounding muscles (Mesin 2020). This is minimised when using needle EMG as the signal is only detected from the recording area (Kotov-Smolenskiy *et al.* 2021). Despite its benefits, it is an invasive method (Karacan and Türker 2024) and in some instances deemed excessive or unnecessary (Al-Ayyad *et al.* 2023).

The other method is using surface EMG. It allows for a non-invasive method (Al-Ayyad *et al.* 2023) and unlike intra-muscular EMG, it detects superimposed motor unit action potentials from many fibres, providing a weighted summation of spatial and temporal activity of the motor units (Woźniak *et al.* 2013). It is frequently utilised in research assessing cervical muscle activity (Falla *et al.* 2003; Lascurain-Aguirrebeña *et al.* 2018b; Tsang *et al.* 2018; Nobe *et al.* 2022) and is seen as a valuable tool for muscle activity acquisition (Medved, Medved and Kovač 2020). There are challenges when using sEMG such as during dynamic muscle contractions where movement occurs between the – electrode-muscle tissue interface, and the depth between the skin and the muscle i.e. adiposity (Karacan and Türker 2024).

The Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) project (www.seniam.org) and the Consensus for Experimental Design in Electromyography (CEDE) project (Besomi *et al.* 2019) provides recommendations for the type of sensors/electrodes, their placement, and location. It is recommended that the skin is adequately prepared using skin abrasion, hair removal and cleaning the

area with a 70% alcohol solution to reduce impedance (Karacan and Türker 2024). An inter-electrode distance of 2cm is recommended using electrodes that consist of silver/silver chloride with a conductive gel to enhance transmission (Merletti 1999; Cavalcanti and Taian Martins 2011; Tankisi *et al.* 2020). Electrode placement must be done to minimise cross talk, which can increase as strength increases and may vary with limb/body position changes (Karacan and Türker 2024).

EMG hardware and software needs to have an optimal 'signal to noise ratio', in other words, the neurophysiological signal voltage needs to be amplified, and the background noise attenuated (Tankisi *et al.* 2020). Myoelectrical activity occurs on the skin in a limited bandwidth between 15 to 400Hz, with an amplitude from micro- to millivolts, thus differential amplifiers are required usually in the range of $\pm 2.5V$ to $\pm 10V$. Amplifiers should also have a high input impedance ($M\Omega$) to prevent disturbance of the signal by power lines and other electrical cables. The degree of cancellation of these signals, the common mode rejection rate (Cavalcanti and Taian Martins 2011), is often between 50 and 60 Hz (Tankisi *et al.* 2020). EMG signals have a frequency range of 20 to approximately 2000 Hz and an amplitude of roughly 50 μV to 20 mV (Cavalcanti and Taian Martins 2011).

SEMG is subject to noise interference, **Figure 2.6**, the noise can arise from movement artefacts or other physiological signals. Filtering the signal allows the dampening of these signals, reducing their impact on the EMG signal (Song *et al.* 2015). Filters can be low-pass, high-pass or band-pass (Tankisi *et al.* 2020). When reporting EMG the Consensus for experimental design in electromyography (CEDE) project, produced a checklist (CEDE-Check) to assist in the consistent and comprehensive reporting of EMG (Besomi *et al.* 2024).

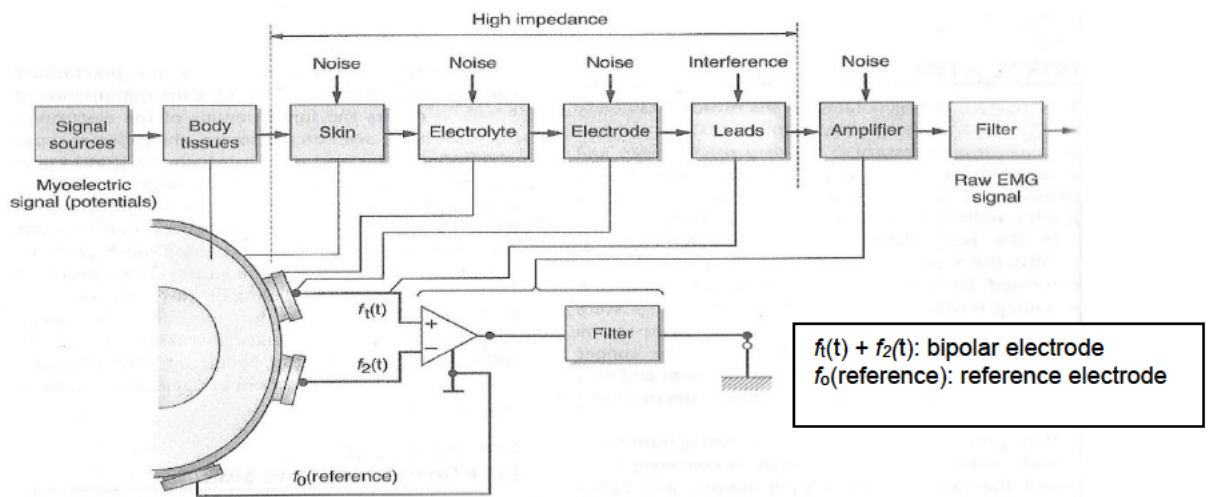


Figure 2.6: Component affecting the EMG signal prior to it reaching the differential amplifier (Soderberg, Safety and Health 1992)

To quantify the amplitude of the sEMG the raw signal needs to be processed, this is most often done using root mean squared (RMS) (Burden 2010) or average rectified value (ARV)(McManus, De Vito and Lowery 2020). RMS of the EMG signal is an estimate of the signals standard deviation and is equal to the square root of the total power within the signal. ARV of the EMG signal calculates the mean of the rectified or absolute value of the EMG signal amplitude (McManus, De Vito and Lowery 2020). This is applied as a moving average to smooth the sEMG signal and dampen random fluctuations (McManus, De Vito and Lowery 2020).

- Normalisation of the EMG signal

The procedure of normalising the EMG allows the EMG data to be compared between participants, muscles and measurement sessions, by removing features that could influence the character of the signal (Besomi *et al.* 2020) and expressing it relative to a reference value. The EMG from a task/event is divided by the EMG from the reference contraction of the same muscle (Burden 2010). This converts the magnitude of the signal from microvolts to a proportion/percentage of the reference value (Clarys 2000). Normalisation allows a repeatable measure, with the percentage of activation

being relevant to maximal activation (Besomi *et al.* 2020). There are several methods to employ normalisation, the most common are maximum voluntary isometric contraction (MVIC), dynamic EMG peak or mean to Normalization to an MVC (Burden, Trew and Baltzopoulos 2003). The method of normalisation can affect the EMG amplitude and inter-subject variability, however, when submaximal peak and mean dynamic normalisation methods were compared activation patterns across task phases were similar during walking (Commandeur *et al.* 2024).

Despite the popularity of the MVIC method it has been criticised for obtaining values in excess of 100% (Clarys 2000) and in some instances it is unreliable (Yang and Winter 1984). There are instances when MVICs are unable to be performed or the task being investigated is not suitable for using this method, such as in patients where the MVIC will result in pain (Ettinger *et al.* 2016; Zellers, Parker and Marmon 2019). Another method of normalisation is to the peak or mean activation level that is obtained by the muscle during a task that is being investigated (Halaki and Ginn 2012). This method can be used for dynamic activities like gait (Ghazwan *et al.* 2017). This method reduces the variability between individuals as it removes real biological variations between participants like strength differences (Yang and Winter 1984; Halaki and Ginn 2012). It is recommended when comparing patterns of muscle activation between individuals over time but precludes the comparison of muscle activity between muscles, tasks or individuals (Halaki and Ginn 2012). In studies assessing the effect of spinal manipulation on muscle activity in neck pain (de Camargo *et al.* 2011; Bracht *et al.* 2018) and in low back pain (Harvey and Descarreaux 2013) use the dynamic method with peak amplitude during the task for normalisation.

When assessing on/off muscle activation, a detection threshold must be set. Common methods include using a percentage of the mean root, mean squared amplitude of the EMG signal (McManus, De Vito and Lowery 2020) or using a detection point where the magnitude of the EMG signal is two to three standard deviations greater than the resting EMG and where the contraction lasts longer than 25 milliseconds (ms) (Hodges and Bui 1996). When the signal passes these thresholds, it is considered 'on', and when it drops below it is considered 'off'. Studies assessing motor tasks in neck pain

determining on/off patterns of muscle activation using EMG have utilised the latter method (Tsang, Szeto and Lee 2014) (Ghaderi *et al.* 2019).

2.6 TREATMENT OF NON-SPECIFIC NECK PAIN

The goal of neck pain treatment is to reduce pain intensity and disability (Fandim *et al.* 2021). It is recommended that patients undergo a comprehensive assessment to identify clinical findings, activity limitations and physical impairments (Blanpied *et al.* 2017). The presence of serious pathology must be assessed for and excluded as red flags and prognostic factors to delay recovery (Côté *et al.* 2016; Lin *et al.* 2020). In uncomplicated neck pain, it is necessary to reassure the patient of its benign, self-limiting nature (Côté *et al.* 2016). Management strategies should integrate clinical practice guidelines with the patient evaluation, their specific condition and concerns, motivating factors and values (Blanpied *et al.* 2017; Kjaer *et al.* 2017). Ensuring a patient centred approach is utilised with shared decision making (Côté *et al.* 2016; Lin *et al.* 2020). The use of radiological imaging should be restricted to when serious pathology is suspected, no response to conservative treatment occurs or when it is likely that the imaging will alter the treatment (Lin *et al.* 2020). Set boundaries should be utilised for the goals of the treatment with regular re-evaluations (Côté *et al.* 2016) and the use of appropriate outcome measures (Lin *et al.* 2020). The conclusion of treatment should occur when there has been no progress within 6 weeks (Bier *et al.* 2018).

A summary of recently (2016-2024) published Clinical Practice Guidelines (CPG) for non-specific neck pain is provided in **Table 2.4**. Generally, the evidence from trials of conservative management of neck pain have been reported to be low (Bussi res *et al.* 2016; Kjaer *et al.* 2017), with few well-designed trials, low participant numbers and short follow-up time frames (Bussi res *et al.* 2016), leading to an inability to strongly recommend interventions. All the guidelines recommend advice and patient education with manual therapy including manipulation and/or mobilisation utilised with exercises or part of a multimodal care programme. Only one CPG guideline recommended including thoracic spine manipulation (Blanpied *et al.* 2017), which contrasts with

recent systematic reviews where thoracic spinal manipulation has been recommended for neck pain (Masaracchio *et al.* 2019).

All guidelines recommended exercises, but the type varied from cervical ROM to supervised programmes with only one guideline including cervicospinal-thoracic exercises and neuromuscular training (Blanpied *et al.* 2017). Four GCP guidelines recommend medication (Bussières *et al.* 2016; Côté *et al.* 2016; Kjaer *et al.* 2017; Corp *et al.* 2021) often with cautionary guidelines. Psychological interventions were mostly recommended when there was a psychological component when patients were not responding and more often in cases with chronic neck pain (Bussières *et al.* 2016; Bier *et al.* 2018; Corp *et al.* 2021). Electromodalities (Bussières *et al.* 2016; Côté *et al.* 2016; Bier *et al.* 2018; Corp *et al.* 2021) and low-level laser therapy (Bussières *et al.* 2016; Bier *et al.* 2018) were the most common interventions recommended to avoid due to insufficient evidence. A Cochrane review highlighted the low to very low level of evidence for electrotherapies (Kroeling *et al.* 2013), indicating that in the last 10 years, there has been little research focus in this area to change the recommendations.

The number one research priority identified in 2019 for neck pain was establishing the effectiveness and cost effectiveness of available treatments (Silva *et al.* 2019). As seen in these GCPs many treatments for neck pain have low to very low levels of evidence due to lack of good clinical trials. For spinal manipulation, it has been recommended that future research clarifies its role either as a stand-alone treatment or as part of multimodal care, especially for recent onset neck pain (Bussières *et al.* 2016). When making recommendations there is a deficit of studies investigating dosage - these are required to optimise treatment (Bussières *et al.* 2016; Côté *et al.* 2016). Underpinning all treatment choices is that clinical reasoning should inform clinical decision making (Bier *et al.* 2018) and that this is done in a biopsychosocial, patient centred paradigm (van Dulmen *et al.* 2015).

2.7 SPINAL MANIPULATION

Spinal manipulation is a therapeutic technique that is commonly used by chiropractors, osteopaths, physiotherapists and medical physicians (Paris 2000; Pettman 2007). It falls under the broad heading of manual therapy (Smith 2007). Hippocrates (460–385 BCE) made reference to manipulative techniques, as did other healers through the centuries (Withington, Jones and Potter 1923; Pettman 2007). Spinal manipulative treatments can be classified into manipulation or mobilization-based techniques (Thomas *et al.* 2020). Both techniques target the joints, with mobilisation techniques aiming to provide repetitive oscillatory movements against a restrictive barrier, using low velocity techniques and graded from I to IV (Fryer, Carub and McIver 2004). Whereas manipulation techniques utilise a high-velocity, low-amplitude thrust technique, described as a grade 5, applied to the joint (Sran and Khan 2002; Fryer, Carub and McIver 2004), it is often associated with a ‘crack/popping’ sound known as cavitation (Dunning *et al.* 2017).

Investigations into the origins of the cavitation, led researchers to assess distractive forces applied to the first metacarpophalangeal joint while recording the events (Roston and Haines 1947; Unsworth, Dowson and Wright 1971; Watson, Kernohan and Mollan 1989; Kawchuk *et al.* 2015). It was found that when the synovial fluid was exposed to increased pressure due to the separating surfaces, a gas bubble formed in the fluid which collapsed with the rapid change in pressure (Roston and Haines 1947; Unsworth, Dowson and Wright 1971; Brodeur 1995).

Contemporary research reveals that the cavitation is a result of cavity inception, indicating that when opposing surfaces resist separation there is a critical point where the separation rapidly occurs, and this results in gas cavities – a process known as tribonucleation (Kawchuk *et al.* 2015; Chandran Suja and Barakat 2018). Kawchuk and Colleagues (Kawchuk *et al.* 2015) found that the cavitation sound occurred concurrently with the formation of the gas bubble and persisted past the sound, thus indicating that it is not the collapse of the gas bubble but rather its formation that makes the cavitation sound. This is contradicted by Chandran Surja and Barakat (2018) (Chandran Suja and Barakat 2018) where, through acoustic waveform patterns, they

indicated that the sounds are consistent with gas bubble collapse. Once a cavitation has occurred it does not take place again until after about 20-minute (Unsworth, Dowson and Wright 1971).

Table 2.4: Summary of conservative clinical practice guidelines for neck pain

Author	Duration	Advice and education	Manual therapy	Mobilization/manipulation	Exercise	Other	Avoid/low evidence
Bussi��res et al 2016 (Bussi��res <i>et al.</i> 2016)	0-3 months	√	√	√	√ ROM home exercise, Grade III supervised graded strengthening	√ Medication	Cervical collar, LLLT
	>3 months	√	√ Multimodal with massage, traction, TENS, acupuncture, heat, exercise, and/or U/S	√ Multimodal care; manipulation with soft tissue therapy	√ Supervised graded/group strengthening + home	√ High-dose massage √ Supervised yoga √ Stress mx	Education – more studies are needed Used alone the following require more research: LLLT, TENS, cervical traction
C��t�� et al 2016	≤ 3 months	√ structured education	N/S	√ *multimodal care with unsupervised CROM	√ *ROM	√ Reassurance √ *Muscle relaxants	Structured patient education alone, strain-counter strain, relaxation massage, cervical collar, clinic-based heat, electroacupuncture/therapy
	> 3 months				√*Supervised	√*Supervised qigong, Iyengar yoga, clinical massage, LLLT √*NSAIDs	In addition to the above: TENS, EMS, relaxation therapy, clinic-based strengthening exercises, pulsed

Author	Duration	Advice and education	Manual therapy	Mobilization/ manipulation	Exercise	Other	Avoid/low evidence
							shortwave diathermy, botulinum injections
Kjaer et al 2017 (Kjaer <i>et al.</i> 2017)	< 3 months	√	√ alone/ combination with un/supervised exercise	√ with ROM exercise	√ Supervised	√ Acupuncture √ **NSAID oral/topical, **opioids	Massage
Blanpied et al (Blanpied <i>et al.</i> 2017)	Acute/ sub-acute	General fitness + stay active	N/S	√ Cervical mobilization/ manipulation √ Thoracic manipulation	√ ROM, stretching + isometric strengthening √ Supervised CST + upper extremity stretching, endurance + strengthening training	N/S	N/S
	Chronic	"Stay active" lifestyle approach		√ Cervical mobilization/ manipulation √ Thoracic manipulation	√ CST + SMT √ Mixed exercise for CST regions √ Neuromuscular exercise: stretching; coordination, proprioception, postural + endurance training; strengthening; aerobic conditioning; + cognitive element √ Supervised individualized	√ DN, LLLT, pulsed or high-power U/S, intermittent mechanical traction, repetitive brain stimulation, TENS, EMS	N/S

Author	Duration	Advice and education	Manual therapy	Mobilization/ manipulation	Exercise	Other	Avoid/low evidence
Bier et al 2018 (Bier <i>et al.</i> 2018)	N/S	✓	N/S	✓ with exercise		✓ Cervical collar for grade III, massage, neurodynamics/ neural tissue mx, pillow, KT, thermal agents, workplace interventions ✓ if not responding/ with a dominant psychosocial profile	DN, LLLT, electrotherapy, U/S, traction, cervical collar for grades I and II
Corp et al 2020 (Corp <i>et al.</i> 2021)	N/S	✓ with physical activity and education	✓ with exercise	N/S	✓	✓ Reassurance ✓ Multidisciplinary treatment for subgroups ✓ Oral analgesia, opioids ✓ subgroups with psychological risk factors to be addressed	Manual therapies without additional active treatments, traction, electro/thermotherapies, cervical orthosis, acupuncture/DN

(SMT-manipulation and/or mobilisation; N/S – not specified; DN-Dry needling; LLLT-low-level laser, TENS-transcutaneous electrical nerve stimulation; EMS-electrical muscle stimulation; U/S-ultrasound; mx-management; KT-Kinesiotape; CST- Cervico-scapulothoracic; *Only one of these with advice; **Careful consideration – not first choice)

Irrespective of how the 'crack/popping' sound is made, the literature is inconsistent about the role of cavitation and its relationship with the effects of HVLA manipulation (Flynn *et al.* 2003; Moorman and Newell 2022). Many randomised controlled trials include that should they not hear joint cavitation during the application of HVLA manipulation they would allow for another attempt at providing manipulation at the same joint to ensure the 'success' of the technique (de Camargo *et al.* 2011; Lopez-Lopez *et al.* 2015; Pires *et al.* 2015; Bracht *et al.* 2018). It has been recommended that cavitation should not be a necessary requirement for determining that the SMT resulted in a mechanical effect, but that it is an indicator that joint gapping has taken place (Evans 2002).

2.7.1 Spinal manipulation and neck pain

As highlighted in Section 2.6, clinical practice guidelines recommended spinal manipulation as a conservative treatment for neck pain, often as part of multimodal care. In two recent systematic reviews on spinal manipulation for acute (Chaibi, Stavem and Russell 2021) and chronic neck pain (Coulter *et al.* 2019) the level of evidence was found to be limited with high heterogeneity. In acute neck pain manipulation was recommended to be utilised either alone or as part of a multimodal approach (Chaibi, Stavem and Russell 2021), whereas in chronic neck pain, the literature favoured its use with exercise or multiple treatment approaches (Coulter *et al.* 2019). As with all treatments, there are risks of side effects (Nielsen *et al.* 2017). Side effects can range from minor and transient effects such as mild discomfort, transient neurological effects, and headaches, to serious effects such as spinal cord injury or death (Carlesso *et al.* 2010; Puentedura *et al.* 2012; Nielsen *et al.* 2017). Most adverse effects resolve within 24 to 72 hours (Carnes *et al.* 2010). A recent review reported the incidence of serious adverse events to range from 1 in 20 000 to 1 in 250 000 000, using the patient as the unit (Nielsen *et al.* 2017). In reviews where adverse events were reported it was found that 46% (n=54) reported SMT to be safe, 13% (n=15) found it harmful and 42% were neutral/unclear about its safety status, however in some cases the reviews provided low evidence and often consisted of case reports where causality cannot be inferred (Nielsen *et al.* 2017). Prior to utilising SMT, chiropractors and manual therapists, undertake a comprehensive clinical examination

to identify and assess the risk-benefit of utilising this technique (Kranenburg *et al.* 2017).

2.7.2 Joint dysfunction / Manipulable lesion

SMT is directed at an area of the spinal column, or appendicular skeleton, where dysfunction is identified through manual palpation of surrounding soft tissues and reduced motion is identified in the joint (Najm *et al.* 2003; Pickar and Bolton 2012). It has been referred to as the manipulable lesion (Triano *et al.* 2013), vertebral subluxation (Haavik *et al.* 2021), functional spinal lesion (Triano 2001) and in the ICD-10 code book, as the biomechanical lesion (WHO 2019). The dysfunction is characterised by 'PARTS' – pain or tenderness, asymmetry or alignment, altered ROM, changes in tone, texture or temperature of the soft tissues and positive special tests (Bergmann and Finer 2000). This results in central segmental motor control issues due to maladaptive neural plastic changes resulting in the dysregulating of neuromuscular function (Haavik *et al.* 2021). Detection of spinal dysfunction can be done via static palpation of bony landmarks, passive and active ROM testing (Najm *et al.* 2003), pressure applied to the zygapophyseal joints (Schneider *et al.* 2013), spinal stiffness (Hofstetter *et al.* 2018), and passive intervertebral motion (Schneider *et al.* 2013) or motion palpation (Nyberg and Russell Smith 2013). The validity and reliability of these tests have been questioned with one review reporting that pain provocation tests were more reliable than palpatory diagnostic tests and that regional ROM testing is better than segmental assessments (Seffinger *et al.* 2004). Several researchers support that intra-examiner reliability is better than inter-examiner reliability (Seffinger *et al.* 2004). The assessment of motion palpation has been difficult to measure in human participants (Najm *et al.* 2003). In response to this, Humphreys and Colleagues, using a patient with a congenital block vertebra as a 'gold standard' found that novice examiners were able to accurately detect the inter-segmental fixations, providing validity for motion palpation as a clinical tool (Humphreys, Delahaye and Peterson 2004). Despite these findings, reviews are inconclusive regarding the validity and reliability of these techniques (Huijbregts 2002; Triano *et al.* 2013; Nolet *et al.* 2021).

The HVLA thrust technique consists of three components: a preload – where the pressure on the joint is increased to remove tissue slack, the thrust – which is where the manipulative force is applied; and lastly the resolution phase (Evans and Breen 2006; Gyer *et al.* 2022). During preload and the thrust phase, somatosensory structures are activated, resulting in a cascade of neurophysiological responses (Pickar 2002; Pickar and Bolton 2012). A review assessing the dosage and frequency effects of SMT found that for cervicogenic headaches and back pain, increasing the frequency of treatment resulted in improved pain and disability outcomes (Haas *et al.* 2018; Pasquier *et al.* 2019).

When dosage was assessed, vertebral displacement and muscular amplitude responses were higher when the SMT force increased, similar findings were not reported for pain pressure threshold measures. The relationship between these changes and clinical outcomes has not been investigated (Pasquier *et al.* 2019). The heterogeneity and varied characteristics of clinicians applying SMT affect the comparability of time-force profiles of SMT (Gorrell *et al.* 2023) (Pickar and Bolton 2012) but at the same time represent the rich diversity that occurs in clinical practice where clinicians selected the appropriate technique for the patients (Gorrell *et al.* 2023). The site of SMT application has also received attention with a basic science trial on anaesthetised cats, showing that when HVLA-SMT is applied at the site of joint dysfunction, a muscle spindle response occurs in the paraspinal muscles, and if delivered to segments 2 vertebrae away from the level of afferent input, can still result in muscle responses of 60 to 80% of those seen when the thrust is delivered at the site of afferent input (Reed and Pickar 2015). A recent systematic review found that clinical outcomes did not seem to be superior when SMT was applied to a ‘clinically relevant’ site as compared to one that was seen as ‘not clinically relevant’ (Nim *et al.* 2021). This may be due to the muscle spindle responses observed by Reed *et al.* (2015) when a site distant from the one seen as ‘clinically relevant’ still resulted in spindle responses.

Due to the nature of SMT, finding a suitable placebo with which to compare has been difficult (Hawk and Long 2000; Vernon *et al.* 2005). In an attempt to do this, some researchers have utilised passive cervical spine lateral flexion, rotation and slight

extension without preload and thrust (Haavik-Taylor and Murphy 2007; Christiansen *et al.* 2018), where others have utilised the drop-piece function on a chiropractic bed (Vernon *et al.* 2005). For the intervention to be plausible, it has been recommended that it consist of skin or body contact, motion and mechanical load similar to that used in the actual treatment with an appropriate sound associated with the actual treatment (Vernon, Puhl and Reinhart 2011). Experts disagree on what an appropriate placebo should be when compared to SMT (Hancock *et al.* 2006).

2.7.3 Theories explaining the effects of spinal manipulation

Despite many investigations into the underlying mechanism of SMT, the exact mechanisms through which it brings about its effects remain unclear (Gyer *et al.* 2019). Theories are divided into two categories: those related to biomechanical effects and those related to neurophysiological mechanisms. The biomechanical theories included the releasing of entrapped synovial folds or meniscoids, breaking down of articular or periarticular adhesions, ‘unbuckling’ of motion segments, and relaxation of hypertonic muscles due to swift stretching (Shekelle 1994). In a critical review of these theories, Evans (2002) argues that only one theory - the releasing of entrapped synovial folds/meniscoids - was plausible as a mechanical model explaining SMT. He also unpacks the effect of SMT on hypertonic muscles highlighting that this effect is mediated neurophysiologically as opposed to the mechanical event of ‘stretching’ (Evans 2002). The mechanical effects of SMT may have more to do with how it is applied, in other words, the dose and frequency rather than the effects of the ‘thrust’ (Gyer *et al.* 2019; Pasquier *et al.* 2019; Gyer *et al.* 2022; Gorrell *et al.* 2023).

In the last 20 years, exploration of the neurophysiological effects responsible for manipulation has increased substantially, resulting in a paradigm shift (Gyer *et al.* 2019). Peripheral, spinal and supraspinal structures have been hypothesised to be modulated by a cascade of neuronal activity following the mechanical event of SMT (Pickar 2002; Pickar and Bolton 2012; Gyer *et al.* 2019; Wirth *et al.* 2019; Gevers-Montoro *et al.* 2021b; Haavik *et al.* 2021).

2.7.3.1 Muscular-reflexogenic effects

A series of studies found reflexogenic effects following HVLA thrust (Herzog *et al.* 1995; Herzog, Scheele and Conway 1999) and Activator Instrument (Symons *et al.* 2000). The effects from HVLA thrust were more widespread, affecting local and distant muscles (Herzog, Scheele and Conway 1999), whereas those induced by the Activator Instrument were more local (Symons *et al.* 2000; Colloca and Keller 2001). The wider effects were attributed to multiple receptors such as those in the skin, joint capsule, proprioceptors: muscle spindles and Golgi tendon organs (Herzog, Scheele and Conway 1999), whereas those induced from the Activator Instrument appeared to come from muscle spindles (Symons *et al.* 2000). It was suggested that the reflexogenic effects may be linked to a reduction in pain, muscle hypertonicity, and improved functional ability (Herzog, Scheele and Conway 1999; Symons *et al.* 2000), yet, as these studies were performed in asymptomatic participants, further investigation in symptomatic populations is required.

Colloca and Keller (2001) supported these findings in a trial on LBP patients subjected to mechanical force and manually assisted spinal manipulative therapy (MFMA). They reported local muscle responses which were greater when applied to the transverse process than over the spinous process, with those with more frequent and severe LBP having more marked responses (Colloca and Keller 2001). This trial lacked a comparison group. Due to the nature of the MFMA, the authors indicated that the rate of change in force and deformation of the tissues were important characteristics of the manipulation over force and stretch magnitude (Colloca and Keller 2001). Several studies support that altering the force applied during the phases of the SMT affects the EMG amplitude response, indicating a dose-response (Colloca *et al.* 2006; Nougrou *et al.* 2014; Pagé *et al.* 2014; Pagé, Nougrou and Descarreaux 2016; Pasquier *et al.* 2019). In contrast to Colloca (2001), Currie *et al.* (2016) found that the reflexogenic muscle effects in those with LBP were less and that they had longer muscle activity onset delays, although these were not significantly different to the asymptomatic group (Currie *et al.* 2016). Page *et al.* (2016) reported no between group differences for neuromuscular responses, similar to Potter *et al.* (2010).

In Potter et al's (2010) study they utilised three treatment sessions with differences only occurring at the third treatment. In this study, the sham consisted of a 'similar thrust that was applied non-specifically'. The use of this sham may explain why no between group differences were observed. It has been reported that applying SMT to a non-clinically relevant joint can result in similar outcomes, to when it is applied to a clinically relevant joint (Reed and Pickar 2015; Nim *et al.* 2021) and that the application of SMT has effects beyond the application site (Herzog, Scheele and Conway 1999; Currie *et al.* 2023). Thus, potentially explaining why the treatment effect may have only been seen following the third intervention.

The presence of muscular effects distant to the site of SMT application have been reported (Herzog, Scheele and Conway 1999; Pagé, Nougrou and Descarreaux 2016). These responses decrease in amplitude and onset timing the further from the contact site they occur (Currie *et al.* 2023). Page et al (2016) using large sEMG assays they were able to topographically represent the neuromuscular effects that occurred following the very specific SMT applied solely to L3, using a servo-controlled linear actuator motor. They suggested these effects may result from adjacent vertebral displacement that creates a regional musculotendinous stretch or via inter-neuronal connections where sensory information is extended over several spinal levels.

Korr (1975), in an attempt to explain the neurophysiological mechanisms through which joint dysfunction occurred, proposed a theoretical model whereby altered paraspinal muscle activity occurred as a result of increased γ - motoneuron discharge. This discharge increased the sensitivity of the paraspinal muscles to stretch, activating the α -motoneurons supplying the paraspinal muscles. SMT then brought about its effect by 'resetting' the γ - bias through high-frequency discharge of the muscle spindles and GTO afferents (Korr 1975; Pickar and Wheeler 2001).

Supporting this theory, Pickar and Colleagues, in a series of studies applying a manipulative-like load on the L6 spinous process in anaesthetised cats found that GTO afferents were silent, except for during the thrust phase whereas muscle spindle afferents were active throughout the HVLA-SMT, with greater discharge rates occurring during the thrust phase, followed by a 4-sec silent period in the recovery

phase, before returning to normal discharge (Pickar and Wheeler 2001). The muscle spindle response was greater than that typically generated by group Ia and II afferents with conduction velocities indicating a rate where the paraspinal spindle discharge rate was more sensitive to changes in velocity than length (Pickar and Kang 2006). The amplitude of the thrust impacted muscle spindle responses with amplitudes of 1mm resulting in twice the discharge than those of 2mm, indicating that HVLA SMT uses the inherent properties of the muscle spindles to bring about its effects (Pickar *et al.* 2007). This afferent discharge was postulated to result in reflex inhibition or dis-facilitation of the α -motoneurons (Pickar and Wheeler 2001), **Figure 2.7**, however, regardless of the duration or amplitude of the HVLA thrust, paraspinal muscle spindles did not respond to changes in vertebral movement or position (Cao *et al.* 2013), indicating that the changes following SMT are more neurophysiological than mechanical in nature.

It has been shown that the biomechanical responses to SMT are mostly likely modulated by the total amount of force applied to the spine (i.e. preload plus thrust force), whilst neuromuscular responses are mostly affected by the rate of force application with peak forces exceeding 200 to 300 newtons' (N) resulting in neuromuscular responses (Nougarou *et al.* 2016). When spinal segments were fused, resulting in intervertebral joint fixation, there were decreased paraspinal muscle spindle responses to a HVLA-SMT thrusts applied at a clinically relevant duration (≤ 150 ms), indicating that motion was necessary to induce spindle response during the thrust phase (Reed and Pickar 2015). The preload phase of the SMT is not inert. The duration of preload influences the sensory input from muscle spindles during the thrust phase less so than the magnitude and downward incisural point (Reed *et al.* 2014).

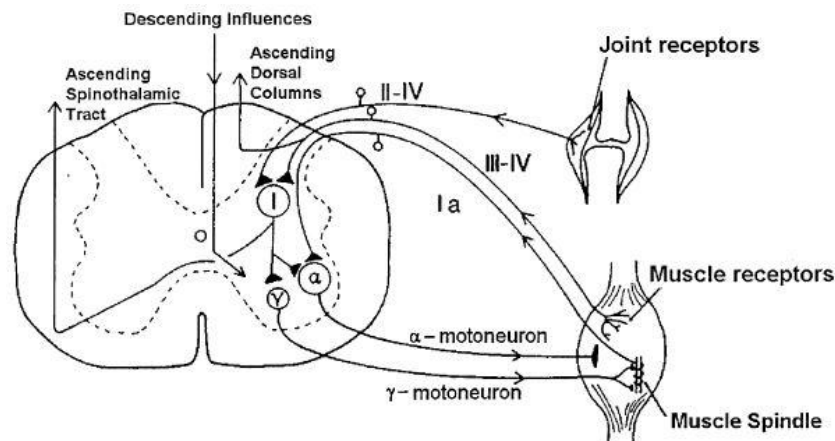


Figure 2.7: Sensory pathways that could modulate γ motoneuron discharge.

2.7.3.2 Motor neuron activity

Several studies using sEMG and kinematic assessments in LBP sufferers to assess changes in the flexion-relaxation phenomena (FRP) following a single spinal manipulation found that at full flexion paraspinal muscles sEMG decreased (Lehman and McGill 2001; Lalanne, Lafond and Descarreaux 2009; Bicalho *et al.* 2010) with an increase in flexion relaxation ratio (FRR) in the SMT group when compared to a control group (Lalanne, Lafond and Descarreaux 2009; Bicalho *et al.* 2010). This indicates a normalisation of muscle activity at the end of the flexion range. Differing results were found by Harvey and Descarreaux (2013) using a similar methodology, whereby the control group had increased sEMG activity and pain after the third flexion-extension cycle at 30min when compared to the SMT group. It was proposed that SMT had either a pain modulatory effect reducing sensitisation that occurred with repeated motions or that SMT resulted in an anti-fatiguing effect during the repeated flexion-extension cycles. These trials also assessed kinematics by determining the onset and cessation of the FRP (Lalanne, Lafond and Descarreaux 2009); lumbar spine ROM (Lehman and McGill 2001) and lumbar to hip ratio (Harvey and Descarreaux 2013). None of the trials reported significant spinal kinematics (Lehman and McGill 2001; Lalanne, Lafond and Descarreaux 2009; Harvey and Descarreaux 2013).

The effect of SMT on FRP in neck pain has been understudied with only one study (Murphy, Marshall and Taylor 2010) assessing FRP in chronic neck pain patients

following cervical manipulation, combined with an 8-week exercise programme. At 12 weeks, increased FR ratios were found in the combination group, with the exercise alone group showing a decrease. Feedforward activation of the SCM improved in both groups with only the exercise alone group showing improvement in the AS, no inter-group statistical analysis was reported as the pilot study aimed to determine effect sizes for an RCT. This study suggests that SMT in the cervical spine has a similar effect to that in LBP.

In terms of hypertonicity, SMTs were found to reduce areas of hypertonicity in the paraspinal muscles post-activator instrument manipulation (DeVocht, Pickar and Wilder 2005), reduce spasticity in cerebral palsy (Shestopalova and Voloshyn 2019) (Kachmar, Voloshyn and Hordiyevych 2016; Kachmar *et al.* 2018) and that occurring post-stroke, although these results require further evaluation (Valente *et al.* 2014). Spasticity occurs due to increased tonic stretch reflex from abnormal intraspinal processing of the primary afferent inputs, reducing inhibition of Ia-afferents on spinal motoneurons (Kachmar *et al.* 2018), thus that spinal manipulation impacts this type of spasticity, it may support the effect of it on muscle spindles and Golgi tendon organs, however, further research is required to understand the mechanism (Shestopalova and Voloshyn 2019).

Mixed results are reported for resting sEMG activity in asymptomatic participants. No significant differences were found for cervical HVLA SMT compared to muscle energy technique on muscle activity of the upper trapezius and posterior cervical muscles, but CROM increased similarly in both groups (King, Docrat and Abdul-Rasheed 2022). Following application of Activator Instrument to the lumbar spine, compared to a sham, resulted in decreased paraspinal muscle resting EMG on the side where the treatment was administered. They also showed a trend of increasing pain pressure thresholds (PPT) which was both local and widespread (Yu *et al.* 2012).

A critical review supported the use of lumbar spine SMT to immediately increase lower-limb strength, although the review only included 3 trials (n=115) (Wong *et al.* 2020). A review of trials on healthy individuals to assess the effect of SMT on muscle strength reported that SMT augments the percentage change in isometric strength

gains when compared to no intervention/sham manipulation (Lo *et al.* 2019), the review only included 3 trials. In contrast, a review of the effects of SMT on sports performance found that there was insufficient evidence to support its use and that further studies were required. Four out of 7 trials included, reported improvement in sports performance (Botelho *et al.* 2017) ranging from improved kicking speed in soccer players (Deutschmann, Jones and Korporaal 2015), grip strength in judo athletes and (Botelho and Andrade 2012), full swing range in golfers (Costa *et al.* 2009) and hip extension but not running velocity in young male athletes (Sandell, Palmgren and Björndahl 2008).

In terms of trials linked to the spine Keller and Colloca (2001) found increased sEMG activity during maximum voluntary contraction (MVC) of the paraspinal muscles following MFMA manipulation when compared to sham or a control (Keller and Colloca 2000). In an observational study, increased lumbar multifidus thickness on contraction during a submaximal task following SMT was seen (Koppenhaver *et al.* 2011). It was postulated that SMT may affect the α -motor neuron system either by facilitation or inhibition through mechanisms in the peripheral, spinal and central nervous system. In asymptomatic (Cleland *et al.* 2004) and neck pain/cervicogenic headache sufferers (Metcalf, Reese and Sydenham 2006) a reduction in muscle inhibition was found in the lower trapezius and anterolateral neck flexors, respectively, following locally applied SMT. Similarly, in participants with a 15% strength difference between hip muscles, SMT applied to muscle spinal innervation levels resulted in a reduction of weak to strong muscle imbalances and improved hip abductor muscle strength (Chilibeck *et al.* 2011).

These studies suggest that SMT can affect motor neuron excitability possibly through mechanoreceptor activation in paraspinal tissues, impacting muscle spindles or Golgi tendon organs discharge, altering pain tolerance or sympathetic nervous system activity (Pickar and Bolton 2012; Gyer *et al.* 2019). Contrasting results were found by Cardinale *et al.* (2015) where they reported no between group differences for force fluctuation tasks or during a modified Sorensen's test, although a trend of an effect was seen for plantar flexion force (Cardinale *et al.* 2015), possibly due to insufficient power in the study due to a small sample size.

Using a different methodology where Soleus muscle evoked V-wave, H-reflex, and M-wave recruitment curves were assessed together with sEMG and MVC, found that sEMG signals during MVC and absolute force increased following SMT and lasted for 30 minutes compared to the control group. The MF power spectrum analysis also showed that the control group had a decrease, indicating fatigue, which did not occur in the SMT group. V-wave assessment (V/max ratio) showed a significant increase in the SMT group with a decrease in the control group, indicating that the cortical drive was increased. This study highlighted that SMT either increased the participant's confidence to increase force output during MVC and/or that motor neuron recruitment patterns were altered from descending drive or afferent modulation (Niazi *et al.* 2015).

Arthrogenic muscle inhibition (AMI) is also an important component to consider. Following joint injury which can result from tissue damage, joint laxity, effusion, pain or inflammation, there is a disruption between the neural signalling from joint receptors to the CNS resulting in inhibition of the surrounding muscles – known as AMI (Hopkins and Ingersoll 2000; Lepley and Lepley 2022; Norte, Rush and Sherman 2022). This weakness and failure of activation occurs due to a decrease in the available motor neurons that can be recruited (reduced motor neuron pool excitability) (Klykken *et al.* 2011), and a reduced ability of normal voluntarily motor neuron recruitment (central activation failure) (Lisee *et al.* 2019), **Figure 2.8**. This response is reflexive and mediated in the spinal cord via presynaptic mechanisms (Hopkins and Ingersoll 2000). A combination of pain, deafferentation and swelling results in a more pronounced effect (Davi *et al.* 2020). During the chronic phase of recovery, decreased output from the motor cortex to the peripheral muscles has been found with brain activity patterns being diverse in people recovering from a joint injury leading to changes in cognitive exertion and attention, leading to the visual system overcompensating during modest motor tasks (Baumeister, Reinecke and Weiss 2008; Norte, Rush and Sherman 2022). Maladaptive neuroplasticity arising from AMI is theorised (Lepley and Lepley 2022; Norte, Rush and Sherman 2022).

The effect of sacroiliac joint manipulation on AMI was assessed in people with quadriceps muscle inhibition and anterior knee pain, where following SMT there was a reduction in muscle inhibition when compared to a control group with a non-

significant increase in muscle force output (Suter *et al.* 2000). Similar results were found in chronic neck pain sufferers with muscle inhibition of the biceps brachii muscle, where following cervical SMT there was decreased inhibition and increased muscle force output (Suter and McMorland 2002), although this trial did not have a control group. The authors suggested that the thrust leads to activation of mechano-receptors and proprioceptors in and around the joint, leading to increased afferent input, that then alters motoneuron pool excitatory and efferent output to the extremities, resulting in decreased muscle inhibition (Suter *et al.* 2000; Suter and McMorland 2002). Niazi and Colleagues following a series of investigations into muscle strength changes post-SMT suggest that the changes are a result of somatosensory processing occurring supraspinally resulting in altered motor unit recruitment (Niazi *et al.* 2015; Niazi *et al.* 2020; Robinault *et al.* 2021).

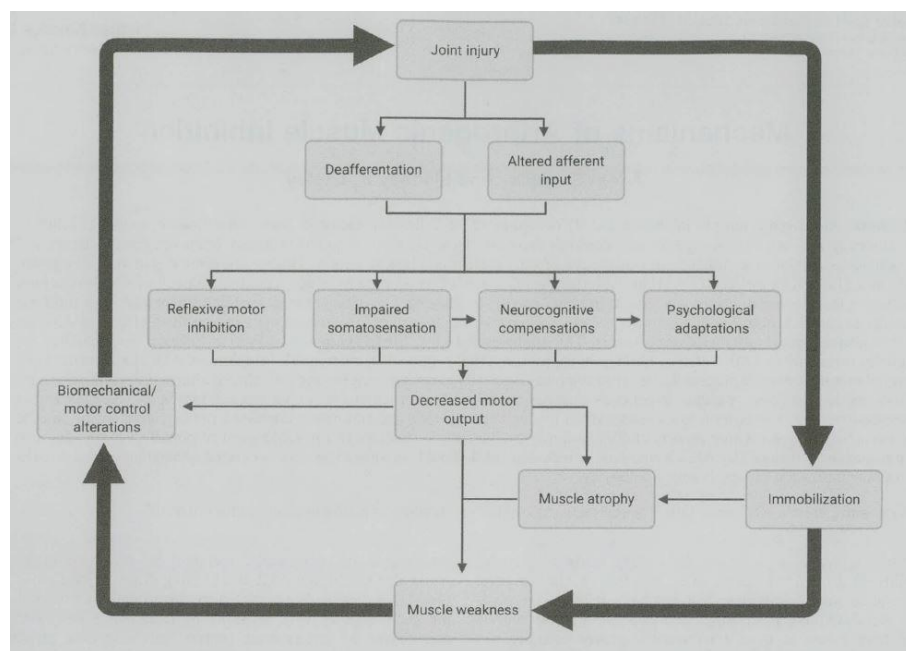


Figure 2.8: Theoretical model explaining the arthrogenic muscle inhibition paradigm (Lepley and Lepley 2022)

2.7.3.3 Excitability of the motoneuron pool (Hoffmann's reflex / corticospinal track)

Several authors have assessed the effect of SMT by motor evoked potentials (MEP) elicited from transcranial magnetic stimulation (TMS)(Dishman, Ball and Burke 2002;

Dishman, Greco and Burke 2008; Clark *et al.* 2011; Fryer and Pearce 2012) and Hoffmann's reflex (Dishman and Bulbulian 2000; Suter, McMorland and Herzog 2005; Fryer and Pearce 2012) in order to assess the effect of SMT on the spinal cord and supraspinal structures. Measuring cortical drive to the gastrocnemius, Dishman and Burke (2002) found significant facilitation as measured by MEP, post-SMT which lasted 20 to 60 seconds (Dishman, Ball and Burke 2002), indicating excitability in the motoneuron pool. Assessing, if similar effects occurred in the spinal muscles of asymptomatic participants, MEP of the ES were assessed following SMT, a control and a preloading procedure with no thrust, a transient spike in MEP at 10-sec post-SMT was found with no changes in the other groups, supporting an excitatory reflexogenic effect of SMT on the motoneuron pool of the erector spinae muscles (ES) from afferent bombardment from SMT (Dishman, Greco and Burke 2008).

This contrasted with results obtained by Clarke *et al* (2011), where asymptomatic and chronic LBP sufferers were assessed for MEP amplitude or short latency reflex effects in the ES muscles post-SMT where no differences were found. The MEP was measured 10 minutes' post-manipulation, where the 10-sec spike seen by Dishman *et al* (2008) would have been missed. In a cross-over RCT in asymptomatic participants, Fryer *et al*'s (2004) results contrasted with those of Dishman (2000) where they found following lumbosacral HVLA that there was a significant decrease in corticospinal excitability, as measured by the MEP/M wave ratio. The discrepancy in these results is unaccounted for.

Several trials have shown a decrease in Hoffmans reflex (H-reflex) following SMT in asymptomatic (Dishman and Bulbulian 2000; Fryer, Carub and McIver 2004) and low back pain (Suter, McMorland and Herzog 2005) participants indicating inhibition of the motoneuron pool affecting alpha motor neuron activity. When H-reflex and MEP/M ratios were assessed, a larger response in H-reflexes was seen indicating that SMT had a larger effect at the SC than in the corticospinal tracts (Fryer, Carub and McIver 2004). In contrast, Suter *et al* (2005) observed no changes in H-reflex in asymptomatic participants, like that reported by Groisman *et al* (2014) (Groisman *et al.* 2014), but when conducted in LBP participants the H-reflex decreased immediately following

SMT, with different patterns of recovery being seen in the participants, with some remaining below the baseline threshold and others going beyond it.

Niazi et al (2015), in subclinical spinal pain patients, found that the threshold for H-reflex was lowered following SMT suggesting that following Ia primary afferent input either the low-threshold motoneurons became more excitable or the synapse became more efficient allowing a lower stimulus to activate the same motoneuron (Niazi *et al.* 2015). This study was unique as it did not only assess the H-reflex peak but looked at the threshold for firing of the H-reflex. Supporting this, but using a different methodology, a single SMT resulted in altered amplitude and number of I-waves (signalling trans-synaptic activation of the pyramidal tract neurons) from identical SMUs, a finding that did not occur in the control situation. Indicating that SMT can alter the firing threshold of low-threshold motor units (Haavik *et al.* 2018).

2.7.3.3 Somatosensory processing

Assessing somatosensory evoked potentials (SEP) following median nerve stimulation, Haavik and Murphy (2007) found reduced parietal N20 and frontal N30 SEPs in those receiving SMT when compared to controls who had no changes. These changes lasted for 20 min, with no changes seen in the N9 peripheral peak which relates to the brachial plexus. The N20 parietal SEP is generated in the somatosensory cortex (S1) and depression of this SEP was thought to result from inhibition affecting the 3b pyramidal cells. The N30 frontal SEP is related to the cortical and subcortical loops, linking the basal ganglia, thalamus, pre-motor areas, and primary motor cortex (Rossini *et al.* 1989), and is suggested to reflect sensorimotor assimilation (Rossi *et al.* 2003). The decreased activity in this area following SMT was postulated to be a result of Ia afferent bombardment at the SC resulting in central inhibition (Haavik-Taylor and Murphy 2007), as the frontal N30 has been found to be sensitive to Ia afferent input (Hoshiyama and Kakigi 2000; Haavik-Taylor and Murphy 2007).

Further research by these authors found that the same two brain areas (P22 and N30) had decreased activity following dual somatosensory input from the median and ulna nerves with no changes in the control group's SEPs. Whereby surround-like inhibition

leads to altered cortical integration suppressing the volley of input in the lemniscal pathway at the cortex (Taylor and Murphy 2010a). This was confirmed when participants underwent a motor task (typing) following cervical SMT with thumb abductions versus thumb abductions alone. Those receiving SMT prior to the task had reduced dual input to the P22-N30 area, in terms of the MU/M+U SEP peak ratio, indicating increased suppression. The cervical SMT resulted in an improved ability to integrate dual input from the upper limb by altering sensorimotor integration at the cortex during a functional task. In addition, this study showed that subclinical neck pain participants had an inability to suppress the dual SEP input at the cortical level after a 20 min typing task (Taylor and Murphy 2010b). These trials allude to the role of SMT in modifying somatosensory processing.

2.7.3.4 Central motor excitability

Assessing cortical drive to upper and lower limb muscles using TMS and MEPs to the abductor pollicis and tibialis anterior muscles, Haavik et al (2017) found that SMT of the cervical and full spine resulted in increased MEPmax but not F-waves, with movement related cortical potentials significantly increasing following full spinal manipulation. Indicating that SMT resulted in short term changes in cortical excitability and that it potentially affected the balance between excitatory and inhibitory components of the corticospinal drive, influencing muscle strength (Haavik *et al.* 2017). The complexity of eliciting a motor task, although originating in the motor cortex could be influenced by descending pathways from corticospinal projections other than those from the M1 (Bestmann and Krakauer 2015) and may explain the lack of spinal cord response noted in this study.

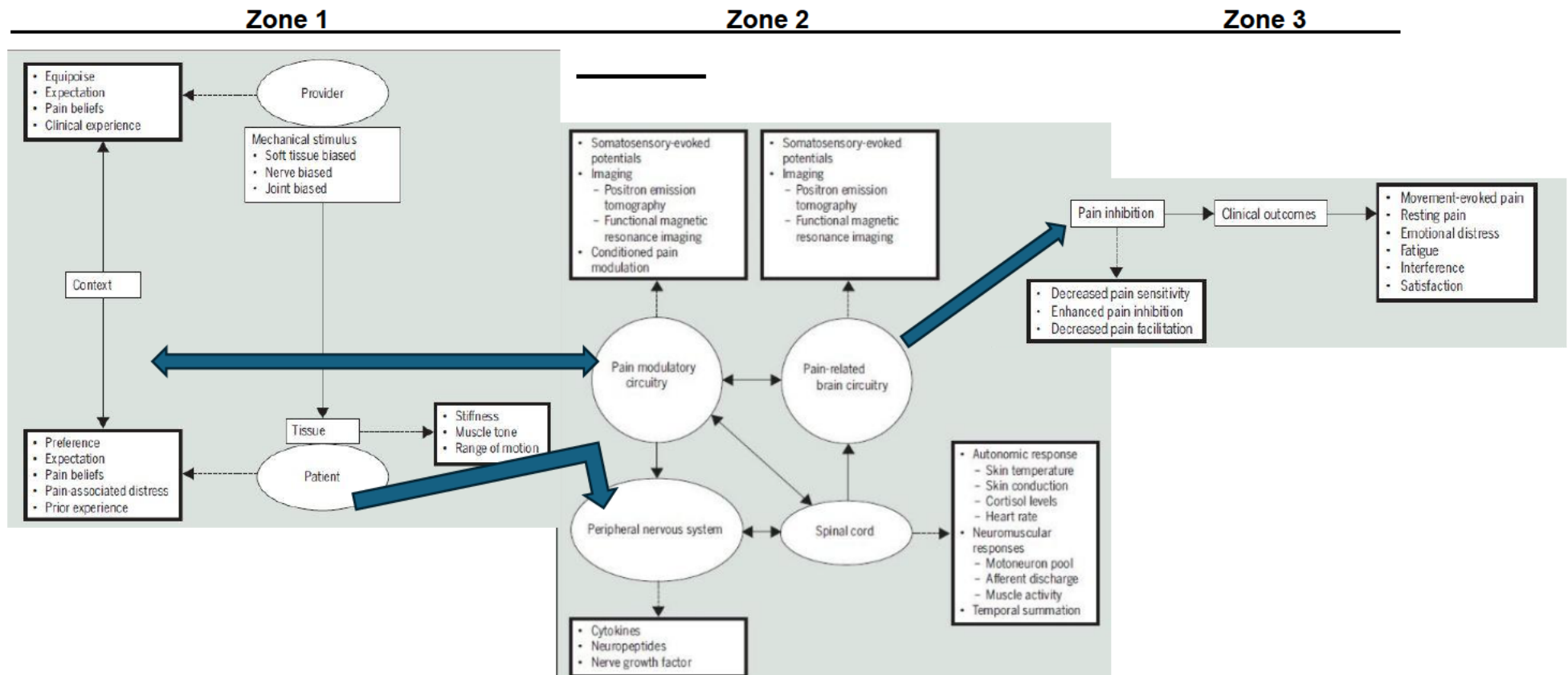
2.7.3.5 Autonomic responses

Reviews assessing the effect of spinal manipulation on the autonomic nervous system advise that there is conflicting to low level evidence supporting spinal manipulation to have an effect on sympatho-excitation (Araujo *et al.* 2019; Kovanur Sampath *et al.* 2024). Effects assessed include heart rate variability, oxy-haemoglobin, blood pressure, epinephrine and nor-epinephrine (Kovanur Sampath *et al.* 2024). Future

studies were recommended to improve methodological rigour (Kovanur Sampath *et al.* 2024).

2.7.3.6 Comprehensive model explaining mechanisms of spinal manipulation

Bailosky and Colleagues presented a model describing the potential mechanisms through which manual therapies bring about their effects (Bialosky *et al.* 2009) which was updated (Bialosky *et al.* 2018), **Figure 2.9**. They divided the effects into three zones: Zone one highlights the role of the practitioner, the patient and the stimulus being applied through the intervention and the various constructs that could influence pain reduction. Zone two shows the neurophysiological course of the signal from the tissue to the peripheral nerve, and spinal cord and onwards to the CNS and pain modulatory centres in the brain. This model highlights the interplay between the various areas resulting in pain inhibition, which occurs in zone three, where there is a change in clinical outcomes. The authors acknowledged that the effects of manual therapy extend beyond only the sensory aspect of pain inhibition which this model was focused on.



(Broken arrows denote an associative relationship, which may include an association between a construct and its measure. Bold boxes indicate measurable constructs/direct nervous system responses for consideration)

Figure 2.9: An updated comprehensive model of the mechanisms of SMT (Bialosky *et al.* 2018)

2.8 CONCLUSION

The high prevalence of neck pain makes it an important public health issue, irrespective of where in the world one may reside. Besides pain and self-reported disability, patients with neck pain frequently present with motor control disturbances. The presentation of motor control alterations in terms of spinal kinematics and muscle activation patterns is not conclusive, thus warranting further exploration. The models that exist to explain the presentation of these motor control variations are related to how the CNS responds to pain. Thus, interventions which have neurophysiological effects can impact the presence of motor control issues in pain conditions like the neck. Spinal manipulation which is commonly utilised in the treatment of neck and back pain has been shown to reduce pain and disability, with some studies showing that it impacts motor control. In particular, the effect of cervical SMT on spinal kinematics and muscle recruitment patterns has been understudied and warrants exploration to add to the growing body of literature in this area.

CHAPTER THREE

MANUSCRIPT ONE:

THE EFFECT OF SPINAL MANIPULATIVE THERAPY ON MUSCLE ACTIVITY AND SPINAL KINEMATICS IN PATIENTS WITH NON-SPECIFIC NECK PAIN: A SYSTEMATIC REVIEW AND META-ANALYSIS

3.1 BACKGROUND TO THIS CHAPTER

Spinal manipulation (SMT) for neck pain is often recommended in the clinical environment (Bryans *et al.* 2014; Masaracchio *et al.* 2019; Hawk *et al.* 2020; Lin *et al.* 2020). It is proposed that the biomechanical event of SMT brings about neurophysiological effects that are responsible for its positive patient outcomes (Pickar and Bolton 2012; Gyer *et al.* 2019). Changes in pain and disability following SMT have been well-documented (Gross *et al.* 2015; Coulter *et al.* 2019; Chaibi, Stavem and Russell 2021), yet a critical review of trials investigating motor effects of SMT such as muscle recruitment and spinal kinematics are less clear in symptomatic populations, particularly those suffering with neck pain.

3.2 MANUSCRIPT

The effect of spinal manipulative therapy on muscle activity and spinal kinematics in patients with non-specific neck pain: A systematic review and meta-analysis

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ABSTRACT

Background: Neck pain presents with sensorimotor disturbances, altered kinematics and neuromuscular control issues. Spinal manipulation is purported to induce a range of neurophysiological effects, reduce pain and improve function. This review assesses the effect of SMT on muscle activity and spinal kinematics in adults with non-specific neck pain.

Method: Randomised controlled trials where spinal manipulation was administered in isolation and included one measure of muscle activity and/or spinal kinematics, and one patient reported outcome was included. Data were extracted in duplicate. Risk of bias was assessed using the Cochrane Risk of Bias 2 tool and level of evidence determined using the Grading of Recommendations, Assessment, Development and Evaluation criteria. Where applicable, meta-analysis was performed.

Results: Twenty trials, with 1166 participants were included. Three trials assessed the effects of spinal manipulation (SMT) on muscle activity. No effect was found for SMT in these trials except for an increased amplitude of the deltoid muscle during a 30 second isometric contraction. Seventeen trials assessed angular displacement during cervical range of motion (ROM). Meta-analysis of two trials found that a single cervical SMT increased all ROM when compared to a control ($p < 0.001$). Meta-analysis of two trials found effects favouring thoracic SMT when compared to a control for extension ($p = 0.03$), left and right rotation ($p = 0.02$; $p < 0.001$). Combined cervical and thoracic SMT improved ROM when compared to a control, but not when compared to an active treatment in neck pain with no specific duration. One trial assessed cervical SMT compared to a control treatment for motion harmony reporting no difference following one treatment.

Conclusion: The evidence was rated as very low to moderate, being downgraded for risk of bias, imprecision and inconsistency. There is a dearth of RCTs assessing spinal kinematic and muscle activity effects following SMT for neck pain. Future research should focus on how spinal manipulation impacts motor control and efficiency to further understand its effects in neck pain.

Keywords: Spinal manipulation, muscle activity, spinal kinematics, systematic review, cervical spine, range of motion

BACKGROUND

Neck pain is a common, multi-factorial problem (Hogg-Johnson *et al.* 2009) (Kazeminasab *et al.* 2022), ranking fourth as a global contributor to years lived in disability (Hoy *et al.* 2014). The annual prevalence is 30% to 50% (Hogg-Johnson *et al.* 2009), with 50% to 85% of people reporting pain 1 to 5 years later (Carroll *et al.* 2009). It is more prevalent among women (Hoy *et al.* 2014), peaking around age 45 years of age, and has a chronic recurrent course (Côté *et al.* 2004). Neck pain has been associated with changes in motor control affecting sensorimotor integration (Falla and Farina 2007; Falla *et al.* 2007; Qu *et al.* 2022). Presenting with changes to muscle activity in the head and neck muscle (Falla, Bilenkij and Jull 2004; Falla, Jull and Hodges 2004; Falla *et al.* 2004), reduced active ROM, velocity, impaired head repositioning accuracy (Hesby *et al.* 2019) and movement time (Franov *et al.* 2022).

Spinal manipulative therapy (SMT) is commonly utilised in the treatment of neck pain by chiropractors, physiotherapists and osteopaths, among other healthcare providers (Pickar and Bolton 2012; Gevers-Montoro *et al.* 2021a). It is recommended as a conservative treatment (Bryans *et al.* 2014; Blanpied *et al.* 2017), usually as part of multimodal care (Galindez-Ibarbengoetxea *et al.* 2018; Whalen *et al.* 2019). SMT is delivered to joints in the spine or appendicular system (Brantingham *et al.* 2012), to normalise motion and bring about physiological restoration of the neuromusculoskeletal system and possibly other physiological systems which may have been affected by the dysfunction (Pickar and Bolton 2012). It comprises mobilisation and HVLA thrust techniques (Evans 2002). It has been recommended that these techniques be investigated independently, possibly due to different effects (Evans 2002). SMT applies a mechanical input that results in neurophysiological changes that bring about its effect (Pickar 2002; Bialosky *et al.* 2009). To date, these effects have not been fully elucidated (Savva, Giakas and Efstathiou 2014; Gyer *et al.*

2019) but may originate from peripheral, spinal cord, and/or supraspinal mechanisms such as descending inhibition (Bialosky *et al.* 2009; Bialosky *et al.* 2018; Gyer *et al.* 2019; Haavik *et al.* 2021).

Several recent reviews (Coulter *et al.* 2019; Chaibi, Stavem and Russell 2021; Gevers-Montoro *et al.* 2021a) have assessed the effect of cervical and thoracic (Masaracchio *et al.* 2019) SMT on neck pain, reporting that manipulation reduces pain and improves function. The functional aspects investigated were mostly limited to self-reported disability, using instruments like the neck disability index, with such tools characterising changes in perceived disability (Vernon 2008). Although frequently utilised and clinically important, they are self-reported and thus are not free from bias. When utilised in trials which fail to employ double blinding/concealment of allocation, the associations reported can be exaggerated (Savović *et al.* 2012; Hróbjartsson *et al.* 2013). This is less likely to occur when objective outcomes are utilised (Savović *et al.* 2012). In manual therapy trials, due to the nature of the techniques being investigated, it is difficult to apply adequate concealment or double blinding strategies for patient-reported outcomes (Kamper 2018) but when using objective outcomes this can be minimised through utilising an assessor who is blinded to treatment allocation.

Cervical ROM is one of the most utilised measures to assess physical impairment in neck pain in clinical practice (Snodgrass *et al.* 2014). Reduced cervical ROM is noted as a feature of neck pain (Stenneberg *et al.* 2017). RCTs assessing the effect of SMT on neck pain often utilise it as an objective outcome measure (Cassidy, Lopes and Yong-Hing 1993; Pikula 1999; Moodley and Brantingham 2002; Martínez-Segura *et al.* 2006; Izquierdo Pérez *et al.* 2014; Pires *et al.* 2015). When assessing cervical ROM changes as a result of SMT in the cervical and lumbar spinal areas, it was reported that a small effect was found in the cervical spine, with little to no effect occurring in the lumbar spine (Millan *et al.* 2012). It has been found that when SMT is used to treat neck pain, changes in cervical ROM were greater when thoracic manipulation was utilised as opposed to cervical SMT (Gevers-Montoro *et al.* 2021a) (Snodgrass *et al.* 2014).

The clinical relevance of cervical ROM remains unclear (Millan *et al.* 2012) with only one review indicating that reduced ROM was associated with a poor treatment outcome i.e. continued pain or return to usual activity (Snodgrass *et al.* 2014). It has been suggested that changes seen in spinal ROM following manipulation may have less to do with angular displacement i.e. absolute ROM, and more to do with spinal kinematics such as velocity and smoothness of motion (Millan *et al.* 2012). These characteristics of movement speak to the quality of the motion, characterising the way the spine moves as opposed to how much the spine moves (Qu *et al.* 2022).

Several systematic reviews have included cervical ROM alongside patient reported outcomes, like pain and disability, when assessing the effects of SMT on the cervical (Schroeder *et al.* 2013; Vincent *et al.* 2013; Hidalgo *et al.* 2017) and thoracic (Cross *et al.* 2011; Vincent *et al.* 2013) manipulation in the treatment of neck pain. Hidalgo *et al.* (2017) when comparing SMT combined with another manual therapy found that improvements occurred in extension ROM in chronic NP and lateral flexion in acute NP (Hidalgo *et al.* 2017). Schroeder *et al.* (2013) reported no difference in cervical ROM following SMT when combined with other interventions like advice or exercise in acute neck pain and for chronic NP the home exercise group had greater improvements than those receiving a combination of cervical SMT, home exercise and detuned ultrasound (Schroeder *et al.* 2013).

In another review, thoracic manipulation combined with electrothermal therapy was effective in alleviating pain and in improving ROM and function in acute neck pain and in chronic neck pain. Improved ROM occurred with SMT combined with infrared heat and education – however, these results were based on one study. Cross *et al.* (2011) investigated the effect of thoracic SMT on cervical ROM and reported that all included trials showed improved cervical ROM and concluded that thoracic SMT reduced pain and improved ROM in patients with acute or subacute mechanical neck pain (Cross *et al.* 2011). The reviews report mixed results for cervical SMT effects on cervical ROM, however, these reviews included trials where SMT was combined with other interventions thus making the conclusion less specific to the effect of SMT alone on ROM. In addition, no review included spinal kinematic outcomes like velocity.

In terms of the effects of SMT on muscle activation, several studies (Suter and McMorland 2002; DeVocht, Pickar and Wilder 2005; Dunning and Rushton 2009; de Camargo *et al.* 2011; Bracht *et al.* 2018; Kingett *et al.* 2019) have been conducted, showing varying effects, with no systematic reviews assessing this outcome in neck pain. In low back pain sufferers, it was found that HVLA thrust manipulation decreased muscle fatigue, possibly due to changes occurring in trunk neuromuscular control (Harvey and Descarreaux 2013). During assessment of flexion-relaxation phenomena in low back pain patients receiving spinal manipulation, paraspinal muscle activity during the full-flexion static and extension phases was reduced. Indicating that spinal manipulation decreased abnormal EMG activity (Bicalho *et al.* 2010). Similar findings were reported by Lalanne *et al.* (Lalanne, Lafond and Descarreaux 2009). In neck pain, thoracic spinal manipulation had a moderate effect ($d > 0.40$) on myoelectric activity of the right and left sternocleidomastoid muscles during isometric shoulder girdle elevation, with no between group difference when compared with a control group (Pires *et al.* 2015). Increased deltoid muscle amplitude and fatigue resistance was found following cervical SMT in neck pain participants when compared to a control group (de Camargo *et al.* 2011).

To comprehensively assess the effect of SMT on the efficiency of movement it would be necessary to undertake a kinematic assessment involving movement synergy, muscle activation-relaxation sequence and muscle tension (Kotov-Smolenskiy *et al.* 2021). Thus, this review aimed to systematically assess the current literature of the effects of spinal manipulation on spinal kinematics and muscle activation patterns in non-specific neck pain.

OBJECTIVE

This systematic review assessed the effect of spinal manipulative therapy on muscle activity and spinal kinematics in patients with non-specific neck pain.

METHODS

The review was reported in line with “The Cochrane Handbook for Systematic Review of Intervention” (Higgins *et al.* 2023) and Preferred Reporting Items for Systematic

Reviews and Meta-analyses guidelines (PRISMA)(**Appendix E**)(Page *et al.* 2021). The review was registered on PROSPERO (CRD42021170235)(**Appendix F**). There is no published protocol. Amendments included adding two authors before data extraction and review, meta-analysis was performed post-hoc where appropriate, and planned analysis of pain and disability outcomes was not performed due to recent reviews assessing the effect of spinal manipulation on acute (Chaibi, Stavem and Russell 2021) and chronic neck pain (Coulter *et al.* 2019). A descriptive analysis of these variables was provided.

Study selection and participants

Randomised and non-randomised controlled trials (RCTs) available in peer-reviewed full text, in English or translated into English, were included. Observational, descriptive studies, case series and case reports, review papers and systematic reviews were excluded. Participants had to be adults (over 18 years), suffering from non-specific neck pain of any duration, without radicular symptoms. Trials were excluded if the neck pain was associated with long tract signs (e.g. myelopathies), other pathologies, co-existing headaches, or if the neck pain was not dominant or provoked by neck movements/postures.

Types of interventions and comparators

All trials had to include at least one group who received high velocity and low amplitude thrust (HVLA) manipulation directed at a specific spinal segment, to any area of the spine, to treat neck pain. This intervention, whether to one or multiple spinal areas, was required to be performed in isolation due to the difficulty of assessing causal relationships in multiple interventions. Comparator interventions were control (administration of no activity that would be deemed a treatment), placebo/sham (an inert treatment mimicking the intervention) (Evers *et al.* 2018) or an active treatment (a treatment with a known benefit). No limit was placed on the number of treatments performed or the study setting.

Outcome measures

For inclusion, each study had to report one spinal kinematic and/or muscle activity outcome with at least one patient-reported outcome measure (PROM) such as pain or self-reported disability. No restrictions were placed on the type of tools measuring these domains, as there are no universally accepted tools (Gross et al. 2010). The two primary outcomes for this review were: 1) spinal kinematics which could be angular displacement, velocity or acceleration (Hill, Mong and Vo 2022), which are often measured using goniometers (Snodgrass *et al.* 2014) and motion capture technology (Vásquez-Ucho *et al.* 2021); 2) muscle activity measures reported as mean/medium frequency, amplitude, timing onset relative to the phase of movement and/or percentage activation of the muscle, usually measured using either surface or needle electromyography (EMG).

Studies were categorised by the duration of symptoms, acute pain being less than three months (Merskey 1986; Treede *et al.* 2015) and chronic pain, lasting longer than three months (Treede *et al.* 2015); and duration of follow-up with immediate being less than 24 hours; intermediate between 25 hours to 1 week, short-term 1 - 4 weeks and medium term greater than 4 weeks, determined as when the intervention was completed.

Search methods for identification of studies

A systematic search was conducted in May 2021 and updated in September 2023. Electronic databases PubMed (MEDLINE; 1966 to present), Scopus (1970 onwards), CINAHL (EBSCOhost CINAHL Complete database, 1937 to present) and the Web of Science (Core collection, 1990 to present) were searched using the medical subject headings (MeSH) and the search words/terms shown in **Table 3.1** and **Supplementary file 3.1**. Databases from 1990 were searched. This was supplemented by searching ClinicaTrials.gov (US National Library of Medicine - <https://ClinicalTrials.gov/>), the Cochrane Central Register of Controlled Trials (<https://www.cochranelibrary.com/central/about-central>) and the ISRCTN registry (BMC part of Springer Nature, from 2020, <https://www.isrctn.com/>) to attempt to capture grey literature that may have not been published. The search strategy was

developed by LO together with a librarian, and checked for completeness by BM. To ensure literature saturation, reference lists of selected trials were checked to ensure studies were not missed and consultation with experts was done. Retrieved citations were exported to Thomson Reuters Endnote™20 (Clarivate Analytics (US), Reference Management Software), and duplicates were removed. Citations were exported to Microsoft Excel for title and abstract screening.

Data collection - study selection and data extraction

Two authors (LO and BM) independently and in an un-blinded, standardised manner screened titles and abstracts trial eligibility, those deemed to meet the review inclusion criteria were progressed to full text review screening.

Table 3.1: Example of the literature search strategy for Pubmed

Search strategy
"Neck pain"[MeSH Terms]) AND "Manipulation, Spinal" OR "Manipulation, Chiropractic" OR "Manipulation, Orthopedic" OR "Musculoskeletal Manipulations" OR "Manipulation, Osteopathic"[MeSH Terms] OR "spinal manipulative" OR "spinal adjustment" OR "chiropractic" OR "chiropractic adjustment" OR "cervical manipulation" OR "high-velocity low-amplitude" OR "manual therapy" OR thrust AND kinesiology OR kinematic* OR "motor control" OR "biomechanical phenomena" OR "head movement" OR "spinal movement" OR "motor pattern" OR "movement coordination" OR "range of motion" OR "motor variability" OR "muscle activity" OR "muscle recruitment" OR "muscle recruitment pattern" OR "muscle pattern" OR myoelectric* OR "neuromuscular function" OR "spinal reflex" OR "muscle function" OR electromyograph* OR "neural responses" OR "reflex responses" OR neurophysiolog*

See **Supplementary file 3.2** for a list of excluded trials. Eligible trials were imported into Covidence systematic review software Extraction 2.0 (Veritas Health Innovation, Melbourne, Australia) and data extraction was done in duplicate by three authors (LO, KP and GM). The Cochrane Back and Neck data extraction template

(<https://back.cochrane.org/forms>) was modified following the Cochrane Effective Practice and Organisation of Care form for intervention review of randomised and non-randomised trials (Cochrane Effective Practice and Organisation of Care 2022). This was pilot tested on one article identified during the search which was not included in the review.

Risk of bias assessment

Risk of bias assessment was performed in duplicate by the review authors (LO, KP and GM) using the Cochrane revised Risk of Bias tool 2 (RoB 2) and the RoB2 MS Excel RoB2 template (version: 22 August 2019) (Sterne *et al.* 2019). The RoB2 algorithms guided decision making (Higgins *et al.* 2019) and the results of the risk of bias assessment will be presented in traffic light figures. Clinical trial registration documents and grey literature were consulted. At each stage of the review, disagreement was reached via consensus, if no resolution was reached a third author acted as an arbitrator.

Data analysis

A narrative synthesis will be done and where possible meta-analyses, using Revman 5.4.1 (Review Manager (RevMan) 2020) will be conducted and the results will be presented in forest plots. Meta-analysis was undertaken when trials were deemed to be clinically homogenous with regards to outcome and there were more than two trials to pool data. Decision rules made during data synthesis included: to enable pair-wise comparisons, studies with three arms, were reduced to two by excluding the third arm or combining the two comparator groups to form one group; when all three arms were included the HVLA group was 'shared' with the same means (M) and standard deviations (SD) being reported for each pair-wise comparison (Higgins *et al.* 2023); calculations were made to produce means and SD's (Higgins *et al.* 2023) (Walter and Yao 2007; Saayman, Hay and Abrahamse 2011) where necessary; missing data were requested from the authors (Puntumetakul *et al.* 2015; Bracht *et al.* 2018) (Erdem *et al.* 2021); if no intention-to-treat analysis was utilised the values were carried forward; where the same outcome domain was measured using different instruments the data from the most commonly utilised instrument was extracted; and to prevent multiplicity

(López-López *et al.* 2018) the data collected at the follow up visit closest to the end of treatment was utilised in the analysis.

A random-effects model with an inverse-variance statistical method was used to perform meta-analysis using mean differences and standardised mean differences when the scale differed across studies. Effect sizes were assessed using Cohen's *d* and 95% confidence intervals (CIs). Statistical heterogeneity was assessed using a forest plot and I^2 statistic. Clinical and methodological heterogeneity was assessed qualitatively (Deeks, Higgins and Altman 2023). Sensitivity analysis was done by including all studies irrespective of their risk of bias rating in the meta-analysis, then excluding them, to determine the impact of their inclusion on the results. Where statistical pooling was not possible, findings were presented in narrative form.

Qualitative analysis of trial results

The certainty of evidence was assessed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach (Guyatt *et al.* 2008). Evidence was downgraded for the following reasons, as outlined by (Prasad 2024): risk of bias - as determined by the RoB-2 assessment, inconsistency - assessed through visual inspection of the forest plots and/or the I^2 statistic; indirectness – when the population, intervention, comparison and outcome differed from those of interest; imprecision - judgements were made using minimally important differences and optimal information size, when available (Zeng *et al.* 2022), minimally important differences are unknown for muscle activity and for cervical ROM the values given by Fletcher and Brady (2008) for neck were utilised: flexion 9.6°, extension 7.0°, right and left lateral flexion 5.9°; 9.1° and right and left rotation 7.6°; 6.7° (Fletcher and Brady 2008); lastly publication bias was considered, due to the low number of studies this was not able to be assessed however methods utilised in the review attempted to obtain all relevant trials. Study certainty was rated as described by Meader *et al.* (2014) (Meader *et al.* 2014) and detailed in **Figure 3.1**. The results of the GRADE assessment will be presented in a Summary of Findings (SOF) tables.

High quality evidence

- Further research is very unlikely to change confidence in the estimate of effect, and consistent findings occurred among 75% of RCTs with low risk of bias that are generalizable to the population in question and there was sufficient data, with narrow confidence intervals. There are no known or suspected reporting biases i.e. all domains are met.

Moderate

- Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate i.e. one of the domains is not met.

Low

- Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate i.e. two of the domains are not met.

Very low

- We are very uncertain about the estimate i.e. three of the domains are not met.

No evidence

- No RCTs were identified that measured the outcome.

Figure 3.1: Certainty of evidence assessment using GRADE

RESULTS

The literature search identified 2182 citations from which 20 RCTs, with 1166 participants were included, **Figure 3.2**. The trials took place in Turkey, South Africa, the United States of America, Germany, India, Canada, Thailand, Brazil and Spain. The sample sizes ranged from 21 to 107. The average age of the participants was 34.6 years. There were more female participants (n=640; 61%), two trials recruited only females and only one male. The trials investigated acute neck pain i.e. less than 2 weeks (n=1), pain of a varied duration (n=7), and chronic pain (n=12). The time frames to follow up were less than 24 hours (n=11; 55%), 25 hours to 1 week (n=4, 20%), 1 to 4 weeks (n=3;15%) and greater than 4 weeks to 3 months (n=2; 10%). Characteristics of the included studies are found in **Table 3.2**.

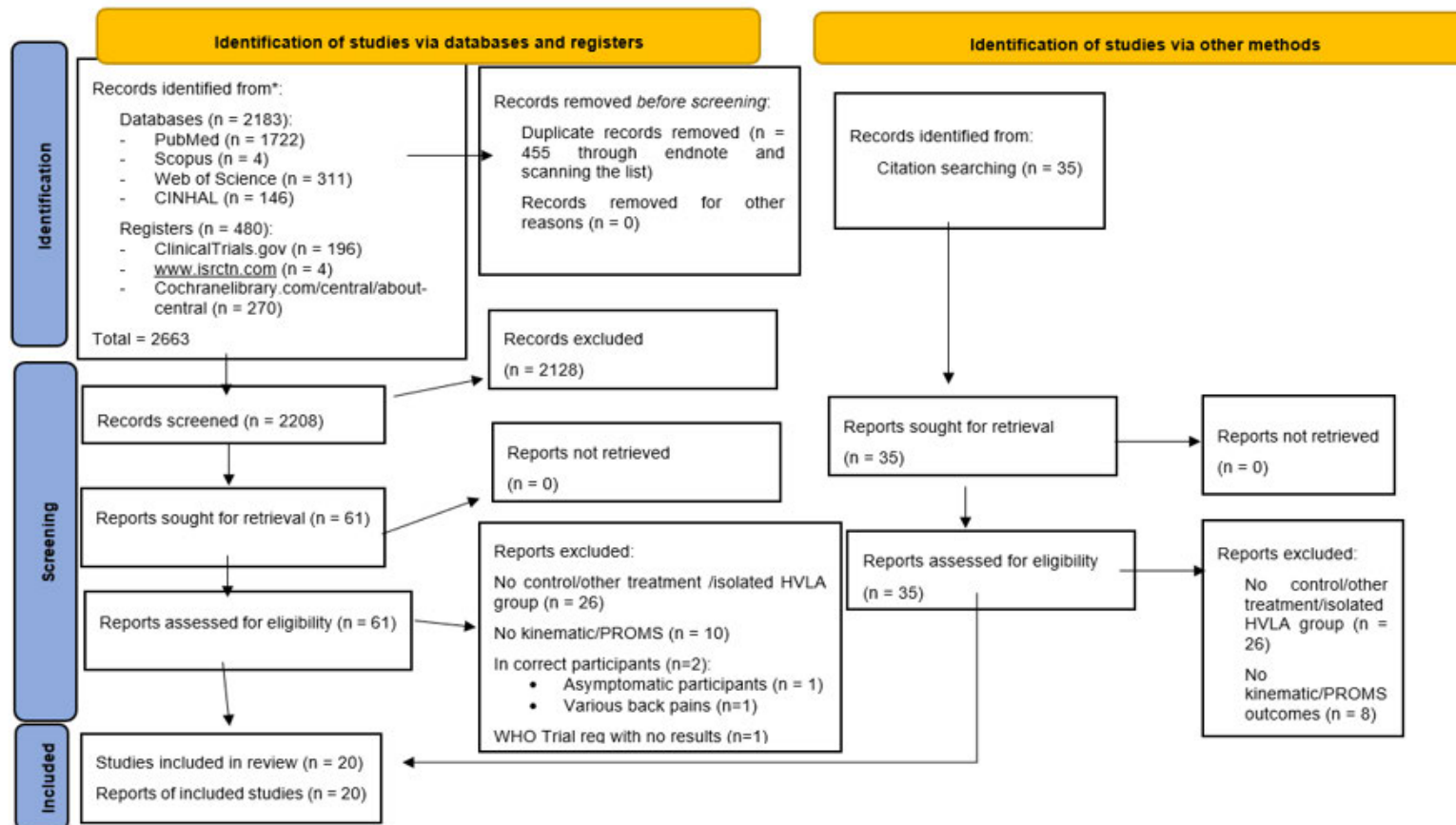


Figure 3.2: PRISMA flow diagram for systematic reviews (Page *et al.* 2021)

Table 3.2: Characteristics of included trials

First author and year	Study population	Methods	Intervention / comparator	Results
Pikula 1999	Canada; n=36; Acute NP (< 2 weeks); F:M 28:8; Age: 42.1 ±7.0	RCT; one treatment assessed pre- and immediately post-; measured: VAS, CROM (flex, ext, contra- and ipsilateral LF and Rot) using the CROM instrument	Private chiropractic practice treatment by chiropractor Grp 1: HVLA ipsilateral side of pain – applied supine to the mid-cervical spine (n=12) Grp 2: HVLA contralateral side of pain – as above (n=12) Grp 3: Sham de-tuned ultrasound – applied in the seated position over the area of pain (n=12).	VAS: sig difference between groups ($p<0.001$), grp 1 greater improvement than grp 2 ($p<0.001$) and 3 ($p<0.001$), no difference between grp 2 and 3 ($p=0.934$) CROM: No difference between the grps for flex ($p=0.058$) and contra-lateral Rot ($p=0.241$). Significant increases in ext ($p=0.42$) and ipsilateral Rot ($p=0.021$), favouring grp 1 over grp 3; and for contralateral ($p=0.016$) and ipsilateral flex ($p<0.001$) favouring grp 1 over grp 2 and grp 1 over grp 3, with no differences between grp 2 and 3.
Valera-Calero 2019	Spain; n=83; Chronic NP (>3 months); F:M 51:32; Age: 36.6 ±9.2	RCT; one treatment; assessed pre and immediately post treatment and 1 week; VAS, NDI (only measured pre and at 1 week), PPT at C5/6 facet joint, CROM using CROM device (flex, ext, LLF, RLF, LRot and RRot)	University outpatient referrals from office workers, treatment by physical therapist Grp 1: cervical HVLA applied supine to C5-C6 (n=28) Grp 2: cervical mobilization - grade III PA joint oscillatory mobilization technique to the articular pillar of C5/6 on the subject's symptomatic side applied prone (n=28). Grp 3: Sham - like HVLA excluded joint preload and thrust components (n=27).	VAS over time ($p=0.010$, $\eta^2=0.07$) with no diff at post-measure ($p>0.05$), 1 week ($p<0.001$) decreased pain favouring the grp 2 over grp 3; NDI over time ($p<0.012$, $\eta^2=0.010$) post-measures grp 1 compared to grp 3 ($p=0.003$) and grp 2 over group 3 ($p=0.012$) had sig decreases in NDI, no diff at 1-week ($p>0.05$); PPT over time ($p=0.652$; $\eta^2=0.015$) no diff between the grps at post and 1 week ($p>0.05$); CROM: Flex over time ($p=0.015$, $\eta^2=0.07$) increased motion post-treatment grp 1 over grp 3 and grp 1 over grp 2 ($p=0.001$), 1-week grp 1 increased compared to grp 3 ($p<0.001$); RRot ($p=0.001$; $\eta^2=0.11$) only within group changes no between group changes; no diff between grps for ext ($p=0.113$; $\eta^2=0.04$), LLF ($p=0.492$; $\eta^2=0.02$), RLF ($p=0.492$; $\eta^2=0.0$) and LRot ($p=0.152$; $\eta^2=0.04$) at post- or 1 week.

Bracht 2018	Brazil; n=32; Three or more episodes of cervical pain in the last three months; Duration: 30.5 ±38.6; F:M 27:3; Age: 27.5 ±4.8	RCT; one treatment; assessed pre and immediately post treatment; PPT (JTECH Commander, Salt Lake City, UT, USA) and EMG (integral) (EMG System of Brazil® model 811C, SP, Brazil) of lower trapezius (LT), upper trapezius (UT), anterior deltoid (AD), biceps brachii (BB), triceps brachii (TB), wrist extensors (WE), wrist flexors (WF), and adductor pollicis (AP); recorded during a seated lifting and gripping task measuring ipsilateral most affected side; grip force parameters.	Treated by a physical therapist with orthopaedic manipulative physical therapy experience. Grp 1: Cervical HVLA to C5 in the supine position (n=15) Grp 2: Control same as HVLA group but only cervical Rot was performed without applying any tissue tension at the end of the movement (n=15).	PPT no significant differences between grps: left UT ($F = 0.21$, $p=0.64$); right MD ($F = 0.03$, $p = 0.95$); left MD ($F = 3.98$, $p=0.05$); right LE ($F = 3.45$, $p=0.07$), left LE ($F = 0.05$, $p=0.81$) and right UT ($F = 7.46$, $p=0.01$). Integral EMG no between grp differences: EMG at pre-lifting interval: UT ($F = 0.45$, $p=0.50$); LT ($F = 0.84$, $p=0.36$); AD ($F = 0.71$, $p=0.40$); BB ($F = 0.40$, $p=0.53$); TB ($F = 1.02$, $p=0.32$); WF ($F = 0.05$, $p=0.82$); WE ($F = 0.09$, $p=0.76$); AP ($F = 0.18$, $p=0.77$) and at the post-lifting interval: UT ($F = 5.19$, $p=0.03$); LT ($F = 0.04$, $p=0.83$); AD ($F = 0.71$, $p=0.40$); BB ($F = 0.15$, $p=0.70$); TB ($F = 0.66$, $p=0.42$); WF ($F = 0.08$, $p=0.77$); WE ($F = 0.57$, $p=0.45$); AP ($F = 0.09$, $p=0.76$). Grip force no sig between grp differences: ($F = 4.02$, $p=0.05$); GFP ($F = 1.04$, $p=0.31$) *p value set at $p<0.01$ due to the large number of co-variables
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de Camargo 2011	Brazil; n=37; NP as a primary complaint in the last 6 months; F:M 16:21; Age: 31.6 ± 7	RCT; one treatment; assessed pre and 5 minutes' post treatment; PPT (Wagner Instruments, FPX 50, Greenwich, CT) of the upper trapezius and deltoid muscle bilaterally and C5 SP; EMG: same muscles homolateral + contralateral side to HVLA: Rest RMS (μV), Isotonic contraction RMS (μV) + ENV (Jenv), Isometric contraction (5 s) RMS (μV) and MF (Hz) Isometric contraction (30 s) RMS (μV), RMS (μV) and MF (Hz) at beginning and end of contraction using MyoSystem-Br1 (DataHommis, Uberlândia, MG, Brazil), recorded with participants in the seated position.	Treated by the Clinician with a postgraduate orthopaedic manual therapy training Grp 1: Cervical applied to the right C5/6 in the seated position (n=17); Grp 2: Control grp patients were seated comfortably on a chair for 2 minutes (n=20).	PPT: Upper trap no significant grp time ($p=0.776$) and grp time side ($p=0.276$) interactions ($0.20 < d < 0.45$). Deltoid muscle significant grp time ($p=0.010$) but not grp time side ($p=0.981$). The HVLA grp had bilateral increases in PPT, whereas the control group exhibited a bilateral decrease. Significant grp time interaction ($p=0.025$) over the C5 spinous process for PPT levels: the HVLA grp had increased PPT, whereas the control grp exhibited decreased PPT ($0.50 < d < 0.80$). EMG: No significant grp time and grp time side interactions for RMS at rest ($p=0.237$; $p=0.535$, respectively) and RMS isotonic contraction ($p=0.898$; $p=0.757$, respectively), and ENV isotonic contraction ($p=0.461$; $p=0.670$), all with small ($d < 0.2$). No significant grp time and group time side interaction for RMS ($p=0.899$; $p=0.994$, respectively) or MF ($p=0.406$; $p=0.293$, respectively) at isometric contraction for 5 seconds. Significant grp time ($p=0.003$) but not grp time side ($p=0.813$) interaction for RMS for isometric contraction for 30 seconds was found; moderate ($0.20 < d < 0.5$). No significant grp time and grp time side interaction for RMS at the beginning ($p=0.166$; $p=0.145$, respectively) or MF at the end ($p=0.732$; $p=0.884$, respectively) of isometric contraction for 30 seconds were found. Significant grp time ($p=0.003$) but not grp time side ($p=0.819$) interaction for RMS at the end of isometric contraction for 30 seconds was found, and changes were small with moderate ($d = 0.40$). Significant grp time ($p=.006$) but not grp time side ($p=0.656$) interaction for MF at the beginning of isometric contraction for 30 seconds was found: the manipulative group had a greater increase in MF at the beginning of the isometric contraction than the control grp, large ($d = 0.82$).
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Lopez-Lopez 2015	Spain; n=48; Chronic neck pain over the last 3 months; F:M 42:6; Age: 36.45±8.8	RCT; one treatment; pre and immediately post treatment, PAIN: VAS at rest and during CROM; CROM: Flex-ext, LF and Rot measured with CROM device (Performance Attainment Associates, Roseville, MN). PPT (FDX 25, Wagner Instruments, Greenwich, CT, USA) measured at C2	Therapist at a Primary Health Care Centre Grp 1: cervical HVLA applied in the supine position (n=15) Grp 2: cervicothoracic junction unilateral posterior-anterior (PA) grade III passive oscillatory mobilization applied in the prone position at 2 Hz (n=16) Grp 3: Sustain apophyseal natural glide (SNAGS) applied to the hypomobile and symptomatic intervertebral level in the seated position while the patient moved their head using the previously more painful movement from a standard position (n=17)	VAS – all grps had a sig decrease in pain during active movement ($p<0.05$), during pain at rest ($p=0.040$, $\eta^2=0.23$) the HVLA grp ($d=4.53$) had a greater decrease in pain than grp 2 ($d=2.87$), with both grp 1 and 2 reducing pain more than grp 3 ($d=0.45$). Pain intensity assessed in flex/ext together with anxiety had better outcomes for HVLA and SNAG when anxiety levels were low but not with medium or high levels, better outcomes were found for mobilization with medium levels of anxiety. PPT over C2 increased in all groups over time ($p<0.05$), with no sig between group effects. CROM all grps showed improved ROMs ($p<0.05$) with no sig between group differences.
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Aki 2020	Turkey; n=40; Neck pain that continued for at least 3 months; F:M 23:17; Age: 37.30 ± 7.35	RCT; 2 treatments per week over 4 weeks; measured pre and at 4 weeks Pain: VAS at rest, during activity and at night CROM: flex, ext, LLF, RLF, LRot, RRot using an inclinometer; NDI Turkish version Cervical Functional Disability Score	Chiropractor at a Physical Medicine and Rehabilitation Polyclinic Grp 1: Cervical diversified HVLA (n=20) Chiropractic diversified technique Grp 2: Dry needling (DN) (no details provided)(n=20)	Pain post-treatment scores showed a sig difference for VAS night pain ($p=0.018$) favouring grp 2; between grp mean difference found greater decreases in grp 2 for the night ($p=0.024$), activity ($p=0.032$) and resting ($p=0.032$) pain; CROM both grps had sig increases in motion; post treatment between grp measures found greater increases for grp 1 for ext ($p=0.040$) and LROT greater effect for grp 2 ($p=0.042$); mean diff between grps over time found no sig diff between grps for all ROM ($p>0.05$); NDI and cervical functional disability both grps had decreased scores with post treatment scores between grp finding no sig between grp differences ($p=0.747$; 0.964 respectively)
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Izquierdo Perez 2014	Spain; n=64; NP of more than 12 weeks duration and without radicular symptoms; F:M 26:35; Age: 36.5 ±9.4	RCT; 4 treatments in 2 weeks; measured immediately and at 1, 2 and 3 months; PAIN: VAS at rest DISABILITY: NDI CROM: flex, ext, Rot and lat flex ACROM device Global impression of change scale (GROC)	Physiotherapist at a Primary Health Care Centre Grp 1: Cervical HVLA in the supine position and directed at most hypomobile in either Rot or lateral flex (n=19, drop out 4 th and 5 th evaluation n=18 and 17) Grp 2: Mobilization patient lay prone unilateral PA oscillatory pressure was applied at a frequency of 2 Hz (with metronome control/steps) for 2 min and repeated 3 times. The rest time between each mobilization was 1 min. (n=21, drop out 4 th and 5 th evaluation n=19 and 18) Grp 3: SNAGS done in the sitting position directed to a hypomobile and painful level and placed his thumbs on the transverse process of that level. The participant performed painful motion actively while the therapist guided that vertebra during the movement and resisted it when returning to neutral. The force was applied parallel to the plane of the joint the procedure was performed in 3 sets of 10 repetitions. (n=21, drop out 4 th and 5 th evaluation n=18 and 16)	VAS all groups reduced pain ($p<0.0001$, $\eta^2=0.54$) with no between grp diff ($p=0.83$, $\eta^2=0.06$). NDI all groups had a disability improvement ($p < 0.0001$, $\eta^2=0.37$) with no between grp interaction ($p=0.41$, $\eta^2=0.03$). CROM all groups improved in all ROM (flex $p<0.0001$, $\eta^2=0.31$; ext $p<0.0001$, $\eta^2 = 0.31$; right Rot $p<0.0001$, $\eta^2 =0.23$; left Rot $p<0.0001$, $\eta^2=0.27$; right lateral flex $p<0.0001$, $\eta^2 =0.24$; left lateral flex $p< 0.0001$, $\eta^2 =0.21$). No between grp differences were found ($p>0.05$) except ext ($p=0.02$, $\eta^2=0.06$) grp 1 had greater increases in ext ($p<0.01$) than the grp 2 and 3 ($p>0.05$) groups at all the follow-up months. Grp 2 increased ext movement immediately ($p<0.01$) but not during the follow-up ($p>0.05$). Grp 3 increased only during the one-month follow-up ($p<0.01$). PGIC: No significant effects between groups were found ($p>0.05$)
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Akguller 2022	Turkey; n=60; >3 months; mean duration 12.02±6.55; F:M 34:26; Age: 31.45 ± 7.31	RCT; 12 treatments over 6 weeks; measured at pre and 12th visit Pain: VAS – during rest, ADL and at night Disability: NDI PPT bilaterally over the upper trapezius using a Baseline Push-Pull Force Gauge® pressure algometer Active CROM: flex, ext, LLF, RLF, LRot and RRot using “Baseline CROM Deluxe” cervical goniometer Health status: Short form-36 Global Rating of Change scale	University treated by a physiotherapist Grp 1: Cervical HVLA to the most sensitive and constrained segment between C2 and C7 applied in the supine position (n=21, 12 visit n=20) Grp 2: Progressive stabilization and strengthening exercises with postural education (n=21, 12 visit n=20) Grp 3: Combined cervical SMT and exercise (n=21, 12 visit n=20)	Pain – within group comparisons found all groups improved over the duration of the study for pain at rest, activity and night ($p<0.001$), inter-group comparisons found no difference between the groups for pain during activity or at night but for rest favoured the grp 3 over grp 2 ($p=0.016$) and grp 1 ($p=0.008$) with large ES ($\eta^2=0.17$), no difference between grp 1 and 2 ($p=1.00$). Disability – within group comparisons found all groups improved over the duration of the study ($p<0.001$), inter-group comparisons favoured grp 3 over grp 2 ($p<0.001$) and grp 1 ($p<0.001$) with large ES ($\eta^2=0.36$), no difference between grp 1 and 2 ($p=1.00$). PPT within group comparisons found all groups improved over the duration of the study for left and right PPT ($p<0.002$), inter-group comparisons favoured grp 3 for right ($p=0.022$) with a large ES ($\eta^2=0.12$) when compared to grp 2 ($p=0.038$) (not grp 1 $p=0.067$), with no difference between grp 1 and 2 ($p=1.00$), on the left comparisons favoured grp 3 ($p=0.012$) with a large ($\eta^2=0.14$) compared to grp 1 ($p=0.032$) and grp 2 ($p=0.025$), with no difference between grp 1 and 2 ($p=1.00$). CROM: within group, improvements were found for all ROMs ($p<0.005$) except for grp 2 in flex ($p=0.74$). Between grp comparisons for RLF ($p=0.003$, $\eta^2=0.18$) favoured grp 3 over grp 2 ($p=0.00$) but not grp 1 ($p=0.79$), with no between group grp effects for grp 1 compared to grp 2 ($p=0.056$); LLF ($p=0.003$, $\eta^2=0.19$) favoured grp 3 over grp 2 ($p=0.003$) but not grp 1 ($p=1.00$), with grp 1 improving more than grp 2 ($p=0.043$); RROT ($p=0.012$, $\eta^2=0.14$) favoured grp 3 over grp 2 ($p=0.010$) but not grp 1 ($p=0.37$), with no between grp effects for grp 1 and 2 ($p=0.40$); LROT ($p=0.010$, $\eta^2=0.15$) favoured grp 3 over grp 2 ($p=0.013$) but not grp 1 ($p=1.00$), with grp 2 having greater range than grp 1 ($p=0.049$). SF-36 all grps showed within grp improvements for all items ($p<0.05$) except grp 2 for emotional welling ($p=0.46$). Between grp effects were found for vitality ($p=0.002$, $\eta^2=0.20$) with greater
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				improvements in grp 3 than grp 1 ($p=0.010$) and 2 ($p=0.003$), with no difference between grp 1 and 2 ($p=1.0$); and for emotional well-being ($p=0.002$, $\eta^2=0.20$) greater improvements in grp 3 than grp 2 ($p=0.003$) but not grp 1 ($p=0.61$), with no difference between grp 1 and 2 ($p=0.08$). GROC greater number of participants reported being 'much better' in grp 3 ($p=0.043$).
Martínez-Segura 2006	Spain n=71; NP at least one month duration averaged at 4 months; F:M: 45:26; Age: 35(± 10)	RCT, one treatment, measured pre and post Pain: VAS at rest CROM measured with a goniometer: Flex, ext, LLF, RLF, LRot and RRot	Private physical therapy and osteopathy clinic treated by a therapist Grp 1: Cervical HVLA – directed to dysfunctional cervical segment applied in the supine Grp 2: Control Mobilization – same as above but no thrust instead the position was held for 30 seconds without any additional tension. The side of the manual contact was randomized.	HVLA group had significant improvements in neck pain at rest and all CROM compared to the mobilisation group ($p < 0.001$). Pre-post effects sizes within groups were large for all outcomes for the HVLA grp ($d > 1$) and for the mobilisation group, they were small to medium ($0.2 < d < 0.6$). Pearsons correlation found a negative association between improved neck pain at rest and CROM: flex ($r = -0.6$, $p < 0.001$), ext ($r = -0.6$, $p < 0.001$), left lateral flex ($r = -0.65$, $p < 0.05$), right lateral flex ($r = -0.7$, $p < 0.001$), left Rot ($r = -0.7$, $p < 0.001$), and right Rot ($r = -0.65$, $p < 0.001$)

Serra- Ano et al 2023	Spain; n=50; Neck pain longer than 1 month duration; F:M 35:13; Age: 32.7±12	RCT, one treatment measured pre and Immediate post Disability – Spanish NDI Patient Global Impression of Change (PGIC) scale CROM and Harmony of movement (HARM)Flex, ext, LLF, RLF, LRot, RRot measured using a video-photogrammetry system (Kinescan-IBV, Valencia, Spain) taken while seated, with trunk fastened to the backrest, 8 technical markers attached to a helmet placed on the head. Each ROM was performed 7 times consecutively to obtain a smooth continuous movement with maximum range and comfortable speed. HARM is defined as the absolute value of the correlation coefficient between the angle (Θ) and the angular acceleration ($\ddot{\Theta}$)	University laboratory treatment by a Physiotherapist Grp 1: Cervical HVLA in the supine position to a maximum of 3 per individual with one per upper, middle and lower segments (n=25) Grp 2: Control a series of brief pressure-less touches over head and shoulder for 10 min, followed by light superficial touches on standardised anatomical areas for 2 min (n=23)	Disability both grps showed a sig reduction in disability at FU ($p<0.05$) PGIC mean scores showed grp1 to have greater impairments compared to grp 2 ($p<0.05$). CROM no between grp effects were found for all ROM except RLF ($p<0.05$) and LROT ($p<0.05$) with medium to large ($d=35$; $d=0.30$) HARM no between grp effects was found for all measures except flex ($p<0.05$) with medium to large ($d=32$)
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Saavedra - Hernández 2012	Spain; n=80; Mechanical NP, non-specified duration; F:M 36/44; Age: 45 ± 10	RCT; one treatment measured at pre and 7 days; Pain: NPRS Adverse events Disability: NDI CROM: Flex, ext, LLF, RLF, LRot, RRot using CROM goniometer	Private physical therapy clinic treated by the therapist Grp 1: mid-cervical at C3 administered in the supine position and bilateral cervicothoracic junction HVLA in eth prone position (n=40) Grp 2: Kinesio tape (Kinesio Tex; Kinesio USA, Albuquerque, NM) was applied in a Y-strip over the posterior cervical extensor muscles, from the insertion to the origin, with paper-off tension, approximately 15% to 25% stretch (n=40, at day 7 n=36)	Pain both groups had a reduction in pain with no sig between grp effects ($p=0.447$, MD 0.2 (0.0, 0.5)). Disability both groups had improvements in disability with no between grp differences being found ($p=0.736$; MD 0.3 (-1.3, 1.9)) Adverse events (n=5): mild-in-nature, nonserious minor adverse events 3 in the HVLA group (7.5%) experiencing a minor increase in pain or fatigue, 2 in the Kinesio Tape group (5%) who reported cutaneous irritation from the tape. These were resolved within 24 hours. CROM: No between grp differences for flex ($p=0.334$, MD 2.0 (-2.1, 6.0)), ext ($p=0.728$, MD 1.4 (-6.8, 9.7)), and right ($p=0.650$, 1.4 (-6.7, 9.8)) and left ($p=0.535$, 0.9 (-2.1, 4.0)) lateral flex except for right ($p=0.008$, 6.8 (1.8, 11.7)) and left ($p=0.003$, 7.0 (2.5, 11.5)) Rot, where grp 1 had greater increases in CROM.
Cassidy 1992	Canada RCT n=100; unilateral NP varied duration; age grp 1 34.5(13.0), grp 2 37.7(12.5)	RCT; one treatment measure pre and immediately post. Pain: NPRS101, CROM using cervical goniometer (Rangimeter by Marker Inc): flex, ext, lpsi and contralateral lat flex and Rot	Chiropractic clinic treated by an experienced clinician Grp 1: Cervical HVLA applied to the tender site Grp 2: cervical mobilisation in the form of muscle energy technique participant pushes against manual resistance by clinician localised to involved levels, isometric contraction held for 5 sec and repeated 4 times with increased Rot or lateral flex	Pain both treatments decreased pain with no sig between grp effects ($p=0.05$). CROM both treatments increased ROM with no sig between group effect ($p=0.05$).

Saayman 2011	South Africa n=60; Cervical facet dysfunction, female 1-to- 12-month duration; only females	RCT; 2 treatments per week for 3 weeks; measures at pre and 4th week; Pain: NPRS Disability: NDI CROM: flex, ext, LF ave, ROT ave using CROM device (University of Minnesota, Revised, December 1988; www.spineproducts.com) Digital inclinometer using the Performance Attainment Associates and Mednet Technologies, Inc, and the Baseline Digital Inclinometer (BDI) (Fabrication Enterprises, Inc, New York, NY): Flex, Ext, lat flex ave	University chiropractic clinic treatment provided by the researcher Grp 1: cervical diversified HVLA with a max of 3 joints treated per session (n=20); Grp 2: Low-level laser Low-level laser therapy using the Uni-Laser 201 830-nm gallium aluminium arsenide (ASAH-MEDICO A/S, Hvidovre, Denmark) semiconductor laser diode with a hand-held probe (n=20); Grp 3: Combined LLLT + HVLA (n=20)	Pain all grps improved over time ($p<0.001$) with no difference between the grps Disability all grps improved over time ($p<0.001$) with grp 3 having a greater sign improvement than grp 2 ($p<0.001$) and not grp 1. CROM grps had improved ROM over time ($p<0.05$), for flex grp 3 had the greatest improvement over grp 1, and grp 2 greater than grp 1 ($p<0.001$); lateral flex ave grp 3 improved more than group 2 ($p<0.001$); Rot ave grp 3 improved better than grp 1 and grp 2 ($p<0.001$); no differences between the grps for ext ($p>0.05$). BDI grps had improved ROM over time ($p<0.05$), flex grp 3 had a greater improvement than grp 1, but not grp 2 ($p<0.001$); lateral flex ave grp 3 improved more than group 2 ($p<0.001$); no differences between the grps for ext ($p>0.05$).
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Pires 2015	Brazil; n=32; chronic NP; only females; age: grp 1 23.5(±4), grp 2 26(±6.5)	RCT; one treatment; measured pre and immediately post and 48- 72 hours Pain: VAS at rest Disability: NDI EMG: R SCM Rest - L SCM Isometric cervical flex - R SCM Isometric elevation of shoulder girdle - R SCM Isometric elevation of shoulder girdle - L SCM using BIO-EMG 1000 electromyograph (Lynx; São Paulo, Brazil)	University treated by a specialist in Osteopathy and Manual Therapy Grp 1: upper thoracic HVLA applied directly below T1 (n=16) in the supine position with the therapist hand in a pistol grip on vertebrae, contact with sternum over patient's arm, on exhalation the HVLA was delivered Grp 2: Sham patient was placed as above but the therapist's hand in an open position and was asked to take a deep breath but no HVLA was delivered (n=16)	Pain no between group differences was found at post ($p=0.640$; MD 0.18 (-1.52 to 1.89) and short term ($p=0.22$; MD -0.26 (-2.09 to 1.35), with weak intragroup and intergroup ES ($d < 0.20$) EMG No between group effects were found at post measures: RMS (μV) right and left sternocleidomastoid muscles at rest ($p = 0.90$, MD: -0.15 (-2.07 to 1.76); $p=0.47$, MD: -0.15 (-1.27 to 0.96), during isometric movement of cervical flex ($p = 0.15$ MD: -3.12 (-23.16 to 16.92, $p=0.65$, MD: 7.85 (-22.57 to 37.29), isometric movement of elevation of the shoulder girdle ($p = 0.61$, MD: -2.12 (-7.97 to 3.73); $p=0.82$, MD: 0.37 (-4.45 to 5.20), with weak intragroup and intergroup ES for all variables analysed ($d < 0.20$). No between group effects were found at short term RMS (μV) for the right and left sternocleidomastoid muscles at rest ($p=0.83$, -0.34 (-2.14 to 1.45); $p=0.30$, -0.22 (-1.11 to 0.66), during isometric movement of cervical flex ($p=0.60$, 22.71 (-15.29 to 60.73); $p=0.81$, 24.05 (-15.49 to 63.59), during isometric movement of elevation of the shoulder girdle ($p=0.30$, 1.88 (-2.60 to 6.37); $p=0.82$, 1.94 (-5.30 to 9.19). Intragroup EMG activity for right and left sternocleidomastoid muscles during isometric movement of elevation of the shoulder girdle ES moderate ($d < -0.55$; $d < -0.41$)
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Puntumet akul 2015	Thailand; n=48; chronic mechanical neck pain; F:M 23:9; Age: 26.54±8.35	RCT; one treatment; measured pre and 24-hr post and 1 week Pain: VAS at rest Disability: NDI CROM: Flex, ext, LLF, RLF, RROT, LROT using CROM device (Performance Attainment Associates, Lindstrom, MN, USA) Adverse effects	Physical Therapy Unit treated by a physiotherapist Grp 1: single T6/7 HVLA (STM) applied in the prone position the HVLA was directed to both sides of the facet joint using a screw thrust after exhalation (n=16) Grp 2: Multiple T/S HVLA (MTM) as above with therapist moving from upper to lower restricted segments (n=16) Grp 3: Control patient prone lying for 2 min, therapist hands on the facet joint and participant took a deep breath in and out with no thrust (n=16)	Pain sig decreased at 24-hr and 1 week FU, grp 1 and 2 were sig lower than grp 3 at 24-hour ($p<0.001$, MD: 1.56 (0.63, 2.54); $p<0.001$, MD: 1.96 (1.04, 2.95)) and 1-week follow-up ($p<0.001$, MD: 2.08 (0.98, 3.25); $p<0.001$, MD: 2.53 (1.44, 3.71)), with similar reductions in grp 1 and 2 at 24hr and 1 week ($p=0.894$, MD: 0.40 (-0.55, 1.36); ($p=0.979$, 0.45 (-0.68, 1.59)). Disability sig decreased at 24-hr and 1 week FU, grp 1 and 2 were sig lower than grp 3 at 24-hour ($p=0.004$, MD: 7.88 (2.01, 12.53); $p<0.001$, MD: 10.38 (4.21, 14.81)) and 1-week follow-up ($p<0.001$, MD: 9.38 (3.22, 14.00); $p<0.001$, MD: 12.38 (5.85, 16.71)), with similar reductions in grp 1 and 2 at 24hr and 1 week ($p=0.880$, MD: 2.50 (-2.99, 7.74); ($p=0.665$, MD: 3.00 (-2.69, 8.03) CROM no between grp differences were found between grp 1 and 2 at 24-hour and 1-week follow-up ($p<0.05$) when compared with baseline. Grp 2 sig in right Rot at 24 hrs compared with the control group ($p=0.013$, MD: 10.70 (1.61, 17.05)). Grp 1 sig improved in flex ($p=0.038$ MD: 4.97 (0.29, 13.38)) and left lateral flex ($p=0.011$, MD: 6.54 (1.12, 10.65) at one-week FU when compared grp 3. There were no significant differences in CROM between the STM and MTM groups at either follow-up time point ($p<0.05$). Adverse effects in grp 1 included: local soreness (n=1, 6.3%) immediately after treatment and 24 hours later; grp 2 included headache (n=2, 12.5%), local soreness immediately after treatment (n=7, 43.8%), and local soreness 24 hours later (n=3, 18.8%). Local soreness was significantly worse ($p=0.014$) in grp 2 immediately after treatment. No adverse effects were reported at the 1-week follow-up.
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Suvarnna to 2013	Thailand; n=39; Chronic (more than 3 months) NP; F:M: HVLA: 9:4, Mobs: 9:4, Control: 10:3; age: HVLA: 31 (± 12.5) Mobs: 39.9 (± 11.5), Control: 53.3 (± 11)	RCT; one treatment; measured pre, post and 24 hours Pain: VAS at rest CROM: Flex, ext, LLF, RLF, LRot, RRot using CROM measurement device	Physical Therapy Laboratory by a clinician with manual therapy experience, Grp 1: Control participants lay in the prone position on the examination table, clinician's hands placed bilaterally on the zygapophyseal joint at T6-T7 without compressive pressure on the joints for a total of 2 minutes (n=13). Grp 2: Thoracic HVLA at T6/7 facet joint screw thrust HVLA applied bilaterally (n=13) Grp 3: Thoracic mobilisation lay prone and received Grade III unilaterally PA mobilization at the zygapophyseal joint of T6-T7 on both the left and right sides for 1 minute and was completed in 2 minutes (n=13)	Pain within group improvements occurred at post-measure for grp 2 and 3 ($p < 0.05$) and at 24 hours for all 3 groups ($p < 0.05$). No sig between grp differences were found at post-(grp1-2: $p > 0.05$, MD: -1.85 (-10.55-6.84); grp1-3: $p > 0.05$, MD: -2.71 (-11.42-6.00); grp 2-3: $p > 0.05$, -0.85 (-9.54-7.84)) or at the 1 week FU -(grp1-2: $p > 0.05$, MD: -0.21 (-9.99-9.57); grp1-3: $p > 0.05$, MD: -2.15 (-11.94-6.65); grp 2-3: $p > 0.05$, -1.94 (-11.72-7.84)). CROM within group improvements occurred for all ROM in grp 2 ($p < 0.01$) and for grp 3 ($p < 0.05$) except in ext, with no sig changes in grp 1 ($p > 0.05$). Post between grp comparisons found grp 2 for flex ($p < 0.01$, 6.30 (2.37-9.72)), ext ($p < 0.05$, 5.53 (1.30-9.75)), LLF ($p < 0.05$, 3.75 (0.01-7.48)) RLF ($p < 0.05$, 3.54 (0.33-6.74)), LROT ($p < 0.01$, 7.92 (3.68-12.17)) and RROT ($p < 0.05$, 4.90 (-0.02-9.81)) and grp 3 for flex ($p < 0.01$, 5.93 (2.15-9.72)) had sig improvement compared to grp 1, with Grp 1 having sig improved ext ($p < 0.01$, -4.83 (-9.28-0.38)) and LROT ($p < 0.01$, -5.37 (-9.68-31.05)) when compared to grp 3. 24-hr FU within grp comparisons found grp 1 sig had sig increases in all ROMs ($p < 0.05$), grp 3 for only RROT and LROT ($p < 0.05$), and the control grp no differences were found ($p > 0.05$). At 24-hrs grp 2 had sig increases in flex ($p < 0.01$, 6.64 (2.41-10.87)), LLF ($p < 0.05$, 4.33 (0.84-7.83)) and LROT ($p < 0.01$, 8.21 (2.98-13.27)) compared to grp1, grp 3 had sig improvements in flex ($p < 0.05$, 4.49 (0.41-8.57)) and LROT ($p < 0.05$, 6.46 (1.24-11.87)) compared to grp 1, with no difference between grp 2 and 3 ($p > 0.05$).
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Erdem et al 2021	Turkey; n=80 Chronic NP mechanical; Males only; age: HVLA 20, Control 20.5	RCT; one treatment; measured pre and post treatment Neck pain and disability scale (NPAD Turkish version) CROM Flex, ext, LLF, RLF, LRot, RRot using CROM device (CROM Deluxe, Performance Attainment Associates, Roseville, Minnesota, USA). Joint position error	Study setting not given Grp 1: single thoracic ext manipulation delivered in the prone position according to Cyriax concept and applied on the spinous process at the apex of the convexity of the thoracic spine (n=50). Grp 2: Control Rested for 5 min (n=30)	NPAD only taken at baseline CRCOM between grp differences with increased flex ($p<0.001$) and RROT ($p=0.004$) in grp 1 compared to 2, all other ROM were not different between the grps ($p>0.05$). Joint position error no sig difference at 30° and 50° ($p>0.05$).
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Joshi 2020	India; n=42; NP acute/subacu te/chronic (n=21); F:M - HVLA: 11:10; CT junct: 8:13; age: HVLA: 38.5(±11.5), Mobs: 35.1(±10.1)	RCT, one treatment measured pre and 30 min post PAIN: NPRS CROM: Flex, ext, LLF, RLF, LRot, RRot using CROM device	Hospital setting patients are referred to the physiotherapy department. Treatment is given by post graduate students pursuing a Master's in orthopaedic physiotherapy, overseen by an orthopaedic physiotherapist. Grp 1: Mobilization of CT junction (C7-T1) in the motion of primary restriction. The therapist determined the grade to be used. Pt lay prone, treatment delivered for 30-s intervals in three sets. For central PA glide, a central pressure directed towards the participant's head was applied with the superimposed thumbs of the therapist on the spinous process of C7. The therapist's thumbs were placed on the posterior aspect of the articular process to be mobilized (C7 on the side of restriction), and anteriorly applied oscillatory pressure was made for unilateral PA mobilization (n=21) Grp 2: single thoracic HVLA applied to the mid thoracic spine (T3- 6) in the prone position (n=21)	Pain intra-grp improvements in pain (grp 1: $p < 0.01$; MD = 1.19); grp 2: $p < 0.01$; MD = 1.28) were found with no between grp effects ($p > 0.05$). CROM intra-grp comparisons found improvements in grp 1 for all ROMs ($p < 0.02$) with no between grp effects ($p > 0.05$). except LLF, and grp 2 for all ROMs ($p < 0.02$) with no between grp effects ($p > 0.05$).
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Dunning 2012	United States of America; n=107; mechanical neck pain of any duration; F:M HVLA: 38:18; MOBS: 35:16; age: 41.5 (±11.9), Mobs: 42.7 (±13.9)	RCT; one treatment, pre- and 48 hours after treatment, Pain: NPRS Disability: NDI ROM (passive): Flex Rot test - right and left using CROM device Performance Attainment Associates, Roseville, MN) Strength: craniocervical flex test using air-filled pressure biofeedback unit (Chattanooga Group, Inc, Hixson, TN) PGIC	Multi-centre physical therapy clinics where 7 physical therapists allied the treatments Grp 1: Cervical HVLA to C1/2 on the left and right and thoracic HVLA to T1/2 applied supine, patient's arms across their chest, therapist hand on the transverse process of lower vertebrae, applying Rot and lateral flex the therapist contacted the patient's arms with their xiphoid and delivered a thrust (n=56) Grp 2: Mobs to the upper cervical (C1-2) spine, in the prone position, one 30-second bout of left-sided unilateral grade IV PA mobilizations to the C1-2 segment, were applied and repeated on the left. Non-thrust mobilization to the upper thoracic (T1-2) spine was provided in a prone, one 30-second bout of central grade IV PA mobilizations to the T1-2 motion segment was applied (n=51)	Pain sig grp by time effect ($p<0.01$, $\eta^2=0.35$) with grp 1 having sig greater pain reduction than grp 2 ($p<.001$, MD: 2.0 (1.5, 2.5)). Disability sig grp by time effect ($p<0.01$, $\eta^2=0.34$) with grp 1 having sig greater disability reduction than grp 2 ($p<.001$, MD: 8.0 (5.9, 10.2)). ROM (passive): sig grp by time effect for right ($p<0.01$, $\eta^2=0.15$) and left ($p=0.04$, $\eta^2=0.08$) with grp 1 having sig greater increases in ROM on the right ($p<0.001$, MD: 4.9 (2.7, 7.2)) and left ($p=0.004$, MD: 3.4 (1.1, 5.6)) Strength: craniocervical flex test sig grp by time effect ($p<0.01$, $\eta^2=0.20$) with grp 1 having sig greater increases ($p<0.001$, MD: 4 2.2 (1.3, 3.1)) PGIC: Grp 1 had sig greater improvements when compared to grp 2 ($p<0.001$), based on the cut-off score of +4 or better grp 1 had more participants achieve a successful outcome.
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Bruck et al 2021	Germany n=60; Chronic mechanical NP; F:M HVLA: 12:8; Fascial 15:5; Control 15:5; age: HVLA: 50.1 (±11.8); Fascial 48.9 (±9.4); Control 45.7 (±9.4)	RCT; 2 treatments in 2 weeks, measured at pre and at last treatment Pain VAS Neck pain and disability scale (NPAD); CROM Flex, ext, LLF, RLF, LRot, RRot measured with Cervical Range of Motion unit (CROM3)	2 private physiotherapy and osteopathy clinics, treatment by osteopath Grp 1: Cervical and upper thoracic spine HVLA (C0 - T3) applied in the supine position. The cervical spine is treated in Rot, thoracic spine using the "drop technique". Each restricted segment was only treated once. Grp 2: Fascial treatment consisting of fascial treatment to 8 different neck and cervical region fasciae treated in the supine position. Each fascial stretch was held for two minutes or until the therapist felt a release (n=20). Grp 3: Control no treatment (n=20)	VAS within in grp improvements occurred for and grp 1 ($p<0.001$; - MD: -2.3±2.3; $\eta^2=1.14$) and 2 ($p<0.001$; MD: -2.8±2.0; $\eta^2=1.15$) not grp 3; between grp differences were significant ($p<0.001$; $\eta^2=0.26$) with a large ES. NPAD within grp improvements for grp 1 ($p<0.002$; MD: -11.3±12.4; $\eta^2=0.72$) and 2 ($p<0.002$; MD: -11.3±14.1; $\eta^2=0.51$), not grp 3; between grp differences were significant ($p=0.001$; $\eta^2=0.22$) with a large ES. CROM within grp changes occurred for all ROMs for grp 1 and 2, not grp 3: Flex - grp 1 ($p<0.001$; MD: 8.7±10.02 $\eta^2=0.84$); grp 2 ($p<0.001$; MD: 9.5±11.3; $\eta^2=0.83$); ext - grp 1 ($p<0.001$; MD: 9.9±9.7; $\eta^2=0.89$); grp 2 ($p<0.001$; MD: 11.1±9.1; $\eta^2=0.83$); LLF - grp 1 ($p<0.001$; MD: 7.2±7.6; $\eta^2=0.94$); grp 2 ($p<0.001$; MD: -9.2±5.4; $\eta^2=1.03$); RLF - grp 1 ($p<0.001$; MD: 4.8±5.8; $\eta^2=0.57$); grp 2 ($p<0.001$; MD: -9.9±6.2; $\eta^2=1.57$); LROT - grp 1 ($p<0.001$; MD: 8.8±7.4; $\eta^2=0.98$); grp 2 ($p<0.001$; MD: 10.3±7.4; $\eta^2=0.92$) and RROT grp 1 ($p<0.001$; MD: 8.5±10.0; $\eta^2=0.92$); grp 2 ($p<0.001$; MD: 8.9±9.7; $\eta^2=0.91$); between grp effects favoured grp 2 over grp 1 ($p<0.05$), with no changes in grp 1.
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(CROM - cervical range of motion; HVLA - high-velocity, low-amplitude; grp - group; L - left; R - right; sig - significant; RMS - root mean squared; PPT - pain pressure threshold; Mv - microvolts; ENV - envelope; Jenv - integral envelope; PA - posterior-anterior; SNAGS - Sustain apophyseal natural glide; LT - Lower trapezius; UT - Upper trapezius; AD - Anterior deltoid; BB - Biceps brachii; TB - Triceps brachii; WE - Wrist extensors; WF - Wrist flexors; AP - Adductor pollicis; d - Cohen's D; DN - Dry needling; Hz - hertz; GROC - Global impression of change scale; PGIC - Patients global impression of change scale; ADL - Activities of daily living; NDI - Neck disability index; NPRS - Numerical pain rating scale; VAS - visual analogue scale; η^2 - partial eta squared; HARM - Harmony of movement; STM - single thoracic manipulation; MTM - Multiple thoracic manipulation; MD - mean difference; NPAD - Neck pain and disability scale)

Risk of bias assessment

Outcome level risk of bias assessment of muscle activity and movement harmony was rated as some concern. Out of the 17 trials assessing CROM, three were rated as low risk, 12 with some concern and two as a high risk of bias. Bias in randomisation, measurement outcomes and a lack of published study protocol increased the risk of bias, **Table 3.3**.

Outcome assessment

Muscle activity

- *Cervical SMT (CSMT) single session*

No trials were found investigating acute neck pain. Two trials assessed CSMT in chronic neck pain following one session and compared it to a control group. Both trials reported no between-group effects with one trial assessing various muscles of the upper extremity during a gripping and lifting task (Bracht *et al.* 2018) and the other deltoid muscle activity at rest, a 5 second isometric and isotonic contraction (de Camargo *et al.* 2011). Between group effects were found by de Camargo et al (2011) during a 30 second isometric deltoid muscle contraction where increased EMG amplitude signal and fatigue resistance was found in the CSMT group. Methodological variability of the trials prevented meta-analysis.

- *Thoracic SMT (TSMT) single session*

One trial reported no between-group effects for TSMT compared to a sham when assessing sternocleidomastoid muscle activity bilaterally at rest, during isometric cervical flexion or shoulder girdle elevation activity immediately post one treatment or at a 48-72 hour follow up for chronic neck pain (Pires *et al.* 2015).

Table 3.3: Results of Risk of Bias Assessment

Outcome	Study ID	D1: Randomization process	D2: Deviations from intended interventions**	D3: Missing outcome data	D4: Measurement outcome	D5: Selection of reported result	Overall
Muscle activity	Bracht 2018	!	+	+	+	!	!
	de Camargo 2011	!	+	+	+	!	!
	Pires 2014	+	+	+	+	!	!
CROM	Aki 2020	!	-	+	-	!	-
	Akgüllera 2023	+	+	+	+	!	!
	Brück 2021	+	+	+	+	+	+
	Cassidy 1992	!	+	+	+	!	!
	Dunning 2012*	+	+	+	!	!	!
	Erdem 2021	+	+	+	+	!	!
	Izquierdo Perez 2014	+	+	!	+	+	!
	Joshi 2020	+	+	+	+	+	+
	Lopez-Lopez 2015	!	+	+	+	+	!
	Martinez-Segura 2006	!	+	+	+	!	!
	Pikula 1999	!	+	+	+	!	!
	Puntumetakul 2015	!	+	+	+	!	!
	Saayman 2011	+	+	+	-	+	-
	Saavedra-Hernandez 2012	+	+	+	+	!	!
	Serra-Ano 2023	+	+	+	+	!	!
	Suvarnnato 2013	+	+	+	+	!	!
	Valera-calero 2019	+	+	+	+	+	+
Movement harmony	Serra-Ano 2023	+	+	+	+	!	!

+	Low risk
!	Some concerns
-	High risk

(CSM – cervical spinal manipulation; TSM – thoracic spinal manipulation; C/S – cervical spine; T/S – thoracic spine; *passive range of motion was assessed; ** effect of assignment to intervention)

Spinal kinematics

- *Angular displacement*
 - *CSMT single session*

In acute neck pain, one trial reported no between group differences for flexion or contralateral side rotation, with between group effects favouring the CSMT group for extension, left and right lateral flexion and ipsilateral side rotation following one treatment of CSMT compared to a sham (Pikula 1999).

In chronic neck pain when comparing CSMT to a sham between group effects favoured CSMT for flexion but not for other ROMs (Valera-Calero *et al.* 2019). Comparing CSMT to active treatments, Lopez-Lopez *et al.* (2015) reported no immediate between group differences when compared to cervical mobilisation or sustained natural apophyseal glides (SNAG) for flexion-extension, lateral flexion and rotation CROMs (Lopez-Lopez *et al.* 2015). In contrast to Valera-Calero *et al.* (2019) reported a significant effect for CSMT only in flexion range immediately post-treatment, which did not persist at the one-week follow up (Valera-Calero *et al.* 2019). Meta-analysis was not possible due to the measurement of CROM being different between the trials.

For neck pain of a non-specified duration, meta-analysis of two trials (Martínez-Segura *et al.* 2006; Serra-Añó *et al.* 2023) (n=119) comparing CSMT to a control group showed a significant effect favouring CSMT for all ROMs (flexion: $p < 0.001$; MD 6.83; CI 95%: 3.67-10.00; $I^2 = 6\%$; $p = 0.30$), (extension: $p < 0.001$; MD 8.91; CI 95%: 5.43, 12.38, $I^2 = 0\%$; $p = 0.92$)(left and right lateral flexion: $p < 0.001$; MD 5.65; CI 95%: 3.28, 8.03, $I^2 = 0\%$; $p = 0.64$; $p < 0.001$; MD 5.61; CI 95%: 3.08, 8.14, $I^2 = 0\%$; $p = 0.65$)(left and right rotation: $p < 0.001$; MD 9.73; CI 95%: 6.92, 12.55, $I^2 = 0\%$; $p = 0.81$; $p < 0.001$; MD 9.85; CI 95%: 4.63, 15.06, $I^2 = 0\%$; $p = 0.11$), **Figure 3.3**. All ranges had effect sizes above the minimal detectable change scores (MDC) reported by Fletcher *et al.* (2008)(Fletcher and Bandy 2008) and the minimal clinical important differences reported by Jørgenson *et al.* (2017)(Jørgensen *et al.* 2017), as presented in **Table 2.3**. When cervical SMT was compared to cervical mobilisation (Cassidy, Lopes and Yong-Hing 1993) no between group differences were found for any ROMs immediately

following treatment. When compared to kinesio-tape at a one-week only left and right rotation favoured the CSMT group, with left rotation differences exceeding MDC (Saavedra-Hernández et al. 2012). Meta-analysis was not possible due to clinical variability of the trials.

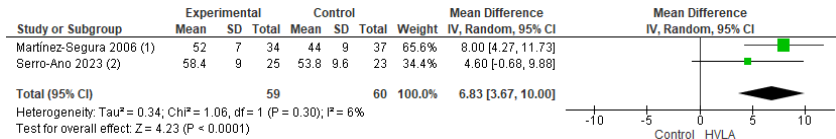
- *CSMT multiple sessions*

Meta-analysis of three trials (n=141) comparing CSMT to cervical mobilisation/SNAGs (Izquierdo Pérez *et al.* 2014), dry needling (Aki *et al.* 2020) and exercise (Akgüller, Coşkun and Analay Akbaba 2023) and assessing flexion and extension ROM in chronic neck pain showed no effect for CSMT at intermediate follow up for flexion ($p = 0.980$, MD 0.03; CI 95%: -2.68, 2.74; $I^2 = 0\%$; $p = 0.84$;) or extension ($p = 0.42$, MD 0.93 CI 95%: -1.00, 3.31; $I^2 = 0\%$, $p = 0.53$). No differences were found for left or right lateral flexion ($p = 0.87$; MD 0.24; CI 95%: -2.51, 2.98, $I^2 = 0\%$; $p = 0.69$; $p = 0.94$; MD 0.16; CI 95%: -4.30, 4.62, $I^2 = 73\%$; $p = 0.05$), or left or right rotation ($p = 0.95$; MD -0.21; CI 95%: -6.47, 6.05, $I^2 = 78\%$; $p = 0.04$; $p = 0.47$; MD -1.09; CI 95%: -4.04, 1.86, $I^2 = 0\%$; $p = 0.58$) when two of these trials with similar outcomes were assessed in meta-analysis (n=100) (Aki *et al.* 2020; Akgüller, Coşkun and Analay Akbaba 2023), **Figure 3.4.**

One trial, excluded from meta-analysis, combined left and right lateral flexion and rotation ROMs and reported no significant effect of CSMT when compared to cervical mobilisation or SNAGs immediately post-treatment (Izquierdo Pérez *et al.* 2014).

In neck pain of a non-specified duration where CSMT was compared to low level laser therapy (LLT), no between group differences were found for CROM, but when compared to a combination of low-level laser therapy and CSMT, the combined group had increased flexion and rotation ROM's, with no differences for extension and lateral flexion measured at 4 weeks (Saayman, Hay and Abrahamse 2011).

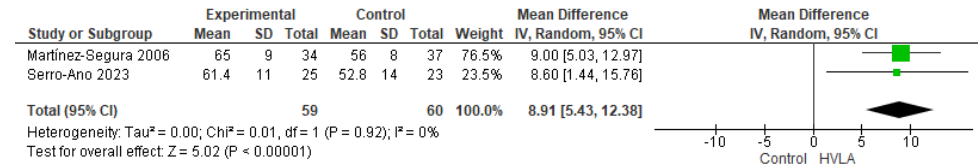
Flexion



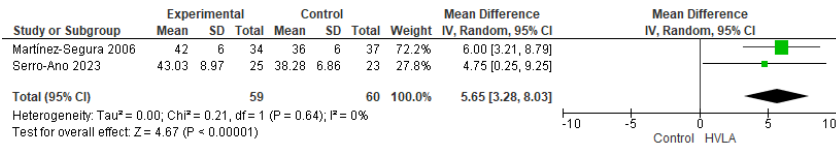
Footnotes

- (1) Only females. Pre-post. Measured with a CROM device.
 (2) Measured pre and post. Measured with video-photogrammetry.

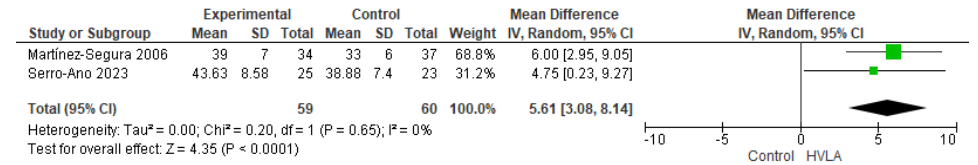
Extension



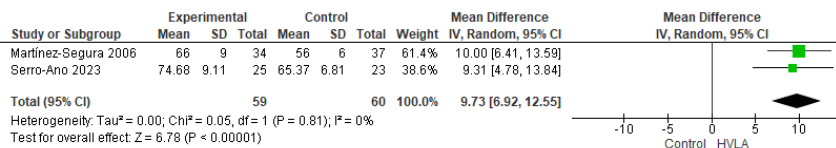
Left lateral flexion



Right lateral flexion



Left rotation



Right rotation

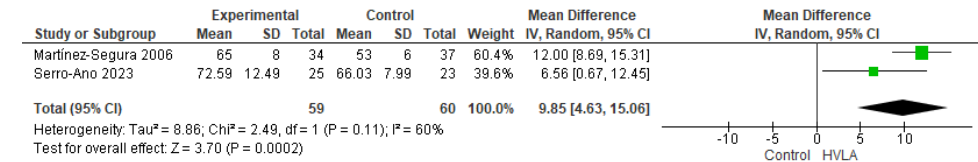
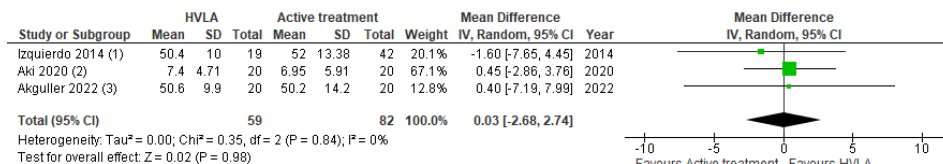


Figure 3.3: The immediate effect of a single cervical HVLA compared to sham/control on ROM for non-specific neck pain of a non-specified duration

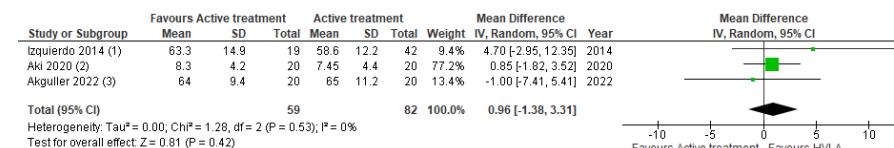
Flexion



Footnotes

- (1) Mobilisation and SNAG group combined. Four treatments over 2 weeks. Measured at 2 weeks.
 (2) Compared to dry needling. Eight treatments over 4 weeks. Measured at 4 weeks.
 (3) Compared to exercise. 12 treatments over 6 weeks. Measured at 6 weeks.

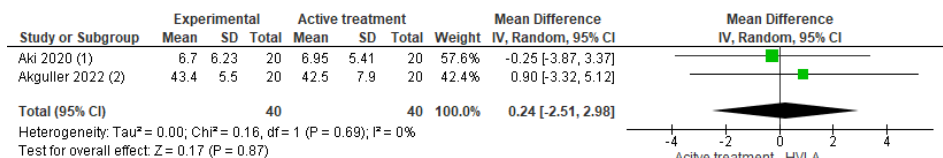
Extension



Footnotes

- (1) Mobilisation and SNAG group combined. Four treatments over 2 weeks. Measured at 2 weeks.
 (2) Compared to dry needling. Eight treatments over 4 weeks. Measured at 4 weeks.
 (3) Compared to exercise. 12 treatments over 6 weeks. Measured at 6 weeks.

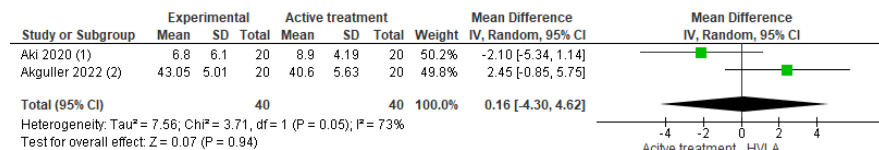
Left lateral flexion



Footnotes

- (1) Compared to dry needling. Eight treatments over 4 weeks. Measured at 4 weeks.
 (2) Compared to exercise. 12 treatments over 6 weeks. Measured at 6 weeks.

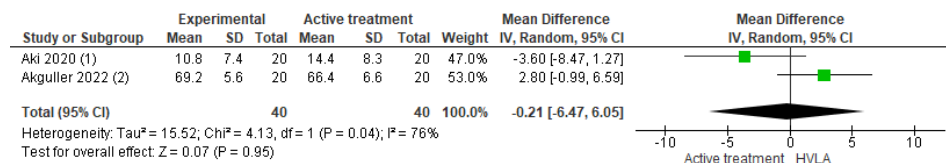
Right lateral flexion



Footnotes

- (1) Compared to dry needling. Eight treatments over 4 weeks. Measured at 4 weeks.
 (2) Compared to exercise. 12 treatments over 6 weeks. Measured at 6 weeks.

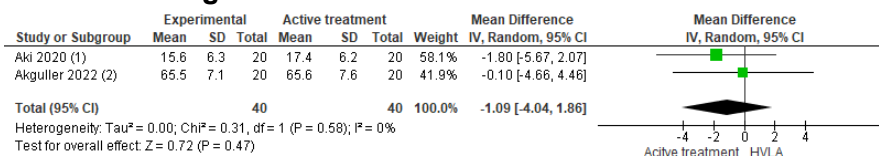
Left rotation



Footnotes

- (1) Compared to dry needling. Eight treatments over 4 weeks. Measured at 4 weeks.
 (2) Compared to exercise. 12 treatments over 6 weeks. Measured at 6 weeks.

Right rotation



Footnotes

- (1) Compared to dry needling. Eight treatments over 4 weeks. Measured at 4 weeks.
 (2) Compared to exercise. 12 treatments over 6 weeks. Measured at 6 weeks.

Figure 3.4: The intermediate effect of multiple sessions of cervical HVLA compared to active treatment on cervical ROM for chronic non-specific neck pain

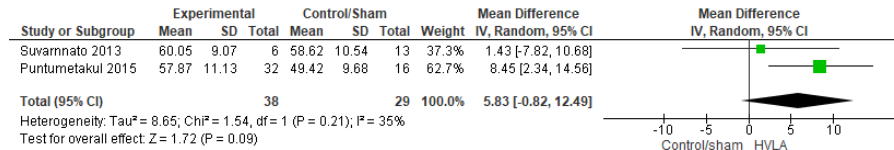
- *TSMT single session*

Meta-analysis of two trials for chronic neck pain (Suvarnnato *et al.* 2013; Puntumetakul *et al.* 2015) (n=67) found no immediate effect of TSMT compared to control for flexion ($p = 0.09$; MD 5.83; CI 95%: -0.82, 12.49, $I^2 = 35\%$; $p = 0.21$), left or right lateral flexion ($p = 0.14$; MD 3.24; CI 95%: -1.06, 7.55, $I^2 = 0\%$; $p = 0.93$; $p = 0.07$; MD 3.51; CI 95%: -0.30, 7.33, $I^2 = 0\%$; $p = 0.67$), with significant between group differences favouring TSMT for extension ($p = 0.03$; MD 6.49; CI 95%: 0.70, 12.29; $I^2 = 0\%$, $p = 0.98$); left and right rotation ($p = 0.02$; MD 6.04; CI 95%: 0.98, 11.10; $I^2 = 0\%$; $p = 0.73$; $p < 0.001$; MD 7.18; CI 95%: 2.70, 11.65; $I^2 = 0\%$; $p = 0.61$), **Figure 3.5**, with effect size exceeding the MDC. One trial (Erdem *et al.* 2021), with non-normally distributed data, reported a significant between group effect favouring TSMT compared to a control for flexion ($p < 0.001$) but other ROMs.

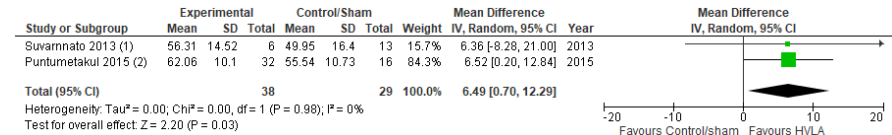
When compared to thoracic mobilisation, no significant differences were found immediately or at a 24 hour follow up for flexion, left and right lateral flexion and right rotation. Differences were found in extension and left rotation immediately following treatment, favouring the TSMT group, but the effects were not sustained at 24 hours follow up (Suvarnnato *et al.* 2013) in chronic pain.

In non-specified duration neck pain after a single session of TSMT compared to cervicothoracic junction mobilisation no significant between group differences were found immediately following treatment or at 24-hour follow up for all CROMs (Joshi, Balthillaya and Neelapala 2020).

Flexion



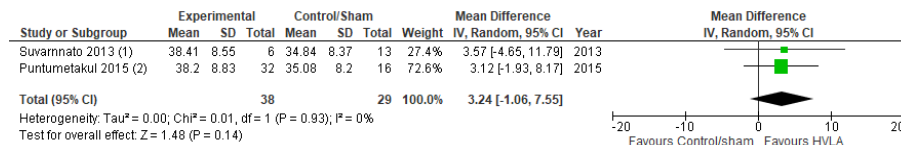
Extension



Footnotes

- (1) Measured post treatment.
 (2) Measured at 24 hour follow up.

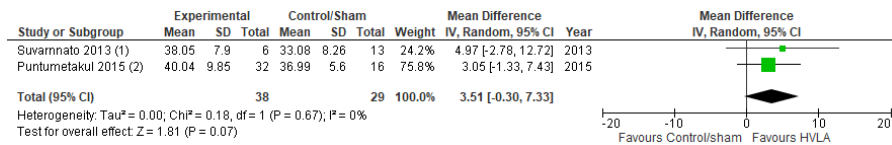
Left lateral flexion



Footnotes

- (1) Measured post treatment.
 (2) Measured at 24 hour follow up.

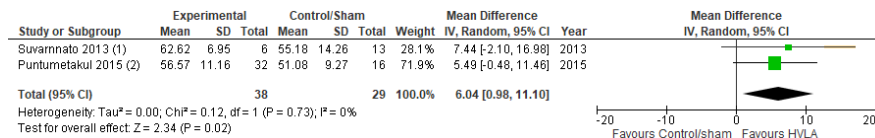
Right lateral flexion



Footnotes

- (1) Measured post treatment.
 (2) Measured at 24 hour follow up.

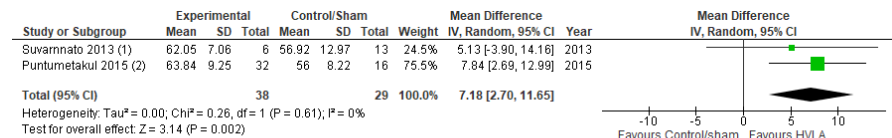
Left rotation



Footnotes

- (1) Measured post treatment.
 (2) Measured at 24 hour follow up.

Right rotation



Footnotes

- (1) Measured post treatment.
 (2) Measured at 24 hour follow up.

Figure 3.5: The immediate effect of a single session of thoracic HVLA compared to sham/control on ROM in chronic, non-specific neck pain

- *Combined CSMT and TSMT single session*

In non-specified neck pain duration combined SMT when compared to cervical and thoracic mobilization, significant effects favouring the HVLA group were found for passive left and right cervical rotation (Dunning *et al.* 2012).

- *Combined CSMT and TSMT multiple session*

When two sessions of combined SMT were compared to a control and a fascial treatment for neck pain of a chronic duration. The significance between group effects were found favouring the SMT group for all ROMs, but not when compared to the fascial treatment (Brück, Jacobi and Schmidt 2021).

- *Cervical motion harmony*

In neck pain of an unspecified duration following a single CSMT compared to a control (Serra-Añó *et al.* 2023) (n=50), no significant differences were found for cervical motion harmony immediately following one treatment.

Summary of findings

- *Evidence for a single session of cervical spinal manipulation compared to sham/control for acute non-specific neck pain:*

The evidence was low for improving cervical ROM, being downgraded for risk of bias and imprecision, **Table 3.4**.

Table 3.4: A single session of cervical spinal manipulation compared to sham/control for acute non-specific neck pain

Outcome*	No of participants	Certainty assessment					Certainty
	(studies)	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	
Cervical flexion ROM	36 (1 RCT) ¹	serious ^a	not serious	not serious	serious ^b	none	⊕⊕○○ Low ^{a,b}
Cervical extension ROM	36 (1 RCT) ¹	serious ^a	not serious	not serious	serious ^b	none	⊕⊕○○ Low ^{a,b}
Cervical ipsilateral lateral flexion ROM	36 (1 RCT) ¹	serious ^a	not serious	not serious	serious ^b	none	⊕⊕○○ Low ^{a,b}
Cervical contralateral lateral flexion ROM	36 (1 RCT) ¹	serious ^a	not serious	not serious	serious ^b	none	⊕⊕○○ Low ^{a,b}
Cervical ipsilateral rotation ROM	36 (1 RCT) ¹	serious ^a	not serious	not serious	serious ^b	none	⊕⊕○○ Low ^{a,b}
Cervical contralateral rotation ROM	36 (1 RCT) ¹	serious ^a	not serious	not serious	serious ^b	none	⊕⊕○○ Low ^{a,b}

* Measured with a goniometer

Explanations

^a. The study was rated as some concerns due to issues with the randomization process and selection of reported results.

^b. Insufficient optimal information size, small sample.

References

¹. Pikula, J.R. 1999. The effect of spinal manipulative therapy (SMT) on pain reduction and range of motion in patients with acute unilateral neck pain: a pilot study. *The Journal of the Canadian Chiropractic Association* 43(2):111-119

- *The evidence for a single session of cervical spinal manipulation compared to sham/control for chronic non-specific neck pain:*

The evidence for muscle activity was rated as low, being downgraded for risk of bias and imprecision and for cervical ROM as low, being downgraded for imprecision, **Table 3.5.**

Table 3.5: A single session of cervical spinal manipulation compared to sham/control for chronic non-specific neck pain

Outcome	No of participants	Certainty assessment					Certainty
	(studies)	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	
Muscle activity*	67 (2 RCT) ^{1,2}	serious ^a	not serious	not serious	very serious ^b	none	⊕○○○ Very low
Cervical flexion ROM**	41 (1 RCT) ³	not serious	not serious	not serious	very serious ^b	none	⊕⊕○○ Low
Cervical extension ROM	41 (1 RCT) ³	not serious	not serious	not serious	very serious ^b	none	⊕⊕○○ Low
Cervical left lateral flexion ROM**	41 (1 RCT) ³	not serious	not serious	not serious	very serious ^b	none	⊕⊕○○ Low
Cervical lateral flexion ROM**	41 (1 RCT) ³	not serious	not serious	not serious	very serious ^b	none	⊕⊕○○ Low
Cervical left rotation ROM**	41 (1 RCT) ³	not serious	not serious	not serious	very serious ^b	none	⊕⊕○○ Low
Cervical right rotation ROM**	41 (1 RCT) ³	not serious	not serious	not serious	very serious ^b	none	⊕⊕○○ Low

* assessed with: Surface electromyography

** assessed with: Goniometer

Explanations

^a. Some concerns regarding the randomization process and selection of reported results

^b. Insufficient optimal information size, small sample size.

References

1. Bracht, M.A., Coan, A.C.B., Yahya, A. and Santos, M.J.d. 2018. Effects of cervical manipulation on pain, grip force control, and upper extremity muscle activity: a randomized controlled trial. *Journal of Manual & Manipulative Therapy* 26(2):78-88
2. de Camargo, V. M., Albuquerque-Sendín, F., Bérzin, F., Stefanelli, V. C., de Souza, D. P. and Fernández-de-las-Peñas, C. 2011. Immediate effects on electromyographic activity and pressure pain thresholds after a cervical manipulation in mechanical neck pain: a randomized controlled trial. *Journal of Manipulative and Physiological* 34(4):211-220
3. Valera-Calero, A., Lluch, G., Gállego-Izquierdo, T., Malfliet, A. and Pecos-Martín, D. 2019. Endocrine response after cervical manipulation and mobilization in people with chronic mechanical neck pain: a randomized controlled trial. *European Journal of Physical and Rehabilitation Medicine* 55(6):792-805

- A single session of cervical spinal manipulation compared to active treatment for chronic non-specific neck pain:

The evidence for CSMT on angular displacement in chronic neck pain was moderate, being downgraded for imprecision, **Table 3.6**.

Table 3.6: A single session of cervical spinal manipulation compared to active treatment for chronic non-specific neck pain

Outcome*	No of participants	Certainty assessment					Certainty
	(studies)#	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	
Cervical flexion ROM	42 (1 RCT) ¹	not serious	not serious	not serious	very serious ^a	none	⊕⊕○○ Low
Cervical extension ROM	42 (1 RCT) ¹	not serious	not serious	not serious	very serious ^a	none	⊕⊕○○ Low
Cervical left lateral flexion ROM	42 (1 RCT) ¹	not serious	not serious	not serious	very serious ^a	none	⊕⊕○○ Low
Cervical lateral flexion ROM	42 (1 RCT) ¹	not serious	not serious	not serious	very serious ^a	none	⊕⊕○○ Low
Cervical left rotation ROM	42 (1 RCT) ¹	not serious	not serious	not serious	very serious ^a	none	⊕⊕○○ Low
Cervical right rotation ROM	42 (1 RCT) ¹	not serious	not serious	not serious	very serious ^a	none	⊕⊕○○ Low

* assessed with: Goniometer

Only one trial (Lopez-Lopez et al 2015) was included in the SoF due to the other trial recording combined measures of ROM (i.e. flexion-extension, rotation and lateral flexion)

Explanations

a. Insufficient optimal information size, small sample size.

References

Valera-Calero, A., Lluch, G., E., Gallego-Izquierdo, T., Malfliet, A. and Pecos-Martín, D. 2019. Endocrine response after cervical manipulation and mobilization in people with chronic mechanical neck pain: a randomized controlled trial. *European Journal of Physical and Rehabilitation Medicine* 55(6):792-805

- *A single session of cervical spinal manipulation compared to sham/control for neck pain of a non-specified duration:*

The evidence was rated as low for cervical ROM, being downgraded for risk of bias, inconsistency, and imprecision, **Table 3.7**; and for motion harmony was rated as moderate, being downgraded for imprecision, **Table 3.8**.

Table 3.7: A single session of cervical spinal manipulation compared to sham/control for neck pain of a non-specified duration for cervical ROM

Outcomes	Anticipated absolute effects* (95% CI)		No of participants (studies)	Certainty of the evidence (GRADE)
	Risk with sham/control	Risk with a single session of cervical spinal manipulation		
Cervical flexion ROM	The mean flexion cervical range of motion was 48.9 Degrees	MD 6.82 Degrees higher (3.67 higher to 10 higher)	119 (2 RCTs) ^{1,2}	⊕⊕○○ Low ^{a,b,c}
Cervical extension ROM	The mean extension cervical range of motion was 54.4 Degrees	MD 8.91 Degrees higher (5.43 higher to 12.38 higher)	119 (2 RCTs) ^{1,2}	⊕⊕○○ Low ^{a,b,c}
Cervical left lateral flexion ROM	The mean left lateral flexion cervical range of motion was 37.14 Degrees	MD 5.65 Degrees higher (3.28 higher to 8.03 higher)	119 (2 RCTs) ^{1,2}	⊕⊕○○ Low ^{a,b,c}
Cervical right lateral flexion ROM	The mean right lateral flexion cervical range of motion was 36.44 Degrees	MD 5.61 Degrees higher (3.08 higher to 8.14 higher)	119 (2 RCTs) ^{1,2}	⊕⊕○○ Low ^{a,b,c}
Cervical left rotation ROM	The mean left rotation cervical range of motion was 60.69 Degrees	MD 9.73 Degrees higher (6.92 higher to 12.55 higher)	119 (2 RCTs) ^{1,2}	⊕⊕○○ Low ^{a,b,c}
Cervical right rotation ROM	The mean right rotation cervical range of motion was 59.52 Degrees	MD 9.85 Degrees higher (4.63 higher to 15.06 higher)	119 (2 RCTs) ^{1,2}	⊕⊕○○ Low ^{a,b,c}

Explanations

a. Some concerns regarding the randomization process and selection of reported result

b. Lack of optimal information size, small sample size.

c. Although there was a large magnitude of effect ($d > 1$) the trial was not upgraded due to concerns in methodology

References

1. Martínez-Segura, R., Fernández-de-las-Peñas, C., Ruiz-Sáez, M., López-Jiménez and C., Rodríguez-Blanco, C. 2006 Immediate effects on neck pain and active range of motion after a single

cervical high-velocity low-amplitude manipulation in subjects presenting with mechanical neck pain: a randomized controlled trial. *Journal of Manipulative and Physiological Therapeutics* 41(7):551-560

2. Serra-Añó, P. Venegas, W., Page, A., Inglés de la Torre, M., Aguilar-Rodríguez, M. and Espí-López, G. 2023. Immediate effects of a single session of cervical spine manipulation on cervical movement patterns in people with nonspecific neck pain: a randomized controlled trial. *Journal of Manipulative and Physiological Therapeutics* 46(1):17-26

Table 3.8: A single session of cervical spinal manipulation compared to sham/control for neck pain of a non-specified duration for cervical motion harmony

Outcome*	No of participants	Certainty assessment					Certainty
	(studies)	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	
HARM Flexion	48 (1 RCT) ¹	not serious	not serious	not serious	serious ^a	none	⊕⊕⊕○ Moderate ^a
HARM Extension	48 (1 RCT) ¹	not serious	not serious	not serious	serious ^a	none	⊕⊕⊕○ Moderate ^a
HARM Left lateral flexion	48 (1 RCT) ¹	not serious	not serious	not serious	serious ^a	none	⊕⊕⊕○ Moderate ^a
HARM Right lateral flexion	48 (1 RCT) ¹	not serious	not serious	not serious	serious ^a	none	⊕⊕⊕○ Moderate ^a
HARM Left rotation	48 (1 RCT) ¹	not serious	not serious	not serious	serious ^a	none	⊕⊕⊕○ Moderate ^a
HARM Right rotation	48 (1 RCT) ¹	not serious	not serious	not serious	serious ^a	none	⊕⊕⊕○ Moderate ^a

* assessed with: Video-photogrammetry

Explanations

a. Some concerns regarding the randomization process and selection of reported result

References

1. Serra-Añó, P. Venegas, W., Page, A., Inglés de la Torre, M., Aguilar-Rodríguez, M. and Espí-López, G. 2023. Immediate effects of a single session of cervical spine manipulation on cervical movement patterns in people with nonspecific neck pain: a randomized controlled trial. *Journal of Manipulative and Physiological Therapeutics* 46(1):17-26

- *A single session of cervical spinal manipulation compared to active treatment for neck pain of a non-specified duration*: The evidence was very low too low for cervical ROM due to the risk of bias and imprecision, **Table 3.9**.

Table 3.9: A single session of cervical spinal manipulation compared to active treatment for neck pain of a non-specified duration

Outcome*	No of participants	Certainty assessment					Certainty
	(studies)	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	
Cervical flexion ROM	180 (2 RCT) ^{1,2}	serious ^a	serious ^b	not serious	very serious ^c	none	⊕○○○ Very low
Cervical extension ROM	180 (2 RCT) ^{1,2}	serious ^a	serious ^b	not serious	very serious ^c	none	⊕○○○ Very low
Cervical left lateral flexion ROM	80 (1 RCT) ¹	serious ^a	not serious	not serious	very serious ^c	none	⊕○○○ Very low
Cervical right lateral flexion ROM	80 (1 RCT) ¹	serious ^a	not serious	not serious	very serious ^c	none	⊕○○○ Very low
Cervical left rotation ROM	80 (1 RCT) ¹	serious ^a	not serious	not serious	very serious ^c	none	⊕○○○ Very low
Cervical right rotation ROM	80 (1 RCT) ¹	serious ^a	not serious	not serious	very serious ^c	none	⊕○○○ Very low

* assessed with: Goniometer

Explanations

a. Both studies had some concern regarding selection of reported results with one study also having issues regarding randomization.

b. Compared to different active treatments; post-treatment measures varied from immediate to 1 week.

c. Lack of optimal information size, small sample size.

²*measured ipsilateral and contralateral thus excluded from lateral flexion and rotation analysis

References

1.Saavedra-Hernández, M., Castro-Sánchez, A. M., Arroyo-Morales, M., Cleland, J. A., Lara-Palomo, I. C., Fernández-de-Las-Peñas, C. 2012. Short-term effects of kinesio taping versus cervical thrust manipulation in patients with mechanical neck pain: a randomized clinical trial. *The Journal of Orthopaedic and Sports Physical Therapy* 42(8):724-730

2.Cassidy, J. D., Lopes, A. A. and Yong-Hing, K. 1993. The immediate effect of manipulation vs. mobilization on pain and range of motion in the cervical spine: a randomized controlled trial. *Journal of Manipulative and Physiological Therapeutics* 16(4):279-280

- *Multiple sessions of cervical spinal manipulation compared to active treatment for chronic non-specific neck pain:*

The evidence for multiple sessions of CSMT compared to active treatment on cervical ROM was rated as very low to low, due to the risk of bias, inconsistency and imprecision issues, **Table 3.10**.

Table 3.10: Multiple sessions of cervical spinal manipulation compared to active treatment for chronic non-specific neck pain

Outcomes*	Anticipated absolute effects* (95% CI)		No of participants (studies)	Certainty of the evidence (GRADE)
	Risk with active treatment	Risk with multiple sessions of cervical spinal manipulation		
Cervical Flexion ROM	The mean flexion cervical ROM was 47.98 Degrees	MD 0.03 Degrees higher (2.68 lower to 2.74 higher)	141 (3 RCTs) ^{1,2,3}	⊕○○○ Very low ^{a,b,c}
Cervical extension ROM	The mean extension cervical ROM was 54.6 Degrees	MD 0.93 Degrees higher (1 lower to 3.31 higher)	141 (3 RCTs) ^{1,2,3}	⊕○○○ Very low ^{a,b,c}
Cervical left lateral flexion ROM	The mean left lateral flexion cervical ROM was 41.88 Degrees	MD 0.24 Degrees higher (2.51 lower to 2.98 higher)	80 (2 RCTs) ^{1,3}	⊕⊕○○ Low ^{c,d}
Cervical right lateral flexion cervical ROM	The mean right lateral flexion cervical ROM was 41.58 Degrees	MD 0.16 Degrees higher (4.3 higher to 4.62 higher)	80 (2 RCTs) ^{1,3}	⊕⊕○○ Low ^{c,d}
Cervical left rotation ROM	The mean left rotation cervical ROM was 58.65 Degrees	MD 21 Degrees lower (6.47 lower to 6.05 higher)	80 (2 RCTs) ^{1,3}	⊕⊕○○ Low ^{c,d}
Cervical right rotation ROM	The mean right rotation cervical ROM was 59.85 Degrees	MD 1.09 Degrees lower (4.04 lower to 1.86 higher)	80 (2 RCTs) ^{1,3}	⊕⊕○○ Low ^{c,d}

* assessed with: Goniometer

Explanations

- One study was rated as high concern and the other as some concern resulting in all domains having at least some concern as a decision (randomization process, deviations from intended interventions, missing outcome data, measurement outcome and selection of reported result)
- Compared to different active treatments; post treatment measurements varied from 2 to 4 weeks.
- Lack of optimal information size, small sample size.
- Study rated as some concern for the domains of missing outcome data and selection of reported results.

References

- Aki, S., Özden, A.V., Alptekin, H.K. and Alptekin, J.O. 2020. Short-term effects of chiropractic application and dry needling treatment on chronic mechanical neck pain. *Manuelle Medizin* 58:237-245
- Izquierdo Pérez, H., Alonso Perez, J. L., Gil Martinez, A., La Touche, R., Lerma-Lara, S., Commeaux Gonzalez, N., Arribas Perez, H., Bishop, M. D. and Fernández-Carnero, J. 2014. Is one better than another? A randomized clinical trial of manual therapy for patients with chronic neck pain. *Manual Therapies* 19:215-221
- Akgüller, T., Coşkun, R. and Akbaba, Y. A. 2023. Comparison of the Effects of Cervical Thrust Manipulation and Exercise in Mechanical Neck Pain: A Randomized Controlled Trial. *Physiotherapy Theory and Practice* 1-15

- *Multiple session of cervical spinal manipulation compared to active treatment for neck pain of a non-specified duration:*

The evidence for CSMT in non-specific neck pain was low for cervical ROM, being downgraded for risk of bias and imprecision, **Table 3.11**.

Table 3.11: Multiple session of cervical spinal manipulation compared to active treatment for neck pain of a non-specified duration

Outcome*	No of participants	Certainty assessment					Certainty
	(studies)	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	
Cervical flexion ROM	40 (1 RCT) ¹	serious ^a	not serious	not serious	very serious ^b	none	⊕○○○ Very low
Cervical extension ROM	40 (1 RCT) ¹	serious ^a	not serious	not serious	very serious ^b	none	⊕○○○ Very low
Average lateral flexion cervical ROM	40 (1 RCT) ¹	serious ^a	not serious	not serious	very serious ^b	none	⊕○○○ Very low
Average rotation cervical ROM	40 (1 RCT) ¹	serious ^a	not serious	not serious	very serious ^b	none	⊕○○○ Very low

* assessed with: Goniometer

Explanations

- a. Risk of bias was high for the domain of measurement outcome.
b. Lack of optimal information size, small sample size.

References

¹.Saayman, L., Hay, C. and Abrahamse, H. 2011. Chiropractic manipulative therapy and low-level laser therapy in the management of cervical facet dysfunction: a randomized controlled study. *Journal of Manipulative and Physiological Therapeutics* 34(3):153-163.

- *A single thoracic spinal manipulation compared to sham/control for chronic non-specific neck pain:*

The evidence for TSMT on muscle activity was rated as moderate, being downgraded for risk of bias and imprecision, **Table 3.12**; and for cervical ROM the evidence was low, being downgraded for risk of bias and imprecision, **Table 3.13**.

Table 3.12: A single thoracic spinal manipulation compared to sham/control for chronic non-specific neck pain for muscle activity

Outcome*	No of participants	Certainty assessment					Certainty
	(studies)	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	
Muscle activity	32 (1 RCT) ¹	serious ^a	not serious	not serious	very serious ^b	none	⊕○○○ Very low

* assessed with surface electromyography

Explanations

a. Risk of bias as some concern due to issues with selection of reported results

b. Lack of optimal information size, small sample size.

References

1. Pires, P. F., Packer, A. C., Dibai-Filho, A. V. and Rodrigues-Bigaton, D. 2015. Immediate and short-term effects of upper thoracic manipulation on myoelectric activity of sternocleidomastoid muscles in young women with chronic neck pain: a randomized blind clinical trial. *Journal of Manipulative and Physiological Therapeutics* 38(8):554-220.

Table 3.13: A single thoracic spinal manipulation compared to sham/control for chronic non-specific neck pain for cervical ROM

Outcomes*	Anticipated absolute effects* (95% CI)		No of participants (studies)	Certainty of the evidence (GRADE)
	Risk with active treatment	Risk with multiple sessions of cervical spinal manipulation		
Cervical flexion ROM	The mean flexion cervical ROM was 47.98 Degrees	MD 0.03 Degrees higher (2.68 lower to 2.74 higher)	141 (3 RCTs) ^{1,2,3}	⊕○○○ Very low ^{a,b,c}
Cervical extension ROM	The mean extension cervical ROM was 54.6 Degrees	MD 0.93 Degrees higher (1 lower to 3.31 higher)	141 (3 RCTs) ^{1,2,3}	⊕○○○ Very low ^{a,b,c}
Cervical left lateral flexion ROM	The mean left lateral flexion ROM was 41.88 Degrees	MD 0.24 Degrees higher (2.51 lower to 2.98 higher)	80 (2 RCTs) ^{1,3}	⊕⊕○○ Low ^{c,d}
Cervical right lateral flexion ROM	The mean right lateral flexion cervical ROM was 41.58 Degrees	MD 0.16 Degrees higher (4.3 higher to 4.62 higher)	80 (2 RCTs) ^{1,3}	⊕⊕○○ Low ^{c,d}
Cervical left rotation ROM	The mean left rotation cervical ROM was 58.65 Degrees	MD 21 Degrees lower (6.47 lower to 6.05 higher)	80 (2 RCTs) ^{1,3}	⊕⊕○○ Low ^{c,d}
Cervical right rotation ROM	The mean right rotation cervical ROM was 59.85 Degrees	MD 1.09 Degrees lower (4.04 lower to 1.86 higher)	80 (2 RCTs) ^{1,3}	⊕⊕○○ Low ^{c,d}

(RT: randomised trial; CI: confidence interval; MD: mean difference)

* assessed with: Goniometer

Explanations

a. Risk of bias as some concern due to issues with selection of reported results

b. Lack of optimal information size, small sample size.

References

1. Suvarnato, T., Puntumetakul, R., Kaber, D., Boucaut, R., Boonphakob, Y., Arayawichanon, P., Chatchawan, U. 2013. The effects of thoracic manipulation versus mobilization for chronic neck pain: a randomized controlled trial pilot study. *Journal of Physical Therapy Science* 25(7): 865-871.
2. Puntumetakul, R., Suvarnato, T., Werasirirat, P., Uthairak, S., Yamauchi, J. and Boucaut, R. 2015. Acute effects of single and multiple level thoracic manipulations on chronic mechanical neck pain: a randomized controlled trial. *Neuropsychiatric disease and treatment* 11:137-144

- A single thoracic spinal manipulation compared to active treatment for chronic non-specific neck pain:

The evidence for TSMT compared to an active treatment for cervical ROM was moderate, being downgraded for imprecision, **Table 3.14**.

Table 3.14 A single thoracic spinal manipulation compared to active treatment for chronic non-specific neck pain

Outcome*	No of participants	Certainty assessment					Certainty
	(studies)	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	
Cervical flexion ROM	20 (1 RCT) ¹	serious ^a	not serious	not serious	very serious ^b	none	⊕○○○ Very low
Cervical Extension cervical ROM	20 (1 RCT) ¹	serious ^a	not serious	not serious	very serious ^b	none	⊕○○○ Very low
Cervical left lateral flexion ROM	20 (1 RCT) ¹	serious ^a	not serious	not serious	very serious ^b	none	⊕○○○ Very low
Cervical right lateral flexion ROM	20 (1 RCT) ¹	serious ^a	not serious	not serious	very serious ^b	none	⊕○○○ Very low
Cervical left rotation ROM	20 (1 RCT) ¹	serious ^a	not serious	not serious	very serious ^b	none	⊕○○○ Very low
Cervical right rotation ROM	20 (1 RCT) ¹	serious ^a	not serious	not serious	very serious ^b	none	⊕○○○ Very low

* assessed with: Goniometer

Explanations

a. Risk of bias as some concern due to issues with selection of reported results

b. Lack of optimal information size and very small sample

References

1. Suvarnnato, T., Puntumetakul, R., Kaber, D., Boucaut, R., Boonphakob, Y., Arayawichanon, P., Chatchawan, U. 2013. The effects of thoracic manipulation versus mobilization for chronic neck pain: a randomized controlled trial pilot study. *Journal of Physical Therapy Science* 25(7): 865-871.

- A single session of thoracic spinal manipulation compared to active treatment for non-specific neck pain of non-specified duration:

The evidence was rated as moderate for cervical ROM, downgraded for risk of bias, indirectness, and imprecision, **Table 3.15**.

Table 3.15: A single session of thoracic spinal manipulation compared to active treatment for non-specific neck pain of non-specified duration

Outcome*	No of participants	Certainty assessment					Certainty
	(studies)	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	
Cervical flexion ROM	42 (1 RCT) ¹	not serious	not serious	not serious	very serious ^a	none	⊕⊕○○ Low
Cervical extension ROM	42 (1 RCT) ¹	not serious	not serious	not serious	very serious ^a	none	⊕⊕○○ Low
Cervical left lateral flexion ROM	42 (1 RCT) ¹	not serious	not serious	not serious	very serious ^a	none	⊕⊕○○ Low
Cervical right lateral flexion ROM	42 (1 RCT) ¹	not serious	not serious	not serious	very serious ^a	none	⊕⊕○○ Low
Cervical left rotation ROM	42 (1 RCT) ¹	not serious	not serious	not serious	very serious ^a	none	⊕⊕○○ Low
Cervical right rotation ROM	42 (1 RCT) ¹	not serious	not serious	not serious	very serious ^a	none	⊕⊕○○ Low

* assessed with: Goniometer

Explanations

a. Lack of optimal information size, small sample size.

References

1.Joshi, S., Balthillaya, G., Raghava Neelapala, Y. V. 2020. Immediate effects of cervicothoracic junction mobilization versus thoracic manipulation on the range of motion and pain in mechanical neck pain with cervicothoracic junction dysfunction: a pilot randomized controlled trial. *Chiropractic & Manual Therapies* 28:38

- *A single session of combined cervical and thoracic spinal manipulation compared to active treatment for non-specific neck pain of a non-specified duration:*

The evidence for cervical ROM was moderate, being downgraded for imprecision, **Table 3.16.**

Table 3.16: A single session of combined cervical and thoracic spinal manipulation compared to active treatment for non-specific neck pain of a non-specified duration

Outcome*	No of participants	Certainty assessment					Certainty
	(studies)	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	
Passive cervical flexion rotation to the right	107 (1 RCT) ¹	serious ^a	not serious	serious ^b	serious ^c	none	⊕○○○ Very low
Passive cervical flexion rotation to the left	107 (1 RCT) ¹	serious ^a	not serious	serious ^b	serious ^c	none	⊕○○○ Very low

* assessed with: Goniometer

Explanations

- Risk of bias was rated as some concerns due to the domains of measurement outcome and selection of reported result.
- The measurement is not a true representation of cervical range of motion
- Lack of optimal information size

References

1. Dunning, J.R., Cleland, J.A., Waldrop, M.A., Arnot, C.F., and Young, I.A., Turner, M., Sigurdsson, G. 2012. Upper cervical and upper thoracic thrust manipulation versus nonthrust mobilization in patients with mechanical neck pain: a multicenter randomized clinical trial. *The Journal of Orthopaedic and Sports Physical Therapy* 42(1):5-18

- *Multiple sessions of cervical and thoracic spinal manipulation compared to control for chronic non-specific neck pain:*

The evidence for cervical ROM was rated as low, being downgraded for imprecision, **Table 3.17.**

Table 3.17: Multiple sessions of cervical and thoracic spinal manipulation compared to control for chronic non-specific neck pain

Outcome*	No of participants	Certainty assessment					Certainty
	(studies)	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	
Cervical flexion ROM	40 (1 RCT) ¹	not serious	not serious	not serious	very serious ^a	none	⊕⊕○○ Low
Cervical extension ROM	40 (1 RCT) ¹	not serious	not serious	not serious	very serious ^a	none	⊕⊕○○ Low
Cervical left lateral flexion ROM	40 (1 RCT) ¹	not serious	not serious	not serious	very serious ^a	none	⊕⊕○○ Low
Cervical right lateral flexion ROM	40 (1 RCT) ¹	not serious	not serious	not serious	very serious ^a	none	⊕⊕○○ Low
Cervical left rotation ROM	40 (1 RCT) ¹	not serious	not serious	not serious	very serious ^a	none	⊕⊕○○ Low
Cervical right rotation ROM	40 (1 RCT) ¹	not serious	not serious	not serious	very serious ^a	none	⊕⊕○○ Low

* assessed with: CROM Goniometer

Explanations

a. Lack of optimal information size

References

1.Brück, K. Jacobi, K. and Schmidt, T. 2021Fascial treatment versus manual therapy (HVLA) in patients with chronic neck pain: A randomized controlled trial. *Journal of Back and Musculoskeletal Rehabilitation* 34:997-1006

- *Multiple sessions of cervical and thoracic spinal manipulation compared to active treatment for chronic non-specific neck pain:*

The evidence was rated as low, being downgraded for imprecision, **Table 3.18**.

Table 3.18: Multiple sessions of cervical and thoracic spinal manipulation compared to active treatment for chronic non-specific neck pain

Outcome	No of participants	Certainty assessment					Certainty
	(studies)	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	
Cervical flexion ROM	40 (1 RCT) ¹	not serious	not serious	not serious	very serious ^a	none	⊕⊕○○ Low
Cervical extension ROM	40 (1 RCT) ¹	not serious	not serious	not serious	very serious ^a	none	⊕⊕○○ Low
Cervical left lateral flexion ROM	40 (1 RCT) ¹	not serious	not serious	not serious	very serious ^a	none	⊕⊕○○ Low
Cervical right lateral flexion ROM	40 (1 RCT) ¹	not serious	not serious	not serious	very serious ^a	none	⊕⊕○○ Low
Cervical left rotation ROM	40 (1 RCT) ¹	not serious	not serious	not serious	very serious ^a	none	⊕⊕○○ Low
Cervical right rotation ROM	40 (1 RCT) ¹	not serious	not serious	not serious	very serious ^a	none	⊕⊕○○ Low

* assessed with: CROM Goniometer

Explanations

a. Lack of optimal information size

References

1.Brück, K. Jacobi, K. and Schmidt, T. 2021Fascial treatment versus manual therapy (HVLA) in patients with chronic neck pain: A randomized controlled trial. *Journal of Back and Musculoskeletal Rehabilitation* 34:997-1006

DISCUSSION

This review highlights that the evidence to support the use of spinal manipulation to bring about a change in spinal kinematics and muscle recruitment is very low to moderate. There is a paucity of trials and those that are available have small sample sizes and focus on angular displacement, with little attention being paid to other spinal kinematic outcomes in neck pain populations. For angular displacement, measured as CROM, this review showed that spinal manipulation of either the cervical or thoracic

spine increases CROM with this effect being dependent on the chronicity of the neck pain and the area of the spine treated. Previous reviews support the beneficial effect of SMT on CROM with 56% (Millan *et al.* 2012) and 69% (Snodgrass *et al.* 2014) of included trials showing a positive effect.

In the current review, this was considerably higher, with 94% of trials showing a positive effect on cervical ROM. Unlike previous reviews (Hidalgo *et al.* 2017; Coulter *et al.* 2019), this review only included trials where SMT was utilised in isolation and defined as a HVLA, thus excluding those trials where mobilisation was utilised, this may explain the higher frequency of a positive effect of SMT in this review.

Depending on the chronicity of the neck pain, SMT had different effects on ROM. CSMT in acute neck pain increased all ranges except flexion and contra-lateral rotation (Pikula 1999), albeit only one trial with some concerns regarding the risk of bias added to this result, whereas in chronic NP, SMT consistently across the trials showed an increased flexion ROM (Valera-Calero *et al.* 2019; Brück, Jacobi and Schmidt 2021). Previous reviews have not identified a specific pattern of change in ROM following SMT. In acute NP, and with the transition to chronic pain, the peripheral and central nervous system (CNS) show pathological changes (Arendt-Nielsen, Fernández-de-las-Peñas and Graven-Nielsen 2011; Watanabe and Piché 2022). In acute pain, short-term neuromuscular adaptations occur to bring protection, this then results in a wide range of behavioural changes from subtle within or between muscle redistribution of activity to movement avoidance (Merkle, Sluka and Frey-Law 2020). These protective benefits then may lead to long term dysfunctional consequences (Merkle, Sluka and Frey-Law 2020). It is possible that due to the 'acute' nature of the pain, the abnormal movements had not yet been integrated into the CNS, thus when spinal manipulation was applied, the resultant decrease in muscle spasm and activation of neurophysiological mechanisms led to improved sensorimotor integration (Pickar 2002; Bialosky *et al.* 2009; Haavik and Murphy 2012; Gyer *et al.* 2019; Gevers-Montoro *et al.* 2021b) and a more widespread effect on ROM.

It has been found that neck pain sufferers have reduced flexion-extension and rotation ranges of motion (Stenneberg *et al.* 2017), which is in alignment with the ranges that

improved the most following CSMT in this review. It is interesting that in chronic neck pain, flexion was the ROM that mostly increased relative to the comparator group, irrespective of it being a sham/control or active treatment. It has been proposed that SMT results in increased paraspinal muscle efferent output (Pickar and Bolton 2012) and neuromuscular responses (Lalanne, Lafond and Descarreaux 2009; Harvey and Descarreaux 2013), these effects could result in reflex changes in the muscle of the neck allowing for increased flexion motion. The trials (de Camargo *et al.* 2011; Pires *et al.* 2015; Bracht *et al.* 2018) in this review did not focus on this aspect, rather they assessed muscle activity at rest, isometric and isotonic contractions during arm tasks.

In the trials assessing the effect of TSMT, irrespective of the type of comparator, cervical extension ROM increased consistently, surpassing the MDC irrespective of the duration of neck pain (Suvarnnato *et al.* 2013; Puntumetakul *et al.* 2015). People with neck pain have been found to have altered posture, with increased thoracic kyphosis (Joshi, Balhithaya and Neelapala 2019) and anterior head carriage (Mahmoud *et al.* 2019). SMT applied to the thoracic spinal area, according to the biomechanical hypothesis, could improve thoracic spine biomechanics, positively impacting the ability of the cervical region to function. The close relationship (Scheer, Lau and Ames 2021) and overlap of pain referral from structures in these areas (Fukui, Ohseto and Shiotani 1997) could explain these effects.

Central mechanisms, such as reduced cortical excitation may also contribute to the effect seen in the cervical spine in response to thoracic SMT (Ghamkhar *et al.* 2019). In addition, clinical prediction rules have included limited CROM as a predictor for improved treatment outcomes for cervical (Puentedura *et al.* 2012) and thoracic (Cleland *et al.* 2007) spinal manipulation in neck pain. Only one trial assessed changes in muscle activity following TSMT, focusing on the SCM during rest and a shoulder girdle task, reporting no between group effects. No studies were found where ROM and EMG were assessed simultaneously to account for changes in muscle activity relative to ROM.

In many of the trials (Martínez-Segura *et al.* 2006; Suvarnnato *et al.* 2013; Puntumetakul *et al.* 2015; Serra-Añó *et al.* 2023), the CROM results exceeded the

MCD reported by Fletcher and Bandy (2008) and Audette *et al* (2010). It was not possible to assess the changes in CROM against minimally clinically important differences as these have not been documented (de Koning *et al*. 2008). The effects on cervical ROM when compared to sham/control were greater than when compared to active interventions. Similar results have been found for pain and disability in people with neck pain (Gross *et al*. 2015; Chaibi, Stavem and Russell 2021). Manual therapy trials using a placebo, pose a significant challenge, as developing a sham that is indistinguishable from the tested intervention is challenging (Machado *et al*. 2008). Attempts have been made to 'mimic' the HVLA (Hancock *et al*. 2006) (Vernon *et al*. 2005; Vernon *et al*. 2012) with some degree of success. The active treatment comparators in this review fall under manual therapy and thus may impact the same mechanism, explaining less noticeable differences in their effect when compared to SMT (Bialosky *et al*. 2009).

There is a debate regarding the relevance of cervical ROM in the diagnosis and monitoring of neck pain patients (Snodgrass *et al*. 2014; Whalen *et al*. 2019; Childress and Stueck 2020), despite its widespread and recommended use as a component of the clinical examination (Blanpied *et al*. 2017). Few RCTs assess the relationship between changes in pain intensity, disability and cervical ROM, reporting a weak correlation (Howell 2011; Jørgensen *et al*. 2017). In this review, only one trial (Martínez-Segura *et al*. 2006) assessed these relationships and reported that following cervical spine manipulation, as pain decreased, cervical ROM increased. Future RCTs should include these correlations to allow a greater understanding of the role of CROM in neck pain.

The spinal kinematic assessment focused predominantly on angular displacement with only one trial assessing the quality of spinal motion in the form of motion harmony (Serra-Añó *et al*. 2023) following one treatment of cervical SMT compared to a control group. They found that cervical SMT did not result in an effect on motion harmony (Serra-Añó *et al*. 2023). The trial was rated as having some concerns regarding risk of bias, and it is possible that a single session of SMT may have little effect on movement quality, but that this may differ if multiple treatment sessions are utilised. None of the included trials assessed velocity, acceleration or jerk following SMT.

Despite reports of altered head and neck kinematics in neck pain (Moghaddas *et al.* 2019; Franov *et al.* 2022), and suggestions that the effect of spinal manipulation may be more attributed to spinal kinematic outcomes (i.e. how the spine moves) as opposed to angular displacement (Millan *et al.* 2012), RCTs assessing SMT have paid little attention to these outcomes.

Sensorimotor control is integrated into the spinal cord, brainstem and cortex, and relies on accurate sensory input for precise neuromuscular control and movement (Baydal-Bertomeu *et al.* 2011). For SMT to impact neuromuscular control and motion it would need to affect these areas of the nervous system. Several reviews on the neurophysiological effects of SMT suggest these effects (Pickar 2002; Bialosky *et al.* 2009; Pickar and Bolton 2012; Gevers-Montoro *et al.* 2021b; Haavik *et al.* 2021), thus further mechanistic studies are required to elucidate the effect of SMT on spinal kinematics and muscle activity patterns.

Strength, limitations and recommendations

This systematic review and meta-analysis, to our knowledge, is the first review assessing the effect of spinal manipulation on muscle activity and spinal kinematics in participants with non-specific neck pain. This review adds to the literature on SMT and its effects outside of patient reported outcomes, which can assist in the mechanistic understanding of using this modality to treat neck pain. Another strength is that the review utilised the RoB-2 tool, which allowed for assessment per outcome, as opposed to per study, this ensured that each outcome was assessed independently for its effect on neck pain.

There are several limitations that should be considered. Firstly, there were few studies where HVLA-SMT has been used in the treatment of neck pain where spinal kinematic and/or muscle activity outcomes were assessed. Trials favoured angular displacement as a measure of cervical motion and in the few trials where muscle activity was reported, the trials did not include kinematic assessments, highlighting that this is an area for future research.

Most of the included trials suffered from bias but the more recent trials made necessary attempts to reduce the bias which is inherent in manual therapy trials. Publication of trial protocols is becoming a more common practice and will address aspects of bias in reporting. It is recommended that clinical trial databases encourage researchers to detail the statistical methods they plan to utilise in their trials as another mechanism to improve reporting. Publication bias may have influenced the review, although attempts were made to ensure all relevant trials were included, studies that report negative results are less likely to be published (Shi and Lin 2019) and it is possible that search engines and efforts were unsuccessful in reaching these papers. Although the review allowed for non-English articles to be translated for inclusion, it is possible that they were missed during the search. Methodological considerations include that the search strategy was not externally peer reviewed, the decision to proceed with a meta-analysis was done post-formulation of the proposal and the possibility of missing literature.

Although including meta-analysis was a strength of this review, it was often limited due to the limited number of trials, many of which had small sample sizes, leading to imprecision due to a lack of optimal information size.

This review focused on the changes occurring in the first measure taken following the completion of the treatment, thus long-term benefits were not assessed. Many of the trials only assessed immediate changes (75%). Outcomes like muscle activity may be best assessed close to treatment as changes may be transient, but cervical ROM based on the adhesion theory (Evans and Breen 2006) would indicate that multiple treatments over a period of time would increase cervical ROM.

To reduce methodological heterogeneity trialists should be consistent in the report of cervical ROM. Most studies in this review reported the six ROMs of the cervical spine, with others combining motions such as left and right rotation. Consistency in ROM reporting will enable statistical pooling of the data. To understand the role of SMT in affecting the 'qualitative' aspects of ROM, more trials should include kinematic measurements, as these have been reported to differ between healthy and neck pain populations, yet little is known about how SMT could impact this aspect of motion.

Future RCTs should include these correlations to allow a greater understanding of the role of cervical ROM in neck pain.

CONCLUSION

This review indicates that cervical and thoracic SMT may offer short-term benefits for improving ROM in individuals with neck pain. However, the evidence is limited, and more rigorous research is needed to definitively establish the long-term efficacy and mechanisms of action of SMT. Future studies should focus on including muscle activity and spinal kinematics other than cervical ROM, to further understand the mechanistic effects of this intervention. By addressing these knowledge gaps, healthcare providers can make more informed decisions about the appropriate use of SMT in the management of neck pain.

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Author's contributions

LO, BM and JD contributed to the development of the section criteria. LO drafted the manuscript. LO was responsible for literature searches. LO and BM reviewed citations for inclusion. LO, GM and KP conducted risk of bias and data extraction. All authors read, provided feedback and approved the final manuscript.

Authors can be contacted for the template data collection forms, extracted data, and data used for analysis.

Competing interests

None of the authors have any competing interests.

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CHAPTER FOUR

MANUSCRIPT TWO:

THE TEST-RE-TEST RELIABILITY OF CERVICAL SPINE KINEMATICS MEASURED DURING CERVICAL RANGE OF MOTION

4.1 BACKGROUND TO THIS CHAPTER

Several investigations have utilised motion capture technology to determine kinematic differences between those with and without neck pain (Szeto, Straker and O'Sullivan 2005; Grip *et al.* 2008; Descarreaux, Passmore and Cantin 2010; Rutledge *et al.* 2013; Falla *et al.* 2017; Lascurain-Aguirrebeña *et al.* 2018; Alsultan *et al.* 2019; Salehi *et al.* 2021; Moghaddas, Edwards and Snodgrass 2022), with only limited studies (Serra-Añó *et al.* 2023) using this technology to assess changes in kinematics following spinal manipulative treatment. Testing environments and contexts may influence the reliability of the tests and should be considered when the test is used in a different environment (Peeters and Harpe 2020).

Establishing the reliability of testing procedures in research is necessary to ensure that when a test is utilised repeatedly, the results are consistent (Bruton, Conway and Holgate 2000; Matheson 2019), providing reassurance (Vaz *et al.* 2013). Reliability studies are often performed in healthy populations, with a need for investigation in symptomatic populations (Matheson 2019), where the tests are most often utilised. Thus, in this study, before executing a case-controlled observational study and a randomised controlled trial (RCT), the test-retest reliability of the research procedure and OptiTrack™ motion capture system was assessed for its reliability.

4.2 MANUSCRIPT

The test-retest reliability of cervical spine kinematics measured with the OptiTrack® motion capture system during cervical range of motion

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ABSTRACT

Introduction: Cervical spine kinematics allow for functional assessment of the neck during range of motion (ROM). Motion capture systems can document complex human motion adding value to clinical practice and allowing a greater understanding of movement impairment through research. This study aimed to assess the with-in day, test-retest reliability of cervical spine kinematics during cervical ROM as measured using the OptiTrack™ motion capture system.

Methods: Participants with neck pain (n=10) and without neck pain (n=9) were recruited and assessed at baseline and 20 minutes for peak displacement, peak and mean velocity and jerk during seated cervical ROM. Eight motion capture cameras were utilised to capture 17 reflective markers, kinematic outcomes were calculated from sampled position data. Intra-class correlation coefficient (ICC (A,1)), standard error of measurement (SEM) and minimal detectable change (MDC) were determined.

Results: The ICCs were good to excellent (ICCs 0.542-0.954) for movement duration, peak displacement, average and peak velocity, irrespective of neck pain status. ICCs

for average and peak jerk were poor ($ICC < 0.5$). SEMs and MDCs were acceptable for all measures except those related to jerk.

Conclusions: The spinal kinematics measured during cervical ROM with the OptiTrack® motion capture system was found to be reliable in measuring cervical kinematics except for the jerk measures, which may be more related to intra-participant variability than measurement error.

Keywords: Motion capture, cervical range of motion, reliability, neck pain

INTRODUCTION

Neck pain is a common and disabling condition (Childress and Stueck 2020), with a large economic and personal burden due to the cost of treatment and its impact on workplace productivity (Kazeminasab *et al.* 2022). The majority of people will experience neck pain during their lifetime (Haldeman *et al.* 2008). Together with low back pain, it is the third largest cause of disability-adjusted life years, for non-communicable disease (GBD 2015 DALYs and HALE Collaborators 2016; Safiri *et al.* 2020). It is considered a multifactorial condition with a range of risk factors (Kazeminasab *et al.* 2022), some of which are related to modern day life due to prolonged computer (Keown and Tuchin 2018) and smartphone (Al-Hadidi *et al.* 2019; Derakhshanrad *et al.* 2021) usage, with the largest burden impacting females residing in high income countries (GBD 2015 DALYs and HALE Collaborators 2016; Safiri *et al.* 2020).

When diagnosing and managing neck pain, there is no specific set of recommended outcomes to use (Fandim *et al.* 2021). It has been recommended that, in addition to validated self-report questionnaires to monitor changes in pain, function, disability, and psychosocial well-being, clinicians should include assessments of bodily functional impairments, such as ROM, to determine mobility deficits (Blanpied *et al.* 2017). The assessment of cervical ROM is commonplace in clinical practice to assess impairments and evaluate treatment outcomes in neck pain patients (Guo *et al.* 2012;

Blanpied *et al.* 2017). Individuals with neck pain, irrespective of it being acute or chronic, show clinically relevant decreases in cervical ROM compared to those without neck pain (Stenneberg *et al.* 2017).

There are numerous devices used to measure cervical ROM ranging from those that measure two-dimensional (2-D) aspects such as the Cervical Range of Motion device (Performance Attainment Associates, Minnesota, IL, USA), universal goniometers and inclinometers (Snodgrass *et al.* 2014), to those that can create three-dimensional (3-D) measures such as electromagnetic tracking and optical motion capture (Vásquez-Ucho *et al.* 2021). In a recent review of systems used to assess cervical spine function, it was found that 75% (n=15) of the trials utilised 2-D outcome measures compared to only 25% (n=5) using three dimensional (3-D) analysis methods (Vásquez-Ucho *et al.* 2021) when measuring cervical ROM. Assessing 3-D motion may provide added insight into understanding neck pain and the effect of various treatments for this condition (Snodgrass *et al.* 2014). Although many of the 3-D methods are expensive and require high tech installation, they are considered to provide more reliable results and are often referred to as the gold standard (Mihcin *et al.* 2019; Vásquez-Ucho *et al.* 2021). Developments in this field have led to highly accurate systems (Topley and Richards 2020), to record human motion.

During functional movement, motion capture enables the measurement of movement patterns (Roggio *et al.* 2021). Given the complexities of human motion, sophisticated software programmes are utilised (Mihcin *et al.* 2019). When utilising optoelectronic motion capture systems, the human frame of the participant is modelled using information sent to the programme, for example from reflective markers placed on bony prominences, which are tracked during motion. In the software, movement information is processed and mapped onto a biomechanical model which then displays movement kinematics (van der Kruk and Reijne 2018; Guduru and Domeika 2019). STT Insight® (STT Systems Group, San Sebastian, Spain) is an example of such a software programme. This software receives unlabelled markers from the OptiTrack® motion capture Motive software (Natural Point, Inc., Corvallis, Oregon, USA). STT Insight through a streamlined workflow allocates labels to collect data on joint locations, bone positions and orientations.

This information allows for the measurement of biomechanical data, including displacement, velocity, acceleration and joint angles {Natural Point Corporation, 2023 #16}. A systematic review (Franov *et al.* 2022) found several studies investigating these kinematic variables and their association with neck pain, with less emphasis being placed on jerk as an outcome measure, particularly in the clinical literature (Zhang *et al.* 2019). The authors reported mixed levels of evidence ranging from limited to moderate. Jerk as a kinematic measure speaks to the smoothness of motion (Sejnowski 1998), and has been found to increase in several neuromuscular disease such as stroke (Mohamed Refai *et al.* 2021) but has been understudied in non-specific back and neck pain.

The OptiTrack® motion capture systems have been shown to be accurate and valid (Nagymáté and Kiss 2018). The software used in STT Insight was developed specifically for this study and its methodology. Thus prior to utilising the system in future studies the test-re-test reliability was investigated. This study aimed to assess the test-retest reliability of this motion capture system to determine cervical kinematics in healthy and neck pain participants during cervical ROM when measures were repeated on the same day.

MATERIAL AND METHODS

Study design, participants and approval

A test-retest reliability design was used to recruit adult volunteers, with (n=10) and without (n=10) neck pain through word of mouth or pamphlets distributed within the local area (**Appendix G**). This study took place at a university chiropractic clinic (**Appendix H**). Ethical approval was obtained from an Institutional Research Ethics Committee (17/20) which operates in accordance with the Declaration of Helsinki, 1975 (**Appendix I**). All participants provided informed consent (**Appendix J**) and the studies is reported according to the Guidelines for Reporting Reliability and Agreement Studies (GRRAS) guidelines (**Appendix K**).

Sampling

Those without neck pain were required to have no history of spinal or arm pain requiring medical treatment over the last twelve months, with no major medical concerns such as neurological or musculoskeletal disease. Neck pain participants had to have neck pain of a non-specific cause, with a duration of more than 3 months, and at a level severe enough to warrant treatment. They were excluded if they had any neurological involvement, required further investigation, or had any orthopaedic abnormalities that would impact spinal and upper extremity motion such as an un-united clavicular fracture or spinal surgery.

The sample size was determined based on the methodology of the mean of three observations per participant being taken at baseline and then at 20 minutes. Using a power of 80%, alpha of 0.5 and beta of 0.18 to detect an intra-class correlation of 0.5, resulted in a minimum of 11 participants plus three for drop-out. Resulting in 10 participants per group being recruited (n=20).

Measurement instruments

Demographic and patient reported outcomes

Participants underwent a case history, and physical and orthopaedic examination before data collection, from these clinical records demographic characteristics were extracted. RAND 36-Item Health Survey 1.0 (SF-36) survey was completed to determine the general health and disease burden (Ware 2000)(**Appendix L**). Neck pain participants completed the numerical pain rating scale (NPRS-101)(**Appendix M**), where they rated their neck pain over the last week on a scale of zero (no pain) to 10 (severe pain) to assess neck pain intensity. This measure has been found to be valid (Ferreira-Valente, Pais-Ribeiro and Jensen 2011) and reliable (Young *et al.* 2019) to assess neck pain. Disability due to neck pain was assessed using the neck disability index (NDI) consisting of 10 components (**Appendix N**). This tool has been found to be valid (Vernon and Mior 1991) and reliable (Young *et al.* 2019) when used in neck pain populations, the higher the score the higher the disability (Vernon and Mior 1991).

Spinal kinematic assessment

Kinematic assessment was performed using the OptiTrack® motion capture system (Naturalpoint, Inc., OR, USA), which has been reported to track markers accurately and reliably, and is comparable to other systems such as the Vicon 6 12® (Carse et al., 2013). Eight Prime 13 motion capture cameras, with a resolution of 1.3 megapixels (MP) (1280 × 1024) and 240Hz frame rate, sampling frequency of 120 Hz per camera (Muyor *et al.* 2017) were wall or tripod mounted around the test area. Pre-capture calibration was performed and the capture volume set {NaturalPoint Corporation, 2023 #18}. Masking was used to remove any unwanted light reflections in the capture volume.

Reflective markers (14mm) were placed on 17 sites on the participant (**Figure 4.1**), by either the research assistant or LO. Bony landmarks guided placement. The participant stood upright, with their hands facing their thighs, while the markers were detected by the OptiTrack cameras, streamed to Motive™ tracker and onto STT Insight™ software (STT systems group, Spain), where each reflective marker was allocated to the appropriate anatomical site (**Figure 4.1**). A 3D custom-made digital human model was constructed, calibrated to the participants anthropometry, syncing the position and orientation of each reflective marker to the correct body segment, to complete the matrix transformation. This took approximately 5 seconds. Throughout the capture the markers were assessed to ensure that the model maintained its form. The model constructed cervical spinal kinematics from the reflectors from the external occipital protuberance to C7. A kinematical estimation model was developed in STT-systems™ and provided 6 degrees of freedom (DOF) in three cardinal planes.

Experimental procedure

Participants sat upright on a stool, which had no backrest, their feet below their knees, eyes focused ahead at eye level, in line with a point on the wall, arms hanging loosely by their sides. They were instructed to perform full cervical spine ROM: flexion – moving head towards their chest, extension – moving their head to look up towards the ceiling, left/right rotation – moving their chin towards their shoulder, and left/right lateral flexion – bending their head so that their ear moved towards their shoulder,

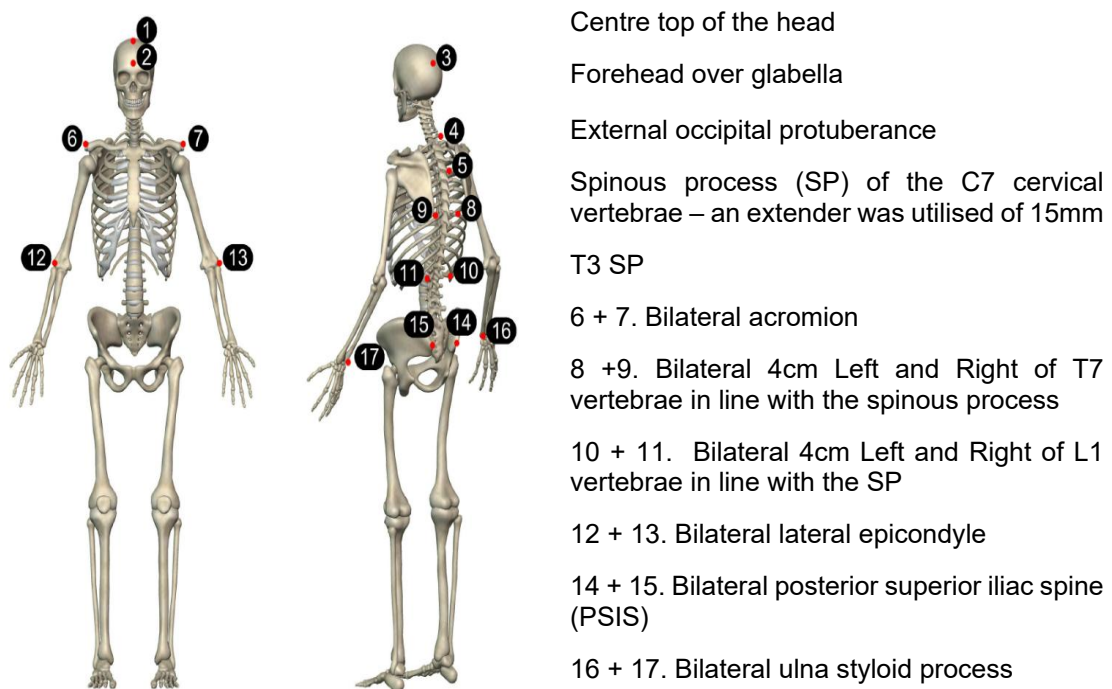


Figure 4.1: Location of reflective markers (STT systems group, Spain)

without allowing movement of their shoulder girdle. Each movement was repeated three times, returning their head to neutral between each motion. Prior to data collection, participants were allowed to practice, two to three times, to ensure familiarity with the task. No attempts were made to correct their movement strategy, nor was the timing of their motion regulated. This allowed for capturing of the participant's natural motion. On completion of the task, the participants sat quietly in the laboratory for 20 minutes before re-doing the activity. Between readings, no markers were removed. A script was used to ensure standardization of the research procedure (**Appendix O**).

Data processing

Data files (CSV) were exported from STT Insight™ software (STT systems group, Spain) and imported into MATLAB (R2023a) (MathWorks® Inc., Natick, Massachusetts, United States) where a customized code processed the signals. The

signal was smoothed using a 4th order Butterworth low pass (5Hz) filter. Various different smoothing options between two and 10Hz were tested with the 5Hz used by Descarreaux et al (2010) being the preferable one. The filtered signal was then segmented into tasks and subphases. The tasks consisted of alternating sequences of repeated excursions with start and end points, for each of the motions: flexion-extension, left and right lateral flexion and rotation cycles. To register as an excursion the following thresholds were applied:

1. Excursion exceeded 25°,
2. Lasted at least 0.5 seconds (adjusted for individual cases where necessary),
3. Maximum excursion time of 3 seconds,
4. With a minimum of 4 and a maximum of 6 excursions consecutively (2 in each direction),
5. A maximum transition time of 1.5 seconds.

The excursions started and stopped at the neutral cross over point i.e. zero line. Excursions were categorised as positive – when the excursion occurred above the neutral line or negative – excursions occurring below the neutral line. For the flexion/extension phase, the motions above the neutral line were in the flexion phase and those below the line were in the extension phase. For left and right lateral flexion and rotation, the motion in the positive i.e. above the line was a motion to the right, whereas that occurring below the neutral line was a motion to the left. **Figure 4.2** illustrates the signal and how it was broken down into excursions and sub-phases.

Position data determined the kinematics with the following equations being used to determine: velocity $v = \frac{ds}{dt}$, acceleration $a = \frac{dv}{dt}$ and jerk $j = \frac{da}{dt} = \frac{d^3s}{dt^3}$.

The sub-phases of the tasks were:

1. Duration (s) - was calculated as the time spent in an excursion zone.
2. Peak displacement (°) – identified as the point furthest away from neutral (Hogan 1984, Sjölander, Michaelson et al. 2008), this was recorded for the positive and negative excursions.

3. Mean velocity ($^{\circ}/s$) – mean velocity was determined by averaging the velocity from when the velocity threshold exceeded $10^{\circ}/s$ (to indicate actual motion) to end of range, excluding the dead space at the end of the range where the participant paused temporarily before resuming the motion. For both the positive and negative excursions this was recorded twice – the mean away and mean return velocity.
4. Peak velocity ($^{\circ}/s$) – was the maximum recorded velocity per subphase from motion initiation to peak angle (Vorro, Bush et al. 2013). For both the positive and negative excursions this was recorded twice – the peak away and peak return velocity.
5. Mean jerk ($^{\circ}/s^3$) - jerk is the average rate of change in acceleration with respect to time (Ponsiglione *et al.* 2022). Mean was recorded as the jerk was measured from the start of the excursion to the peak angle (Bigoni *et al.* 2016). For both the positive and negative excursions mean jerk was recorded twice in the away and return parts of the excursion.
6. Peak jerk ($^{\circ}/s^3$) – was the maximum jerk during the excursion from motion initiation to peak angle. For both the positive and negative excursions this was recorded twice – the peak away and peak return jerk.
- 7.

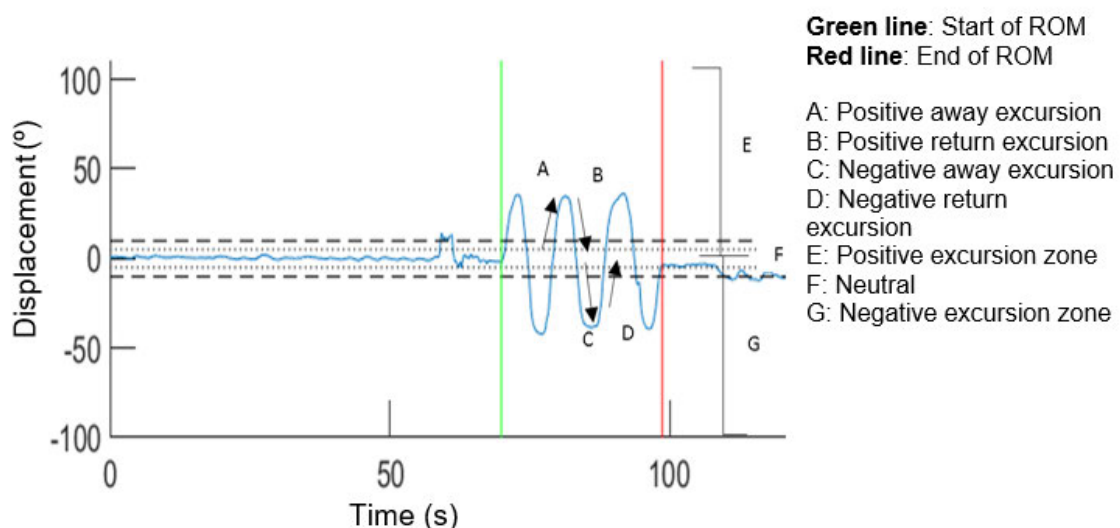


Figure 4.2: Description of how the motion capture signal was broken down into excursions and sub-phases

Following the segmentation of the signal, event and outcome images, which visually displayed the signal, excursions and sub-phases for the kinematic variables, were produced and assessed per participant to determine the quality of the signal. An example is provided in **Figure 4.3**. When the signal was distorted and lacked conformability to the tasks it was excluded, this was done in consultation with a biomechanist. One participant's data was removed from the study due to technical issues with the captured data across the measures (n=19). Where isolated technical issues were found, for example where the marker was lost resulting in severe signal distortion, the data for only that measurement was excluded from the analysis for that participant. Once satisfied that the signals were acceptable the data for each of the three trials together with the calculated average of the three measures (i.e. the mean) for each of the subphases was exported to an Excel spreadsheet for statistical analysis.

SPSS (IBM Corp. Released 2023) was used to analyse the data. The average of the three repetitions was used to compare pre- and post-trials. Intra-class correlation coefficient (ICC) with a 95% confidence interval (CI), using a two-way mixed effects model, with absolute agreement, and single measures was performed. This was selected as only one rater was utilised (Liljequist, Elfving and Skavberg Roaldsen 2019) and agreement between multiple measures was the requirement (Koo and Li 2016). Qualitative interpretations of ICC values were "poor" (< 0.5), "moderate" (0.5–0.75), "good" (0.75–0.9) and "excellent" (ICC > 0.9)(Koo and Li 2016). Standard error of measurement (SEM) was calculated as $SEM = SD\sqrt{1 - ICC}$ (Weir, 2005) (Haley and Fragala-Pinkham 2006). Pooled mean and standard deviations (SD) were calculated as described by Higgins and Green (2011). SEM was considered poor when the value reached the SD of the mean. The minimal detectable change was calculated as $MDC = (SEM * \sqrt{2}) * (zscore)$, with a z score of 95% (1.96) confidence level (Weir, 2005), it allowed measurement of the absolute reliability, by producing an estimate of the error change versus the true change (Alahmari *et al.* 2017).

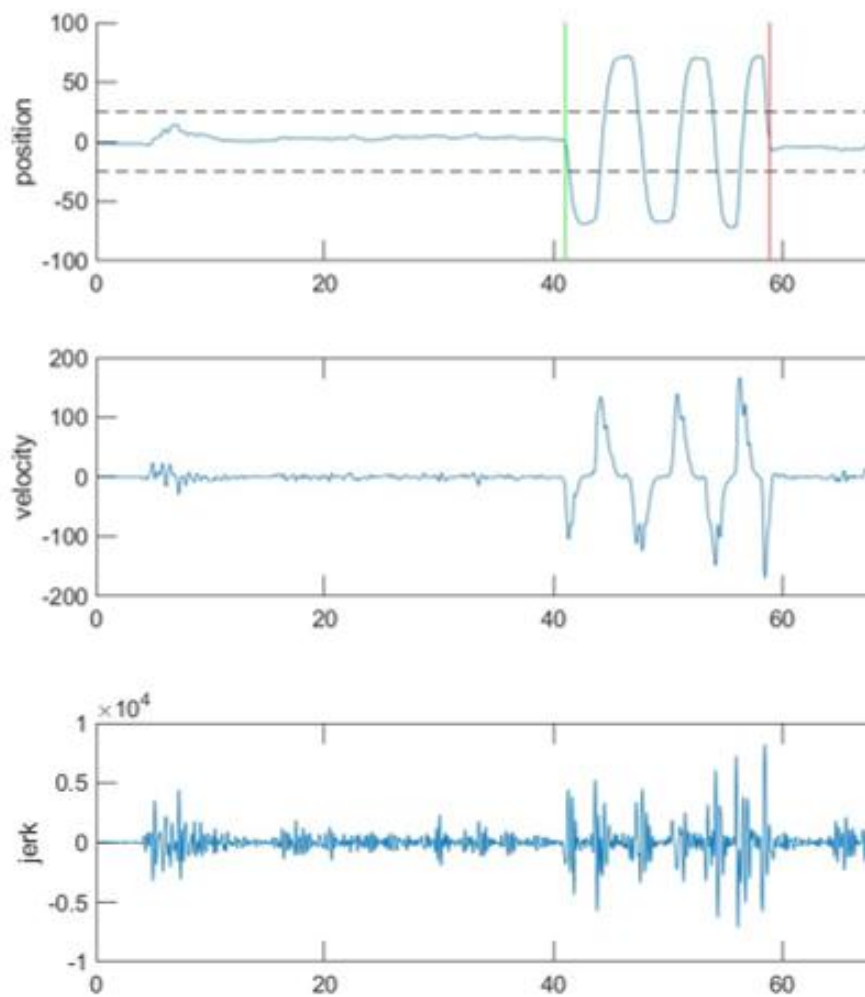


Figure 4.3: An example of displacement (°), velocity (m/s) and jerk (m/s³) signals obtained from one participant while performing the neck rotation task

RESULTS

Participants' characteristics are presented in **Table 4.1**. There were no between group differences for sex, age and anthropometric characteristics. Neck pain participants scored poorly on the SF-36 for health outcomes for physical health, emotional problems and pain. Those with neck pain (n=10) described their pain as bilateral (90%, n=9), moderate in nature (4.7 ± 1.6) and mildly disabling (15.0 ± 9.2).

Table 4.1: Demographic characteristics of the participants

Characteristic	Total			Neck pain			Healthy			<i>p</i> value
	<i>n</i>	<i>M</i>	$\pm$ SD	<i>n</i>	<i>M</i>	$\pm$ SD	<i>n</i>	<i>M</i>	$\pm$ SD	
Sex <i>n</i> (%)										
Female	12	63.2		7	70		5	55.6		0.650*
Male	7	36.8		3	30		4	44.4		
Race <i>n</i> (%)										
Black	7	36.8		4	40		3	33.3		
Coloured	2	10.5		1	10		1	11.1		
Indian	6	31.6		2	20		4	44.4		
White	5	26.3		3	30		2	22.2		
Age	19	28.2	6.9	10	29.7	7.6	9	26.6	6.1	0.337
Height (m)	19	1.7	0.13	10	1.7	0.1	9	1.7	0.1	0.944
Weight (kg)	19	72.5	15.9	10	72.3	14.5	9	72.7	18.2	0.957
BMI	19	25.5	4.8	10	25.3	4.1	9	25.7	5.8	0.876
Health status (SF-36):										
Physical functioning	19	81.6	31.2	10	70.5	36.9	9	93.9	18.3	0.098
Physical health	19	65.8	41.8	10	42.5	40.9	9	91.7	25.0	0.006
Emotional problem	19	60.9	42.0	10	33.3	38.5	9	91.7	16.7	0.001
Energy/fatigue	19	55.8	23.1	9	48.9	26.0	9	62.8	18.7	0.211
Emotional well-being	19	61.0	23.5	9	55.1	22.0	9	66.9	24.8	0.302
Social functioning	19	69.1	31.9	9	56.9	38.1	9	81.1	19.8	0.117
Pain	19	69.7	26.1	9	51.7	25.2	9	87.2	10.6	0.003
General health	19	58.6	20.8	10	53.8	22.1	9	63.9	19.0	0.301

(*Fisher's Exact test, all other tests were independent samples t-test)

Spinal kinematics

Duration (s) and peak displacement (°)

The participants took less than 3 seconds to reach peak displacement, irrespective of neck pain status. Peak displacement values were the largest for rotation ROM, as seen in **Table 4.2**. **Table 4.3** shows the ICC, SEM and MDC for duration and peak displacement. The ICCs ranged from moderate to excellent (0.700 to 0.957) across the groups except for extension peak displacement which showed poor reliability (0.416) in the combined group. Confidence intervals were wide for most measures. The SEMs for duration were below one for all ranges, with those for peak displacement being below four. MDCs were below 1.58 for duration and ranged from 1.51 to 10.69 for peak displacement, with the combined group showing larger MDCs.

Table 4.2: Duration to peak duration (s) and peak displacement (°) during cervical ROM

Measure		Total (n=19)				NP (n=10)				NNP (n=9)			
		Pre		Post		Pre		Post		Pre		Post	
		M	±SD	M	±SD	M	±SD	M	±SD	M	±SD	M	±SD
Duration													
FE	Flex	2.5	1.4	2.1	1.2	2.6	1.4	2.4	1.5	2.4	1.6	1.8	0.9
	Ext	2.5	1.6	2.2	1.3	2.5	1.4	2.4	1.5	2.6	2.0	2.1	1.1
LF	RLF	2.1	1.1	1.8	0.9	2.2	1.2	1.8	1.0	2.1	1.1	1.7	0.8
	LLF	2.1	0.9	1.8	0.9	2.2	1.0	1.9	0.9	1.9	1.0	1.8	0.9
Rot	RRot	2.6	1.6	2.0	1.1	2.9	1.9	2.1	1.2	2.2	1.2	1.9	1.1
	LRot	2.5	1.5	2.1	1.2	2.8	1.8	2.2	1.3	2.1	1.1	2.0	1.2
Peak disp.													
FE	Flex	40.4	9.4	39.4	7.5	40.0	8.8	39.1	7.2	40.9	10.5	39.8	8.3
	Ext	38.1	7.8	37.5	6.4	36.7	7.8	38.0	5.7	39.6	7.9	36.9	7.4
LF	RLF	35.3	7.9	36.3	6.9	34.9	9.9	37.7	8.9	35.8	5.3	34.7	3.7
	LLF	35.9	7.5	35.8	7.4	35.3	8.7	37.3	8.6	36.5	6.2	34.2	5.8
Rot	RRot	57.1	9.9	58.8	10.4	56.4	11.6	57.9	11.7	58.0	8.2	59.9	9.3
	LRot	56.4	11.6	57.6	9.4	56.6	14.4	57.5	11.5	56.2	8.2	57.6	7.2

(ROM – range of motion, FE – flexion/extension, LF – lateral flexion, Rot – rotation, disp. – displacement, flex – flexion, ext – extension, R – right, L – left, M – mean, SD – standard deviation)

Peak and average velocity (m/s)

Peak and average velocities were greatest for the away than the return motion, for all CROM assessed irrespective of neck pain status, seen in **Table 4.4**. **Table 4.5** shows the ICCs, SEM and MDC for the peak and average velocity obtained during the ROM. The ICCs were moderate to excellent (0.627-0.950) across the groups except for extension away peak (0.551) and away average (0.469) velocity. Confidence intervals were wide for most measures. SEMs showed great variation across the ROMs with the largest SEMs being found for rotation and the lowest for lateral flexion. MDCs for peak velocity ranged from 10.26 to 44.40 and for average velocity from 9.59 to 49.95, with the lower MDCs being found for lateral flexion motion.

Peak and average jerk (m/s³)

There was more variability in the jerk measures as seen in **Table 4.6**. Peak jerk measures were greater during the positive away as opposed to the return motion, whereas for the negative cycles, it was the opposite way around. The average jerk measures were less consistent, varying in smoothness irrespective of positive or

Table 4.3: ICC, SEM and MDC's for the duration (s) and peak displacement (°) during cervical ROM (n=19)

Measure	ROM	Total (n=19)					NP (n=10)					NNP (n=9)				
		ICC	CI		SEM	MDC ₉₅	ICC	CI		SEM	MD _{C95}	ICC	CI		SEM	MDC ₉₅
			Low	High				Low	High				Low	High		
<i>Duration</i>																
<i>FE</i>	Flex	0.841	0.60	0.94	0.37	1.04	0.955	0.84	0.99	0.21	0.59	0.700	0.16	0.92	0.49	1.35
	Ext	0.821	0.57	0.93	0.44	1.22	0.957	0.84	0.99	0.21	0.58	0.739	0.25	0.93	0.57	1.58
<i>LF</i>	RLF	0.730	0.39	0.89	0.37	1.02	0.728	0.26	0.92	0.40	1.10	0.758	0.27	0.94	0.34	0.93
	LLF	0.868	0.66	0.95	0.23	0.65	0.846	0.46	0.96	0.26	0.72	0.906	0.66	0.98	0.20	0.57
<i>Rot</i>	RRot	0.774	0.35	0.92	0.47	1.31	0.756	0.18	0.94	0.57	1.57	0.945	0.71	0.99	0.19	0.53
	LRot	0.798	0.54	0.92	0.43	1.19	0.782	0.24	0.94	0.51	1.41	0.954	0.82	0.99	0.17	0.47
<i>Peak displacement</i>																
<i>FE</i>	Flex	0.808	0.57	0.92	2.63	7.30	0.831	0.47	0.96	2.33	6.46	0.907	0.66	0.98	2.04	5.67
	Ext	0.416	0.01	0.72	3.86	10.69	0.846	0.52	0.96	1.90	5.26	0.814	0.35	0.96	2.34	6.49
<i>LF</i>	RLF	0.836	0.63	0.93	2.12	5.88	0.906	0.50	0.98	2.04	5.65	0.542	0.14	0.87	2.20	6.08
	LLF	0.866	0.69	0.95	1.92	5.32	0.939	0.67	0.99	1.51	4.19	0.732	0.22	0.93	2.21	6.12
<i>Rot</i>	RRot	0.860	0.67	0.94	2.68	7.44	0.953	0.83	0.99	1.79	4.95	0.883	0.59	0.97	2.12	5.87
	LRot	0.857	0.66	0.94	2.82	7.82	0.957	0.84	0.99	1.91	5.29	0.826	0.44	0.96	2.28	6.32

(ROM – range of motion, FE – flexion/extension, Flex – flexion, Ext – extension, LF – lateral flexion, RLF – right lateral flexion, LLFT – left lateral flexion, Rot – rotation, Rot – right rotation, LRot – left rotation, disp. – displacement)

negative excursion. Out of the 72 jerk measures, 21 had poor ICCs (29%), as seen in **Table 4.7** which shows the ICCs, SEM and MDC for the peak and average jerk obtained during the ROM. The ICCs differed across the groups and ROMs.

For the flexion-extension cycle, the ICCs ranged from poor to moderate, with the extension phase having poorer ICC values, specifically for the non-neck pain group. For lateral flexion ICCs ranged from poor to excellent, with left lateral flexion in the neck pain group having more ICCs that were rated as poor. For rotation, the ICCs were good to excellent, except for 2 outcomes in the neck pain group which had poor ICCs. Confidence intervals were wide for most measures. SEMs ranged from relatively small to large, depending on the ROM, lateral flexion motion across the groups had the lowest SEMs compared to the other motions. MDCs ranged from 23.92 to 4325.54, with average jerk MDCs ranging from 383.20 to 2472.08, the lowest MDCs were seen for lateral flexion.

Table 4.4: Peak and average velocity measurements (°/s) during cervical ROM

ROM	Measure (°/s)	Total (n=19)				NP (n=10)				NNP (n=9)			
		Pre		Post		Pre		Post		Pre		Post	
		M	SD	M	SD	M	±SD	M	±SD	M	±SD	M	±SD
<i>FE</i> Flex	Away peak	79.8	38.0	86.6	43.8	75.2	39.8	83.2	44.5	84.9	37.5	90.3	45.3
	Return peak	90.5	40.2	92.5	36.1	81.2	40.0	89.9	40.6	100.8	40.0	95.4	32.6
	Away avg	37.3	17.6	40.7	19.9	34.1	15.2	36.1	16.8	40.9	20.2	45.7	22.7
	Return avg	59.3	26.3	61.0	22.9	52.3	24.9	58.3	24.4	67.0	27.0	64.0	22.1
	Away peak	78.2	36.9	78.6	30.4	67.8	33.7	73.9	33.7	89.7	38.8	83.7	27.2
	Return peak	87.2	36.8	98.7	43.4	81.4	36.3	96.4	49.0	93.6	38.5	101.2	38.9
	Away avg	40.1	19.7	40.4	14.0	37.8	17.9	41.5	16.3	42.7	22.3	39.1	11.8
	Return avg	49.2	21.4	57.5	24.4	46.0	16.4	57.4	22.6	52.8	26.4	57.6	27.6
<i>LF</i> RLF	Away peak	75.8	41.5	86.5	40.6	67.3	42.8	82.0	43.5	85.4	40.3	91.4	39.2
	Return peak	79.5	41.0	89.2	35.6	73.6	47.4	89.8	39.5	86.0	34.0	88.5	33.0
	Away avg	38.9	18.1	44.6	17.9	35.5	20.2	43.0	20.7	42.6	15.7	46.4	15.3
	Return avg	54.9	27.6	59.9	21.6	51.9	32.1	58.8	23.1	58.3	22.9	61.2	21.0
	Away peak	72.2	39.2	77.4	39.7	66.0	44.1	81.3	48.9	79.0	34.4	73.1	28.5
	Return peak	86.1	41.5	94.0	38.5	78.3	45.4	91.0	42.4	94.7	37.4	97.3	36.0
	Away avg	36.6	16.4	40.1	16.2	33.2	16.3	40.2	18.8	40.3	16.7	40.0	13.9
	Return avg	60.3	27.9	66.6	26.3	57.7	32.5	65.9	28.2	63.2	23.4	67.3	25.8
<i>Rot</i> RRot	Away peak	131.7	63.5	154.2	71.5	115.0	54.1	149.4	79.6	150.4	71.1	159.5	65.7
	Return peak	144.0	71.4	166.6	75.3	122.0	63.7	146.4	69.3	168.4	75.1	189.1	79.2
	Away avg	63.0	29.2	73.1	31.8	59.5	32.8	71.6	35.4	66.8	26.0	74.8	29.3
	Return avg	86.2	45.6	108.3	45.5	70.1	39.3	97.5	44.0	104.0	47.5	120.4	46.5
	Away peak	131.6	63.1	144.3	69.0	116.5	64.8	135.1	70.2	148.4	60.2	154.6	70.2
	Return peak	144.7	68.2	167.9	74.4	127.1	63.5	160.9	79.9	164.3	71.6	175.7	71.7
	Away avg	58.9	24.9	61.2	26.0	55.2	27.9	61.5	29.2	63.0	22.0	60.9	23.6
	Return avg	91.4	41.3	108.6	48.5	79.7	41.3	106.9	51.3	104.3	39.4	110.6	48.3
LRot	Away peak	131.6	63.1	144.3	69.0	116.5	64.8	135.1	70.2	148.4	60.2	154.6	70.2
	Return peak	144.7	68.2	167.9	74.4	127.1	63.5	160.9	79.9	164.3	71.6	175.7	71.7
	Away avg	58.9	24.9	61.2	26.0	55.2	27.9	61.5	29.2	63.0	22.0	60.9	23.6
	Return avg	91.4	41.3	108.6	48.5	79.7	41.3	106.9	51.3	104.3	39.4	110.6	48.3

(ROM – range of motion, FE – flexion/extension, Flex – flexion, Ext – extension, LF – lateral flexion, RLF – right lateral flexion, LLFT – left lateral flexion, Rot – rotation, Rot – right rotation, LRot – left rotation, disp. – displacement)

Table 4.5: ICC, SEM and MDC for peak and average velocity (°/s) during cervical ROM

ROM	Measure	Total (n=19)					NP (n=10)					NNP (n=9)					
		ICC	CI		SEM	MDC ₉₅	ICC	CI		SEM	MDC ₉₅	ICC	CI		SEM	MDC ₉₅	
			Low	High				Low	High				Low	High			
FE	Flex	Away peak	0.778	0.50	0.91	13.66	37.87	0.882	0.62	0.97	10.26	28.44	0.854	0.50	0.96	11.25	31.17
		Return peak	0.748	0.46	0.89	13.56	37.57	0.882	0.61	0.97	9.78	27.11	0.768	0.27	0.94	12.44	34.48
		Away avg	0.706	0.38	0.88	7.19	19.94	0.865	0.56	0.96	4.17	11.55	0.877	0.57	0.97	5.33	14.77
		Return avg	0.716	0.41	0.88	9.28	25.73	0.877	0.58	0.97	6.11	16.93	0.763	0.25	0.94	8.50	23.56
	Ext	Away peak	0.551	0.13	0.80	16.02	44.40	0.773	0.34	0.94	11.36	31.49	0.781	0.32	0.95	11.08	30.71
		Return peak	0.711	0.40	0.88	15.29	42.40	0.829	0.40	0.96	12.62	34.97	0.721	0.18	0.93	14.45	40.06
		Away avg	0.469	0.02	0.76	8.80	24.40	0.808	0.43	0.95	5.31	14.71	0.614	0.03	0.90	7.83	21.71
		Return avg	0.683	0.35	0.86	9.13	25.30	0.627	0.05	0.89	8.53	23.65	0.817	0.41	0.95	8.17	22.65
LF	RLF	Away peak	0.932	0.76	0.98	7.58	21.00	0.909	0.26	0.98	9.21	25.53	0.947	0.79	0.99	6.47	17.93
		Return peak	0.895	0.72	0.96	8.79	24.36	0.875	0.29	0.97	10.91	30.24	0.903	0.64	0.98	7.38	20.46
		Away avg	0.842	0.60	0.94	5.05	14.01	0.805	0.36	0.95	6.38	17.69	0.900	0.61	0.98	3.46	9.59
		Return avg	0.839	0.64	0.93	7.02	19.46	0.842	0.51	0.96	7.87	21.81	0.816	0.39	0.96	6.66	18.47
	LLF	Away peak	0.862	0.68	0.94	10.37	28.73	0.910	0.32	0.98	9.87	27.36	0.893	0.62	0.97	7.31	20.25
		Return peak	0.911	0.76	0.97	8.44	23.40	0.890	0.53	0.97	10.30	28.54	0.954	0.82	0.99	5.56	15.42
		Away avg	0.774	0.51	0.91	5.48	15.18	0.829	0.31	0.96	5.13	14.23	0.880	0.55	0.97	3.76	10.42
		Return avg	0.875	0.68	0.95	6.79	18.81	0.881	0.56	0.97	7.42	20.58	0.881	0.59	0.97	6.01	16.66
Rot	RRot	Away peak	0.828	0.57	0.93	19.84	55.00	0.796	0.09	0.95	21.74	60.25	0.909	0.67	0.98	14.60	40.48
		Return peak	0.923	0.66	0.98	14.40	39.91	0.877	0.31	0.97	16.50	45.75	0.896	0.56	0.98	17.60	48.79
		Away avg	0.844	0.58	0.94	8.52	23.62	0.844	0.39	0.96	9.53	26.41	0.890	0.52	0.98	6.49	17.99
		Return avg	0.782	0.32	0.92	15.03	41.67	0.627	0.01	0.90	18.02	49.95	0.867	0.38	0.97	12.12	33.60
	LRot	Away peak	0.906	0.71	0.97	14.33	39.71	0.950	0.18	0.99	10.68	29.60	0.927	0.73	0.98	12.50	34.64
		Return peak	0.861	0.35	0.96	18.82	52.16	0.846	0.06	0.97	20.02	55.49	0.907	0.67	0.98	15.45	42.82
		Away avg	0.856	0.67	0.94	6.83	18.93	0.868	0.57	0.97	7.34	20.36	0.852	0.48	0.96	6.21	17.20
		Return avg	0.851	0.18	0.96	12.29	34.07	0.808	0.06	0.96	14.43	39.99	0.896	0.63	0.98	10.05	27.85

(ROM – range of motion, FE – flexion/extension, Flex – flexion, Ext – extension, LF – lateral flexion, RLF – right lateral flexion, LLF – left lateral flexion, Rot – rotation, Rot – right rotation, LRot – left rotation, disp. – displacement, ICC – intraclass correlation coefficient, SEM – standard error of measurement, MDC₉₅ – minimal detectable change at the 95 percent confidence interval)

Table 4.6: Peak and average jerk ($^{\circ}/s^3$) measurements during cervical ROM

ROM	Measure	Total (n=19)				NP (n=10)				NNP (n=9)			
		Pre		Post		Pre		Post		Pre		Post	
		M	$\pm$ SD	M	$\pm$ SD	M	$\pm$ SD	M	$\pm$ SD	M	$\pm$ SD	M	$\pm$ SD
<i>FE</i> Flex	Away peak	4426.3	2714.7	5021.9	4024.3	4705.0	3154.0	5498.6	4780.2	4116.6	2277.1	4492.3	3183.1
	Return peak	50.9	81.5	55.2	65.9	41.0	48.9	73.5	84.3	61.9	109.5	34.9	29.6
	Away avg	1432.3	945.5	1679.2	1506.9	1548.0	1057.0	1637.0	1645.9	1303.7	848.0	1726.2	1434.2
	Return avg	1781.9	1496.0	2026.0	1764.2	1678.0	1250.1	2347.6	2343.1	1897.3	1802.5	1668.7	744.4
	Ext	25.0	34.4	34.9	70.1	24.5	34.4	55.1	93.4	25.6	36.6	12.4	12.6
	Return peak	4940.8	2712.0	5772.9	3057.4	4790.9	2978.9	6074.9	4072.5	5107.3	2550.9	5437.3	1460.3
	Away avg	1434.6	862.6	1385.9	1328.5	1395.0	970.5	1741.0	1760.6	1478.6	781.2	991.4	388.9
	Return avg	1826.1	1303.8	1999.5	1099.8	1779.2	1429.9	2080.5	1269.2	1878.1	1232.4	1909.6	944.6
<i>LF</i> RLF	Away peak	3389.0	2116.9	3448.2	2108.8	3071.1	2079.8	3033.3	1734.2	3742.1	2224.9	3909.3	2483.6
	Return peak	36.8	42.2	36.7	31.6	30.5	43.0	23.9	17.3	43.8	42.7	50.9	38.4
	Away avg	1338.2	960.1	1350.3	949.5	1155.9	832.6	1167.5	768.6	1540.8	1098.3	1553.4	1129.5
	Return avg	1400.3	829.7	1851.4	856.1	1303.6	823.1	1704.0	783.7	1507.8	873.0	2015.1	949.2
	LLF	19.4	21.1	20.2	15.2	21.1	23.8	21.1	19.5	17.4	19.0	19.3	9.7
	Return peak	3475.9	1374.6	4091.4	1572.6	3263.0	1388.4	3895.9	1467.1	3712.4	1401.3	4308.5	1744.2
	Away avg	1281.8	823.3	1363.1	630.1	1278.0	987.3	1361.5	764.3	1286.0	654.7	1364.9	486.0
	Return avg	1451.3	742.5	1814.5	868.8	1419.6	853.8	1697.5	767.8	1486.5	646.3	1944.6	999.5
<i>Rot</i> RRot	Away peak	4634.9	2417.1	4681.8	2177.0	4584.4	2191.5	4219.1	2321.1	4690.9	2781.4	5195.9	2009.4
	Return peak	68.6	72.0	121.3	151.4	58.6	85.6	93.5	150.2	79.7	56.3	152.2	155.4
	Away avg	1678.6	1046.8	1816.5	1045.3	1650.3	1111.3	1731.0	1232.0	1709.9	1036.5	1911.6	855.5
	Return avg	2833.1	2241.3	3879.7	2791.8	1927.4	1150.7	3064.9	2292.5	3839.3	2765.7	4785.0	3142.1
	LRot	22.6	27.9	37.2	71.3	23.2	22.9	26.7	28.8	22.0	34.1	48.8	101.0
	Return peak	5680.1	2869.9	6832.8	3915.9	5105.5	2371.7	6105.1	3553.0	6318.6	3366.5	7641.3	4347.7
	Away avg	1828.4	1046.5	1952.3	1218.7	1771.8	1180.6	1791.5	1130.5	1891.4	942.1	2130.9	1354.9
	Return avg	2788.0	1929.9	3554.1	2634.6	2366.2	1472.6	3310.2	2660.9	3256.8	2339.0	3825.2	2737.7

Table 4.7: ICC, SEM and MDC for peak and average jerk ($^{\circ}/s^3$) during cervical ROM

ROM	Measure	Total (n=19)					NP (n=10)					NNP (n=9)				
		ICC	CI		SEM	MDC ₉₅	ICC	CI		SEM	MDC ₉₅	ICC	CI		SEM	MDC ₉₅
			Low	High				Low	High				Low	High		
<i>FE</i>																
Flex	Away peak	0.718	0.41	0.88	1288.91	3572.67	0.703	0.19	0.92	1560.52	4325.54	0.843	0.47	0.96	775.38	2149.25
	Return peak	0.278	0.21	0.65	44.51	123.38	0.434	0.15	0.81	36.66	101.62	0.311	0.40	0.79	47.08	130.51
Ext	Away avg	0.611	0.25	0.83	554.77	1537.75	0.600	0.04	0.89	618.56	1714.56	0.803	0.34	0.95	369.76	1024.93
	Return avg	0.552	0.15	0.80	774.11	2145.74	0.689	0.19	0.91	740.50	2052.55	0.399	0.37	0.83	755.92	2095.31
	Away peak	0.098	0.38	0.53	37.08	102.78	0.178	0.45	0.70	45.12	125.05	0.094	0.55	0.68	18.42	51.04
	Return peak	0.483	0.06	0.76	1469.29	4072.65	0.556	0.02	0.86	1681.05	4659.64	0.074	0.70	0.69	1414.22	3920.03
	Away avg	0.137	0.36	0.56	735.73	2039.35	0.245	0.46	0.74	873.42	2420.98	0.237	0.27	0.72	381.11	1056.39
	Return avg	0.564	0.16	0.81	563.15	1560.98	0.517	0.13	0.85	664.37	1841.55	0.614	0.08	0.90	482.36	1337.02
<i>LF</i>																
RLF	Away peak	0.881	0.72	0.95	515.39	1428.57	0.788	0.34	0.94	623.42	1728.03	0.938	0.76	0.99	415.13	1150.69
	Return peak	0.658	0.29	0.85	15.41	42.72	0.369	0.34	0.80	18.39	50.98	0.828	0.44	0.96	11.91	33.02
LLF	Away avg	0.914	0.79	0.97	198.00	548.82	0.896	0.63	0.97	182.72	506.48	0.921	0.69	0.98	221.41	613.71
	Return avg	0.720	0.24	0.90	315.43	874.33	0.754	0.15	0.94	281.85	781.25	0.665	0.06	0.91	373.20	1034.45
	Away peak	0.010	0.49	0.45	13.07	36.23	0.112	0.63	0.69	14.48	40.13	0.009	0.77	0.65	10.73	29.74
	Return peak	0.664	0.29	0.86	605.38	1678.02	0.466	0.12	0.83	738.03	2045.71	0.853	0.32	0.97	428.92	1188.90
	Away avg	0.709	0.38	0.88	279.64	775.13	0.766	0.30	0.94	301.98	837.06	0.885	0.60	0.97	138.25	383.20
	Return avg	0.584	0.19	0.82	368.56	1021.61	0.464	0.16	0.83	420.34	1165.12	0.717	0.08	0.93	316.59	877.55
<i>Rot</i>																
RRot	Away peak	0.790	0.53	0.91	1054.09	2066.01	0.761	0.30	0.93	780.28	2162.84	0.830	0.45	0.96	707.38	1960.77
	Return peak	0.532	0.14	0.79	81.11	158.98	0.701	0.21	0.91	47.28	131.06	0.278	0.30	0.76	70.22	194.63
LRot	Away avg	0.781	0.52	0.91	489.54	959.51	0.781	0.33	0.94	388.22	1076.09	0.838	0.47	0.96	270.46	749.68
	Return avg	0.841	0.42	0.95	1009.47	1978.56	0.568	0.01	0.87	842.96	2336.55	0.910	0.36	0.98	627.89	1740.43
	Away peak	0.059	0.40	0.49	52.49	102.89	0.779	0.34	0.94	8.65	23.97	0.034	0.71	0.62	54.20	150.23
	Return peak	0.753	0.40	0.90	1706.16	3344.07	0.742	0.29	0.93	1084.91	3007.21	0.849	0.40	0.97	1068.37	2961.36
	Away avg	0.745	0.46	0.89	573.59	1124.23	0.807	0.38	0.95	359.04	995.22	0.716	0.17	0.93	439.74	1218.89
	Return avg	0.788	0.45	0.92	1063.28	2084.02	0.656	0.13	0.90	891.85	2472.08	0.926	0.67	0.98	489.77	1357.57

DISCUSSION

The results of this study demonstrated the reliability of the OptiTrack® motion capture system together with the 3DMA Insight software in assessing kinematic outcomes during cervical ROM in those with and without neck pain. The ICCs demonstrated overall moderate to excellent test-retest reliability, with the jerk measures being less reliable than the velocity measures. This study also provided SEM and MDC for the kinematic outcomes assessed.

Duration and peak displacement

When assessing the duration of the excursions, the system showed moderate to excellent reliability. The participants moved at their own self-selected pace as the aim was to assess natural motion and therefore the movement was not restricted by using a metronome or other means. Vinke et al (2013) in asymptomatic participants reported longer durations for the execution of the sub-phases of flexion-extension than reported in the current study but with similar ICC values when using an electromagnetic tracking device (Vikne *et al.* 2013). For peak displacement, the reliability statistics were good to excellent except for extension in the combined group and right lateral flexion in those without neck pain. These findings indicate that this motion capture system can reliably assess peak displacement in neck pain patients.

Vicon® is considered the gold standard in motion capture technology, with newer systems like OptiTrack® becoming more popular (Nagymáté and Kiss 2018). Several studies have compared the validity of OptiTrack® to Vicon for human motion capture, reporting comparable accuracy (Carse et al. 2013; Thewlis et al. 2013; Nagymáté and Kiss 2018). The SEMs reported by Lascurain- Aguirrebeña et al (2018) were larger than those in the current study, further supporting the reliability of the OptiTrack® system.

With regards to the ICC values in those without neck pain, similar results were reported by Feng et al (2019) (Feng *et al.* 2019) who assessed cervical ROM peak displacement using OptiTrack® motion camera instead of the eight-camera set up utilised in this study they used the OptiTrack® V120: Trio device™ (NaturalPoint, Inc.). They reported ICC values as good to excellent for all ROMs. The current study differed

in that right and left lateral flexion ICC values were lower – rated as moderate to good. Their study also reported lower SEMs and MDC values compared to this study. Besides the different types of OptiTrack® system utilised to obtain the data the manner in which data collection occurred differed between the studies. In Feng et al (2019)'s study, the participants were seated in a chair with a back support, whereas in the current study, they sat with their backs unsupported. The cervical and thoracic regions are intimately related, with motion in the thoracic spine affecting cervical ROM (Tsang, Szeto and Lee 2013), this may have influenced the results.

Peak and mean velocity

The ICC rating for the peak and mean velocity measures ranged from good to excellent for both the neck pain and non-neck pain groups. Thus, indicating that the system can be utilised in both populations to capture velocity measures during cervical ROM. Two trials on asymptomatic participants assessed the velocity of cervical ROM using an electromagnetic tracking device, one study utilised a virtual reality game and reported similar ICC values for peak and mean velocity (Sarig Bahat *et al.* 2016); the other trial, assessed cervical flexion-extension motion in sub-phases, in the seated position, like the current study, reporting peak and mean velocity ICC values between moderate and excellent (Vikne *et al.* 2013). Although the tool utilised to measure the velocity differed, the similarity in the reliability statistics supports the use of an advanced motion tracking system in spinal kinematic assessment.

Few trials have assessed the sub-phases of cervical ROM for kinematics comparing those with and without neck pain. Vinke et al (2013) assessed the effect of slow, self-paced and fast cervical movement during the sub-phases of flexion-extension (Vikne *et al.* 2013). The results for self-paced motion were like those found in this study, indicating that the participants did not move excessively slow or with speed to complete the ROMs. This is important, as if the participants used increased speed, it would affect the peak displacement outcomes by increasing them (Bonnechère *et al.* 2014), and would not be representative of naturally paced movement. Comparison of SEMs and MDCs to these studies was not possible due to differences in methodology (Bonnechère *et al.* 2014; Sarig Bahat *et al.* 2016) and standard error measurement (Vikne *et al.* 2013) utilised.

Peak and mean jerk

The jerk outcomes ranged from poor to excellent depending on the sub-phase and ROM being assessed and they showed the greatest variability of the kinematic outcomes measured, supporting previous research (Röijezon *et al.* 2010; Vikne *et al.* 2013; Sarig Bahat *et al.* 2016). Similar variability in the ICCs was found by Vinke *et al.* (2013), in an asymptomatic population, when flexion-extension sub-phases of cervical ROM were assessed for jerk reliability – two out of the six measures were rated as poor (Vikne *et al.* 2013). Similarly, using a virtual reality environment and assessing the number of velocity peaks as a measure of smoothness in asymptomatic participants' ICCs ranged from poor to good, with wide confidence intervals (Sarig Bahat *et al.* 2016).

Jerk is dependent on displacement, duration and intervals of arrest (Hogan and Sternad 2009), meaning that slower movements are associated with reduced movement smoothness i.e. increased jerkiness (Röijezon *et al.* 2010; Vikne *et al.* 2013). People with neck pain have been shown to execute cervical spine ROM more slowly than those without neck pain (Sarig Bahat, Weiss and Laufer 2010; Tsang, Szeto and Lee 2013; Sarig Bahat *et al.* 2015). Thus, one would have expected higher jerk measures with less reliable ICCs in the neck pain group however the ICCs were not dissimilar to those without neck pain.

The peak jerk values were less reliable than the mean jerk, across the ROMs. This could be due to the averaging of the jerk making it smoother and thus more robust. Jerk as a measure is subject to physiological tremor, which normally occurs at 8 to 12 Hz in normal healthy people. It can be exaggerated in cases of fatigue and stress (McAuley and Marsden 2000). The participants were required to execute three repetitions of each motion, although not a strenuous task, the testing environment may have resulted in distress or fatigue, which may have altered their physiological state, with the effect being more noticeable in the peak jerk readings.

Strengths, limitations and recommendations

A strength of this study is that it assessed the within day test-re-test reliability of the motion capture system in obtaining kinematic outcomes during cervical ROM, in both

symptomatic and asymptomatic populations, in addition to a combination group. This allowed the reliability of the system to be tested in varied populations, with the results showing the system to be reliable. Another strength is that few studies have assessed the reliability of measuring kinematic outcomes in the cervical spine, particularly in those with neck pain. Symptomatic participants are not similar to asymptomatic participants, thus requiring instruments or research procedures to be tested for reliability in diverse populations (Matheson 2019), ensuring meaningful interpretation of results. Once reliability is established, the instrument or procedure can be utilised to enhance clinical practice and research (Bogduk 2022). Thus, this study adds to this emerging field.

Some limitations worth noting are that the test-retest reliability results were obtained following a 20-minute rest period on the same day, thus between day measures may result in different outcomes. In addition, the participants were instructed on how to perform the motions and were advised throughout the data collection of what was required, it is possible that they may have either overextended the motion or stopped pre-maturely, influencing the results. Marker-based motion capture technology requires the placement of anatomical markers. Although care was taken to ensure an accurate placement by utilising bony landmarks and rulers, it is possible that there was some variation in placement. From the pre- to post-measures the markers on the participants were not moved or removed; thus, this would not have negatively impacted the reliability of the results.

This study assessed young adults, which limits the extrapolation of these findings to older and younger populations. Future studies should determine the reliability of this system in younger and older populations, as these groups are also afflicted with neck disorders. By establishing reliability, the system can then be utilised in case-controlled trials to determine the effect of neck pain on the musculoskeletal system or in randomised controlled trials to establish the effects of various treatment interventions in neck pain.

CONCLUSION

This study showed the within day reliability of measuring duration, peak displacement, peak and mean velocity in those with and without neck pain. The variability in jerk measurements highlights the importance of camera system set-up and consideration of individual differences, and refining data analysis techniques accordingly. Future research should explore factors influencing jerk measurements and investigate the system's validity in a wider range of clinical populations. By addressing these limitations, the accuracy and clinical utility of motion capture technology in the assessment and management of cervical spine disorders can be enhanced.

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Author's contribution

Drafting of the original protocol LO, JDP and BM. Coordination of the study and data acquisition LO. Design of the statistical analysis plan LO, JDP and BM. Analysis of data LO. Drafting of the manuscript LO, JDP and BM. Final approval LO, JDP and BM.

Competing interests

The authors have no competing interests related to this study.

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CHAPTER FIVE

MANUSCRIPT THREE:

CASE-CONTROLLED INVESTIGATION OF SPINAL KINEMATIC AND MUSCLE RECRUITMENT PATTERNS DURING CERVICAL RANGE OF MOTION

5.1 BACKGROUND TO THE CHAPTER

Pain negatively affects the motor system either through movement avoidance or changes in muscle coordination (Hodges and Smeets 2015). These effects have been seen in neck pain, documented in the clinical environment as reduced cervical ROM (Snodgrass *et al.* 2014; Stenneberg *et al.* 2017), muscle hypertonicity and under activity (Falla, Bilenkij and Jull 2004; Falla *et al.* 2004a; Falla, Jull and Hodges 2004a; Falla and Farina 2005) and changes in proprioception (Hesby *et al.* 2019).

More recently the focus has shifted from solely measuring peak displacement to looking at the 'quality' of the movement in those with neck pain (Qu *et al.* 2022). A recent systematic review reported strong to conflicting certainty in the level of evidence for kinematic outcomes in neck pain, with more research being required to further elucidate the effect of neck pain on movement smoothness and velocity (Franov *et al.* 2022). However, to holistically understand the effect of neck pain, a combined assessment of kinematics and muscle activation is required, which has only been assessed in a few studies (Vikne *et al.* 2013; Tsang, Szeto and Lee 2014; Park *et al.* 2017; Lascurain-Aguirrebeña *et al.* 2018), with varied methodologies and conflicting results.

This study was designed to further explore the relationship between neck pain, spinal kinematics and muscle recruitment patterns between those with and without neck pain. In addition to which there has not been an investigation of this nature into people with neck pain residing in South Africa. Thus, before implementing a randomised controlled trial to assess the effect of SMT on spinal kinematics and muscle recruitment patterns it was deemed necessary to assess differences between those with and with not neck in terms of these outcomes.

5.2 MANUSCRIPT

Spinal kinematics and muscle recruitment patterns in those with and without neck pain assessed during cervical range of motion – an observational study

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ABSTRACT

Background: Neck pain is a common and disabling condition which results in increased burden for the sufferer and the economy. It results in sensorimotor disturbances and alters motor control patterns. The presentation of motor control changes is not conclusive in the literature; thus, further investigation is necessary. This study aimed to compare the cervical ROM in terms of spinal kinematics and muscle recruitment patterns in people with and without neck pain, to further investigate the effect of neck pain on motor control.

Methods: Participants with chronic, non-specific neck pain (n=23) were age and sex matched to asymptomatic controls (n=23) in a case-controlled design. The cervical ROM was performed in the seated position and assessed using motion capture to obtain kinematics of peak displacement, velocity and jerk; surface electromyography was used to assess muscle recruitment patterns during sub-phases of the cardinal

motion planes. Informed consent and ethics approval was obtained. Data were analysed using SPSS.

Results: Those with neck pain took longer to complete right lateral flexion ($p = 0,018$, $r = 0.35$), with no differences between the groups for peak displacement, peak and mean velocity and jerk ($p > 0.05$). During the flexion/extension cycle, the neck pain group had less left posterior cervical muscle activation time during the extension phase ($p = 0,026$, $r = 0.34$), and during right lateral flexion there was increased left paraspinal muscle activation time during the away and return phase ($p = 0.042$, $r = 0.27$; $p = 0.026$, $r = 0.34$), with decreased peak activation during left and right away lateral flexion ($p = 0.030$, $r = 0.32$; $p = 0.047$, $r = 0.29$). For rotation, increased muscle activation time was found in the left paraspinal on right rotation during the away and return phase ($p = 0.041$, $r = 0.30$; $p = 0.002$, $r = 0.46$), with increased peak and mean activation in the away and return phases ($p < 0.05$, medium effects sizes), the left anterior scalene had decreased activation in right rotation ($p = 0.049$, $r = 0.29$).

Conclusions: People with neck pain had altered muscle recruitment patterns, taking longer to complete lateral flexion motion, with no differences in velocity and jerk measures during cervical ROM when compared to asymptomatic controls. These findings suggest an adaption of the nervous system to maintain motor function in individuals with neck pain.

Keywords: Neck pain, muscle recruitment, kinematics, cervical range of motion, velocity, jerk, electromyography

INTRODUCTION

Neck pain is a global, public health problem (Safiri *et al.* 2020), ranking fourth for disability (Hoy *et al.* 2014). There is no disparity between developed and developing nations, with most regions having a high prevalence (Childs *et al.* 2008; Vos *et al.* 2012; Hoy *et al.* 2014), which has risen over the last 25 years (Hurwitz *et al.* 2018). It consists of a vicious cycle of physical, psychological, social and financial causes that

can be or become consequences of neck pain (van Randeraad-van der Zee *et al.* 2016), impacting the sufferer negatively and increasing the burden. It has been recommended that a comprehensive assessment of a patient's pain, behaviour, and psychological and functional limitations, together with a neuro-muscular examination be undertaken to rule out red flags such as unexplained weight loss and night pain (El-Tallawy *et al.* 2021) and identify those at risk of chronicity (Shahidi, Curran-Everett and Maluf 2015).

Functional deficits, in neck pain, include alterations in gross ROM (Stenneberg *et al.* 2017; Hesby *et al.* 2019), neuromuscular control (Falla, Bilenkij and Jull 2004; Falla *et al.* 2004a; Falla, Jull and Hodges 2004a; Baghi *et al.* 2017), and changes in sensorimotor function (Sarig Bahat *et al.* 2015; Bocos-Corredor *et al.* 2023). This altered motor control is suggested to be due to maladaptive neural plasticity, resulting in loss of nervous system coordination and function leading to impairment (Qu *et al.* 2022). In the clinical examination of neck pain, cervical ROM is utilised, to assist clinical decision making, provide a baseline and monitor change (Blanpied *et al.* 2017; Stenneberg *et al.* 2017). It has been the predominant clinical and research outcome that is consistently assessed in neck pain (Tsang, Szeto and Lee 2013a).

Neck pain sufferers have been shown to have decreased cervical ROM compared to healthy controls (Hesby *et al.* 2019) (Stenneberg *et al.* 2017). There are various ways to measure cervical ROM from goniometric to more advanced systems like electromagnetic and motion capture technology (Williams *et al.* 2010; Franov *et al.* 2022). The benefit of more technologically advanced systems is that they provide high resolution data and other movement outcomes measures can be calculated to allow assessment of both quantitative and qualitative aspects of motion (Qu *et al.* 2022).

Kinematic parameters such as velocity, acceleration and jerk - derivatives of angular displacement, can describe motor task execution and are more likely to reflect altered motor control strategies (Qu *et al.* 2022). Reduced peak and mean velocity have been found in those with neck pain during seated cervical ROM (Tsang, Szeto and Lee 2013a) and while playing a virtual reality game (Sarig Bahat, Weiss and Laufer 2010; Sarig Bahat *et al.* 2015). Contracting to standing cervical rotations where peak velocity

did not differ between those with and without neck pain, but increased variability of the motion was seen in those with neck pain (Sjölander *et al.* 2008). In terms of motion smoothness, similar inconsistencies were reported. Motion smoothness refers to the ability of motion to be skilled and co-ordinated and is empirically measured as jerk (Hogan and Sternad 2009).

During a virtual reality game (Sarig Bahat, Weiss and Laufer 2010; Sarig Bahat *et al.* 2015) and when performing standing cervical ROM (Sjölander *et al.* 2008; Salehi *et al.* 2021) reduced motion smoothness was found, whereas when seated cervical ROM was assessed, there were no differences between those with and without neck pain (Lemmers *et al.* 2018), indicating postural effects. Due to the conflicted current evidence regarding differences in spinal kinematics between those with and without neck pain (Franov *et al.* 2022), further investigation is warranted (Moghaddas *et al.* 2019; Franov *et al.* 2022; Moghaddas, Edwards and Snodgrass 2022). Due to the discrepancies in these results, the effect that neck pain has on kinematics, posture and tasks require further investigation

The complexity of motor control systems requires multi-dimensional assessments. Combining electromyographic and nerve conduction studies with kinematic assessments allows an appreciation of when a muscle(s) becomes active during a movement and the position, speed and acceleration of that motion (Hande and Hasan 2013). Upper trapezius muscle average conduction velocity was found to be higher in neck pain sufferers, decreasing more rapidly on multiple contractions, than in asymptomatic controls (Falla and Farina 2005). In contrast, no differences were found between neck pain and healthy controls when voluntary activation of the trapezius muscle was assessed, despite a 20% lower maximum voluntary contraction (MVC) in the symptomatic group. It was proposed that alterations in the co-activation of antagonists and synergists reduced the voluntary force despite strong activation of the muscle (Bech *et al.* 2017). Pain is also known to reduce force through inhibition (Davi *et al.* 2020) During the performance of the cranio-cervical flexion test, altered muscle activation patterns were observed with the deep cervical flexors having reduced activity when neck pain sufferers were compared to controls, with a trend of increased

sternocleidomastoid (SCM) and anterior scalene (AS) muscle activity, especially when the demands of the task were increased (Falla, Jull and Hodges 2004b).

Conflicting results have been reported when combining the assessment of cervical kinematics and muscle activity. In cervical ROM assessment, it was found that those with neck pain did not differ from healthy controls in terms of cervical kinematics but displayed lower scalene muscle activity during neck flexion and extension (Lascurain-Aguirrebeña *et al.* 2018). Whereas, when sagittal cervical motion was assessed reduced movement velocity and acceleration was found, with no between group differences in agonist-antagonistic muscle activity when comparing those with whiplash associated disorder to healthy control subjects (Vikne *et al.* 2013). When assessing prone cervical extension in unilateral neck pain compared to healthy controls, it was found that those with neck pain had greater extension deviation and delayed posterior cervical muscle activation on the involved side (Park *et al.* 2017).

These studies highlight the varied presentation of motor impairment in neck pain. Given that a vital function of the cervical spine is turning the head precisely, with a proper velocity in various situations of activities of daily living (Salehi *et al.* 2021), combining measurements of kinematics and muscle activity can provide a more comprehensive understanding of the impact of neck pain (Tsang, Szeto and Lee 2013a). Thus, this study aimed to compare cervical spine kinematics and muscle recruitment patterns of selected cervical and thoracic spinal muscles during active cervical ROM in participants with and without neck pain. It was hypothesised that those with neck pain would differ from the healthy controls in cervical spine kinematics and/or cervicothoracic muscle recruitment patterns.

METHODS

The study utilised an observational, age and sex matched, case-controlled design. It took place at a Chiropractic clinic on a university campus (**Appendix H**) following approval by an Institutional Research and Ethics Committee (IREC 017/20) which operates in accordance with the Declaration of Helsinki, 1975 (**Appendix I**). All participants provided informed consent (**Appendix P**). This study was reported in line with the STROBE guidelines (**Appendix Q**).

Participants

Adult volunteers (18 to 50 years of age) were recruited from the local community using flyers, social media adverts (**Appendix G**) and word of mouth between November 2022 and August 2023. They were required to be right-handed to prevent differences in muscle activity due to hand dominance (Sainburg 2002; Amar, Cochran and Woldstad 2017). Those with neck pain had to have chronic, non-specific neck pain, of more than a three-month duration or mostly over the last 12 months (Tsang, Szeto and Lee 2014), with it being of a severity sufficient to seek care. Age and sex matched healthy participants were required to have had no history of neck or spinal pain requiring medical treatment over the last twelve months, with no pain in the upper extremity.

Participants were excluded if they suffered from any neurological/orthopaedic/rheumatic disorder, suffered severe trauma or surgery to the brain or spine, or had sensory or vestibular deficits. They were required to have no open wounds in the neck and trunk region, which would prevent electrode placement, and a skin fold thickness of less than 19mm over the upper trunk to ensure adiposity did not affect transmission of the sEMG signal (Baniqued *et al.* 2016). All participants were screened for central sensitisation (**Appendix R**), using a cut off score of 40 (Mayer *et al.* 2012; Neblett *et al.* 2013), and Fear Avoidance Behaviours (FAB) (Kori, Miller and Todd 1990) (**Appendix S**), using a cut off score of 37 (Roelofs *et al.* 2004), if scores exceeded these values they were excluded. All participants underwent a case history, orthopaedic examination and collection of age, height, and weight, conducted by a registered chiropractor with over 20 years of experience.

Sample size

An *a priori* sample size was calculated using pilot testing data with an independent student t-test, powered for large effect size (0.8) to minimise the chance of a type I error, an α of 0.05, and power at 0.8 (beta of 0.2) with two groups resulted in a required sample size of 40 (20 per group). A minimum of 22 participants per group were recruited to allow for dropout. Sample size calculation was done using G*Power (Faul *et al.* 2007).

Measurement tools

Participants completed the RAND 36-Item Health Survey 1.0 to assess quality of life in terms of physical, mental, and general health (RAND Corporation 2023)(**Appendix L**). This instrument has been shown to have good responsiveness, reliability (Beaton, Hogg-Johnson and Bombardier 1997) and construct validity in neck pain (de Vries *et al.* 2015). The higher the score the better the persons general health (RAND Corporation 2023). Those with neck pain rated the intensity of their pain over the last week using the numerical pain rating scale-101 (NPRS)(**Appendix M**). This scale is commonly utilised (Pool *et al.* 2007) and is valid, reliable, and responsive (Ferreira-Valente, Pais-Ribeiro and Jensen 2011) and can be used in neck pain to complement other patient-reported outcome measures (Modarresi *et al.* 2022). The scale ranges from zero indicating no pain to 10 being severe pain (Pool *et al.* 2007). The neck disability Index (NDI) was used to determine participants' self-reported, perceived level of disability arising due to neck pain (**Appendix N**). The NDI has been shown to have good content validity in patients with chronic, non-traumatic neck pain. It is scored out of 50 with a high score indicating greater disability (En, Clair and Edmondston 2009).

Kinematics

An 8-camera OptiTrack motion capture system (OptiTrack, Natural Point, OR, USA), using Prime 13 cameras, with a resolution of 1.3 MP (1280 × 1024), 240 frame rate and a sampling frequency of 120 Hz per camera (Muyor *et al.* 2017) were used. OptiTrack motion capture system (OptiTrack, Natural Point, OR, USA) has been found to track markers accurately and reliably and is comparable to other motion capture systems (Carse *et al.* 2013). Cameras were wall or tripod mounted around the test area. Pre-capture calibration was performed and the capture volume set {NaturalPoint Corporation, 2023 #18}. Masking was used to remove any unwanted light reflections in the capture volume. Reflective markers (14 mm) were attached to 17 anatomical sites, guided by bony anatomy, as detailed in **Figure 5.1**, using either electrodes or Velcro stickers. An extended reflector was utilised on the C7 marker of one centimetre. The participant stood upright, with their hands facing their thighs, while the markers were detected by the OptiTrack cameras, streamed to Motive™ tracker and onto STT

Insight™ software (STT systems group, Spain). Each reflective marker was allocated to the appropriate anatomical site, producing a custom-made digital human model calibrated to the participants anthropometry, syncing the position and orientation of each reflective marker to the correct body segment, to complete the matrix transformation. This took approximately five seconds. At the same time baseline EMG activity was recorded for 50ms.

Marker location was monitored during the capturing process. The model constructed cervical spinal kinematics from the reflectors from the external occipital protuberance to C7, and a kinematical estimation model was developed in STT-systems™ and provided 6 degrees of freedom (DOF) in three cardinal planes.

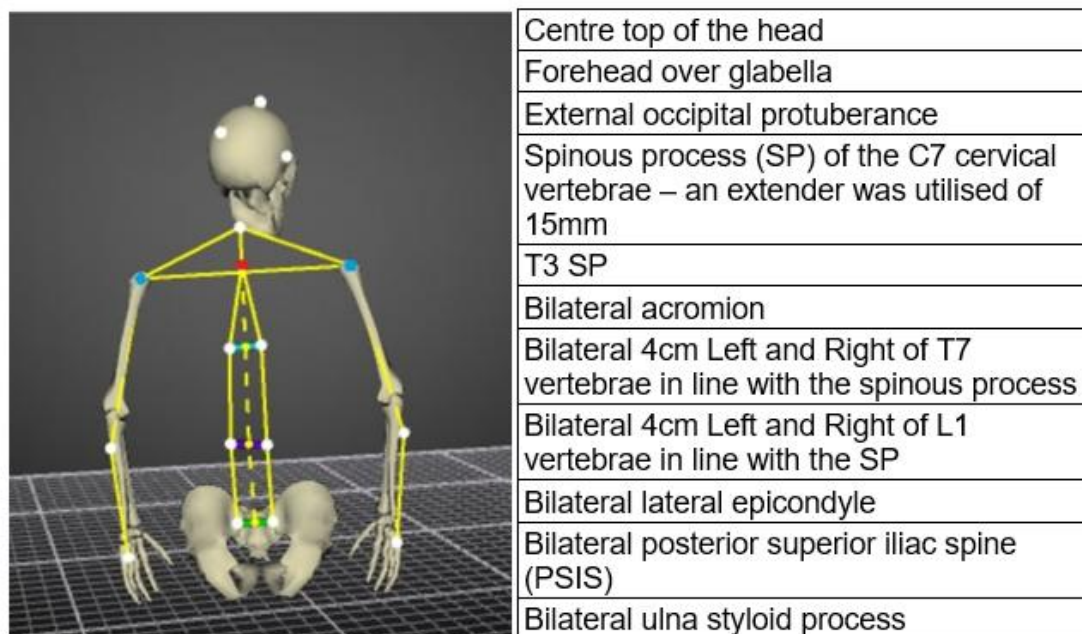


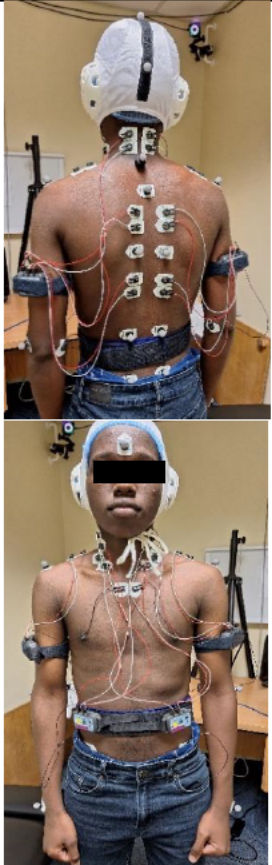
Figure 5.1: Location of reflective markers

Electromyography

The Biopac Bionomadix MP150 Data Acquisition System (Biopac systems® Inc.) was utilised together with a wireless transmitter and receiver pair. The system has a differential amplifier with a common mode rejection rate (CMRR) of 110dB at 50/60 Hz, gain of 2000, input impedance of 2 MΩ with signal to noise ratio over 65dBs). Data

were transmitted at 2000 Hz. Prior to placement of electrodes, the skin was lightly abraded, shaved where necessary, and cleaned with alcohol (Hermens *et al.* 2000). Disposable, rectangular, pre-gelled Ag/AgCl surface electrodes (30x25mm) (Vitatrode™ Electro Spyres, Johannesburg) were placed on the six muscles bilaterally, parallel to the muscle fibre, and in the mid-line, with an inter-electrode distance of 20 mm (Hermens *et al.* 2000). Care was taken to accurately locate electrode placement sites through palpation of bony anatomy and the use of a tape measure, (see **Table 5.1** for details). Reference electrodes were placed on the closest bony prominence.

Table 5.1: Electrode placement

Muscle	Placement	Reference electrode	
Upper trapezius (UT)	One third from the distal edge of the acromion on a line drawn between the acromial and C7 spinous process (Farina <i>et al.</i> 2002)	Manubrium	
Posterior cervical paraspinal (PC)	2 cm lateral to the C4 spinous process bilaterally (Criswell 2011; Tsang, Szeto and Lee 2014)		
Sternocleidomastoid (SCM)	Midpoint between the mastoid process and the sternal insertion, slightly posterior to the muscle belly (Criswell 2011; Tsang, Szeto and Lee 2014)		
Anterior Scalene (AS)	Lateral to the SCM's attachment on the clavicle, above the clavicle and anterior to the upper trapezius, placed at a slightly oblique angle (Criswell 2011)	Anterior superior iliac spine (ASIS).	
Thoracic paraspinal upper T4 (T4)	4 cm lateral to the T4 spinous process bilaterally (Tsang, Szeto and Lee 2014)		
Thoracic paraspinal lower T9 (T9)	4 cm lateral to the T9 spinous process bilaterally (Tsang, Szeto and Lee 2014)		

All data were collected by LO and one of two trained research assistants, depending on their availability on the test day. Standard procedures were used to ensure consistency. The trained assistance obtained all motion capture and sEMG data.

Cervical ROM tasks

The participant sat on a stool, with no backrest, their feet flat on the floor and evenly spaced. They were instructed to sit upright with their back and neck straight, arms hanging at the side and looking straight ahead at eye level in line with a marker on the wall. Each motion was done three times starting with the head in neutral and moving into flexion, by bringing their chin to their chest, then looking up at the ceiling (extension), this was followed by rotation whereby they turned their head to the left as far as they could and then to the right, for rotation, ending with side bending, by bringing their left ear to their left shoulder, and repeating on the right (lateral flexion). On reaching the end of the motion the participant paused and continued moving ending in the neutral position. Participants were instructed not to move their shoulders during the assessment. Movement time was not standardised to allow them to move at their own pace. Participants were given an opportunity to practice two to three times prior to the start of data collection. If they were not performing the motion correctly, such as moving their shoulders, or not reaching the end limit, their motion was corrected. The process and script are outlined in **Appendix O**.

Data processing

Motion capture and sEMG data were exported from STT Insight™ software (STT systems group, Spain) and AcqKnowledge® software, respectively and imported into MATLAB (R2023a) (MathWorks® Inc., Natick, Massachusetts, United States) where a customised code processed the signals.

Motion capture: The signals were filtered using a fourth order low pass (5Hz) Butterworth filter (Descarreaux, Passmore and Cantin 2010). Various smoothing options between two and 10Hz were tested with the 5Hz used by Descarreaux et al (2010) being the preferable one. Data were then segmented into the three cardinal ranges of motion consisting of alternating sequences of repeated excursions, with start and end points. To register as an excursion the following thresholds were applied:

1. Excursion exceeded 25°,
2. Lasted at least 0.5 seconds (adjusted for individual cases where necessary),

3. Maximum excursion time of 3 seconds,
4. With a minimum of 4 and a maximum of 6 excursions consecutively (2 in each direction),
5. A maximum transition time of 1.5 seconds.

The excursions started and stopped at the neutral cross over point i.e. zero line. Excursions were labelled as either positive (those occurring above the neutral line) or negative (those occurring below the neutral line). Movements occurring in the positive zone were flexion, right lateral flexion and rotation, whereas those in the negative zone were extension, left lateral flexion and rotation.

The excursions were broken into sub-phases allowing cervical ROM to be described in half cycles. The away subphase was the motion from neutral to maximum endpoint (the point of peak displacement), and the return subphase occurred from maximal endpoint to neutral, **Figure 5.2**.

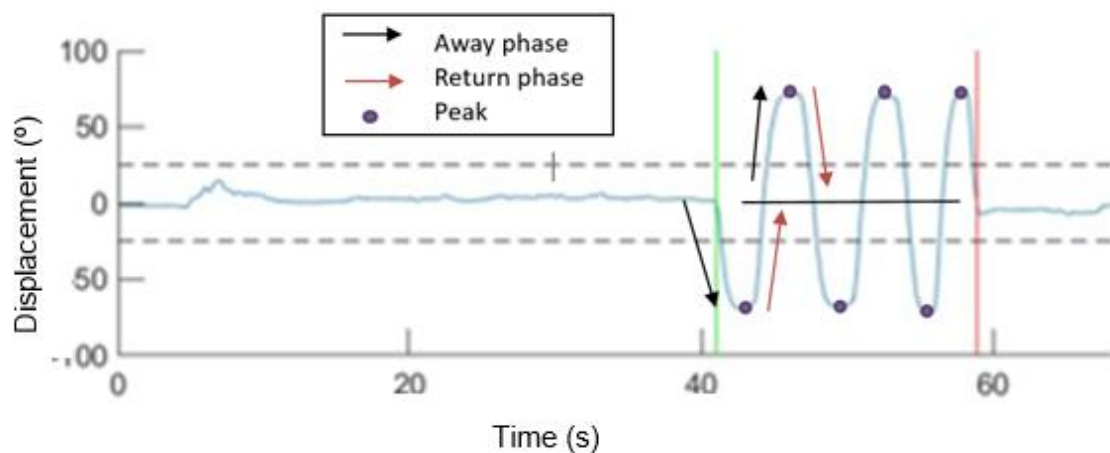


Figure 5.2: Data segmentation of motion cycles into sub-phases of away and return

The outcomes were derived as follows:

1. Duration (s) - calculated as the time spent in an excursion zone.

2. Peak displacement ($^{\circ}$) – identified as the point furthest away from neutral (Hogan 1984, Sjölander, Michaelson et al. 2008), this was recorded for the positive and negative excursions.
3. Mean velocity ($^{\circ}/s$) – mean velocity was determined by averaging the velocity from when the velocity threshold exceeded $10^{\circ}/s$ (to indicate actual motion) to end of range, excluding the dead space at the end of the range where the participant paused temporarily before resuming the motion. For both the positive and negative excursions this was recorded twice – the mean away and mean return velocity. Position data was used to determine velocity and jerk with gradient functions establishing velocity and jerk.
4. Peak velocity ($^{\circ}/s$) – was the maximum recorded velocity per subphase from motion initiation to peak angle (Vorro, Bush et al. 2013). For both the positive and negative excursions this was recorded twice – the peak away and peak return velocity.
5. Mean jerk ($^{\circ}/s^3$) - jerk is the average rate of change in acceleration with respect to time (Ponsiglione *et al.* 2022), and was measured from the start of the excursion to the peak displacement (Bigoni *et al.* 2016). For both the positive and negative excursions mean jerk was recorded twice, in the away and in the return subphases.
6. Peak jerk ($^{\circ}/s^3$) – was the maximum jerk during the excursion from motion initiation to peak angle. For both the positive and negative excursions this was recorded twice – the peak away and peak return jerk.

EMG: The raw EMG signal was synced to the kinematic data, then processed using a fourth bidirectional Butterworth filter (a bandpass filter with a low pass cut off 150 Hz to remove electrical noise, and a high pass cut off of 50Hz to remove low frequency noise such as movement artifacts). Thereafter the signal was full wave rectified and then smoothed using a moving average over a 300ms sliding window. Following smoothing the data was normalised to the peak amplitude achieved by each muscle across the task (Halaki and Ginn 2012).

This signal was then used to determine activity onset which was detected as the data point where the magnitude of the EMG signal was three standard deviations larger

than the baseline and where the duration of contraction was greater than 25 ms (Hodges and Bui 1996). The onset and offset of muscle activity during the tasks were quantified into a percentage of muscle activation duration. Allowing for the temporal characteristics of the muscle activity to be examined during the half-cycles of cervical ROM. Data were exported as normalised percentage peak, mean and activation time percentage per sub-phase of motion. When activity was 100% during any one phase, this indicated that the muscle was active for the entire duration of that sub-phase.

Following the segmentation of the motion capture and EMG signal, event and outcome images, which visually displayed the signal, tasks and sub-phases, were produced and assessed per participant to determine the quality of the signal. When the signal was distorted and lack conformability to the tasks it was excluded, this was done in consultation with a biomechanist. Where isolated technical issues were found, for example where the marker was lost resulting in severe signal distortion or when the electrode failed to detect the signal, the data for only that measurement was excluded from the analysis for that participant. Once satisfied that the signals were acceptable the data for each of the three trials together with the calculated average of the three measures (i.e. the mean) for each of the subphases was exported to an Excel spreadsheet for statistical analysis.

Data analysis

SPSS (version 27, IBM Corp. Released 2020. IBM SPSS Statistics for Windows, Armonk, NY: IBM Corp) was used to analyse the data. Normality was assessed using skewness and kurtosis. Between group assessment of demographic variables was performed using Chi-squared or independent samples t-tests. Kinematic and EMG variables were non-normally distributed and analysed using the Mann-Whitney U test to compare the groups. Effect sizes were calculated for the Mann-Whitney U test using r and were reported as: small being less than 0.3, medium between 0.3 to 0.5, and a large effect being greater than 0.5. Statistical significance was set at $p < 0.05$.

RESULTS

A total of 46 participants joined the study, 23 in each group. The demographic and anthropometric characteristics of the participants are presented in **Table 5.2**. There were no significant differences between the groups, except for the pain scale of the SF-36 general health screen ($p < 0,001$), where the neck pain group had poorer scores. The participants with neck pain rated their pain as moderate ($5.4 \pm 1,7$), with mild disability (13.3 ± 6.9), suffering on average for $28,6 (\pm 21,4)$ months and experiencing bilateral pain (83%).

Cervical kinematics

No between group differences were found for the time taken to complete flexion ($p = 0,114$; z-score: -1,582), extension ($p = 0,17$; z-score: -1,373), left lateral flexion ($p = 0,095$; z-score: -1,67), left rotation ($p = 0,153$; z-score: -1,824), right rotation ($p = 0,068$; z-score: -1,428), with those with neck pain taking 0.3 seconds longer to complete right lateral flexion ($p = 0,018$, z-score: -2,373; $r = 0.35$), with a medium effect size.

Table 5.2: Demographic and health related status

	Total			NP			NNP			P value*
	n	M	±SD	n	M	±SD	n	M	±SD	
Sex (n%)										
Female	25	54,3	-	12	52,2	-	13	56,5	-	0,767*
Male	21	45,7	-	11	47,8	-	10	43,5	-	
Age	46	24,3	(5,6)	23	24,3	(5,7)	23	24,4	(5,6)	0,979
Height (m)	46	1,7	(0,1)	23	1,7	(0,1)	23	1,7	(0,1)	0,742
Weight (kg)	46	70,7	(17,1)	23	68,5	(17,9)	23	73,0	(16,3)	0,382
BMI	46	25,2	(4,8)	23	24,1	(4,2)	23	26,3	(5,2)	0,121
General health status according to SF-36:										
Physical functioning	46	88,0	(19,1)	23	84,8	(19,9)	23	91,2	(18,1)	0,256
Physical health	46	70,4	(38,4)	23	65,2	(40,4)	23	75,5	(36,4)	0,370
Emotional problems	46	65,0	(44,4)	23	56,5	(46,5)	23	73,6	(41,5)	0,197
Energy/fatigue	46	50,0	(15,9)	23	51,1	(14,7)	23	48,9	(17,3)	0,648
Emotional well-being	46	47,4	(16,5)	23	44,7	(13,6)	23	50,1	(18,8)	0,271
Social functioning	46	69,6	(27,3)	23	64,2	(30,0)	23	75,0	(23,8)	0,195
Pain	46	64,9	(23,1)	23	52,7	(19,1)	23	77,2	(20,3)	<0,001
General health	46	55,7	(8,8)	23	55,0	(9,0)	23	56,4	(8,7)	0,597

(NP – neck pain, NNP – non-neck pain group, Independent samples t-test; *Fischer's Exact test)

There were no significant differences between the groups for peak displacement, **Figure 5.3**, peak or average velocity, **Figure 5.4**, or jerk measures, **Figure 5.5**, for the half cycles of cervical ROM.

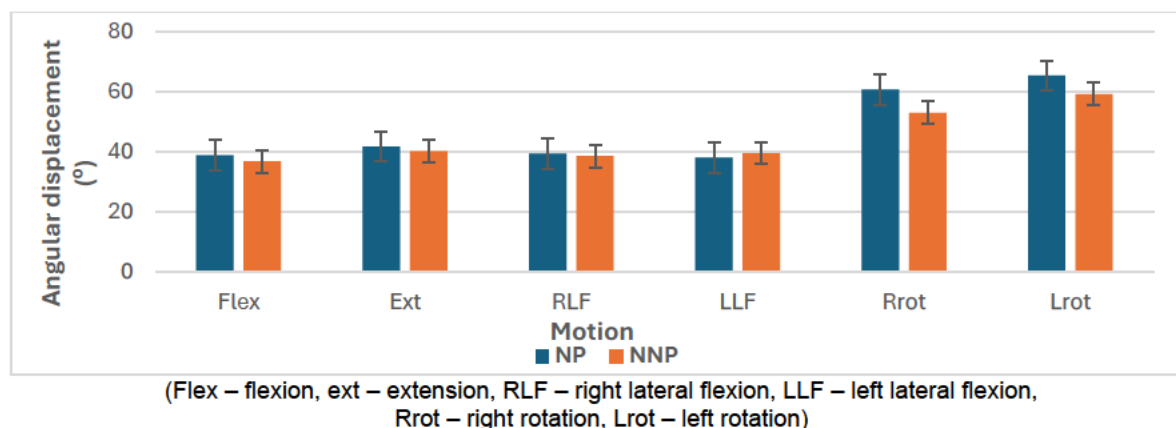


Figure 5.3: Peak angular displacement (degrees) during a cervical ROM

Muscle activation patterns

- Flexion-extension cycle

There were no between group differences ($p > 0.05$) during the flexion cycle for activation time percentage. During the extension cycle in the away sub-phase, the left posterior cervical muscles in the neck pain group had less median activation time percentage (69.3, IQR 41) compared to the control group (median 100, IQR 32.8) ($p = 0.026$; z-score: -2,224; $r = 0.34$), with a medium effect size. For peak and mean muscle activity, no between group differences were found during the flexion-extension cycle ($p > 0.05$), **Supplementary file 5.1**.

- Right and left lateral flexion cycle

The neck pain group had greater activation time percentage during right lateral flexion in the away sub-phase at the left paraspinal muscle at T4 ($p=0.016$; z-score: -2,411; $r = 0.37$), with a medium (ES: 0.37) effect size, and at T9 for both the away ($p=0.042$; z-score: -2,033; $r = 0.27$) and return ($p=0.026$; z-score: -2,234; $r = 0.34$) sub-phases,

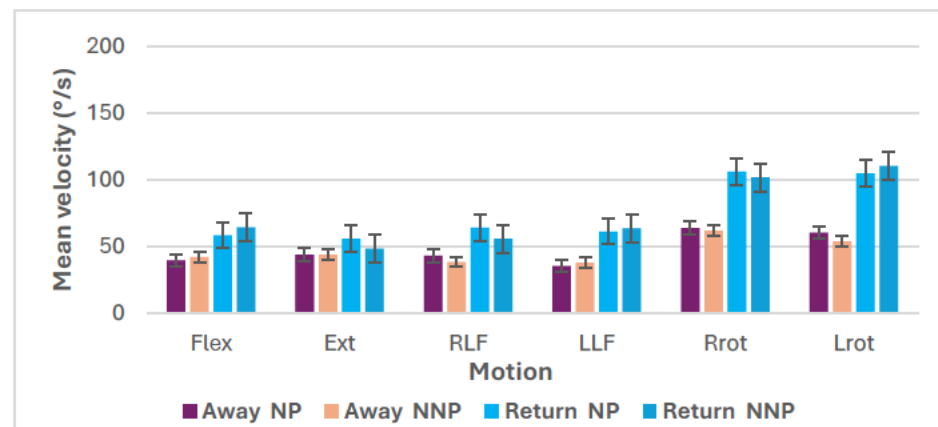
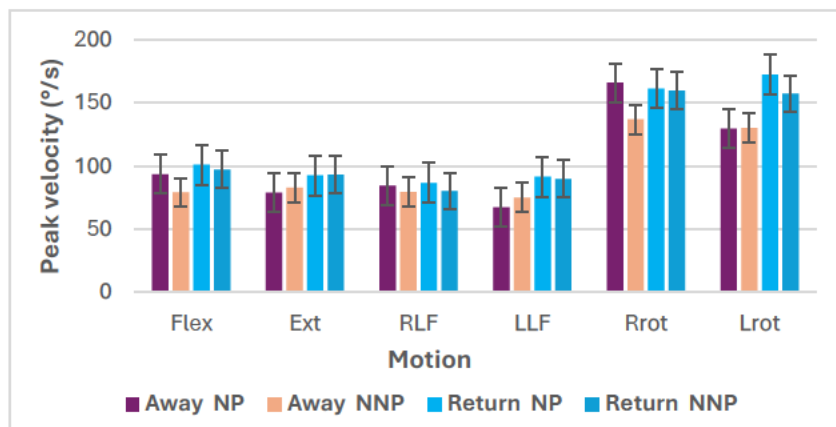


Figure 5.4: Peak and mean velocity (°/s) during cervical spine ROM

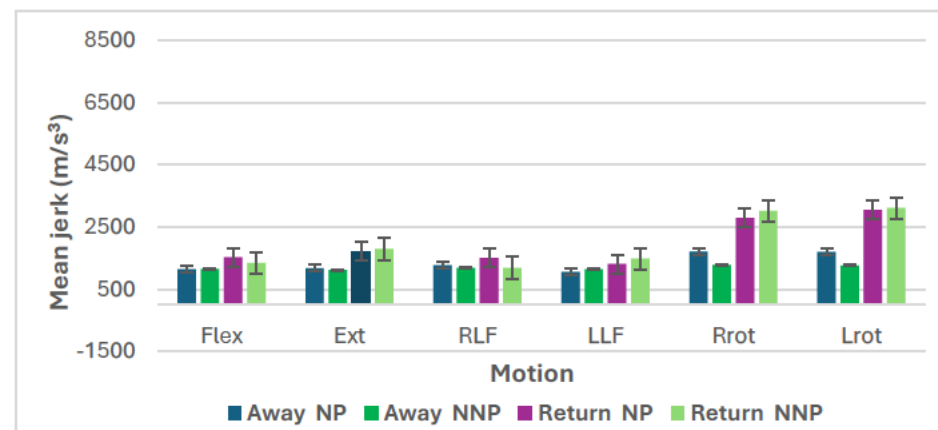
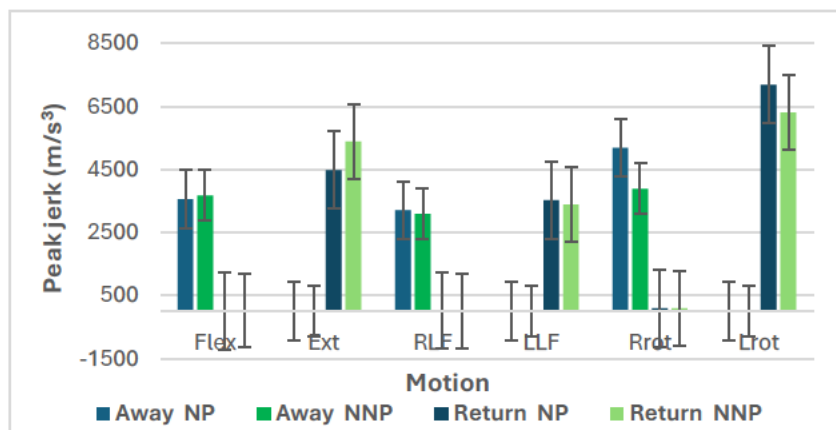


Figure 5.5: Peak and mean jerk (m/s³) during cervical spine ROM
(Flex – flexion, ext – extension, RLF – right lateral flexion, LLF – left lateral flexion, Rrot – right rotation, Lrot – left rotation)

with a small and medium effect size respectively. The neck pain group had less peak muscle activation in the left paraspinal muscle at T4, during right ($p=0,030$; z-score: -2.164; $r = 0.32$) and left ($p=0,047$; z-score: -1.988; $r = 0.29$) lateral flexion, in the away phase, with medium and small effect size, respectively as seen in **Figure 5.6 and 5.7**. No other between group differences were found for peak or mean muscle activation, **Supplementary file 5.2**.

- *Right and left rotation cycle*

The neck pain group had a greater activation time percentage in the left paraspinal at T9 during right rotation away ($p = 0.041$; z-score: -2,041; $r = 0.30$) and return ($p = 0.002$; z-score: -3,098; $r = 0.46$), where activation was 100% (IQR: 0) throughout the motion, with a medium effect size respectively, **Supplementary file 5.3**. There were no other between group differences for activation time percentage in rotation. The neck pain group had lower peak activation during right rotation in the away sub-phase for the left anterior scalene muscle ($p = 0.049$; z-score: -1,966; $r = 0.29$), with a small effect size.

The right paraspinal at T9 had higher peak away and return activation ($p = 0.004$, z-score: -2,054; $r = 0.30$; $p = 0.023$, z-score: -2,274; $r = 0.34$), **Figure 5.8 and 5.9**; and mean away and return activation ($p = 0.004$, z-score: -2,054; $r = 0.30$; $p = 0.026$, z-score: -2,230; $r = 0.33$), **Figure 5.10 and 5.11**, in the neck pain group during left rotation, with medium effect sizes. No other between group differences were found for peak and mean activation, **Supplementary file 5.3**.

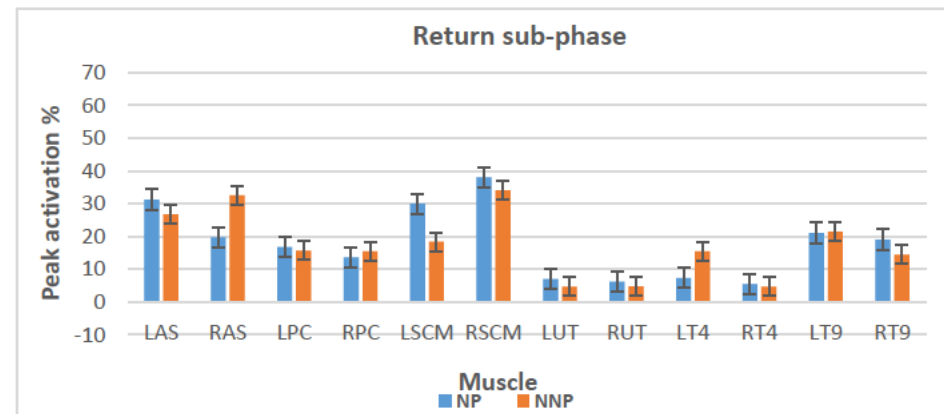
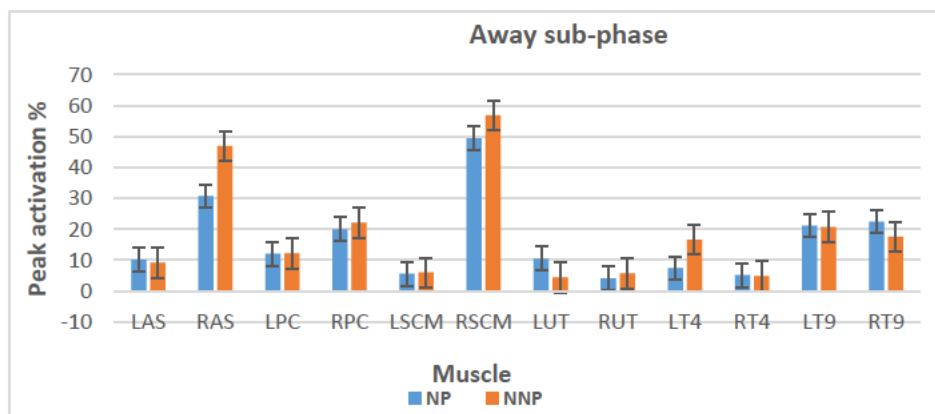


Figure 5.6: Peak muscle activation percentage during right lateral flexion

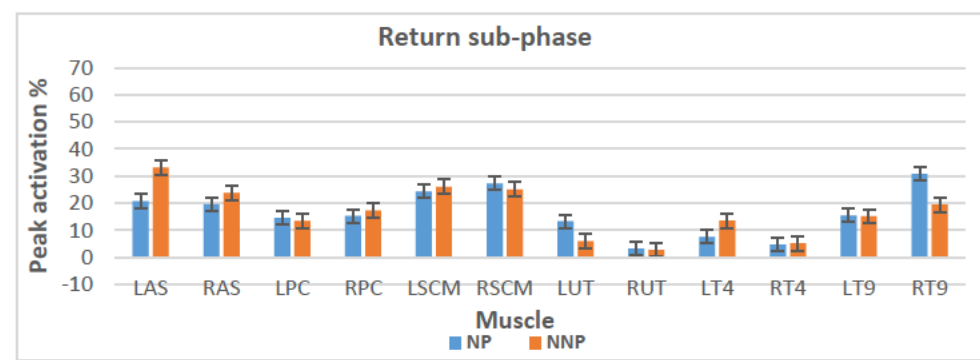
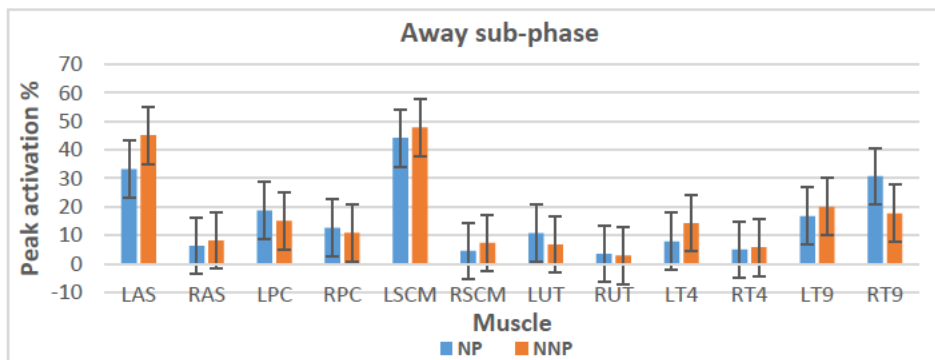


Figure 5.7: Peak muscle activation percentage during left lateral flexion

(% - percentage; L – left; R – right; AS – anterior scalene; PC – posterior cervical; SCM – sternocleidomastoid; UT – upper trapezius; T4 paraspinal at T4; T9 – paraspinal at T9)

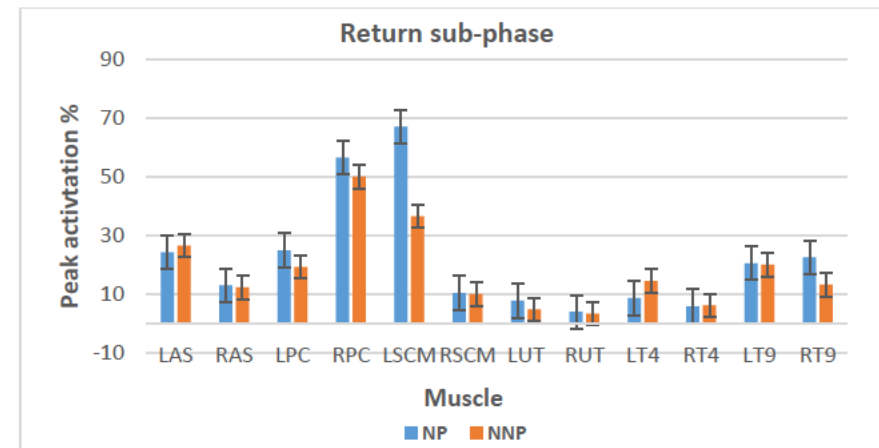
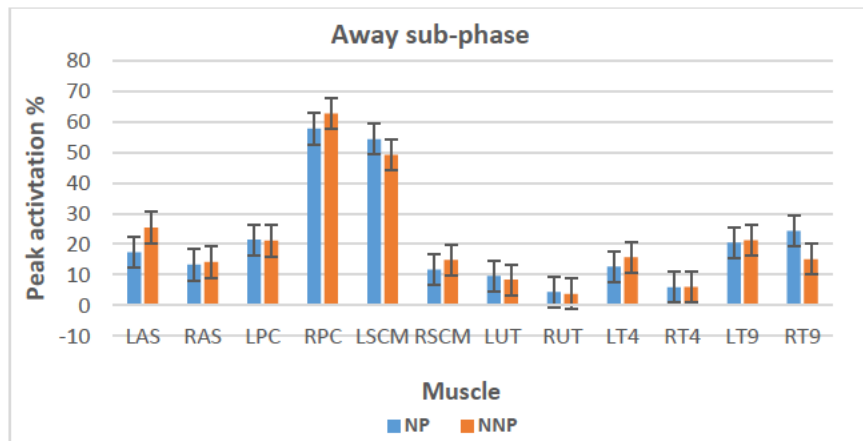
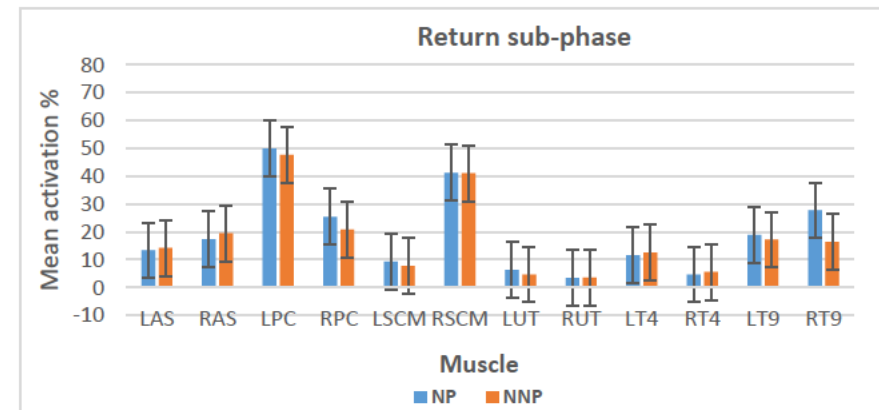
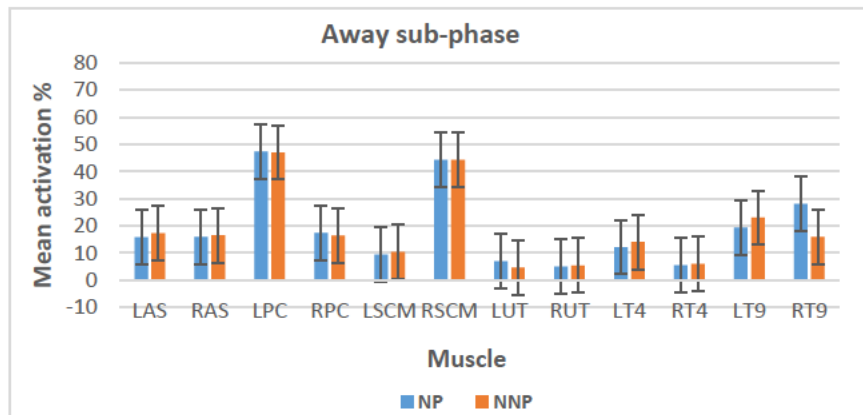


Figure 5.8: Peak muscle activation percentage during right rotation



(% - percentage; L – left; R – right; AS – anterior scalene; PC – posterior cervical; SCM – sternocleidomastoid; UT – upper trapezius; T4 paraspinal at T4; T9 – paraspinal at T9)

Figure 5.9: Peak muscle activation percentage during left rotation

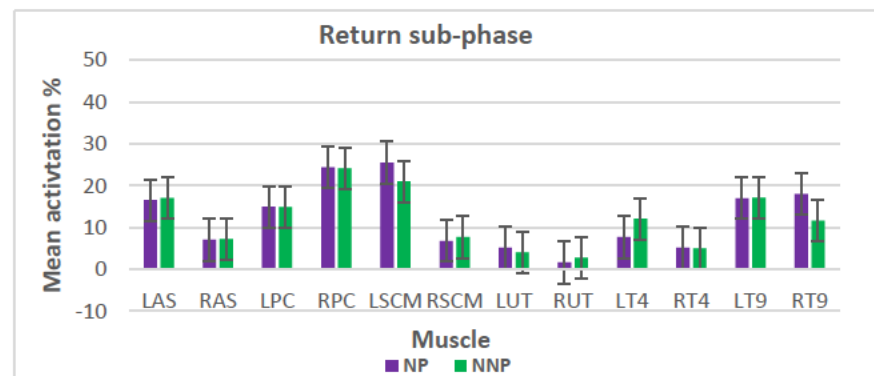
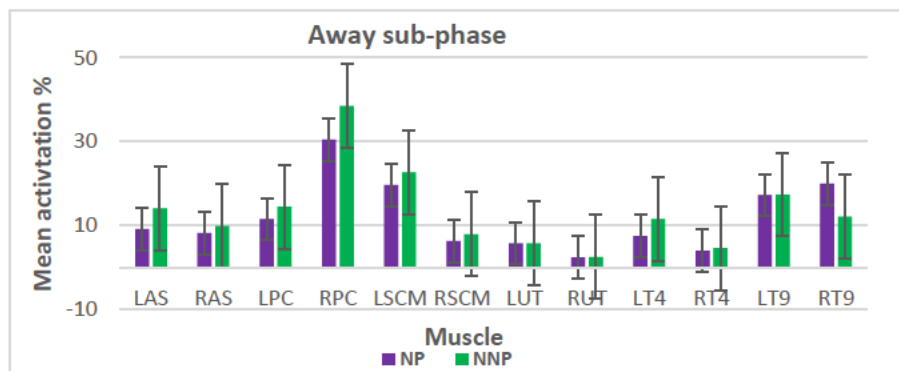


Figure 5.10: Mean muscle activation percentage during right rotation

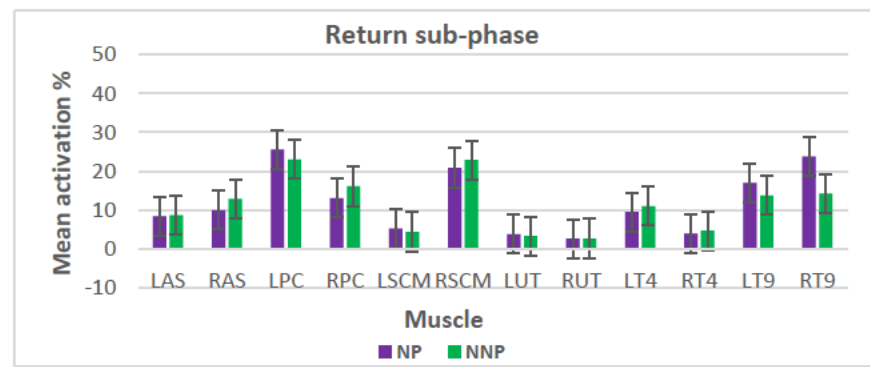
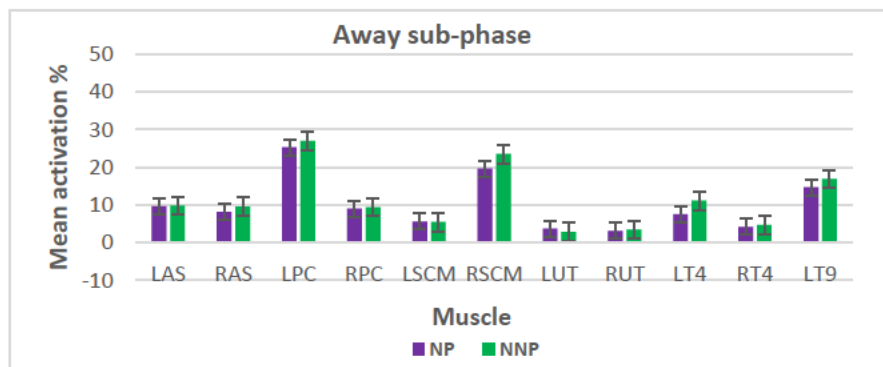


Figure 5.11: Mean muscle activation percentage during left rotation

(% - percentage; L – left; R – right; AS – anterior scalene; PC – posterior cervical; SCM – sternocleidomastoid; UT – upper trapezius; T4 paraspinal at T4; T9 – paraspinal at T9)

DISCUSSION

This study found that those with and without neck pain had similar cervical spinal kinematics patterns, only deviating from the neck pain group taking longer to execute right lateral flexion, albeit by a very small difference. The muscle activation patterns differed between the groups affecting the cervical and thoracic paraspinal and anterior scalene muscles, the muscle activation patterns either increased or decreased relative to the cervical ROM.

Cervical kinematics

It is common in clinical practice to find a reduced active ROM in those presenting with neck pain (Childs *et al.* 2008; Millan *et al.* 2012; Blanpied *et al.* 2017), a stance that was supported by a recent review (Stenneberg *et al.* 2017), but this has been questioned (Snodgrass *et al.* 2014). Our results support previous work (Sjölander *et al.* 2008; Tsang, Szeto and Lee 2013a; Lascurain-Aguirrebeña *et al.* 2018; Lemmers *et al.* 2018) that neck pain does not present with reduced ROM and conflicted with other trials which support its association (Woodhouse and Vasseljen 2008; Meisingset *et al.* 2015; Salehi *et al.* 2021). A possible explanation for the variations in these may be due to the methodologies employed.

When cervical ROM was recorded in the seated position several studies required that the trunk be secured to the chair (Woodhouse and Vasseljen 2008; Meisingset *et al.* 2015; Treleaven, Chen and Sarig Bahat 2016) or that the participants were encouraged to anchor their thoracic and/or lumbar spines to a backrest (Lemmers *et al.* 2018). This was not possible in the current study, due to the positioning of reflective markers along the spine preventing the use of a chair with a backrest. The use of the back rest may impact the presence of neck pain during cervical ROM as two of the three studies that used a back rest/secured the trunk to the chair reported reduced cervical ROM. In an attempt to compensate for a lack of a backrest participants were encouraged to not move their shoulders during the assessment, which may not have had the same effect as anchoring

the trunk. Of interest is that Lemmers *et al* (2018) who also did not secure the trunk to the chair but rather asked participants to anchor their thoracic and lumbar spines to the chair, also reported that cervical ROM was not affected in neck pain.

The cervical and thoracic spines have an intimate relationship with cervical spine motion being dependent on thoracic posture and mobility (Lau *et al.* 2010; Oxland 2016), with the thoracic spine contributing between 9.9% to 25.1% to motion across the six cervical ranges (Tsang, Szeto and Lee 2013b). Thus, by not restraining the thoracic spine the natural interplay between regions was able to occur, allowing for the assessment of a more normal pattern of motion (Tsang, Szeto and Lee 2013b).

When comparing the peak displacement values found in this study, they were lower than those reported in a recent systematic review assessing cervical ROM using The Cervical Range of Motion Measuring device (CROM) (Thoomes-de Graaf *et al.* 2020), but similar to two trials where three dimensional motion characteristics were assessed via an electromagnetic tracking device (Tsang, Szeto and Lee 2013a) and motion camera analysis (Salehi *et al.* 2021). The variations suggest that peak displacement not only depends on the position of the assessment i.e. seated with trunk secured or unsupported sitting, but also on the tool utilised to obtain the results.

Assessing the temporal character of cervical ROM, those with neck pain were found to take longer to complete right lateral flexion motion than those without neck pain. Comparing these results with a similar study, Salehi *et al* (2021) also reported that only one motion took longer to execute, which was right rotation, they did not include lateral flexion in their assessment. Not many studies have investigated the time taken to complete cervical ROM, but increased task time was found for those with neck pain when executing cervical circumduction (Yang, Su and Guo 2014; Zhou *et al.* 2018) and proprioceptive tasks (Ernst *et al.* 2019; Sarig Bahat *et al.* 2020). A recent review indicated that there was a strong level of evidence that people with neck pain took longer to execute tasks (Franov *et al.* 2022).

Pain can negatively affect movement by producing hesitancy or movement avoidance (Gatchel *et al.* 2016) reducing task execution time as a mechanism to protect the area from further injury (Hodges and Tucker 2011; Merkle, Sluka and Frey-Law 2020). Longer task duration may also be an attempt to increase accuracy (Sarig Bahat *et al.* 2020), as the feedback and feedforward mechanisms may be working sub-optimally leading to longer execution time (Nijs *et al.* 2012; Kantak, Johnson and Zarzycki 2022).

The velocity and jerk measures assessed in this study were not found to differ between the groups during cervical ROM. The participants with neck pain reported moderate pain with mild disability, thus it was anticipated that velocity and jerk would be affected. These findings concur with Lemmers *et al.* (2018)(Lemmers *et al.* 2018) but differ from other studies where differences in both velocity and jerk were found in cervical ROM (Sarig Bahat, Weiss and Laufer 2010; Salehi *et al.* 2021). In an earlier study O'Connor *et al.* (2025)(Chapter four) reported that velocity measures using the OptiTrack system were reliable, however those related to jerk were more varied. A recent systematic review reported that there is conflicting evidence for these kinematic variables being associated with neck pain (Franov *et al.* 2022), requiring further research to delineate their association with neck pain.

Comparing the current study to one of the first studies where motion smoothness was assessed during standing cervical rotations with sub-phase analysis, no differences in peak displacement or velocity were reported, similar to the current study, but increased jerk measures were found in those with neck pain (Sjölander *et al.* 2008). In this trial, participants were required to move their heads as far and fast as possible, differing from the current study where self-paced speed was selected. Jerk increases with slower speeds (Röijezon *et al.* 2010; Vikne *et al.* 2013), thus it is possible that those with neck pain moved slower than those without neck pain and this was not detected, as only peak velocity was recorded. Whereas in the current study, both peak and mean velocity were assessed and found to not differ between those with and without neck pain.

To further compare our results to another similar study where full, cervical ROM in flexion, extension and rotation was assessed and performed at a self-selected pace, but in the standing position, those with neck pain had reduced velocity of motion and increased jerk (Salehi *et al.* 2021). An important difference in this study was that the participants had their eyes closed during the motion, whereas in the current study, the participant's eyes were open. Visual feedback during the execution of the cervical ROM may act as a compensatory, sensorimotor mechanism reducing the negative effect of neck pain on kinematic performance. When actions are goal-directed, a quick assimilation of the environment is required from the sensory systems to plan motor processes (Kantak, Johnson and Zarzycki 2022), where visual input is restricted, the system is forced to rely on other receptors for this information which may be negatively affected by afferent nociceptive input (Nijs *et al.* 2012).

Another difference worth noting is the mean age of participants reported by Salehi *et al.*, (2021) was 10 years older than in the current study, where young adults in their mid-twenties partook, with the duration of neck pain being similar across the two trials. A negative relationship has been shown between increasing age and ROM (Chen *et al.* 1999) with a positive relationship between the variability of cervical ROM and increasing age (Lansade *et al.* 2009). Although the participants had chronic neck pain (greater than 3 months), their relatively young age may have counter-acted the potential negative motor control effects that have been observed in older populations with neck pain.

Muscle recruitment patterns

Two muscles of the neck were found to have reduced activation - the left paraspinal muscle during the away cycle of cervical extension ROM and the left anterior scalene muscle in the right rotation during the away sub-phase. These findings contrast with those proposed by Falla and Colleagues where people with neck pain present with augmented superficial and impaired deep cervical flexor muscle activity (Falla *et al.* 2004a; Jull and Falla 2016); and where increased muscle activity in the cervical flexor and extensor

muscles was found during cervical ROM in those with neck pain when compared to those without (Nobe *et al.* 2022).

During extension, the cervical paraspinal muscle works concentrically, as an agonist, with the sternocleidomastoid and scalene muscles working antagonistically during extension. The reduced activation time in this muscle contrasts with Lascurain-Aguirrebeña *et al.* (2018) who found that there was no difference between those with and without neck pain in the cervical paraspinal but rather found reduced right scalene muscle activity in extension (Lascurain-Aguirrebeña *et al.* 2018). Experimentally induced pain during cervical extension in the splenius capitis muscle has been found to result in reduced muscle activation on the side of pain (Falla *et al.* 2007) which would explain the finding in the current study, they also reported an increase in the upper trapezius muscle activation in relation to this change, which was not observed in the current study. Pain affects motor control via central mechanisms (Nijs *et al.* 2012; Peng *et al.* 2021) resulting in re-organisation of the motor response within and between muscles (Hodges and Tucker 2011), yet during extension, this was the only muscle that differed between those with and without neck pain. The reduced activation level aligns with the pain adaption model proposed by Lund *et al.* (1991)(Lund *et al.* 1991) but would not support the reduced activation found in the left anterior scalene muscle when it was acting in an eccentric manner during right rotation.

The scalene muscles in those with neck pain have been shown to have increased activation (Falla *et al.* 2003; Falla *et al.* 2004a; Falla and Farina 2007) and according to the contemporary theory of motor adaption in pain, there is a re-organisation within the muscle, with some motor units being de-recruited and others recruited (Tucker *et al.* 2009) impacting movement (Merkle, Sluka and Frey-Law 2020). Unlike previous studies (Falla *et al.* 2003; Falla *et al.* 2004a; Lascurain-Aguirrebeña *et al.* 2018) where the scalene muscle has been assessed no other muscle adaptations were simultaneously noted in the neck muscles.

In this study during lateral flexion and rotation differences in activation were noted between those with and without neck pain. In right lateral flexion, the left paraspinal muscles were active for longer with lower peak activation levels while during right rotation the left paraspinal muscles had greater activation time while the right paraspinal muscles had greater peak and mean activation levels when compared to those without neck pain. During the study, the participants sat with their backs unsupported, which would increase activation of the paraspinal muscles as they maintain stability and mobility (Lok Wong *et al.* 2022). When performing the active cervical ROM, the thoracic paraspinal acts by stabilising the thoracic spine (Tsang, Szeto and Lee 2016). The changes observed may have occurred in response to bringing stability to those with neck pain while they moved through the various cervical ROMs. There were no studies with which to compare these results with as no studies assessed activation of the thoracic paraspinal muscle in those with and without neck pain during cervical ROM. Thoracic spine dysfunction has been linked to neck pain (Joshi, Balthillaya and Neelapala 2019), with treatment of this area resulting in improved neck pain outcomes (Joshi, Balthillaya and Neelapala 2020; Tsegay *et al.* 2023). The results from this study would support the necessity for assessment of this area of the spine when treating neck pain.

Strengths and limitations

To our knowledge this is the first study to combine the assessment of spinal kinematics and muscle recruitment patterns during the assessment of sub-phases of the three cardinal planes of cervical ROM, when comparing those with and without neck pain, enabling a holistic view of motor control. The assessment of the sub-phases of cervical ROM allowed the isolation of the individual parts of each cardinal plane of motion, linking this together with the assessed muscle. In addition, muscles beyond those in the cervical region were assessed, adding to the growing literature in this area. In a South African context there have been no studies investigating the kinematic and muscle activation effects of neck pain. Thus, this study has allowed the exploration of spinal kinematics and

muscle recruitment patterns in this population and comparison to those studies done in other regions, adding to the understating of the impact of neck pain on motor control.

In light of these benefits, the following limitations need to be considered. The participants in this study were mostly young adults and those with neck pain had moderate, chronic pain, with a self-reported disability as mild. Extrapolation of these results to older populations should be done with care. Participants moved through the cervical ROM cycles at their own pace, as the aim was to capture 'normal' neck motion. Results may be different if the movement was 'normalised' for example with a metronome. Although care was taken to accurately place reflectors and electrodes and prevent motion interference, it is possible that during the trial motion artefacts occurred.

CONCLUSION

Functional joint stability occurs as a result of the passive joint structures (e.g. joint capsule and bony anatomy) working together with the dynamic muscular components (Riemann and Lephart 2002), modulated by the nervous system (Panjabi 1992). The ability to move (and remain stable) occurs due to the concurrent activity of many neurons working in the peripheral and central nervous systems (Bizzi and Ajemian 2020). The nervous system uses the derivatives of position and velocity to prepare the body for anticipated motion allowing it to change and act appropriately (Honarvar *et al.* 2021). In the presence of altered sensorimotor input, the quality of the motor output would be affected (Riemann and Lephart 2002) despite reports that neck pain sufferers have altered motor control (Qu *et al.* 2022) with changes in neuromuscular control (Falla *et al.* 2004a; Falla, Jull and Hodges 2004a; Falla *et al.* 2004b) and sensorimotor disturbances (Peng *et al.* 2021). This study did not find evidence of alterations in spinal kinematics but reported longer durations to execute a task and changes to muscle recruitment strategies, particularly of the cervical and thoracic paraspinal spinal muscles, in those with neck pain. The relationship between pain and motor control is complex and further research is warranted to understand the impact of neck pain on neuromuscular control.

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Conflict of interest

The authors declare no conflict of interest related to this research.

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CHAPTER SIX

MANUSCRIPT FOUR:

CASE-CONTROLLED INVESTIGATION OF CERVICOTHORACIC SPINAL KINEMATICS AND MUSCLE RECRUITMENT PATTERNS DURING TWO FUNCTIONAL UPPER LIMB TASKS

6.1 BACKGROUND TO THE CHAPTER

The cervical spine has many important roles among them mobility, which occurs within the cervical range of motion (ROM), maintenance of horizontal gaze (Scheer *et al.* 2013) and execution of several activities of daily living (ADL) (Tan, Riew and Traynelis 2017). When a person develops neck pain, it negatively affects their quality of life, impacting their ability to self-care and execute daily activities (Kaljić *et al.* 2022a), particularly those related to the upper limb (McLean *et al.* 2010; Osborn and Jull 2013; Alreni *et al.* 2017).

Upper limb motion results in spinal perturbations (Gorski and Schwartz 2003; Falla, Jull and Hodges 2004a), resulting in postural responses from spinal structures (Hodges, Cresswell and Thorstensson 2001). In neck pain, these responses are altered with cervical spinal muscles having delayed muscle onset and altered muscle activation patterns (Falla, Jull and Hodges 2004a; Hsu *et al.* 2020). An investigation into a unilateral, loaded, upper limb task found prolonged coactivation of the cervical and thoracic muscles with decreased cervical spine velocity and acceleration profiles in those with neck pain (Tsang, Szeto and Lee 2014). These findings allude to altered motor control strategies in people with neck pain during functional tasks.

Yet few studies have aimed to assess spinal kinematics during functional tasks in those with neck pain (Moghaddas *et al.* 2019), and where they have, the tasks have been unilateral. Bilateral arm tasks bring complexity to motor control due to the need for coordinated movement (Nemanich and Schindler-Ivens 2025). Thus, this chapter details

a study of people with and without neck pain executing a unilateral and bilateral upper limb task while assessing cervicothoracic spinal kinematics and muscle activation patterns to further assess the effect of neck pain on motor control. The data for this study was captured at the same time, and after, the cervical ROM data from chapter five.

6.2 MANUSCRIPT

A comparison of cervicothoracic spinal kinematics and muscle recruitment patterns during two arm lifting tasks in people with and without neck pain – an observational study

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ABSTRACT

Background: Execution of daily tasks requires coordination between the spine and the upper limb. People with neck pain report disability when executing daily activities, suffering from motor control disturbances. This study aimed to assess cervicothoracic spinal kinematics and muscle recruitment patterns in those with and without neck pain during the execution of a unilateral and bilateral arm task.

Methods: Age and gender matched participants with (n=23) and without neck pain (n=23) partook in a unilateral, dominant arm lift while sitting, and a bilateral, overhead lift while standing. Cervicothoracic spinal kinematics, recorded using motion capture technology, and muscle recruitment patterns using surface electromyography were obtained during the tasks. Data were analysed using SPSS with a p value of less than 0.05.

Results: The unilateral arm task resulted in those with neck pain having less peak displacement in upper thoracic spine rotation ($p = 0.017$, $r = 0.35$) and greater displacement in lateral flexion ($p = 0.006$, $r = 0.40$) and rotation ($p = 0.038$, $r = 0.31$) in the lower thoracic spine. During lifting and lowering, the neck pain group had a greater lower thoracic spine rotation range ($p = 0.036$, $r = 0.31$; $p = 0.004$, $r = 0.42$). Muscle activation showed a greater percentage of activation time in the right upper trapezius and left paraspinal at T4 ($p = 0.039$, $r = 0.30$; $p = 0.039$, $r = 0.30$) in lifting and lower peak activation in the left paraspinal at T4 ($p = 0.032$, $r = 0.32$) in lifting. During lowering, the left paraspinal muscle at T4 had a greater activation time percentage ($p = 0.005$, $r = 0.34$), lower peak ($p = 0.019$, $r = 0.42$) and mean ($p = 0.044$, $r = 0.24$) activation in the neck pain group. The bilateral task showed greater cervical lateral flexion velocity ($p = 0.024$, $r = 0.34$) in those without neck pain, and an increased rotation range in the upper and lower thoracic spines ($p = 0.024$, $r = 0.34$; $p = 0.016$, $r = 0.37$) in those with neck pain while lifting. During lowering those without neck pain had increased average velocity in cervical lateral flexion ($p = 0.012$, $r = 0.34$) and rotation ($p = 0.022$, $r = 0.35$). No significant differences between the groups were found for muscle activation patterns in the bilateral arm task.

Conclusions: Neck pain was associated with an altered pattern of motor control where during the unilateral task the upper thoracic spine was more rigid with compensation in greater lower thoracic spine displacement and greater activation of the contra-lateral paraspinal muscle. The bilateral arm task showed neck pain participants moved their cervical spines more slowly with greater thoracic spine range. These findings require further investigation in the clinical environment to understand their clinical relevance.

Keywords: Neck pain, muscle recruitment pattern, cervical spine, thoracic spine, range of motion, velocity, jerk, electromyography

INTRODUCTION

Upper limb mobility is complex, involving more than 70 muscles and 34 rotational degrees of freedom (Veeger and van der Helm 2007; Sobinov and Bensmaia 2021; Mulla and Keir 2023), allowing for the execution of activities of daily living such as reaching, lifting and self-care (Edemekong *et al.* 2023). Weight from the upper extremity is transferred through to the spine via the clavicle (Shah and Routatal 2015), with the scapulothoracic muscles playing an important role in shoulder tasks (Seth *et al.* 2019) and the spine acting as an axial tower (Bain *et al.* 2019). Spinal muscles and structures then adapt to this force and stabilise the moving arm allowing for task execution. Motion coordinated between the upper limb; cervical and thoracic spine forms a kinematic chain (Henmi *et al.* 2006; Heneghan *et al.* 2019; Ellenbecker and Aoki 2020). Successful execution of an upper limb task relies on the complex integration of many systems in the body, including neuromuscular control and sensorimotor efficiency (Riemann and Lephart 2002), which are often impaired in neck pain (Sjölander *et al.* 2008; Alalawi *et al.* 2022; Särkilahti *et al.* 2024).

Neck pain, a common worldwide musculoskeletal problem (Kazeminasab *et al.* 2022), is often associated with high levels of disability, negatively impacting leisure activities, mobility, sleep and activities of daily living (Kaljić *et al.* 2022b). Neck pain sufferers have been found to modify their movement patterns to achieve the same functional task as individuals without neck pain (Tsang, Szeto and Lee 2013). Neuromuscular disturbances such as altered deep neck flexor muscle activity with increased fatigability of the anterior scalene (AS) and sternocleidomastoid (SCM) muscles (Falla *et al.* 2003; Falla, Jull and Hodges 2004b) and increased cervical flexor and extensor muscle activity during neck motion in the sagittal, coronal and horizontal planes (Nobe *et al.* 2022) have been found

in those with neck pain. These findings suggest that the stability of the cervical spine is compromised leading to or exacerbating neck pain (Falla *et al.* 2003; Falla *et al.* 2004a; Falla and Farina 2007). Reduced cervical ROM and altered spinal kinematics negatively impact task execution and result in increased time to execute tasks (Descarreaux, Passmore and Cantin 2010; Ernst *et al.* 2019; Sarig Bahat *et al.* 2020) and alter the quality of spinal motion (Qu *et al.* 2022).

Several studies compared the performance of upper limb tasks between those with and without neck pain by assessing muscle activation patterns in order to understand the effect of neck pain on motor control. Falla *et al.* (2004) found during a repetitive unloaded arm task, altered neuromuscular function in the AS, SCM and upper trapezius (UT) muscles in people with neck pain (Falla, Bilenkij and Jull 2004). Similar effects in the UT were found by Leonard *et al.* (2010) during a 30min writing task, where neck pain participants had increased UT muscle activity when compared to asymptomatic controls (Leonard *et al.* 2010). In contrast, during isometric contraction of the shoulder in abduction (Zakharova-Luneva *et al.* 2012) or during the performance of a bilateral computer typing task, no differences in UT muscle activity were found between those with and without neck pain (Voerman, Vollenbroek-Hutten and Hermens 2007). These findings suggest that the effect of neck pain on motor control is dependent on the activity concerned.

Assessing spinal kinematic differences in those with and without neck pain during various tasks shows differences between the groups. During a single overhead reaching task to the left and right, and when putting on a seat belt, increased neck flexion angles, decreased sagittal cervical ROM and increased velocity peaks in flexion and rotation of the cervical spine were found in those with neck pain sufferers (Moghaddas, Edwards and Snodgrass 2022). This contrasted with Constand *et al.* (2013) who also assessed unilateral, standing overhead reach and reading tasks, when no between group differences were found (Constand and MacDermid 2013). In a more challenging bilateral dynamic task of seated, ball catching - anterior displacement of the centre of rotation of the cervical helical axis was found to reduce and restrict upper body movements in those

with neck pain (Grip *et al.* 2008). Hand dominance can impact the performance of tasks/functions (Sainburg 2002) with bilateral arm tasks requiring a higher degree of cognitive function, due to multi-tasking.

Bilateral arm tasks have been studied less frequently than unilateral arm tasks (Swinnen and Wenderoth 2004), particularly in regard to lifting tasks, where unilateral arm lifts have mostly been investigated in neck pain (Constand and MacDermid 2013; Tsang, Szeto and Lee 2013; Xie *et al.* 2018; Moghaddas, Edwards and Snodgrass 2022). Overhead tasks require the involvement of the upper limb, neck and trunk, and they are associated with increased injury risk in the work environment (Panariello *et al.* 2022; da Silva Vieira Rosa, Marques Vieira Rosa and Padula 2024).

The motor control required for the execution of a task is comprehensive and includes motor, sensory, and integrative processes (van Dieën *et al.* 2019). To assess the impact of neck pain on task execution, biomechanics and neuroscience need to be blended (Mulla and Keir 2023). Few trials have assessed spinal kinematic and muscle activation patterns simultaneously during task performance when comparing those with and without neck pain. Tsang *et al.* (2014) found that during a seated, unilateral, lifting task that those with neck pain had significantly decreased cervical kinematics of velocity and acceleration with prolonged co-activation of cervical and thoracic muscles during the task. This alteration of movement strategy in those with neck pain could be an attempt to stabilise the spine allowing for task execution (Grip *et al.* 2008). Further changes to motor control were found during a bilateral one-hour computer typing task, where those with high discomfort and neck pain displayed increased head flexion angles together with increased UT and decreased cervical paraspinal muscle activity. This altered recruitment pattern was suggested to be a mal-adaptive motor response whereby the UT muscle assisted the extensor muscles during increased neck flexion to allow for task execution (Szeto, Straker and O'Sullivan 2005).

These studies highlight the importance of assessing various components of the motor system simultaneously and during different tasks to further determine the impact of neck

pain on motor control. Given the paucity of studies that combine measurement of kinematics and muscle activation, this study aimed to advance our understanding of the impact of neck pain on motor control by evaluating cervicothoracic spinal kinematics and muscle recruitment patterns between those with and without neck pain while performing a unilateral and bilateral lifting task. It was hypothesised that those with neck pain would have reduced displacement and velocity and increased jerk indicating altered motor control strategies.

METHODS

Study design and permissions

This study used age and sex-matched participants in a case-controlled design. Permission to utilise a Chiropractic clinic on a university campus (**Appendix H**) was obtained together with approval from an Institutional Research and Ethics Committee (IREC 017/20) which operates in accordance with the Declaration of Helsinki, 1975 (**Appendix I**). The data used in this study was collected as part of a bigger project where kinematics and sEMG during cervical ROM (chapter five) was also obtained.

Participants

Volunteers were recruited via flyers, social media adverts and word of mouth and provided informed consent (**Appendix G**). Inclusion criteria were that they were right-handed, to prevent differences in muscle activity due to hand dominance (Sainburg 2002; Amar, Cochran and Woldstad 2017) and aged 18 to 50 years. Those with neck pain had to have chronic (> 3 months), non-specific neck pain, of a severity sufficient to seek care. Those without neck pain had to have no history of neck or spinal pain, requiring medical treatment over the last twelve months, with no pain in the upper extremity.

Participants were excluded if they suffered from any neurological/orthopaedic/rheumatic disorder, suffered severe trauma or surgery to the brain or spine, or had sensory or vestibular deficits. They were required to have no open wounds in the neck and trunk

region, which would prevent electrode placement, and a skin fold thickness of less than 19mm over the upper trunk to ensure adiposity did not affect transmission of the surface electromyogram (sEMG) signal (Baniqued *et al.* 2016). All participants were screened for central sensitisation (**Appendix R**), using a cut off score of 40 (Mayer *et al.* 2012; Neblett *et al.* 2013), and Fear Avoidance Behaviours (FAB) (Kori, Miller and Todd 1990) (**Appendix S**), using a cut off score of 37 (Roelofs *et al.* 2004), if scores exceeded these values they were excluded. All participants were subject to history taking, orthopaedic examination and collection of anthropometric data by a registered chiropractor with over 20 years of experience. Participants were recruited between November 2022 and August 2023.

Sample size

An *a priori*, sample size was determined from pilot test data. Using an independent student t-test, a large effect size (0.9), an α of 0.05, and a power of 0.8, 40 participants were required (20 per group). To allow for dropout, a further three participants were recruited. Sample size calculation was done using G*Power (Faul *et al.* 2007).

Measurement instruments

To assess the general health and quality of life of the participants they were required to complete the RAND 36-Item Health Survey 1.0 (RAND Corporation 2023)(**Appendix L**). This tool is widely utilised (Ohlsson-Nevo *et al.* 2021) with good responsiveness, reliability (Beaton, Hogg-Johnson and Bombardier 1997) and construct validity in neck pain populations (de Vries *et al.* 2015). The higher the score the better the self-reported health status (RAND Corporation 2023). Neck pain participants rated the intensity of their neck pain over the last week using the numerical pain rating scale 101 (NPRS)(**Appendix M**). This scale is commonly utilised (Pool *et al.* 2007), valid, reliable, and responsive (Ferreira-Valente, Pais-Ribeiro and Jensen 2011) and can be used in neck pain (Modarresi *et al.* 2022). It is scored from zero, being no pain, to 10 which indicates severe pain (Pool *et al.* 2007). To assess perceived disability from neck, pain the Neck Disability Index (NDI) was

utilised (**Appendix N**). This tool has good content validity in patients with chronic, non-traumatic neck pain (En, Clair and Edmondston 2009). The percentage score was determined out of a total of 50, the higher the score the greater the disability (Young *et al.* 2009). The Neck Outcome Score (NOOS) was included to collect data on the level of impairment, activity and participation (Juul *et al.* 2015b), it has been found to have excellent content validity (Juul *et al.* 2015a) and is reliable and responsive in neck pain (Juul *et al.* 2016). Scores were calculated for mobility, symptoms, sleep disturbance, activity and pain, and participation. The higher the score the better the responses (Juul *et al.* 2016).

Objective measures

Kinematics

The OptiTrack™ motion capture system (Optitrack, Natural Point, OR, USA), with eight Prime 13 cameras, with a resolution of 1.3 MP (1280 × 1024) and 240 frame rates, with a sampling frequency of 120 Hz per camera (Muyor *et al.* 2017) were used. OptiTrack motion capture system (OptiTrack, Natural Point, OR, USA) has been found to track markers accurately and reliably and is comparable to other motion capture systems (Carse *et al.* 2013). Cameras were wall or tripod mounted around the test area. Pre-capture calibration was performed and the capture volume set {NaturalPoint Corporation, 2023 #18}. Masking was used to remove any unwanted light reflections in the capture volume. Reflective markers (14 mm) were attached, using either electrodes or Velcro stickers, to anatomical sites on the head, trunk and arms using bony anatomy to guide placement as seen in **Table 6.1**. The C7 marker had a one-centimetre extender.

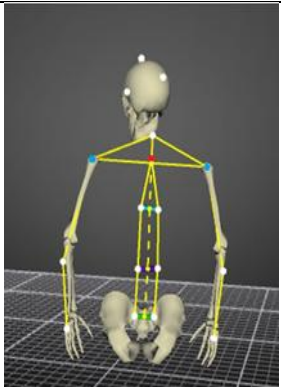
Unlabelled markers were streamed through motive™ to 3DMA STT-system™ to allow for movement processing (STT systems group, Spain). Each reflective marker was allocated to the appropriate anatomical site, producing a custom-made digital human model calibrated to the participants anthropometry, syncing the position and orientation of each reflective marker to the correct body segment, to complete the matrix transformation.

Marker allocation was assessed throughout the capture. The model constructed cervical spinal kinematics from the reflectors from the external occipital protuberance to C7, and a kinematical estimation model was developed in STT-systems™ and provided six degrees of freedom (DOF) in three cardinal planes.

Electromyography

The Biopac Bionomadix MP150 Data Acquisition System (Biopac systems® Inc.) was utilised together with a wireless transmitter and receiver pair. The system has a differential amplifier with a common mode rejection rate (CMRR) of 110dB at 50/60 Hz, gain of 2000, input impedance of 2 MΩ with signal to noise ratio over 65dBs). Data were transmitted at 2000 Hz. The data acquisition software (Acqknowledge 4.1, BIOPAC systems Inc.) was set to a sampling frequency of 2000 Hz. Prior to placement of electrodes, the skin was lightly abraded, shaved where necessary, and cleaned with alcohol (Hermens *et al.* 2000). Disposable, rectangular, pre-gelled Ag/AgCl surface electrodes (30x25mm) (Vitatrode™ Electro Spyres, Johannesburg) were placed on the six muscles bilaterally, parallel to the muscle fibers, and in the mid-line, with an inter-electrode distance of 20 mm (Hermens *et al.* 2000). Care was taken to accurately locate electrode placement sites through palpation of bony landmarks and the use of a tape measure, (see **Table 6.1** for details). Reference electrodes were placed on the closest bony prominence.

Table 6.1: Location of reflective markers

Location	Instruction	
Top of head	Centre of the top of the head	
Front of head	Centre of the forehead	
Back of head	Centre of the back of the head	
C7	C7 spinous process	
T3	T3 spinous process	
R and L shoulder	Acromion	
R and L T7	4 cm to the right/left of the T7 vertebrae	
R and L L1	4 cm to the right/left of the L1 vertebrae	
R and L elbow	Right or left lateral epicondyle of the humerus	
R and L PSIS	Protuberance of the PSIS	
R and L wrist	Right or left ulna styloid	

(C – cervical, T thoracic, R - right, L – left, cm – centimetres, PSIS – posterior superior iliac spines)

Tasks undertaken

The participant stood upright, with their hands facing their thighs, while the markers were detected by the OptiTrack cameras, streamed to Motive™ tracker and onto STT Insight™ software (STT systems group, Spain). This took approximately 5 seconds. At the same time baseline EMG activity was recorded for 50ms. Once the calibration was complete participants were required to undertake the following upper limb tasks:

Unilateral arm lift – participants sat upright on a wooden stool (45cm high), with no backrest, looking straight ahead at eye level in line with a mark on the wall, with their feet flat on the floor and arms hanging by their sides. A tripod was situated in front and to the right of the stool. It consisted of two shelves, one 70 cm off the floor and a higher shelf 70cm above it. A circular glass jar weighing 2kg was placed on the lower shelf and was required to be lifted by the participants from this shelf to the top shelf, where it was held for two counts then lowered to the lower shelf, **Figure 6.1**.

Table 6.2: Details of electrode placement

Muscle	Placement	Reference electrode
Upper trapezius (UT)	One third from distal edge of acromion on a line drawn between the acromial and C7 spinous process (Farina <i>et al.</i> 2002)	Manubrium
Cervical erector spinae (CES)	2 cm lateral to the C4 spinous process bilaterally (Criswell 2011; Tsang, Szeto and Lee 2014)	
Sternocleidomastoid (SCM)	Midpoint between the mastoid process and the sternal insertion, slightly posterior to the muscle belly (Criswell 2011; Tsang, Szeto and Lee 2014)	Anterior superior iliac spine (ASIS).
Anterior Scalene (AS)	Lateral to the SCM's attachment on the clavicle, above the clavicle and anterior to the upper trapezius, placed at a slightly oblique angle (Criswell 2011)	
Thoracic erector spinae upper T4 (T4)	4 cm lateral to the T4 spinous process bilaterally (Tsang, Szeto and Lee 2014)	Ipsilateral medial epicondyle
Thoracic erector spinae lower T9 (T9)	4 cm lateral to the T9 spinous process bilaterally (Tsang, Szeto and Lee 2014)	

This was repeated three times and participants were encouraged to track the motion with their head and neck. This task mimicked the everyday activity of reaching overhead (Constand and MacDermid 2013) together with weight transfer (Taylor *et al.* 2018). Both these tasks have been associated with neck pain (Genebra *et al.* 2017) and occur as items in disability questionnaires such as the Neck Disability Index (NDI)(Young *et al.* 2009). This task was similar to that used by Tsang *et al.* (2014). The seat and tripod location were marked on the floor to ensure that they did not move during the data collection process.



Figure 6.1: The unilateral arm task

Bilateral arm task - Participants stood behind the stool. A box 34x52x35 cm was placed on the stool with a 2kg metal bar (48cm in length) resting on top of the box. Participants grasped the bar with both hands (one on each end), raised the bar above their head, held it there for two counts, and then lowered the bar back to rest on top of the box, **Figure 6.2**. Participants were encouraged to track the bar movement with their head and neck. This was repeated three times. Bilateral overhead activities are commonplace in day-to-day life such as washing hair and hanging clothes on a washing line and frequently take place in the work environments (Garosi *et al.* 2022).



Figure 6.2: The bilateral arm task

Before undertaking the two tasks, participants were given an opportunity to practice two to three times prior to the start of data collection. If they were not performing the motion correctly, such as moving their shoulders, or not reaching the end limit, their motion was corrected. The unilateral task was performed first, followed by the bilateral task. Tasks were completed at the participants' self-selected pace. No attempts were made to correct the chosen movement strategy. During the procedure, they gave verbal instructions encouraging a 2-count pause at maximal lifting and when returning to the original starting procedure position, as outlined in **Appendix O**.

Data was collected by LO and one of two trained research assistants. All motion capture and sEMG data was collected the research assistant depending on their availability the day of data collection.

Data processing

Motion capture data were exported from STT Insight™ software (STT systems group, Spain) and sEMG data from AcqKnowledge® software and imported into MATLAB (R2023a) (MathWorks® Inc., Natick, Massachusetts, United States) where a customised code processed the signals.

Motion capture: The signals were filtered using a 4th order low pass (5Hz) Butterworth filter (Descarreaux, Passmore and Cantin 2010). Various different smoothing options between two and 10Hz were tested with the 5Hz used by Descarreaux et al (2010) being the preferable one. Data were then segmented into phases of the lifting object – away being the motion of the arm away from the body, and return being when the arm returns to the starting position. The shoulder marker was used to differentiate these stages. Thresholds to register an excursion required that the:

1. Shoulder marker needed to exceed 60°
2. Have a minimum velocity of 2 (°/s)
3. Minimum excursion time of 0.67 seconds and a maximum excursion time of 15 seconds
4. With a minimum of 2 and a maximum of 3 excursions consecutively
5. A minimum transition time of 1.0 seconds and a maximum transition time of 15 seconds
6. Neutral threshold of 45°

The maximum peak of shoulder motion is the value at the top and breaks the task into away and return phases. An example of the signal is presented in **Figure 6.3**. Spinal motion was then assessed per away and return phases based on the cardinal planes of motion and recorded as:

1. Peak displacement – the maximum displacement recorded in the excursion
2. Range – the range of motion (ROM) during the away or return phase of motion,
3. Average velocity – the average speed of the spinal motion per phase (m/s), the segment was deemed to be moving when the displacement was greater than 10 degrees per second,
4. Average jerk – the average smoothness of the spinal motion per phase (m/s³).

sEMG: The raw EMG signal was synced to the kinematic data, then processed using a fourth bidirectional Butterworth filter (a bandpass filter with a low pass cut off 150 hz to remove electrical noise, and a high pass cut off of 50hz to remove low frequency noise such as movement artifacts). Thereafter the signal was full wave rectified and then

smoothed using a moving average over a 300ms sliding window. Following smoothing the data was normalised to the peak amplitude achieved by each muscle across the task (Halaki and Ginn 2012).

This signal was then used to determine activity onset which was detected as the data point where the magnitude of the sEMG signal was three standard deviations larger than the baseline and where the duration of contraction was greater than 25 ms (Hodges and Bui 1996). The onset and offset of muscle activity during the tasks were quantified into a percentage of muscle activation duration. Allowing for the temporal characteristics of the muscle activity to be examined during the half-cycles of cervical ROM. Data were exported as normalised percentage peak, mean and activation time per sub-phase of motion. When activity was 100% during any one phase, this indicated that the muscle was active for the entire duration of that phase. The EMG data was recorded for each movement (i.e. away and lowering) as:

1. Peak – the maximum normalised amplitude of the EMG signal during the phase of motion (mv),
2. Mean – the mean value of the normalised signal during the motion (mv), and
5. Activation time percentage – which represents the amount of time that the muscle was active during the phase. The activity of 100% during any one phase would indicate that the muscle was active for the whole time during that phase.

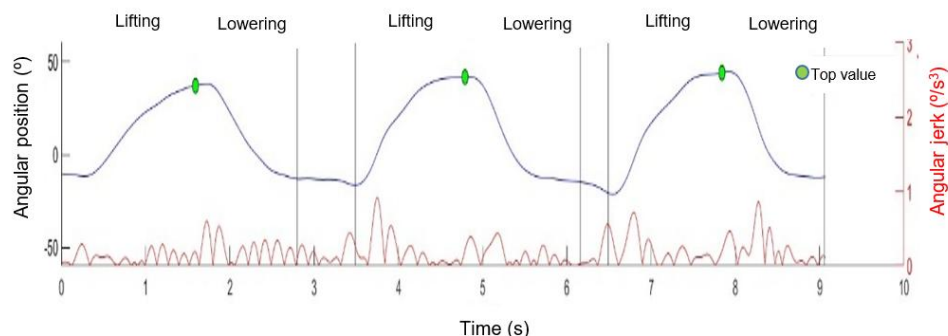


Figure 6.3: Cervical flexion-extension ROM during the bilateral arm task with sub-phases

Following the segmentation of the motion capture and EMG data, event and outcome images (which visually displayed the signal, tasks and sub-phases) were produced and assessed per participant to determine the quality of the signal. When the signal was distorted and lack conformability to the tasks it was excluded, this was done in consultation with a biomechanist. Where isolated technical issues were found, for example where the marker was lost resulting in severe signal distortion or when the electrode failed to detect the signal, the data for only that measurement was excluded from the analysis for that participant. Once satisfied that the signals were acceptable the data for each of the three trials together with the calculated average of the three measures (i.e. the mean) for each of the phases were exported to an Excel spreadsheet for statistical analysis.

Data analysis

Data were analysed using SPSS (version 27, IBM Corp. Released 2020. IBM SPSS Statistics for Windows, Armonk, NY: IBM Corp). Normality was assessed using skewness and kurtosis. Between group assessment of demographic variables was performed using Chi-squared or independent samples t-tests. Kinematic and EMG variables were non-normally distributed and analysed using the Mann-Whitney U test to compare the groups. Effect sizes were reported using rank-biserial correlation coefficient (r) and were reported as: small being less than 0.3, medium between 0.3 to 0.5, and a large effect being greater than 0.5. Statistical significance was set at $p < 0.05$.

RESULTS

Forty-six participants – 23 in each group – were recruited. There were no significant differences between the groups at baseline except for the SF-36 pain scale rating, **Table 6.3**. The neck pain participants characterised their neck pain as moderate (5.4 ± 1.7), bilateral (83%, $n=19$), minimally disabling (13.3 ± 6.9), with NOOS scores for mobility of $61.0 (\pm 17.8)$, symptoms $44.8 (\pm 20.5)$, sleep disturbance $67.1 (\pm 24.7)$, activity and pain $61.5 (\pm 20.0)$ and participation $66.8 (\pm 17.0)$.

Table 6.3: Demographic and health related status

	Total			NP			NNP			p value*
	n	M	±SD	n	M	±SD	n	M	±SD	
Sex (n%)										
Female	25	54,3		12	52,2		13	56,5		0,767**
Male	21	45,7		11	47,8		10	43,5		
Age	46	24,3	(5,6)	23	24,3	(5,7)	23	24,4	(5,6)	0,979
Height (m)	46	1,7	(0,1)	23	1,7	(0,1)	23	1,7	(0,1)	0,742
Weight (kg)	46	70,7	(17,1)	23	68,5	(17,9)	23	73,0	(16,3)	0,382
BMI	46	25,2	(4,8)	23	24,1	(4,2)	23	26,3	(5,2)	0,121
General health status										
Physical functioning	46	88,0	(19,1)	23	84,8	(19,9)	23	91,2	(18,1)	0,256
Physical health	46	70,4	(38,4)	23	65,2	(40,4)	23	75,5	(36,4)	0,370
Emotional problems	46	65,0	(44,4)	23	56,5	(46,5)	23	73,6	(41,5)	0,197
Energy/fatigue	46	50,0	(15,9)	23	51,1	(14,7)	23	48,9	(17,3)	0,648
Emotional well-being	46	47,4	(16,5)	23	44,7	(13,6)	23	50,1	(18,8)	0,271
Social functioning	46	69,6	(27,3)	23	64,2	(30,0)	23	75,0	(23,8)	0,195
Pain	46	64,9	(23,1)	23	52,7	(19,1)	23	77,2	(20,3)	<0,001
General Health	46	55,7	(8,8)	23	55,0	(9,0)	23	56,4	(8,7)	0,597

(NP – neck pain, NNP –no neck pain, * Independent samples t-tests; **Chi-squared test)

Unilateral arm task

- *Spinal kinematics*

Differences between the groups for peak spinal displacement are reported in **Table 6.4**. Those without neck pain had greater upper thoracic right rotation displacement ($p = 0,017$; z-score: -2,384; $r = 0.35$) with a medium effect, whereas the neck pain group had greater displacement in the lower thoracic spine in left lateral flexion ($p = 0,006$; z-score: -2,735; $r = 0.40$) and left rotation ($p = 0,038$; z-score: -2,076; $r = 0.31$) with a medium effect.

During the lifting ($p = 0,036$; z-score: -2,098; $r = 0.31$) and lowering ($p = 0,004$; z-score: -2,878; $r = 0.42$) the neck pain group had increased the lower thoracic spine rotation range with a medium effect. No significant between group differences were seen for average velocity and jerk in the cervical, upper or lower thoracic spines during unilateral arm lifting and lowering phases, **Table 6.5**.

Table 6.4: Peak displacement (°) in the cardinal planes during the unilateral arm task

ROM	NP Mdn	IQR	NNP Mdn	IQR	<i>p</i> value
Cervical					
Flex/ext	11,1	17,1	8,9	13,6	0,801
LF	2,8	8,1	3,3	9,1	0,590
Rot	16,16	8,9	12,28	7,5	0,068
UT					
Flex/ext	-1,56	2,8	-1,97	3,2	0,835
LF	-7,5	4,2	-7,19	5,5	0,801
Rot	9,16	7,5	11,7	5,9	0,017
LT					
Flex/ext	-8,08	3,8	-7,97	5,4	0,660
LF	-7,04	5,3	-3,52	4,7	0,006
Rot	-0,1	3,5	1,98	3,1	0,038

(NP – neck pain, NNP – no neck pain, ROM – range of motion, Flex/ext – flexion/extension, LF – lateral flexion, Rot – rotation, UT – upper thoracic, LT – lower thoracic, Mdn – median, IQR – interquartile range, *negative values indicate motion in extension or to the left)

- *Muscle activity*

All the muscles in the neck pain group, except the right SCM were 100% active during the lifting phase, compared to eight muscles in those without neck pain. Greater activation time percentage was found in the neck pain group in the right UT ($p = 0.039$, z-score: -2.068, $r = 0.30$) and the left paraspinal at T4 during lifting ($p = 0.039$, z-score: -2.068, $r = 0.30$). During lowering, all muscles in the neck pain group displayed a 100% activation time percentage compared to 9 muscles in those without neck pain, **Table 6.6**. The left paraspinal at T4, in the neck pain group had a greater percentage time activation during lowering compared to those without neck pain ($p = 0.005$; z-score: -2.829, $r = 0.34$).

During the lifting and lowering phase in both groups the right UT and right paraspinal muscle at T4 had the greatest peak and mean activation levels, with all the muscles on the right, except for the right SCM and the right paraspinal at T9, showing higher peak and mean activation levels than the muscles on the left, **Figure 6.4 and 6.5**. Significant

group effects were found for peak muscle activation which was lower in the left paraspinal muscle at T4 during lifting in the neck pain group ($p = 0.032$, z-score: -2,142, $r = 0.32$). During the lowering phase, lower peak ($p = 0.019$, z-score: -2.340, $r = 0.42$) and mean ($p=0.044$, z-score: -2,010, $r = 0.24$) activation of the left paraspinal at T4 was found in the neck pain group.

Table 6.5: Cervicothoracic kinematic assessment during the unilateral arm task in those with (n=23) and without (n=23) neck pain

ROM	Outcome	Lifting					Lowering				
		NP		NNP		p value	NP		NNP		p value
		Mdn	IQR	Mdn	IQR		Mdn	IQR	Mdn	IQR	
Cervical:	Range	25,9	12,7	18,8	20,9	0,362	20,9	10,4	15,1	15	0,231
	Ave velocity	16,8	5,7	12,3	14,2	0,606	11,7	3,5	11,1	7,1	0,684
	Ave jerk	974,0	489,3	852,0	587,3	0,701	907	441,9	986,6	605	0,939
LF	Range	11,0	4,7	10,0	3,0	0,517	10,1	8,0	7,5	11,6	0,546
	Ave velocity	7,2	5,4	7,05	4,4	0,869	5,7	3,6	5,8	4,4	0,725
	Ave jerk	572,5	277,5	612,2	300,8	0,801	635,0	245,5	725,9	365,9	0,339
Rot	Range	6,6	6,7	6,3	2,7	0,750	8,6	5,7	9,4	3,1	0,684
	Ave velocity	5,7	3,3	5,5	3,0	0,913	6,7	3,9	6,1	4,0	0,835
	Ave jerk	666,3	368,3	676,3	463,1	0,750	650,8	413,6	641,3	353,2	0,637
UT:	Range	2,14	1,1	1,6	0,9	0,138	3,4	1,6	2,6	1,3	0,517
	Ave velocity	2,17	1,7	1,6	1,00	0,302	1,9	2,0	1,9	1,6	0,947
	Ave jerk	384,6	401,8	295,4	353,6	0,590	328,5	309,2	319,5	433,8	0,801
LF	Range	7,8	4,1	7,5	4,7	0,991	8,8	5,4	7,8	5,7	0,758
	Ave velocity	4,8	1,7	5,1	4,5	0,517	3,8	1,3	4,0	1,9	0,852
	Ave jerk	350,2	186,6	396,0	389,0	0,818	293,8	166,4	368,5	253,2	0,637
Rot	Range	10,1	5,1	11,2	4,3	0,429	9,9	3	10,9	5,2	0,652
	Ave velocity	7,3	4,2	8,7	5,3	0,956	6,5	3,8	6,2	2,9	0,801
	Ave jerk	556,6	397	782,1	691,4	0,350	586,4	282,4	580,0	471,5	0,852
LT:	Range	3,5	1,6	4,3	2,5	0,187	4,8	2,8	4,6	2,5	0,835
	Ave velocity	2,5	1,7	2,8	2,4	0,448	2,3	0,8	2,61	1,3	0,442
	Ave jerk	287,8	240	315,7	370,4	0,974	280,6	213,9	321,3	329,8	0,546
LF	Range	6,8	3,4	5,2	3,9	0,191	6,6	4,6	4,9	3,2	0,215
	Ave velocity	4,3	2,9	3,9	1,9	0,660	3,2	1,7	2,9	2,2	0,613
	Ave jerk	497,1	332,8	478,8	419,6	0,991	429,9	252,2	438,9	308,6	0,835
Rot	Range	3,6	2,6	3,0	1,6	0,036	4,8	2,1	2,8	2,1	0,004
	Ave velocity	3,4	2,2	3,6	2,3	0,886	3,7	2,5	3,2	1,2	0,253
	Ave jerk	708,6	548,2	812,8	640,3	0,531	691,3	473,2	708,7	584,6	0,904

(NP – neck pain, NNP – no neck pain, ROM – range of motion, Flex/ext – flexion/extension, LF – lateral flexion, Rot – rotation, UT – upper thoracic, LT – lower thoracic ave- average, Mdn – median, IQR – interquartile range)

Table 6.6: Muscle activation time percentage during the lifting and lowering phases of the unilateral task

Muscle	Lifting					Lowering				
	NP		NNP		p value	NP		NNP		p value
	Mdn	IQR	Mdn	IQR		Mdn	IQR	Mdn	IQR	
LAS	100.0	18.3	99.9	30.0	0.698	100.0	37.7	95.9	44.5	0.229
RAS	100.0	0.0	100.0	4.0	0.081	100.0	0.0	100.0	5.9	0.166
LPC	100.0	7.6	99.0	9.1	0.386	100.0	13.7	97.1	15.4	0.277
RPC	100.0	0.0	100.0	0.7	0.803	100.0	0.4	100.0	1.7	0.726
LT4	100.0	0.0	97.1	8.0	0.039	100.0	0.0	93.2	18.2	0.005
RT4	100.0	0.0	100.0	0.0	0.317	100.0	0.0	100.0	0.0	0.153
LSCM	100.0	0.0	100.0	2.0	0.401	100.0	0.8	100.0	5.9	0.733
RSCM	98.2	24.7	99.4	7.8	0.481	100.0	24.0	100.0	30.9	0.876
LUT	100.0	4.7	100.0	8.4	0.454	100.0	1.0	100.0	6.0	0.333
RUT	100.0	0.0	100.0	0.0	0.039	100.0	0.0	100.0	0.0	0.928
LT9	100.0	0.0	100.0	0.0	0.077	100.0	0.0	100.0	0.0	0.200
RT9	100.0	3.4	100.0	4.3	0.925	100.0	4.4	100.0	0.0	0.649

(LAS – left anterior scalene, RAS – right anterior scalene, LPC – left posterior cervical, RPC – right posterior cervical, LT4 – left paraspinal at T4, RT4 – right paraspinal at T4, LSCM – left sternocleidomastoid, RSCM – right sternocleidomastoid, LUT – left upper trapezius, RUT – right upper trapezius, LT9 - left paraspinal at T9, RT9 - right paraspinal at T9)

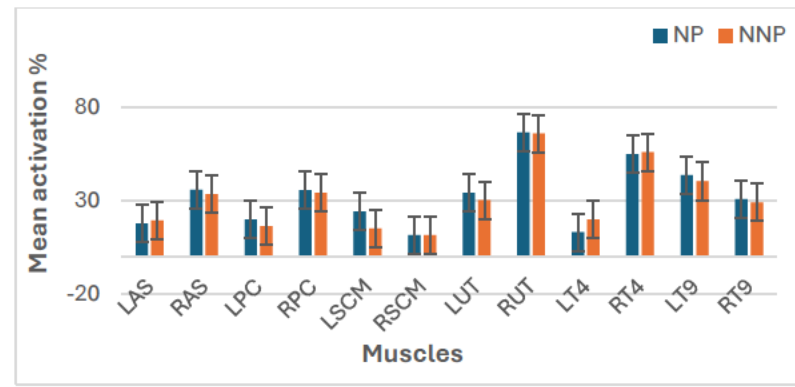
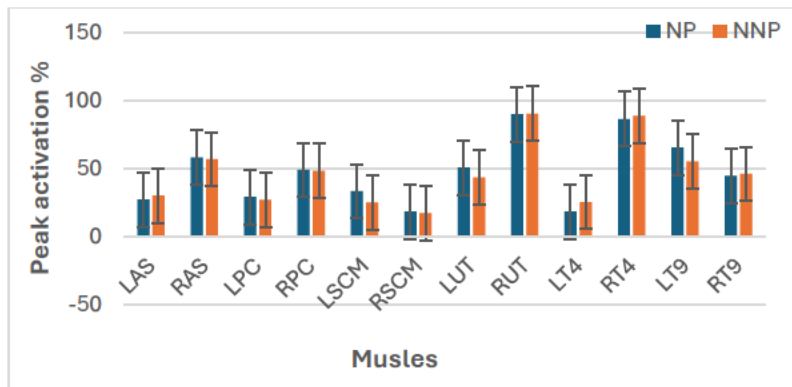


Figure 6.4: Peak and mean muscle activation during the lifting phase of the unilateral arm task

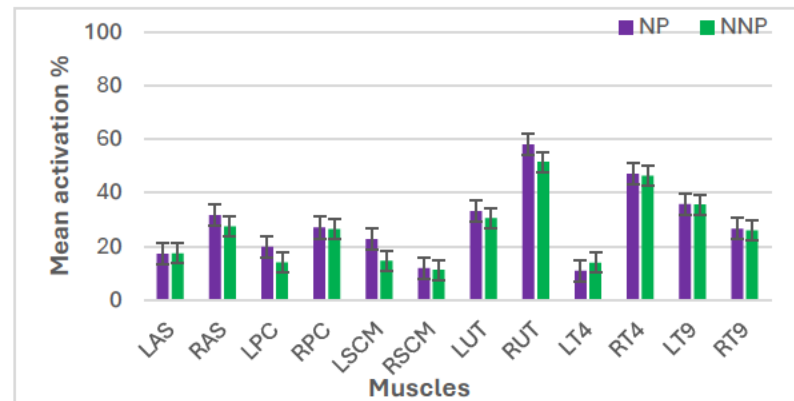
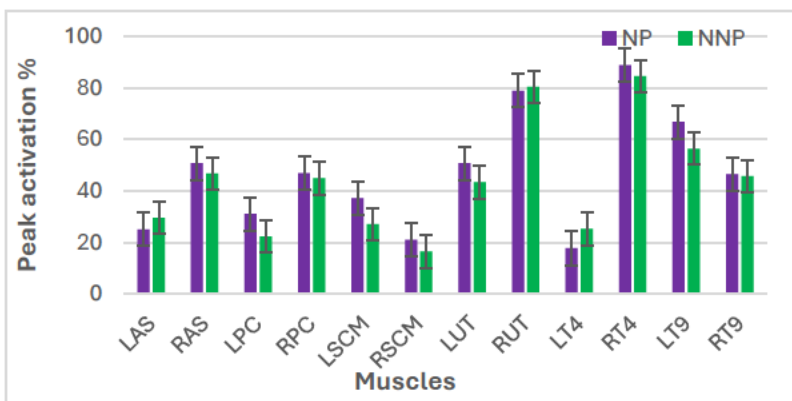


Figure 6.5: Peak and mean activation during the lowering phase of the unilateral arm task

(% - percentage; L – left; R – right; AS – anterior scalene; PC – posterior cervical; SCM – sternocleidomastoid; UT – upper trapezius; T4 paraspinal at T4; T9 – paraspinal at T9)

Bilateral arm task

- *Spinal kinematics*

Table 6.7 shows the peak spinal displacements during the bilateral arm task for the two groups. Significant differences were found for upper thoracic lateral flexion where the neck pain group exhibited left lateral flexion, whereas the non-neck pain had right lateral flexion motion ($p = 0,041$; z-score: -2,042, $r = 0.31$).

Table 6.7: Peak displacement (°) during the bilateral arm task for those with (n=22) and without (n=21) neck pain

ROM	NP		NNP		p value
	Mdn	IQR	Mdn	IQR	
Cervical					
Flex/ext	18,7	32,2	20,5	31,8	0,884
LF	0,0	2,4	0,7	3,0	0,576
Rot	0,1	3,9	0,9	8,0	0,903
UT					
Flex/ext	-2,8	4,7	-3,4	3,2	0,742
LF	-1,0	3,3	1,4	3,2	0,041
Rot	0,2	5,5	0,2	4,6	0,690
LT					
Flex/ext	-7,2	5,2	-6,8	4,5	0,942
LF	-0,5	3,2	-0,08	3,6	0,680
Rot	-0,1	2,5	0,3	2,4	0,923

(NP – neck pain, NNP – no neck pain, ROM – range of motion, Flex/ext – flexion/extension, LF – lateral flexion, Rot – rotation, UT – upper thoracic, LT – lower thoracic, Mdn – median, IQR – interquartile range, *negative values indicate motion in extension or to the left)

Table 6.8 shows the data for range, average velocity and jerk during the bilateral arm task. The neck pain group had a great rotation range in the upper ($p = 0,024$; z-score: -2,253, $r = 0.34$) and lower thoracic spine ($p = 0,016$; z-score: -2,405, $r = 0.37$) during lowering. The non-neck pain group had greater average velocity in cervical lateral flexion during lifting ($p = 0,024$; z-score: -2,26; $r = 0.34$) and lowering ($p = 0,012$; z-score: -2,527; $r = 0.3.9$) and in cervical rotation in the lowering phase ($p = 0,022$; z-score: -2,284; $r = 0.35$) with a medium effect. All other between group comparisons were not significant.

Table 6.8: Range (°), average velocity (°/s) and jerk (°/s³) measured during the bilateral arm task in those with (n=22) and without (n=22) neck pain

ROM	Outcome	Lifting					Lowering				
		NP		NNP		p value	NP		NNP		p value
		Mdn	IQR	Mdn	IQR		Mdn	IQR	Mdn	IQR	
Cervical:	Range	46,1	37,8	38,8*	34,7	0,662	29,6	35,9	29,5*	33,4	0,846
	Ave velocity	36,2*	31,8	39,5*	22,7	0,399	23,5*	24,4	25,7*	17,7	0,521
	Ave jerk	1439,0	1582,5	1845*	810,2	0,389	1812,8	872,7	2147,8*	886,4	0,201
LF	Range	2,9	2,6	3,9*	4,1	0,481	3,1	2,6	5,1*	5,1	0,12
	Ave velocity	3,4	2,2	5,3*	3,2	0,024	3,6	2,6	6,4*	4,1	0,012
	Ave jerk	617,5*	398,8	768,2*	340	0,263	779,8	642,6	909,9*	646,3	0,068
Rot	Range	3,7	3,9	5,2*	3,2	0,224	4,2	3,3	5,9*	4,5	0,094
	Ave velocity	4,6	3,0	6,2*	2,9	0,104	4,5	3,8	7,3*	4,7	0,022
	Ave jerk	770,3	541,3	778,4*	514,5	0,680	712,3	582,4	939,7*	475,2	0,138
UT:	Range	4,2	4	3,9	3,0	0,589	5,6	5,2	5,1	3,2	0,888
	Ave velocity	3,6	2,2	4,3	3,4	0,213	4,3	2,4	4,7	3,8	0,360
	Ave jerk	402,8	223,3	436,4	382,2	0,511	389,7	257,7	410	382	0,925
LF	Range	2,5	3,6	2,4	2,2	0,526	3,1	2,7	3,0	2,7	0,606
	Ave velocity	2,9	1,6	2,4	1,7	0,778	3,2	1,6	3,0	2,4	0,796
	Ave jerk	435,6	225	344,5	216,9	0,205	568,9	282,8	483,9	303	0,467
Rot	Range	4,2	4,1	3	2,3	0,067	4,3	2,3	3,4	1,3	0,024
	Ave velocity	3,8	2,3	3,5	2,2	0,606	4,2	1,7	4	1,5	0,360
	Ave jerk	620,8	315,7	522,5	270,5	0,166	701,6	430,9	735,6	274,7	0,725
LT:	Range	8,4	4,2	7,8*	3	0,512	7,9	3,6	7,5*	3,7	1,00
	Ave velocity	5,1	2,6	5,8*	2,6	0,234	4,8	3,0	6,2*	3,6	0,215
	Ave jerk	382,8	269,6	338,5*	231,9	0,481	356,9	275,7	379,7*	198,9	0,942
LF	Range	2,1	1,3	2,1*	1,6	0,827	2,5	2,1	2,0*	2,3	0,395
	Ave velocity	2,4	1,4	2,0*	1,8	0,846	2,8	1,6	2,4*	1,7	0,528
	Ave jerk	489,7	172,3	373,5*	241,3	0,159	525,6	368,2	425,3*	271,8	0,120
Rot	Range	2,3	1,9	1,8*	1,1	0,120	2,8	2,8	2,0	0,9	0,016
	Ave velocity	3	2,2	2,7*	1,3	0,274	3,2	2,0	2,5	1,4	0,094
	Ave jerk	738,2	438,3	573,4*	413,8	0,126	786,1	843,4	657,1	280,3	0,181

(NP – neck pain, NNP – no neck pain, ROM – range of motion, Flex/ext – flexion/extension, LF – lateral flexion, Rot – rotation, UT – upper thoracic, LT – lower thoracic, Mdn – median, IQR – interquartile range, *n=21)

- *Muscle activity*

During the lifting and lowering phases there were no between group differences in activation time percentage ($p < 0.05$)(**Supplementary file 6.1**). Assessing peak and mean activation during the lifting and lowering phases, the greatest activity occurred in the UT bilaterally and left paraspinal at T4, with the SCMs bilaterally having the lowest

activation, **Figures 6.6 and 6.7**. The peak and mean muscle activation was lower in all muscles in both groups on the lowering phase. No between group differences ($p < 0.05$) were found for, peak or mean activation during either phase.

DISCUSSION

This study aimed to assess cervical and thoracic spinal kinematic and muscle recruitment patterns during a unilateral and bilateral, loaded, arm lifting task in those with and without neck pain. The study found that there were variations in the motor control strategy utilised during each of the tasks, with the unilateral arm task showing changes in spinal kinematics and muscle recruitment whereas in the bilateral arm task, only kinematics between group differences were found. Various theories suggest how the musculoskeletal system adapts to pain (Travell, Rinzler and Herman 1942; Roland 1986; Lund *et al.* 1991; Hodges and Tucker 2011) and that pain alters movement (Hodges and Smeets 2015; Kantak, Johnson and Zarzycki 2022). These initial adaptations act to protect, but over time they can become maladaptive (Merkle, Sluka and Frey-Law 2020; Kantak, Johnson and Zarzycki 2022).

Spinal kinematics

In the seated, unilateral lifting task, the neck pain participants had a more rigid upper thoracic spinal posture with increased lower thoracic spine motion as compensation, with no differences in average velocity or jerk. This contrasts with Tsang *et al.* (2014) who utilised a similar task and found no between group differences in spinal displacement.

This variation may be due to the placement of the object that was lifted, in our study it was to the right of the participant, whereas in the Tsang *et al.* (2014) study it was placed posterior shear stress, whereas side lifting increases lateral shear stress (Weston *et al.* 2020). Comparison to studies assessing unilateral arm lifting in healthy subjects is limited due to the assessments being undertaken in the standing position (van Dieën and de Looze 1999; Hodges *et al.* 2000; Takahashi *et al.* 2015; Weston *et al.* 2020).

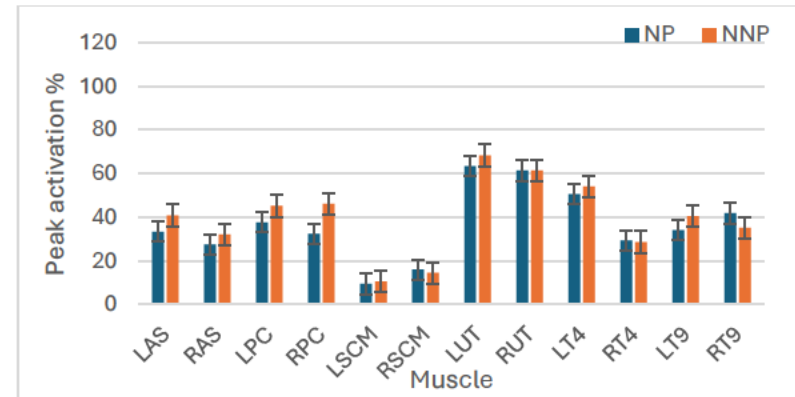
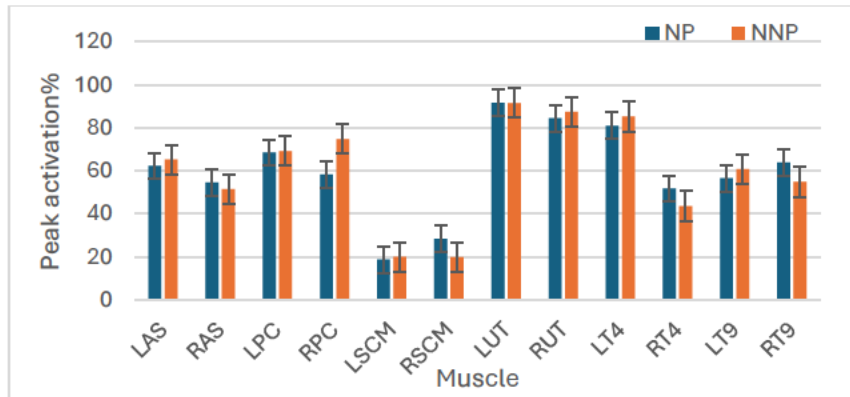


Figure 6.6: Peak and mean muscle activation time percentage during the lifting phase of the bilateral arm task

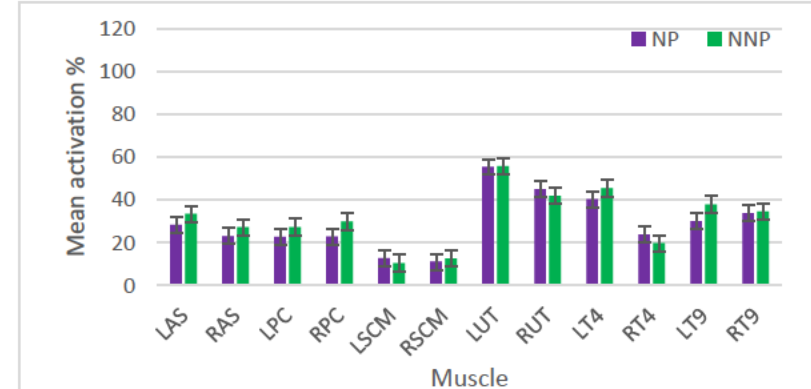
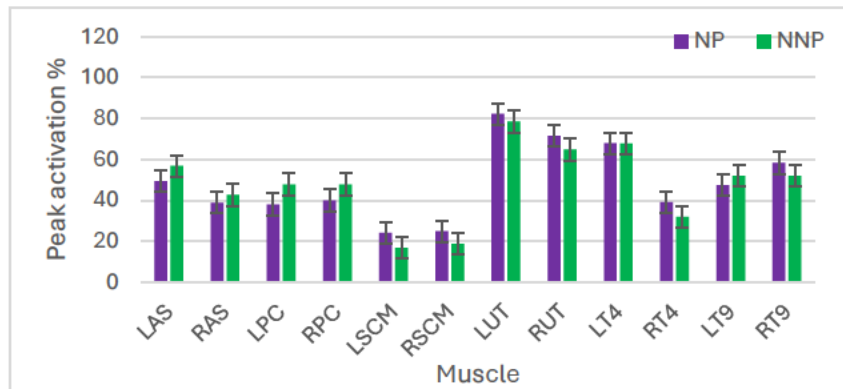


Figure 6.7: Peak and mean muscle activation time percentage during the lowering phase of the bilateral arm task

(% - percentage; L – left; R – right; AS – anterior scalene; PC – posterior cervical; SCM – sternocleidomastoid; UT – upper trapezius; T4 paraspinal at T4; T9 – paraspinal at T9)

However, increased thoracic rotation was observed during unilateral lifting in healthy participants, proposed to have occurred to assist scapular motion during the task (Takahashi *et al.* 2015), with another study reporting small spinal motions in all three cardinal planes during unilateral arm activity (Hodges *et al.* 2000). These deviations vary from those in the current study. Moghaddas *et al.* (2022), assessed those with and without neck pain during various standing, unilateral, and loaded arm tasks and found that the neck pain participants had less total sagittal ROM during the tasks and reduced thoracolumbar left rotation (although not significant) (Moghaddas, Edwards and Snodgrass 2022), which supports the increased lower thoracic displacement seen in the current study. The authors reported lower velocity for head-neck segment motion in flexion in those with neck pain, similar to that reported by Tsang *et al.* (2014) who found reduced velocity and acceleration profiles during a seated, loaded unilateral arm lift. These results conflict with the current study where no differences in velocity were found in the unilateral arm task. In these studies, like the current one, participants were asked to move at their self-selected pace in motion, as close to their normal motion as possible.

In the standing bilateral arm task, variations in peak displacement of the upper thoracic spine occurred in lateral flexion with the groups having motion in the opposite direction and those with neck pain had increased thoracic rotation range in the upper and lower thoracic spines on the lifting phase. These differences may be a compensatory mechanism as a result of altered spinal stabilising mechanism in those with neck pain, where reactive constraint of motion, when exposed to load, was diminished (Aruin and Latash 1995; Hodges *et al.* 2000).

To enable stable kinematics of the trunk, the body must produce appropriate motor patterns to modulate muscle force and stiffness and be responsive to biomechanical perturbations and/or neuromuscular control errors (Graham and Brown 2014). Interestingly, no differences in muscle activation patterns were found in the bilateral arm task between those with and without neck pain. Neck pain has been associated with greater postural instability (Ruhe, Fejer and Walker 2011), with upper limb motions resulting in postural corrections and perturbations in the spine (Hsu *et al.*

2020), which from this study, appear to occur not only in the cervical but also in the thoracic spine.

Reduced velocity of motion was found in cervical lateral flexion and rotation in those with neck pain, during the standing bilateral arm task, which occurred in the sagittal plane. Altered coupled motions have been reported in studies comparing those with and without neck pain during cervical ROM (Guo *et al.* 2012; Meisingset *et al.* 2015) and reduced cervical velocity has been found in seated unilateral (Grip *et al.* 2008; Tsang, Szeto and Lee 2014) and bilateral arm tasks (Grip *et al.* 2008), standing unilateral tasks (Moghaddas, Edwards and Snodgrass 2022) and during a virtual reality game (Sarig Bahat, Weiss and Laufer 2010; Sarig Bahat *et al.* 2015). Bilateral arm tasks are more challenging (Swinnen and Wenderoth 2004) and in this study may have tested the neuromuscular control of the cervical spine more than unilateral tasks, resulting in differences in velocity measures.

Few trials have investigated spinal kinematics in neck pain during functional tasks (Moghaddas *et al.* 2019), with most trials assessing unloaded tasks (Sarig Bahat, Weiss and Laufer 2010; Sarig Bahat *et al.* 2015; Falla *et al.* 2017; Moghaddas, Edwards and Snodgrass 2022). The participants in this study reported moderate pain with mild disability, this may have been at a level insufficient to result in reduced primary motion, but enough to affect the conjunct motion. Fear of movement may also be responsible, having a negative impact on a person in pain, by preventing them from moving the area of complaint, leading to maladaptive behaviours (Kori, Miller and Todd 1990; Lundberg and Archer 2022). Prior to participation, participants were screened for fear avoidance behaviours (Lundberg, Styf and Carlsson 2004; Dupuis *et al.* 2023) and excluded, thus minimising the likelihood that this influenced this finding.

It was anticipated that due to the nature of the loaded tasks, those with neck pain would display more jerky spinal movement patterns, as several studies have shown increased jerk during the execution of cervical ROM (Sjölander *et al.* 2008; Vikne *et al.* 2013; Yang, Su and Guo 2014; Zhou *et al.* 2018). The motor system is highly adaptable and responsive to mechanisms across the nervous system (Merkle, Sluka and Frey-Law 2020). The central nervous system uses motor synergies, building

blocks of certain motions, to simplify and coordinate movement execution (Bizzi and Ajemian 2020). These synergies have great adaptability (Kantak, Johnson and Zarzycki 2022), which can result in different patterns between individuals in spite of similar diagnoses (Merkle, Sluka and Frey-Law 2020). A possible explanation for the lack of differences in velocity and jerk measures may be that those with neck pain had developed altered motor strategies as a compensation mechanism as these are common tasks, executed daily. In addition, the young age of the participants in the current study may have been a 'protective' factor in the development of maladaptive motor control strategies.

Muscle recruitment patterns

During the unilateral arm task, the neck pain group had all muscles, except the right SCM, at 100 per cent activation time, whereas those without neck pain only had 8 muscles activate for 100 per cent of the activity time indicating that there was greater recruitment of the cervicothoracic muscles in those with neck pain during the task. Although a different task, Nobe et al (2022) reported increased activation of the cervical flexors and extensors during cervical ROM in those with neck pain compared to healthy controls (Nobe *et al.* 2022). Significant between group effects were found for activation time percentage with those with neck pain having greater activation time of the left paraspinal at T4 and right UT. The left paraspinal muscle was contralateral to the arm raising the load, and during lifting and lowering it was found to have lower activation magnitude in those with neck pain, indicating that the muscle required longer periods of activation with less amplitude to allow for the execution of the task.

Reduced neuromuscular efficiency during a low load, isometric, voluntary contraction of the SCM and AS was found in the neck pain group, where greater electrical activity was needed to allow equivalent force output to non-neck pain controls (Falla *et al.* 2004a). Although their study assessed force, in the current study the paraspinal muscle would have been acting in a stabilising manner bringing stability to the spine during the arm lifting perturbations.

This finding was contradictory to that reported by Tsang et al (2014), in that they reported longer activation duration in the right paraspinal muscle during a front lifting,

unilateral right-hand task. In both studies, the participants lifted the object with the right hand, by right hand dominant participants. Bilateral paraspinal muscle activation has been reported in healthy participants during the dominant arm, unilateral lifting, with greater activation occurring in the left paraspinal in the initial stages of the activity (Takahashi *et al.* 2015), but not throughout the task, like was observed in the current study. Thus, altered paraspinal muscle activations observed in the neck pain participants indicate a maladaptive response to unilateral loaded tasks.

Most studies assessing the paraspinal muscles in neck pain focused on the cervical paraspinals, where delayed (Park *et al.* 2017) and reduced (Shahidi *et al.* 2012; Baghi *et al.* 2017) activations have been reported. The theory of regional interdependence speaks to the role of various parts, either anatomically related or distant, in the body in the clinical presentation of conditions (Wainner *et al.* 2007). The inclusion of the thoracic spine in the assessment and treatment of neck pain has been recommended (Huisman, Speksnijder and de Wijer 2013; Joshi, Balthillaya and Neelapala 2019) and based on these results, its inclusion in treatment regimens for neck pain is recommended.

The right UT muscle displayed an increased activation time percentage in those with neck pain during the lifting phase. The UT contracts concentrically during shoulder elevation, and in people with neck and shoulder pain it is often a site of tenderness (Brandt *et al.* 2014). Increased activity in upper limb tasks in neck pain has been reported in this muscle (Falla, Bilenkij and Jull 2004; Szeto, Straker and O'Sullivan 2005; Leonard *et al.* 2010)(Leonard *et al.* 2010), but during an isometric contraction in shoulder abduction, no differences were observed (Voerman, Vollenbroek-Hutten and Hermens 2007; Zakharova-Luneva *et al.* 2012). During a low load task, increased SCM and AS muscle activity was found together with increased left UT activity in those with neck pain (Falla, Bilenkij and Jull 2004). In the current study, there were no differences between the groups for the SCM or AS muscles during either task. Previous work has shown reduced deep cervical flexor muscle activation with increased SCM and AS activity (Falla *et al.* 2003; Falla, Bilenkij and Jull 2004; Falla *et al.* 2004a; Falla, Jull and Hodges 2004a; Falla *et al.* 2004b; Falla *et al.* 2007) in neck pain, thus it was anticipated that during a loaded upper limb task the superficial neck

flexor muscles would show altered activation patterns compared to those without neck pain, however, this was not the case. The current study findings do concur with an ultrasonographic study assessing cervical muscle thickness during shoulder isometric contraction, where no difference in the superficial neck muscle activation was seen in those with and without neck pain (Karimi *et al.* 2016), supporting the findings of the current study.

In the bilateral upper limb task, no differences were observed in muscle activation patterns, despite changes in spinal kinematics, between the groups. There is a paucity of studies assessing the effect of neck pain on bilateral task execution, those that do include this assessment focus on the low back (Siu, Schinkel-Ivy and Drake 2016; Weston *et al.* 2020). The high adaptability of the body to execute movement is influenced by many mechanisms throughout the nervous system (Merkle, Sluka and Frey-Law 2020), this complexity is associated with redundancy (Zhao *et al.* 2023) and alterations occurring within and between muscles (Hodges and Tucker 2011). This high level of adaptability may explain the lack of muscle activation pattern differences between those with and without neck pain.

Strengths and limitations

A strength of this study is that it adds to a body of knowledge that has very few studies in this area (Moghaddas *et al.* 2019). Bilateral lifting tasks have not previously been compared between those with and without neck pain, despite lifting being an occupational hazard (Hulshof *et al.* 2021). Further research should ascertain the impact that neck pain has on upper limb function.

Some study limitations to consider are that this study used a cross-sectional design, thus cause and effect cannot be implied. It is possible that the findings could be transient manifestations of shifts in motor control during the two upper extremity loaded tasks. Future studies should adopt a longitudinal methodology to further investigate these findings. Other factors such as myofascial trigger points may have been present in the muscles assessed which may have altered the EMG findings, future studies should include this assessment.

The experimental set up did not allow for adjustment of stool height or arm reach. The mean height of the participants in the study was within the normal range for ergonomic furniture (De Bruyne *et al.* 2016), however this standardisation may have influenced the normal movement patterns of the participants and their ability to execute the arm task. In addition, we attempted to mimic activities which occur commonly in daily life such as hanging washing on a line; thus, we did not control the motion timing as the aim was to assess as near normal motion as possible. The lack of standardisation may have influenced the results and is something that should be considered in future research.

CONCLUSION

This study found that a unilateral seated arm task resulted in increased spinal displacement and range in the thoracic spine with the right upper trapezius and left paraspinal muscles showing greater activation time with the left paraspinal muscle having less peak and mean activation magnitude during the task. The bilateral standing arm task resulted in greater rotational range in the thoracic spine, with slower conjunct motions in the cervical spine, with no differences being found for muscle activation patterns. These findings suggest altered motor control under loaded tasks in those with neck pain and suggest that both unilateral and bilateral lifting may have additional risk for those with neck pain.

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Conflict of interest

The authors declare no conflict of interest related to this research.

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CHAPTER SEVEN

MANUSCRIPT FIVE:

RANDOMISED CONTROLLED TRIAL INVESTIGATING CERVICAL SPINAL KINEMATICS AND MUSCLE RECRUITMENT PATTERN RESPONSES DURING CERVICAL RANGE OF MOTION FOLLOWING CERVICAL SPINAL MANIPULATION

7.1 BACKGROUND TO THE CHAPTER

Neck pain has a high prevalence (Safiri *et al.* 2020; Kazeminasab *et al.* 2022), affecting most people at some point in their lives (Haldeman *et al.* 2008). The costs of managing neck pain and the associated disability negatively impacts the sufferer, their family and the economy (Driessen, Lin and van Tulder 2012; GBD 2021 Neck Pain Collaborators 2024). It presents with pain, disability and a loss of function, reducing efficacy during the execution of activities of daily living. Neck pain affects motor control increasing the time to execute tasks (Descarreaux, Passmore and Cantin 2010; Yang, Su and Guo 2014; Franov *et al.* 2022), reduces movement variability (Sjölander *et al.* 2008; Falla *et al.* 2017; Alsultan *et al.* 2019)(Chapter five), affecting spinal kinematics like velocity (Sarig Bahat, Weiss and Laufer 2010; Vikne *et al.* 2013; Tsang, Szeto and Lee 2014; Sarig Bahat *et al.* 2015)(Chapter six), acceleration (Tsang, Szeto and Lee 2014) and jerk (Sarig Bahat, Weiss and Laufer 2010; Sarig Bahat *et al.* 2015), and neuromuscular control (Falla *et al.* 2003; Falla *et al.* 2004b; Falla and Farina 2007; Falla *et al.* 2007; Pinheiro, dos Santos and Chaves 2016; Park *et al.* 2017; Nobe *et al.* 2022)(Chapter five). Treatments targeting these deficits are needed to minimise the long-term impact of neck pain (Sarig Bahat *et al.* 2014; Lascurain-Aguirrebeña *et al.* 2018b).

Spinal manipulation is often utilised (Hurwitz 2012) and is considered cost-effective (Michaleff *et al.* 2012; Leininger *et al.* 2016) in the treatment of neck pain. Its use has been recommended in clinical practice guidelines (Bussi res *et al.* 2016; Blanpied *et al.* 2017; Whalen *et al.* 2019) and systematic reviews (Bronfort *et al.* 2004; Gross *et al.* 2015; Coulter *et al.* 2019; Chaibi, Stavem and Russell 2021), often as part of a

multimodal treatment approach (Coulter *et al.* 2019; Corp *et al.* 2021). SMT has been shown to result in neurophysiological changes such as increased mechanoreceptor firing (Herzog *et al.* 1995; Symons *et al.* 2000; Pickar and Bolton 2012), altered motor neuron excitability (Murphy, Dawson and Slack 1995; Dishman and Bulbulian 2000; Suter, McMorland and Herzog 2005; Bicalho *et al.* 2010; Haavik *et al.* 2018), increased cortical drive (Haavik *et al.* 2017) and central motor excitability (Pickar 2002; Niazi *et al.* 2015). Many of these mechanistic studies were undertaken on asymptomatic participants, where immediate or short-term effects were assessed making their relevance to clinical outcomes elusive (Gyer *et al.* 2019). In order to further understand the effect of cervical SMT a randomised controlled trial was designed to determine its effect on spinal kinematic and muscle recruitment patterns in people with neck pain while performing cervical ROM compared to a control.

7.2 MANUSCRIPT

The effect of cervical spinal manipulation on cervical spinal kinematics and muscle recruitment patterns – a randomised control trial

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ABSTRACT

Background: Spinal manipulation (SMT) has been shown to impact neurophysiological processes and affect neuromuscular control. There is a lack of studies assessing these effects on neck pain. This study aimed to determine the effect of cervical SMT on cervical kinematics, muscle recruitment patterns, pain and disability in participants with non-specific neck pain.

Methods: Participants (n=39) were randomly assigned to receive cervical SMT or a control. Four treatments were given over two weeks, with a one week follow up. Optical motion capture was used to determine cervical kinematics and surface electromyography captured muscle recruitment patterns during cervical range of motion (ROM). These measures were taken pre-and post- the initial intervention and at the third consultation. Pain and disability were recorded over the study period. Data were analysed using SPSS.

Results: A significant group effect was found for pain at the fourth visit ($p = 0.010$, $\eta^2 = 0.22$) favouring the SMT group, with no difference between the groups at the one week follow up ($p = 0.340$, $\eta^2 = 0.03$). Disability improvement at one week with greater improvements in the SMT group ($p = 0.006$, $\eta^2 = 0.24$). No difference between the groups were found for a global impression of change scale or level of satisfaction ($p > 0.05$) except for those receiving SMT reporting improved emotions ($p = 0.001$) and quality of life ($p = 0.025$). After one treatment, increased velocity in left rotation ($p = 0.040$, $\eta^2 = 0.119$) and jerk in flexion ($p < 0.05$), right ($p = 0.023$, $\eta^2 = 0.148$) and left ($p = 0.025$, $\eta^2 = 0.144$) lateral flexion and left rotation ($p < 0.05$) were found in the SMT group. Muscle activation patterns differed with the control group having greater activation in the left posterior cervical (LPC) ($p = 0.012$, $\eta^2 = 0.180$) in flexion, left anterior scalene (LAS) ($p = 0.007$, $\eta^2 = 0.215$) and left sternocleidomastoid ($p = 0.019$, $\eta^2 = 0.164$) in extension and the left paraspinal at T9 (LT9) during right lateral flexion ($p = 0.049$, $\eta^2 = 0.116$). Less activation occurred in the control group for mean ($p = 0.041$, $\eta^2 = 0.128$) and activation time ($p = 0.045$, $\eta^2 = 0.123$) in the LAS and the left upper trapezius (LUT) ($p = 0.008$, $\eta^2 = 0.192$) in right lateral flexion; peak ($p = 0.029$, $\eta^2 = 0.145$) and mean ($p = 0.025$, $\eta^2 = 0.151$) activation in the right anterior scalene

(RAS) and in the LT9 for away time percentage ($p = 0.019$, $\eta^2 = 0.116$) in left lateral flexion and the right posterior cervical (RPC) ($p = 0.024$, $\eta^2 = 0.146$), left paraspinal at T4 (LT4) ($p = 0.021$, $\eta^2 = 0.147$) and right sternocleidomastoid (RSCM) ($p = 0.038$, $\eta^2 = 0.127$) for right rotation.

After three treatments the SMT group had increased return peak jerk in flexion ($p = 0.034$, $\eta^2 = 0.146$) and return peak ($p = 0.028$, $\eta^2 = 0.134$) and away average jerk ($p = 0.008$, $\eta^2 = 0.191$) in left rotation. Muscle activation was less in the control group in the RAS during flexion ($p = 0.024$, $\eta^2 = 0.175$) and greater for RPC for peak ($p = 0.034$, $\eta^2 = 0.149$) and mean activation ($p = 0.002$, $\eta^2 = 0.179$) and LUT ($p = 0.015$, $\eta^2 = 0.187$) in extension, LAS in away ($p = 0.048$, $\eta^2 = 0.142$) and return ($p = 0.042$, $\eta^2 = 0.042$) right lateral flexion and in the LPC away (peak ($p = 0.029$, $\eta^2 = 0.159$) and mean ($p = 0.029$, $\eta^2 = 0.134$) activation in left lateral flexion. The intervention group had greater activation in the left paraspinal at T4 during the return phase of flexion ($p = 0.035$, $\eta^2 = 0.149$).

Conclusions: Cervical SMT improved pain and disability having a negligible effect on velocity with increased jerk in flexion, lateral flexion and left rotation immediately after one treatment and in the short term, indicating reduced motion smoothness. There was increased activation patterns of cervicothoracic muscles during lateral flexion and rotation after one treatment with lower activation levels occurring after three treatments in the SMT group, possibly indicating a normalisation of muscle activation. These findings indicate that cervical SMT in neck pain impacted cervical kinematics and muscle recruitment patterns.

Keywords: Neck pain; motion capture; cervical kinematics; electromyography; muscle recruitment

INTRODUCTION

Non-specific neck pain is pain occurring in the area between the nuchal line and the T1 spinous process, boarded by the lateral neck margins (Bogduk 2011; Fandim *et al.*

2021) with no known specific underlying cause (Binder 2007; Cohen 2015). In 2020, neck pain affected 203 million people, and its prevalence is expected to rise (GBD 2021 Neck Pain Collaborators 2024), with two out of three people succumbing to neck pain during the course of their life (Elbinoune *et al.* 2016). Neck pain has a favourable prognosis in the first six weeks but for many the symptoms persist (Fandim *et al.* 2021). The associated disability is high affecting concentration, social participation, activities of daily living, finances and is often associated with psychological consequences (van Randeraad-van der Zee *et al.* 2016). In terms of motor function people with neck pain have movement impairments (Falla and Farina 2007; Meisingset *et al.* 2016; Hesby *et al.* 2019; Peng *et al.* 2021; Franov *et al.* 2022; Qu *et al.* 2022) and may report clumsiness (Harman *et al.* 2021).

Case controlled studies comparing those with and without neck pain have found that those with neck pain have increased task execution time (Descarreaux, Passmore and Cantin 2010; Yang, Su and Guo 2014; Ernst *et al.* 2019; Franov *et al.* 2022) and a reduction in movement variability (Sjölander *et al.* 2008; Woodhouse and Vasseljen 2008; Falla *et al.* 2017; Alsultan *et al.* 2019). When assessing how the spine moves, cervical ROM is the most commonly assessed measure in the clinical environment and it is often reduced in those with neck pain (ROM) (Snodgrass *et al.* 2014; Stenneberg *et al.* 2017). When assessing the quality of cervical motion in neck pain reduced velocity (Sarig Bahat, Weiss and Laufer 2010; Vikne *et al.* 2013; Tsang, Szeto and Lee 2014; Sarig Bahat *et al.* 2015)(Chapter six), acceleration (Tsang, Szeto and Lee 2014) and increased jerkiness (Sarig Bahat, Weiss and Laufer 2010; Sarig Bahat *et al.* 2015) have been reported. Indicating that the sensorimotor control system is affected in neck pain (Luc *et al.* 2022; Qu *et al.* 2022).

Further support of this is found in studies assessing neuromuscular control in neck pain where altered motor control strategies are characterised by increased activation of the superficial neck muscles, with delayed and direction specific responses occurring in the deep cervical flexor muscles, when compared to healthy controls (Falla, Bilenkij and Jull 2004; Falla, Jull and Hodges 2004a). Neck pain sufferers have been shown to have an inability to relax the anterior scalene (AS), sternocleidomastoid (SCM) and upper trapezius (UT) muscles after activation (Barton and Hayes 1996;

Nederhand *et al.* 2002; Falla, Bilenkij and Jull 2004). These changes are proposed to occur due to reflex neuromuscular changes and alterations in higher nervous system mechanisms (Hodges and Smeets 2015). Falla and Colleagues (Falla *et al.* 2004a) found that neuromuscular efficiency was altered in neck pain, with the SCM and AS requiring greater amount of muscle activity to produce the same force as healthy controls. This was attributed to increased excitability of the motoneuronal pool, or alterations in muscle activation patterns to compensate for muscle weakness or inhibition, alternatively a combination of these mechanisms may be at play.

Spinal manipulation (SMT) is a popular, non-invasive, cost-effective treatment (Michaleff *et al.* 2012) which is recommended by several systematic reviews and clinical practice guidelines for the treatment of neck pain (Gross *et al.* 2015; Coulter *et al.* 2019; Chaibi, Stavem and Russell 2021; Gevers-Montoro *et al.* 2021a). The underlying mechanism of how this technique brings about its effects are not well understood (Gyer *et al.* 2019; Young *et al.* 2024). The biomechanical stimulus of SMT, is proposed to activate a series of neurophysiological mechanisms, which are suggested to result in its therapeutic effect (Pickar and Bolton 2012; Bialosky *et al.* 2018; Gyer *et al.* 2019; Gevers-Montoro *et al.* 2021b; Haavik *et al.* 2021). High-velocity, low-amplitude thrust SMT is suggested to release entrapped synovial folds, ‘unbuckled’ motion segments and/or disrupt articular adhesions (Evans 2002), resulting in increased facet joint space and decreased spinal stiffness (Young *et al.* 2024). Supporting the common observation by clinicians of increased spinal ROM following SMT (Snodgrass *et al.* 2014).

In the last two decades more emphasis has been placed on the neurophysiological consequences to understand the treatment outcome from SMT (Pickar and Bolton 2012; Gyer *et al.* 2019). Neuromuscular effects are thought to occur via several mechanisms (Gyer *et al.* 2019) such as reflexogenic responses (Herzog, Scheele and Conway 1999; Pickar 2002), modulation of gamma (Korr 1975) or alpha motor neurons (Murphy, Dawson and Slack 1995; Dishman and Bulbulian 2000; Dishman, Ball and Burke 2002; Niazi *et al.* 2015) and changes in cortical processing of somatosensory information (Haavik-Taylor and Murphy 2007; Haavik and Murphy 2012; Haavik *et al.* 2017). Kinematic changes following SMT of the lumbar spine in people with low back

pain found modulation of paraspinal muscle activity during lumbar spine flexion-extension tasks (Lalanne, Lafond and Descarreaux 2009; Bicalho *et al.* 2010). In neck pain improved flexion relaxation ratios have been reported following combined cervical SMT and exercise compared to a exercise-only group who showed a deterioration of the ratio (Murphy, Marshall and Taylor 2010). Yet the exact mechanism driving these changes remains elusive (Gyer *et al.* 2019).

Several studies (de Camargo *et al.* 2011; Pires *et al.* 2015; Bracht *et al.* 2018) have assessed the effect of SMT on muscle activation patterns in neck pain. Two trials assessed an upper limb task (de Camargo *et al.* 2011; Bracht *et al.* 2018) following cervical SMT, while the other assessed cervical flexion and shoulder girdle elevation following upper thoracic SMT (Pires *et al.* 2015). Two (de Camargo *et al.* 2011; Pires *et al.* 2015) out of the three studies reported changes to muscle activation following SMT. Only Pires *et al.* (2015) included muscles of the head and neck (sternocleidomastoid muscles bilaterally) with other studies (de Camargo *et al.* 2011; Bracht *et al.* 2018) assessing muscles of the shoulder and arm. The effect that cervical SMT has on muscles intimately related to the cervical spine during cervical motion, in those with neck pain, has received little attention (chapter three).

In terms of spinal kinematics there are numerous studies assessing the effect of SMT on cervical ROM in neck pain (Millan *et al.* 2012; Saavedra-Hernández *et al.* 2012; Izquierdo Pérez *et al.* 2014; Snodgrass *et al.* 2014; Joshi, Balthillaya and Neelapala 2020; Serra-Añó *et al.* 2023; chapter three) where mixed results have been reported (Millan *et al.* 2012; Snodgrass *et al.* 2014). Other spinal kinematic outcomes are less frequently investigated. Only one study (Serra-Añó *et al.* 2023) was found that investigated cervical kinematics in the form of movement harmony during cervical ROM comparing cervical SMT to a control (chapter three). No between group differences were reported for the spinal kinematics but the SMT group had a greater reduction in pain. This study utilised a single treatment with measures taken immediately following the treatment. It has been suggested that multiple session of SMT may be more likely to induce changes in ROM than a single session (Snodgrass *et al.* 2014). Assessing the effect of cervical mobilisation compared to a control in the treatment of neck pain following a single session, those receiving mobilisation had

increased velocity and range when compared to the controls, but this only occurred in those who had baseline restrictions (Lascurain-Aguirrebeña *et al.* 2018a).

In a recent systematic review assessing the effect of SMT on spinal kinematics and muscle recruitment patterns (Chapter 3) found no trials where spinal kinematics were assessed together with muscle activation patterns following SMT in neck pain. Thus, this study aimed to determine the effect of cervical SMT on muscle recruitment patterns and spinal kinematics compared to control, to add to the understanding of the effects of SMT in the management of neck pain. It was hypothesised that cervical SMT would result in improved spinal kinematic and muscle recruitment patterns when compared to the control group.

METHODS

This study was a randomised, controlled, clinical trial. It took place at a university chiropractic clinic (**Appendix H**) following approval from an Institutional Research and Ethics Committee (IREC 017/20) which operates in accordance with the Declaration of Helsinki, 1975 (**Appendix I**). The trial was registered on the Pan African clinical trial registry (PACTR 202006491989074)(**Appendix V**). All participants gave informed consent (**Appendix L**). The study was reported in line with the CONSORT statement (**Appendix W**).

Participants

Adults (18 to 50 years of age) with chronic, non-specific neck pain were recruited via pamphlets, social media adverts and word of mouth between September 2022 and December 2023 (**Appendix G**). Inclusion criteria were neck pain of more than a three-month duration or mostly over the last 12 months (Tsang, Szeto and Lee 2014), with a severity sufficient to seek care. They were required to be right-handed to prevent differences in muscle activity due to handedness (Sainburg 2002; Amar, Cochran and Woldstad 2017). Participants were excluded if they suffered from any neurological/orthopaedic/rheumatic disorder, suffered severe trauma or surgery to the brain or spine, or had sensory or vestibular deficits. They were required to have no open wounds in the neck and trunk region, which would prevent electrode placement,

and a skin fold thickness of less than 19mm over the upper trunk to ensure adiposity did not affect transmission of the sEMG signal (Baniqued *et al.* 2016). All participants were screened for central sensitisation (**Appendix R**), using a cut off score of 40 (Mayer *et al.* 2012; Neblett *et al.* 2013), and Fear Avoidance Behaviours (FAB) (Kori, Miller and Todd 1990) (**Appendix S**), using a cut off score of 37 (Roelofs *et al.* 2004), if scores exceeded these values they were excluded. All participants underwent an orthopaedic examination which was conducted by a registered chiropractor with over 20 years of experience.

Sampling

An *a priori* sample size was calculated using pilot testing data (n=6) of cervical ROM in the positive excursion using the motion capture data. An independent student t-test, powered for large effect size (0.8) to minimize the chance of a type I error, an α of 0.05, and power at 0.8 (beta of 0.2) with two groups resulting in a sample size of 36 (17 per group). This was increased to 20 per group to allow for dropout. A person not involved in the study utilised the Random.org Integer website (Generator© 1998-2024 RANDOM.ORG [RANDOM.ORG - Integer Generator](https://www.random.org)) to produce a list of random numbers consisting of either group one (cervical spinal manipulation) or two (control).

The randomised numbers were placed into sealed, opaque envelopes and labelled consecutively starting at one. The envelopes were stored at the data collection site. LO was responsible for scheduling patients and conducting the consultations and treatments. When a participant met the eligibility criteria the consecutive envelope was selected and opened revealing the participants group allocation. LO then administered the treatment; thus, LO was not blinded to the treatments. **Figure 7.1** shows the consort flow diagram of participation throughout the study.

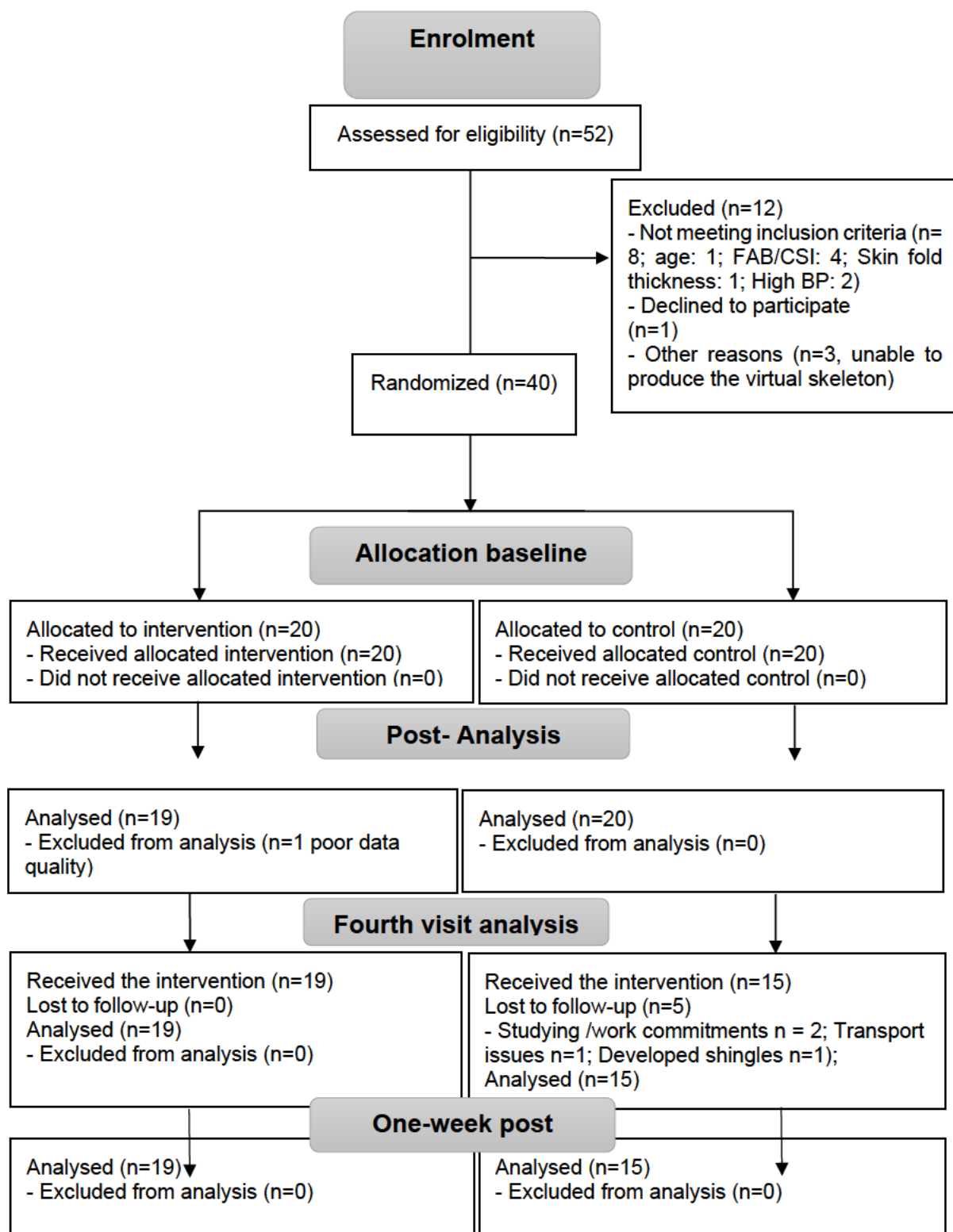


Figure 7.1: Consort flow diagram

Measurement instruments

Patient reported outcome measures (PROM)

The following PROMs were collected prior to the administration of the interventions, with follow up data collected as detailed below:

RAND 36-Item Health Survey 1.0 to assess quality of life (**Appendix L**) in terms of physical functioning, bodily pain, role limitations due to physical health problems, role limitations due to personal or emotional problems, emotional well-being, social functioning, energy/fatigue, and general health perceptions. The domains are scored as a percentage with the higher the percentage the more favourable the health status (RAND Corporation 2023). This instrument has good responsiveness, reliability (Beaton, Hogg-Johnson and Bombardier 1997) and construct validity in neck pain (de Vries *et al.* 2015). This was administered prior to the start of the intervention to determine the participant's health status.

The Numerical Pain Rating scale-101 (NPRS) to assess intensity over the last week (**Appendix M**), this tool has been found to be valid, reliable, and responsive (Ferreira-Valente, Pais-Ribeiro and Jensen 2011) in neck pain populations (Modarresi *et al.* 2022). It is an 11-point rating scale which is easy to administer with zero being no pain and 10 being the worst pain imaginable (Pool *et al.* 2007). This was measured prior to the start of treatment, at the fourth consultation prior to the application of the last intervention and at the one-week post-intervention follow up. A change of 1.5 points was considered a clinically important change (Young *et al.* 2019). The NRS has been shown to be responsive within 48 hours of treatment in neck pain (Young *et al.* 2019).

The Neck disability index (NDI) is a self-reported instrument to measure the perceived level of disability due to neck pain (**Appendix N**). It has been shown to have good content validity in patients with chronic, non-traumatic neck pain (En, Clair and Edmondston 2009). It consists of 10 items related to functional activities with each item having five options of responses ranging from zero indicating no disability to five being total disability, resulting in a score out 50. The higher the score the more disability experienced (Pool *et al.* 2007). This was administered at the first visit before

treatment was received and again at the one week follow up after the two-week treatment period. Responsiveness of the NDI has been demonstrated in three weeks in neck pain (Young *et al.* 2009). A change of five points or more indicated a minimal clinical detectable change (Vernon and Mior 1991; Young *et al.* 2019).

The patient global impression of change scale (PGICS) is easy to understand, quick to complete and allows for self-assessment of response to treatment (Kamper, Maher and Mackay 2009) (**Appendix W**). Concurrent validity of this scale with other patient reported outcomes has been reported as very good with very good-to-excellent quality between neck disability changes scores and PGICS (Bobos *et al.* 2019). This was administered one week post the completion of the intervention. Responsiveness of the NDI has been demonstrated in three weeks in neck pain (Young *et al.* 2009).

Patient satisfaction assessment was conducted to assess participants' level of satisfaction with the treatment (**Appendix X**). This form was adapted from a survey used by Haneline (2005) who assessed perceived satisfaction levels of chiropractic patients with a primary diagnosis of acute neck pain (Haneline 2006). Participants were asked to describe the change, if any, since beginning treatment in terms of their ability to be active, the symptom character, emotions, and overall quality of life and to indicate their level of satisfaction with the change in their neck pain, whether they would choose chiropractic care or spinal manipulation in the future for neck pain and if they would return to the facility for care in the future. This was administered one week post the completion of the intervention.

The PROMs were collected either by LO or one of two trained research assistants, who were students registered for a Master's Degree in Chiropractic. The kinematic and surface EMG data was collected by one of the two trained research assistants depending on their availability on the day. All data was collected in a systematic way guided by a script (**Appendix O**).

Kinematics

An eight-camera OptiTrack motion capture system (Optitrack, Natural Point, OR, USA), using Prime 13 cameras with a resolution of 1.3 MP (1280 × 1024) and 240

frame rate and a sampling frequency of 120 Hz per camera (Muyor *et al.* 2017) were used to collect three-dimensional kinematics. This system has been found to track markers accurately and reliably and is comparable to other motion capture systems (Carse *et al.* 2013). Cameras were wall or tripod mounted around the test area. Pre-capture calibration was performed and the capture volume set {NaturalPoint Corporation, 2023 #18}. Masking was used to remove any unwanted light reflections in the capture volume. Reflective markers (14 mm) were attached to 17 anatomical sites, guided by bony anatomy, as shown in **Figure 7.2**, using either electrodes or Velcro stickers. The C7 marker had a one-centimetre extension.

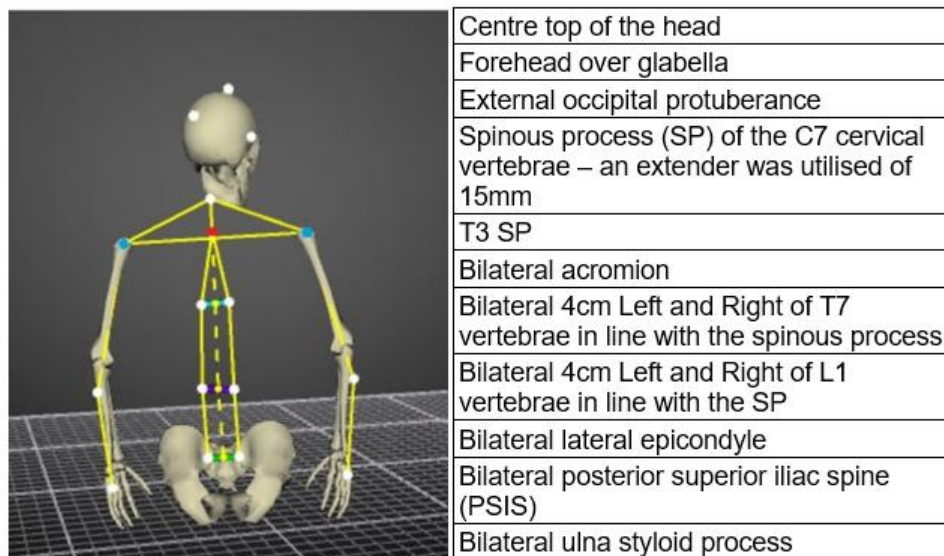


Figure 7.2: Location of the reflective markers

Electromyography

The Biopac Bionomadix MP150 Data Acquisition System (Biopac systems® Inc.) was utilised together with a wireless transmitter and receiver pair. The system has a differential amplifier with a common mode rejection rate (CMRR) of 110dB at 50/60 Hz, gain of 2000, input impedance of 2 MΩ with signal to noise ratio over 65dBs. Data were transmitted at 2000 Hz. The data acquisition software Acqknowledge 4.1,

(BIOPAC systems Inc.) was set to a sampling frequency of 2000 Hz. Prior to placement of electrodes, the skin was lightly abraded, shaved where necessary, and cleaned with alcohol (Hermens *et al.* 2000). Disposable, rectangular, pre-gelled Ag/AgCl surface electrodes (30x25mm) (Vitatrode™ Electro Spyres, Johannesburg) were placed on the six muscles bilaterally, parallel to the muscle fibres, and in the mid-line, with an inter-electrode distance of 20 mm (Hermens *et al.* 2000). Care was taken to accurately locate electrode placement sites through palpation of bony landmarks and the use of a tape measure, **Table 7.1**. Reference electrodes (RE) were placed on the closest bony prominence.

Table 7.1: Details of electrode placement

Muscle	Placement	Reference electrode
Upper trapezius (UT)	One third from the distal edge of the acromion on a line drawn between the acromial and C7 spinous process (Farina <i>et al.</i> 2002)	Manubrium
Posterior cervical (PC)	2 cm lateral to the C4 spinous process bilaterally (Criswell 2011; Tsang, Szeto and Lee 2014)	
Sternocleidomastoid (SCM)	Midpoint between the mastoid process and the sternal insertion, slightly posterior to the muscle belly (Criswell 2011; Tsang, Szeto and Lee 2014)	Ipsilateral anterior superior iliac spine (ASIS)
Anterior Scalene (AS)	Lateral to the SCM's attachment on the clavicle, above the clavicle and anterior to the upper trapezius, placed at a slightly oblique angle (Criswell 2011)	
Thoracic paraspinal upper T4 (T4)	4 cm lateral to the T4 spinous process bilaterally (Tsang, Szeto and Lee 2014)	Ipsilateral medial epicondyle
Thoracic paraspinal lower T9 (T9)	4 cm lateral to the T9 spinous process bilaterally (Tsang, Szeto and Lee 2014)	

Procedure

The participant stood upright, with their hands facing their thighs, while the markers were detected by the OptiTrack cameras, streamed to Motive™ tracker and onto STT Insight™ software (STT systems group, Spain). Each reflective marker was allocated to the appropriate anatomical site, producing a custom-made digital human model calibrated to the participants anthropometry, syncing the position and orientation of

each reflective marker to the correct body segment, to complete the matrix transformation. This took approximately five seconds. During this time baseline sEMG activity was recorded for 50ms.

Marker position and allocation were monitored throughout the capture. The model constructed cervical spinal kinematics from the reflectors from the external occipital protuberance to C7, and a kinematical estimation model was developed in STT-systems™ and provided six degrees of freedom (DOF) in three cardinal planes.

Participants then sat on a stool, with no backrest, their feet flat on the floor and evenly spaced. They were instructed to sit upright with their back and neck straight, arms hanging at the side and looking straight ahead towards the wall in front of the seat, at their eyeline in line with a marker on the wall. Participants were asked to bring their chin to their chest and then look up at the ceiling (flexion/extension), then to turn their head to the left as far as they could and then to the right (left and right rotation), and lastly to bring their left ear to their left shoulder then to repeat on the right (left and right lateral flexion). They were requested to pause at the end of each motion and then return to neutral. Each cycle was repeated three times, and they were instructed to not move their shoulders or trunk. Movement time was not standardised to allow participants to move at their own pace. Prior to the start of data collection participants were given an opportunity to practice two to three times. If they were not performing the motion correctly, such as moving their shoulders, or not reaching the end limit, their motion was corrected. The research assistant talked the participants through the various motions to standardise the execution (**Appendix O**). A summary of the research procedure is presented in **Figure 7.3**.

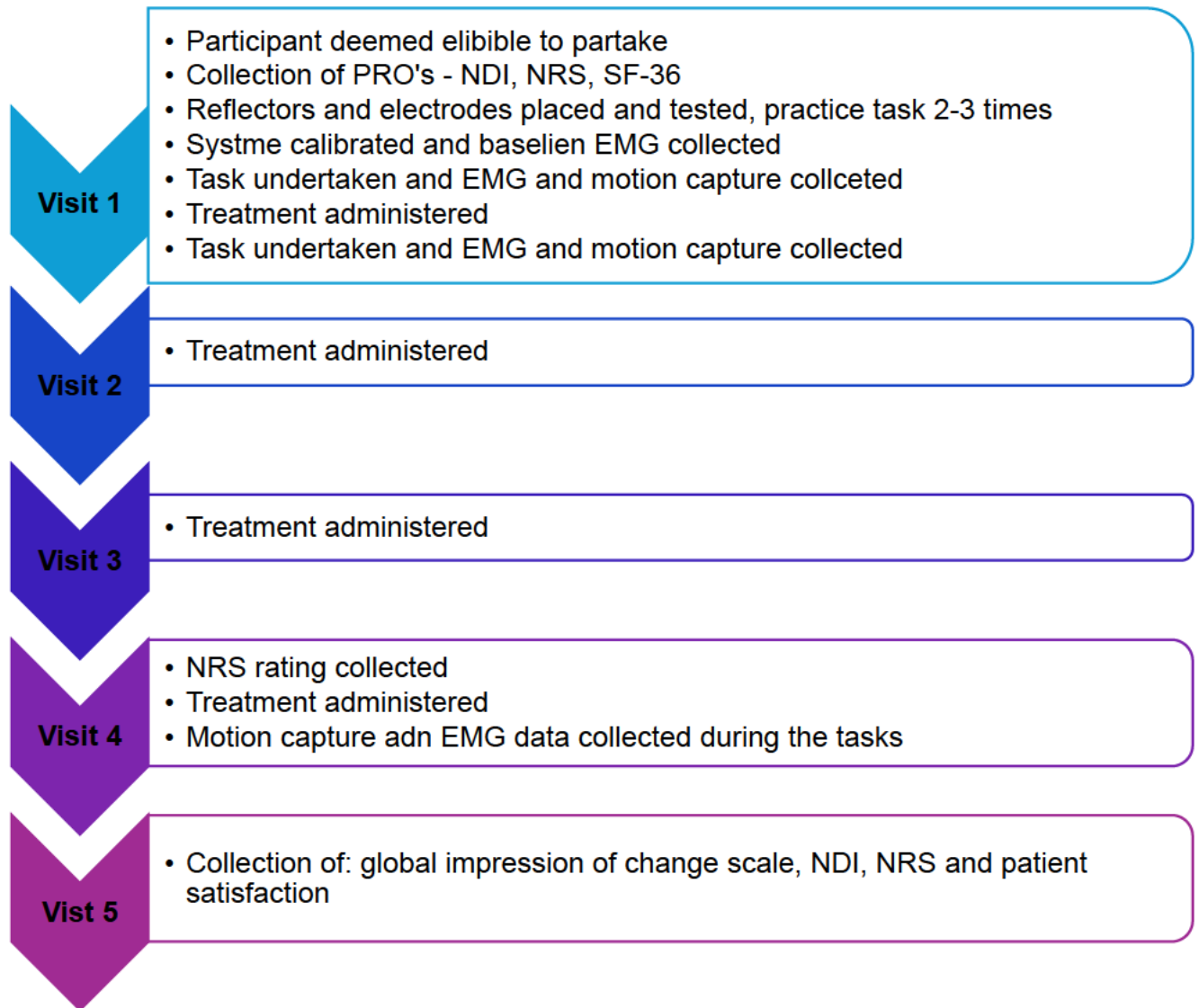


Figure 7.3: Summary of the data collection process

Interventions

A standardised musculoskeletal examination was conducted, using motion palpation, to identify areas of intersegmental motion restriction and tenderness to palpation (Hubka and Phelan 1994; Smedmark, Wallin and Arvidsson 2000). Motion palpation of the cervical spine has been validated in detecting hyper- and hypomobile joints in the cervical spine with a high level of agreement between examiners ($K = 0.65$) and a sensitivity ranging between 55-78%, with high overall specificity (91-98%) (Humphreys, Delahaye and Peterson 2004).

Each participant received four treatments over two weeks, in line with a similar study (Izquierdo Pérez *et al.* 2014). Treatment was individualized to participants and by treatment session based on the motion palpation findings. On completion of the trial, all participants were provided with a voucher to receive four free treatments at the institutional chiropractic clinic, where the study took place, for their participation in the study. Interventions are described according to the Template for Intervention Description and Replication (TIDieR) guide, **Table 7.2**.

Data processing

Motion capture data were exported from STT Insight™ software (STT systems group, Spain) and sEMG data from AcqKnowledge® software and imported into MATLAB (R2023a) (MathWorks® Inc., Natick, Massachusetts, United States) where a customised code processed the signals.

Motion capture: The signals were filtered using a 4th order low pass (5Hz) Butterworth filter (Descarreaux, Passmore and Cantin 2010). Various smoothing options between two and 10Hz were tested with the 5Hz used by Descarreaux et al (2010) being the preferable one. Data were segmented into the three cardinal ROM consisting of alternating sequences of repeated excursions, with start and end points. To register as an excursion the following thresholds were applied:

1. Excursion exceeded 25°,
2. Lasted at least 0.5 seconds (adjusted for individual cases where necessary),
3. Maximum excursion time of 3 seconds,
4. With a minimum of 4 and a maximum of 6 excursions consecutively (2 in each direction),
5. A maximum transition time of 1.5 seconds.

The excursions started and stopped at the neutral cross over point i.e. zero line. Excursions were labelled as either positive (those occurring above the neutral line) or negative (those occurring below the neutral line). Movements occurring in the positive zone were flexion, right lateral flexion and rotation, whereas those in the negative zone were extension, left lateral flexion and rotation.

Table 7.2: Description of interventions according to TIDieR

Item	Description	
Brief name	Cervical spinal manipulation HVLA technique	Control
Why	SMT has been purported to result in neurophysiological changes that affect pain rating, neuromuscular response and motor control.	This comparator was selected to allow for the activation of skin mechanoreceptors but exclude the thrust component of the HVLA.
What material	Bergman and Peterson (2011) (Bergmann and Peterson 2010) were used to direct the application of the intervention.	The procedure as detailed by Haavik Taylor and Murphy (2010) (Taylor and Murphy 2010; Blanpied <i>et al.</i> 2017) was utilised with light pressure applied of the articular pillar during the procedure.
What procedures	Participants lay supine with their cervical spine in neutral the clinician contacted the posterolateral articular pillar of the hypermobile cervical vertebrae, with her index middle phalanx of the index finger, joint slack was removed and a high-velocity low-amplitude thrust manipulation was executed. The HVLA manipulation was performed either in rotation or lateral flexion depending on which motion was most restricted (Izquierdo Pérez <i>et al.</i> 2014).	The same procedure as outlined for the HVLA manipulation was followed except that no thrust was administer, instead the clinician held the position for 2 counts and released.
Who provided	A chiropractor with more than 20 years of experience.	A chiropractor with more than 20 years of experience.
How	In person	In person
Where	Private clinic room at an institutional chiropractic teaching clinic	Private clinic room at an institutional chiropractic teaching clinic
When and how much	Treatment was administered 4 times over 2 weeks. Each treatment lasted approximately 2 minutes, including the time taken to position the patient correctly. When no-audible cavitation occurred on the first attempt a second attempt was performed (Puntumetakul <i>et al.</i> 2015).	It was administered 4 times over 2 weeks. Each treatment lasted approximately 2 minutes, including the time taken to position the patient correctly.
Tailoring	The technique was applied at the level of joint hypermobility identified for each patient with each patient receiving on average 2 HVLA thrusts, with a maximum of 3.	The technique was applied at the level of joint hypermobility identified for each patient with each patient experiencing the clinician touching their neck twice, with a maximum of 3 times.
	Treatment was individualized to participants	
Modification	No modification to the technique occurred	No modification to the technique occurred
How well (planned)	The technique was to be applied as outlined by (Bergmann and Peterson 2010).	The technique was to be applied as outlined by (Taylor and Murphy 2010) including light pressure.
	Care was taken not to mention the 'cracking/popping' sound that may occur with SMT during the informed consent stage, to not allude participants to their group allocation.	
How well (actually)	Intervention adherence or fidelity was not assessed.	Intervention adherence or fidelity was not assessed.

The excursions were broken into sub-phases allowing cervical ROM to be described in half cycles. The away subphase was the motion from neutral to maximum endpoint (the point of peak displacement), and the return subphase occurred from maximal endpoint to neutral, as detailed in Chapter five.

The outcomes were derived as follows:

1. Duration (s) - calculated as the time spent in an excursion zone.
2. Peak displacement ($^{\circ}$) – identified as the point furthest away from neutral (Hogan 1984, Sjölander, Michaelson et al. 2008), this was recorded for the positive and negative excursions.
3. Mean velocity ($^{\circ}/s$) – mean velocity was determined by averaging the velocity from when the velocity threshold exceeded $10^{\circ}/s$ (to indicate actual motion) to end of range, excluding the dead space at the end of the range where the participant paused temporarily before resuming the motion. For both the positive and negative excursions this was recorded twice – the mean away and mean return velocity. Position data was used to determine velocity and jerk with gradient functions establishing velocity and jerk.
4. Peak velocity ($^{\circ}/s$) – was the maximum recorded velocity per subphase from motion initiation to peak angle (Vorro, Bush et al. 2013). For both the positive and negative excursions this was recorded twice – the peak away and peak return velocity.
5. Mean jerk ($^{\circ}/s^3$) - jerk is the average rate of change in acceleration with respect to time (Ponsiglione *et al.* 2022) and was measured from the start of the excursion to the peak displacement (Bigoni *et al.* 2016). For both the positive and negative excursions mean jerk was recorded twice, in the away and in the return subphases.
6. Peak jerk ($^{\circ}/s^3$) – was the maximum jerk during the excursion from motion initiation to peak angle. For both the positive and negative excursions this was recorded twice – the peak away and peak return jerk.

EMG: The raw EMG signal was synced to the kinematic data, then processed using a fourth bidirectional Butterworth filter (a bandpass filter with a low pass cut off 150 Hz

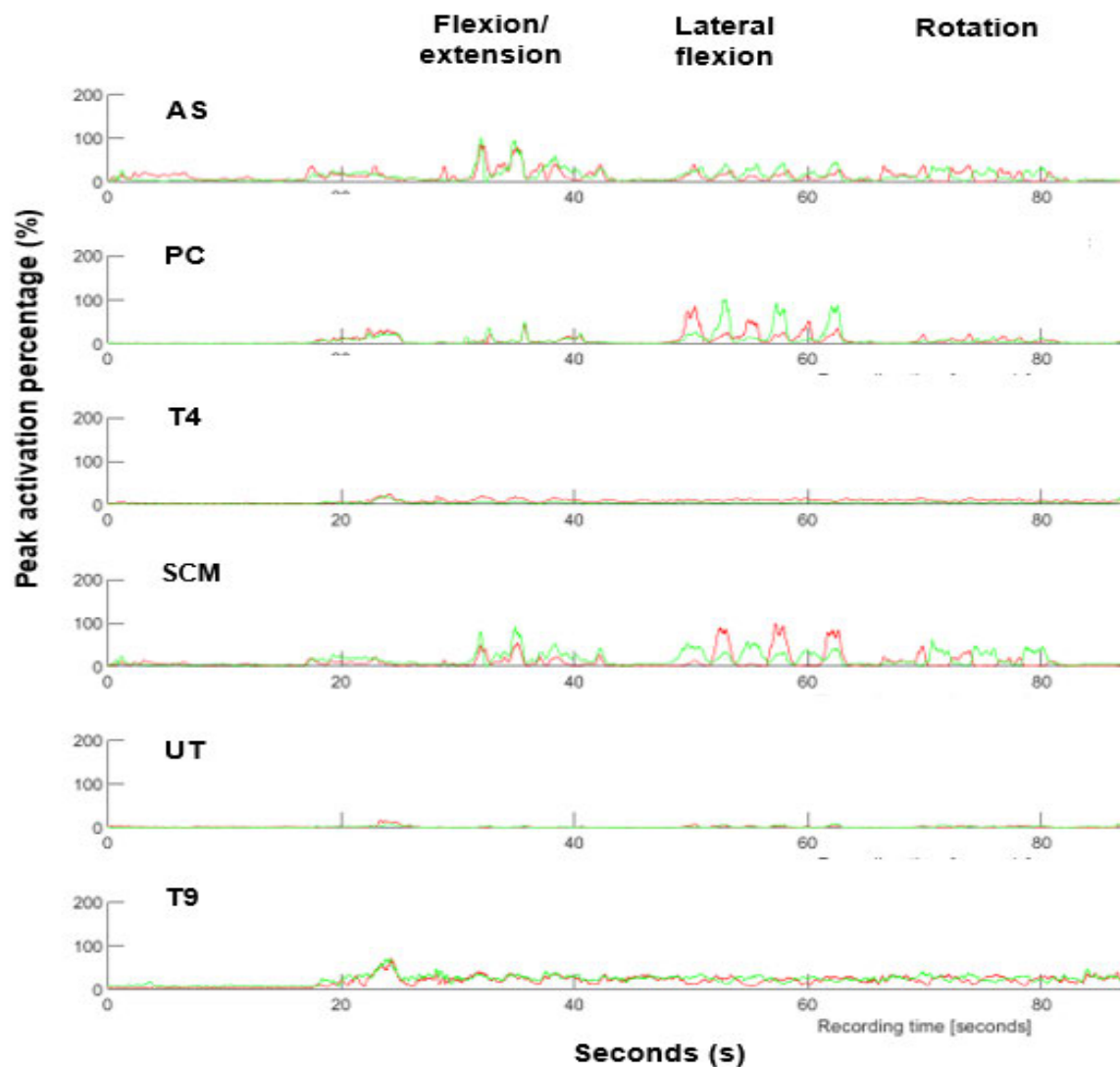
to remove electrical noise, and a high pass cut off of 50hz to remove low frequency noise such as movement artifacts). Thereafter the signal was full wave rectified and then smoothed using a moving average over a 300ms sliding window. Following smoothing, the data was normalised to the peak amplitude achieved by each muscle across the task (Halaki and Ginn 2012) and utilised by de Camargo *et al* (2011) and Bracht *et al* (2018) (de Camargo *et al.* 2011; Bracht *et al.* 2018). This method decreases between subject variability (Yang and Winter 1984), by reducing amplitude differences and giving the same 'weight' to each participant's sEMG data. It provides quantification of the level of activity of a muscle relative to a specific task, highlighting muscle activation patterns (Yang and Winter 1984; Winter and Yack 1987). sEMG signals can vary between days and between people, thus normalisation is necessary for comparison (Kadaba *et al.* 1989; Halaki and Ginn 2012; Commandeur *et al.* 2024).

The baseline signal was used to determine activity onset which was identified as the data point where the sEMG signal magnitude was three standard deviations larger than the baseline EMG and where the muscle contraction duration was greater than 25 ms (Hodges and Bui 1996). The onset and offset of muscle activity during the tasks were quantified into a percentage of muscle activation duration, to enable between group comparisons. Allowing for the temporal characteristics of the muscle activity to be examined during the sub-phases of cervical ROM. The activity of 100% during any one phase would indicate that the muscle was active for the whole time during that phase.

Figure 7.4 shows the signal obtained from one participant during flexion/extension neck motion. For each cervical movement away and return outcomes were obtained for peak (%), mean (%) and time activation percentage (%), as described in chapter five. Following the segmentation of the motion capture and EMG data, event and outcome images (which visually displayed the signal, tasks and sub-phases) were produced and assessed per participant to determine the quality of the signal.

When the signal was distorted and lack conformability to the tasks it was excluded, this was done in consultation with a biomechanist. Where isolated technical issues were found, for example where the marker was lost resulting in severe signal distortion

or when the electrode failed to detect the signal, the data for only that measurement was excluded from the analysis for that participant. Once satisfied that the signals were acceptable the data for each of the three trials together with the calculated average of the three measures (i.e. the mean) for each of the subphases were exported to an Excel spreadsheet for statistical analysis.



(AS – anterior scalene, PC – posterior cervical, T4 – thoracic paraspinal at T4, SCM – sternocleidomastoid, UT – upper trapezius, T9 – thoracic paraspinal at T9)

Figure 7.4: EMG of a participant in the intervention pre-intervention signal of the 6 pairs of muscles (I18)

Data analysis

Descriptive statistics were calculated for group characteristics. Baseline categorical variables were compared between groups using Chi square and Fischer's Exact test and independent samples t-tests for numerical variables. Between group differences were assessed using Analysis of Covariance (ANCOVA) allowing for adjustment in baseline measures and controlling for age and sex. A p -value of 0.05 indicated significance. Statistical analysis was conducted using SPSS (version 27, IBM Corp. Released 2020. IBM SPSS Statistics for Windows, Armonk, NY: IBM Corp).

Normality was assessed using kurtosis and skewness. Effect sizes were calculated using Partial Eta Squared (η^2) and considered small, medium and large if $\eta^2 = 0.01$, $\eta^2 = 0.06$ or $\eta^2 = 0.14$, respectively (Yagin, Pinar and de Sousa Fernandes 2024). Pearson's correlational analysis (r) was utilised to assess the strength and direction of relationships between change in pain, and cervical kinematic and muscle activation outcomes. A sensitivity analysis was performed to assess the effect of missing data (Groenwold, Moons and Vandenbroucke 2014; Li and Stuart 2019). A significant outcome per section was selected and data imputation was performed. This resulted in no differences in the outcomes. Thus, intention to treat analysis was not performed.

RESULTS

Demographic characteristics

Participants were mostly female (56.4%), single (84.6%) students (76.9%) with a mean age of 24.9 (± 7.2) and a normal body mass index (24.1 ± 3.7). No between group differences were found for the demographic and anthropometric characteristics except for sex ($p = 0.034$), where the control group had significantly more males, **Table 7.3**. Health assessment showed that the control group fared poorly in physical health ($p = 0.036$) and social functioning ($p = 0.031$) compared to the control group. Most of the participants had no previous experience with chiropractic treatment 64% ($n=25$), with no between group differences ($p = 0.584$).

Table 7.3: Demographic and anthropometric characteristics of the participants

Characteristic	Total			Intervention			Control			p-value	CI	
	n	M	SD	n	M	SD	n	M	SD		Low	High
Sex n(%)												
Female		22	56.4		14	73.7		8	40	0.034*		
Male		17	43.6		5	26.3		12	60			
Marital status n(%)												
Single		33	84.6		17	89.5		16	80	0.342**		
Married		5	12.8		1	5.3		4	20			
Divorced		1	2.6		1	5.3		0	0			
Occupation n(%)												
Student		29	74.4		16	84.2		13	75	0.273**		
Other e.g. teacher, administrator, sales		10	25.6		3	15.8		7	35			
Age	39	24.9	7.2	19	24.1	7.9	20	25.7	6.6	0.510	-6.2	3.2
Height (m)	39	1.7	0.1	19	1.6	0.1	20	1.7	0.1	0.665	-0.1	0.0
Weight (kg)	39	66.4	15.3	19	64.5	10.0	20	68.1	19.2	0.471	-13.6	6.4
BMI	39	24.1	3.7	19	23.7	2.6	20	24.4	4.5	0.568	-3.1	1.7
Health status (SF-36)												
Physical functioning	39	88.5	21.2	19	95.1	24.8	20	82.3	15.3	0.059	-0.9	26.3
Physical health	39	61.1	38.2	19	74.1	29.9	20	48.8	41.7	0.036	1.7	49.0
Emotional problem	39	53.9	44.3	19	54.4	43.3	20	53.5	46.3	0.951	-28.3	30.0
Energy/fatigue	39	51.1	16.3	19	52.7	15.8	20	49.6	16.9	0.558	-7.5	13.8
Emotional	39	42.5	13.2	19	40.7	8.4	20	44.2	16.6	0.421	-12.1	5.2
Social functioning	39	61.5	31.3	19	72.5	32.1	20	51.1	27.3	0.031	2.1	40.7
Pain	39	52.0	21.4	19	57.2	21.8	20	47.0	20.4	0.137	-3.4	23.9
General health	39	53.1	12.7	19	55.0	8.0	20	51.3	16.0	0.366	-4.5	12.0

(n – sample, M – mean, SD – standard deviation, CI – confidence interval, SF – short form, *Fischer's Exact test;

**Chi-squared test, all other tests independent samples t-test)

Neck pain characteristics

Most participants experienced neck pain that was moderate in nature (5.3 ± 1.8), bilateral (74.4%), reporting a mild level of disability (24.4 ± 10.0). There were no between group differences for neck pain characteristics, **Table 7.4**.

Table 7.4: Neck pain characteristics between the group

Characteristics	Total			Intervention			Control			p-value	CI	
	n	M	SD	n	M	SD	n	M	SD		Low	High
Location (n%)												
Unilateral	10	25.6		6	31.6		4	20		0.500*		
Bilateral	29	74.4		13	68.4		16	80				
Associated with HA (n%)												
Yes	16	41		8	42.1		8	40		1.000		
No	23	59		11	57.9		12	60				
Pain intensity (NPRS)	39	5.3	1.8	19	4.9	1.8	20	5.7	1.8	0.168	-2.0	0.4
Duration (months)	38	26.9	22.6	19	24.8	18.5	19	29.1	26.4	0.573	-19.2	10.8
McGill pain score												
Sensory	39	7.4	4.3	19	6.9	3.1	20	7.9	5.2	0.473	-3.8	1.8
Affective	39	2.6	2.5	19	2.4	2.2	20	2.9	2.9	0.561	-2.1	1.2
Total	39	10.0	5.7	19	9.3	4.4	20	10.8	6.8	0.424	-5.2	2.2
NDI	39	24.4	10.0	19	21.8	6.5	20	26.9	12.1	0.120	-11.4	1.4
Neck Outcome Score												
Mobility	39	58.3	17.9	19	60.0	18.3	20	56.8	17.9	0.587	-8.6	14.9
Symptoms	39	49.0	17.9	19	46.3	17.7	20	51.5	18.2	0.374	-16.8	6.5
Sleep disturbance	39	64.9	22.2	19	66.8	22.4	20	63.1	22.4	0.614	-10.9	18.2
Activity and pain	39	59.1	27.1	19	64.1	17.6	20	54.2	33.5	0.253	-7.5	27.3
Participation	38	65.7	14.7	19	70.3	12.5	19	61.2	15.7	0.056	-0.3	18.4

(M – mean, SD – standard deviation, n-sample, %-percentage, NDI-neck disability index % score, CI – confidence interval, HA – headache, NPRS – numerical pain rating scale, NDI – neck disability index, *Chi-squared test, all other tests were Independent samples t-test)

Pain intensity and disability

Table 7.5 shows the means and standard deviations and results of the ANVOCA analysis, adjusted for sex and age, for pain and disability. The intervention group experienced a greater decrease in pain intensity at visit four, with a large effect size ($F(1, 27) = 7.718, p = 0.010; \eta^2 = 0.22$), which was slightly below the clinically significant cut off of 1.5. No between group differences were found at the one week follow up ($F(1,29) = 0.941, p = 0.340; \eta^2 = 0.03$). The intervention group had a greater decrease in disability at the one-week follow up, with a large effect size ($F(1,29) = 8.904, p = 0.006, \eta^2 = 0.24$), which was below the clinically significant threshold of 10 percent.

Table 7.5: Pain intensity and disability scores (unadjusted) between the groups at visit 4 and 1-week post-treatment

Outcome	Visit	Pre-measures				Post-measures				p value	Adjusted means				CI	
		CG		EG		CG		EG			MD					
		(n=15)		(n=19)		(n=15)		(n=19)								
		M	SD	M	SD	M	SD	M	SD		M (SE)	M (SE)				
Pain (out of 10)	v1-4	5,7	1,8	4,9	1,8	3,5	1,6	1,8	1,3	0,010	3,4 (0,3)	2 (0,3)	1,4	-2,4	-0,4	
	v1-1w	-	-	-	-	1,6	2,2	3,4	2,1	0,340	-	-	-	-	-	
Disability (%)	v1-1w	26,9	12,1	21,8	6,5	18.1	14.7	7.1	6.8	0.006	8,2 (1,0)	4,1 (0,9)	4,1	-6,9	-1,3	

(V = visit; w = week, CG – control group, EG – experimental group, M – mean, SE – standard error, CI – confidence interval)

Duration and cervical kinematics

The mean and standard deviations of the measures taken at baseline, immediately post the first treatment and at the fourth visit are presented in **Supplementary file 7.1**. Using ANCOVA and controlling for baseline measures, age and sex, no between group differences were found for time to complete the ROM and peak displacement ($p > 0.05$). Significant between group differences in adjusted means were found immediate post the initial treatment, with medium to large effect sizes, where the SMT group had greater left rotation away peak velocity ($F(1,34) = 3.988, p = 0.040; \eta^2 = 0.12$), flexion return peak ($F(1,34) = 4.018, p = 0.044; \eta^2 = 0.114$) and return average jerk ($F(1,34) = 7.661, p = 0.009; \eta^2 = 0.184$), right lateral flexion return average jerk ($F(1,33) = 5.725, p = 0.023; \eta^2 = 0.148$) and left lateral flexion away average jerk ($F(1,33) = 5.545, p = 0.025; \eta^2 = 0.144$) and left rotation peak away ($F(1,34) = 4.413, p = 0.043; \eta^2 = 0.115$), seen in **Table 7.6**.

Analysis of adjusted scores at the fourth visit found no significant differences for the duration and cervical kinematics outcomes between the groups, except for jerk measured during flexion return peak ($F(1, 29) = 4.944, p = 0.034; \eta^2 = 0.146$), left rotation return peak ($F(1,34) = 5.244, p = 0.028; \eta^2 = 0.134$) and away average jerk ($F(1,34) = 8.008, p = 0.008; \eta^2 = 0.191$), where the SMT group had greater jerk, with a medium to large effect, seen in **Table 7.6**. The results of data analysis using ANCOVA and controlling for baseline measures, age and sex are presented in **Supplementary files 7.2 and 7.3**.

Pearson's correlation of change from baseline measures to visit four found a significant positive correlation between pain intensity and away velocity average during the flexion/extension cycle ($r = 0.65, p = 0.009$) in the control group. Indicating that in the control group the faster the participants moved, the more pain they experienced from visit one to four. In the intervention group a positive correlation was found between pain intensity and time/duration during lateral flexion ($r = 0.501, p = 0.041$), where time decreased, so did pain intensity rating. No other significant correlations were found.

Table 7.6: Adjusted means and significance between group comparisons for the cervical kinematic outcomes over the trial

Motion		Time point	Control				Intervention				MD	SE	p value	CI		η²
			M	SE	CI		M	SE	CI							
					Low	High			Low	High						
Flex																
Jerk	Return peak	P-P	37.9	7.5	22.6	53.3	62.0	8.1	45.6	78.5	-24.1	11.5	0.044	-47.5	-0.7	0.11
	Return avg	P-P	1863.2	168.4	1521.0	2205.4	2573.5	181.5	2204.6	2942.3	-710.2	256.6	0.009	-1231.7	-188.7	0.18
	Return peak	P-4	58.3	20.4	16.6	100.1	122.0	19.4	82.4	161.6	-63.7	28.6	0.034	-122.3	-5.1	0.15
RLF																
Jerk	Return avg	P-P	1389.2	190.9	1000.9	1777.4	2085.8	208.3	1662.0	2509.7	-696.7	291.2	0.023	-1289.0	-104.3	0.15
LLF																
Jerk	Away avg	P-P	1351.8	102.0	1144.2	1559.4	1718.1	111.4	1491.5	1944.7	-366.3	155.6	0.025	-682.8	-49.8	0.14
LRot																
Velocity	Away peak	P-P	151.7	7.5	166.9	136.5	176.4	8.1	192.8	159.9	24.7	11.5	0.040	1.2	48.1	0.12
Jerk	Away peak	P-P	22.8	6.6	9.3	36.3	44.4	7.2	29.7	59.1	-21.6	10.3	0.043	-42.5	-0.7	0.12
	Return peak	P-V4	7381.2	523.6	6317.1	8445.2	9246.8	572.1	8084.0	10409.5	-1865.6	814.7	0.028	-3521.3	-209.9	0.13
	Away avg	P-V4	1697.3	156.6	1379.1	2015.5	2377.5	170.3	2031.4	2723.5	-680.1	240.3	0.008	-1168.6	-191.7	0.19

(P-P – pre to post initial treatment, P-V4 – pre to visit 4, η^2 -partial eta squared, avg-average, CI-confidence level, M – mean, SE – standard error, MD- mean difference)

Muscle activation pattern

The mean and standard deviations of the sEMG measures taken at baseline, immediately post the first treatment and at the fourth visit are presented in **Supplementary file 7.4**. The mean differences between the groups, using ANCOVA and controlling for baseline measures, sex and age, are provided in **Table 7.7, 7.8 and 7.9**. Significant between group differences were found immediately after the first treatment for flexion where the control group had greater LPC ($F(1,32) = 7.020, p = 0.012; \eta^2 = 0.180$) return time percentage activation compared to the intervention group; in extension, the control group had greater LAS ($F(1,31) = 8.472, p = 0.007, \eta^2 = 0.215$) and LSCM return time percentage ($F(1,31) = 6.078, p = 0.019; \eta^2 = 0.164$); in right lateral flexion the control group had less away peak ($F(1,31) = 4.548, p = 0.041; \eta^2 = 0.128$) and mean ($F(1,31) = 4.351, p = 0.045; \eta^2 = 0.123$) activation in the LAS and in the LUT during away time percentage ($F(1,32) = 7.860, p = 0.008; \eta^2 = 0.192$) than the intervention group; the paraspinal at LT9 during right lateral flexion showed greater activity in the control group for return mean ($F(1,32) = 4.179, p = 0.049; \eta^2 = 0.116$) than the intervention group. During left lateral flexion, the control group had less away peak ($F(1,31) = 5.242, p = 0.029; \eta^2 = 0.145$) and mean ($F(1,31) = 5.523, p = 0.025; \eta^2 = 0.151$) activation in the RAS and in the LT9 for away time percentage ($F(1,32) = 6.139, p = 0.019; \eta^2 = 0.161$) than the intervention group; for right rotation the control group had less activation in the RPC ($F(1,33) = 5.625, p = 0.024; \eta^2 = 0.146$) and in the LT4 ($F(1,34) = 5.849, p = 0.021; \eta^2 = 0.147$) for return time percentage and in the RSCM ($F(1,32) = 4.664, p = 0.038; \eta^2 = 0.127$) for away time than the intervention group. These results are presented in **Table 7.10**.

From pre to fourth visit significant between group effects were found for flexion where the RAS in the control group had less return mean activity ($F(1,27) = 5.742, p = 0.024, \eta^2 = 0.175$) and the intervention group had greater LT4 return time ($F(1,28) = 4.892, p = 0.035, \eta^2 = 0.149$), in extension the RPC had greater activity in return peak ($F(1,29) = 4.964, p = 0.034, \eta^2 = 0.151$) and return mean ($F(1,29) = 6.125, p = 0.002, \eta^2 = 0.179$) and return

Table 7.7: Mean differences between the groups for sEMG readings during flexion and extension

			Adjusted means					Adjusted means					Adjusted means				
			CG		MD	CI		CG		MD	CI		CG		MD	CI	
			M	M		Lower	Upper	M	M		Lower	Upper	M	M		Lower	Upper
			LAS					LPC					LT4				
Flex	Away	Peak	34.4	25.5	8.9	-1.2	19.0	9.6	13.7	-4.1	-11.6	3.5	13.6	14.9	-1.3	-5.7	3.0
		Mean	16.7	14.9	1.8	-2.8	6.3	6.3	8.3	-2.0	-5.8	1.8	10.6	11.1	-0.4	-3.3	2.5
		Time %	63.1	65.3	-2.2	-21.5	17.1	52.6	32.6	20.0	-1.7	41.8	85.7	95.5	-9.8	-23.8	4.2
	Return	Peak	29.2	23.0	6.2	-6.1	18.5	32.0	31.9	0.1	-10.5	10.7	14.2	17.3	-3.1	-9.0	2.9
		Mean	15.1	14.1	1.0	-6.6	8.7	21.0	21.4	-0.4	-7.2	6.4	11.5	13.7	-2.2	-6.9	2.5
		Time %	56.3	70.4	-14.0	-32.3	4.2	91.4	74.4	17.0	0.3	33.8	93.6	98.4	-4.8	-16.3	6.7
Ext	Away	Peak	23.1	19.9	3.2	-8.8	15.2	23.8	29.9	-6.1	-17.4	5.2	12.5	17.3	-4.8	-11.1	1.4
		Mean	13.5	13.4	0.1	-6.9	7.1	11.2	16.2	-5.0	-11.7	1.7	9.6	13.3	-3.7	-9.2	1.9
		Time %	61.9	64.2	-2.3	-18.6	14.0	78.2	64.4	13.8	-4.9	32.5	90.2	94.5	-4.2	-16.6	8.1
	Return	Peak	34.1	34.1	0.0	-11.2	11.1	9.1	13.8	-4.7	-11.2	1.7	11.0	16.4	-5.5	-13.6	2.6
		Mean	23.3	22.0	1.3	-4.9	7.4	5.1	9.6	-4.5	-8.9	0.0	8.4	11.7	-3.3	-8.0	1.4
		Time %	89.1	76.0	13.1	-2.4	28.6	40.7	25.1	15.6	-6.7	37.8	82.2	88.2	-6.0	-22.8	10.9
			RAS					RPC					RT4				
Flex	Away	Peak	26.8	29.3	-2.6	-11.4	6.3	10.2	11.7	-1.5	-9.0	6.0	7.5	9.4	-1.8	-3.7	0.1
		Mean	13.1	14.3	-1.3	-6.1	3.6	5.9	6.4	-0.5	-3.5	2.5	6.0	7.1	-1.2	-2.5	0.2
		Time %	54.9	57.9	-3.0	-20.0	14.0	46.9	42.4	4.5	-19.9	28.9	94.1	89.2	4.8	-5.2	14.9
	Return	Peak	22.5	24.0	-1.5	-10.9	8.0	33.5	32.3	1.2	-11.3	13.8	7.3	10.0	-2.7	-4.8	-0.5
		Mean	11.6	13.7	-2.1	-7.8	3.6	21.6	19.9	1.7	-4.4	7.8	5.8	8.1	-2.3	-4.2	-0.5
		Time %	59.5	68.0	-8.5	-26.8	9.8	85.9	75.3	10.6	-5.7	26.8	92.0	94.7	-2.7	-12.7	7.2
Ext	Away	Peak	21.4	19.6	1.8	-8.9	12.5	27.0	27.6	-0.6	-8.6	7.4	6.4	8.3	-2.0	-4.2	0.2
		Mean	13.0	12.6	0.4	-6.3	7.2	12.8	13.5	-0.7	-5.4	4.1	4.7	6.6	-1.9	-3.7	0.0
		Time %	65.4	62.8	2.7	-15.1	20.4	76.8	73.7	3.1	-10.4	16.5	87.1	83.4	3.7	-12.6	20.0
	Return	Peak	28.6	29.3	-0.8	-9.1	7.6	9.2	11.9	-2.6	-8.2	2.9	6.0	8.0	-2.0	-5.1	1.1
		Mean	19.0	18.3	0.7	-4.7	6.1	5.1	7.9	-2.8	-6.7	1.1	4.4	5.9	-1.6	-3.4	0.3
		Time %	80.1	70.5	9.6	-5.0	24.2	33.1	39.0	-5.9	-27.0	15.1	84.5	78.2	6.2	-5.9	18.4
			LSCM					LUT					LT9				
Flex	Away	Peak	25.5	21.9	3.6	-5.0	12.2	6.7	8.3	-1.6	-5.0	1.8	30.3	31.4	-1.0	-7.4	5.4
		Mean	12.1	11.0	1.0	-2.8	4.9	4.7	6.1	-1.4	-3.9	1.2	23.9	24.0	-0.1	-5.5	5.3
		Time %	69.8	71.9	-2.1	-18.4	14.1	25.1	47.7	-22.6	-46.1	1.0	86.2	93.6	-7.4	-23.5	8.7
	Return	Peak	23.8	14.9	8.9	-1.2	19.1	6.9	8.5	-1.6	-4.5	1.3	28.1	29.2	-1.1	-5.9	3.6

			Adjusted means					Adjusted means					Adjusted means				
			CG		MD	CI		CG		MD	CI		CG		MD	CI	
			M	EG		Lower	Upper	M	EG		Lower	Upper	M	EG		Lower	Upper
Ext	Away	Mean	12.4	8.0	4.4	-1.6	10.3	5.3	7.0	-1.7	-4.4	1.0	21.8	23.3	-1.5	-6.0	3.0
		Time %	79.6	75.6	4.0	-17.3	25.3	34.3	56.0	-21.7	-51.2	7.8	89.7	97.2	-7.5	-20.2	5.1
		Peak	18.7	14.1	4.6	-6.1	15.3	7.0	8.2	-1.1	-4.1	1.9	21.5	25.8	-4.3	-10.8	2.1
		Mean	10.2	9.2	0.9	-5.6	7.4	5.0	6.1	-1.1	-3.6	1.4	16.7	19.9	-3.2	-8.5	2.1
	Return	Time %	80.3	72.8	7.5	-11.3	26.4	27.4	47.3	-19.9	-46.6	6.9	79.9	92.1	-12.2	-29.3	4.8
		Peak	29.8	27.1	2.7	-5.1	10.4	6.2	7.6	-1.4	-3.9	1.1	22.7	26.1	-3.4	-13.0	6.3
		Mean	18.8	17.5	1.3	-3.7	6.3	4.6	5.9	-1.3	-3.4	0.8	17.1	19.4	-2.3	-7.5	2.9
		Time %	95.7	80.7	15.0	1.2	28.8	25.8	45.6	-19.7	-45.2	5.7	79.6	85.6	-5.9	-23.1	11.3
			RSCM					RUT					RT9				
Flex	Away	Peak	23.9	26.6	-2.7	-14.3	8.9	5.9	4.0	1.9	-0.5	4.4	32.0	35.1	-3.1	-11.0	4.8
		Mean	11.0	13.1	-2.1	-7.5	3.2	3.9	3.0	0.9	-0.6	2.4	25.5	27.5	-2.0	-8.5	4.4
		Time %	63.0	68.8	-5.8	-22.9	11.2	33.3	34.3	-1.0	-20.0	18.1	87.3	89.7	-2.4	-19.8	15.0
	Return	Peak	18.2	23.1	-5.0	-14.3	4.4	6.0	5.1	0.9	-2.1	3.8	28.4	34.0	-5.6	-13.1	1.9
		Mean	10.1	13.8	-3.7	-9.5	2.1	4.3	4.0	0.3	-2.0	2.6	22.3	26.9	-4.6	-10.8	1.6
		Time %	78.4	76.5	1.9	-11.7	15.5	48.4	51.0	-2.6	-24.7	19.5	80.3	92.6	-12.3	-30.8	6.2
	Ext	Peak	17.8	18.7	-1.0	-10.4	8.5	5.6	5.6	0.0	-2.6	2.6	23.2	29.5	-6.3	-13.5	0.9
		Mean	11.0	12.3	-1.3	-7.3	4.7	4.0	4.0	0.0	-2.2	2.2	17.6	22.4	-4.8	-10.4	0.7
		Time %	75.5	71.8	3.6	-12.2	19.4	45.3	43.4	1.9	-18.9	22.7	75.9	82.4	-6.5	-28.9	15.9
	Return	Peak	30.1	31.0	-0.9	-10.2	8.4	5.4	4.9	0.5	-2.0	3.0	23.7	29.0	-5.3	-13.3	2.7
		Mean	19.2	19.5	-0.3	-6.0	5.4	3.7	3.4	0.3	-1.9	2.4	17.8	22.6	-4.8	-11.4	1.8
		Time %	85.7	77.1	8.7	-5.0	22.3	40.9	37.6	3.2	-16.1	22.6	73.2	83.7	-10.5	-31.9	10.9

(CG – control group, EG – experimental group, Flex – flexion, Ext – extension, L – left, R – right, PC – posterior cervical, AS – anterior scalene, SCM – sternocleidomastoid, UT – upper trapezius, T9 – thoracic vertebrae 9, T4 – thoracic vertebrae 4, PC – posterior cervical, M – mean, MD – mean difference, CI – confidence interval, % - percentage)

Table 7.8: Mean differences between the groups for sEMG readings during left and right lateral flexion

			Adjusted means					Adjusted means					Adjusted means				
			CG		MD	CI		CG		MD	CI		CG		MD	CI	
			M	M		Lower	Upper	M	M		Lower	Upper	M	M		Lower	Upper
			LAS					LPC					LT4				
RLF	Away	Peak	12.4	15.8	3.4	-6.1	12.9	11.8	14.4	-2.6	-7.2	2.1	10.8	11.5	-0.6	-3.6	2.4
		Mean	6.4	9.3	-2.8	-6.9	1.2	7.7	9.1	-1.5	-4.0	1.1	9.1	8.9	0.2	-1.9	2.3
		Time %	24.0	47.9	-23.9	-48.7	1.0	66.6	61.6	5.0	-17.6	27.6	74.5	91.3	-16.9	-36.5	2.8
	Return	Peak	35.2	32.3	2.9	-8.6	14.4	15.5	14.4	1.1	-4.0	6.2	11.0	11.5	-0.6	-4.0	2.9
		Mean	20.3	18.1	2.2	-4.4	8.7	11.0	10.0	1.0	-2.3	4.3	8.9	9.6	-0.6	-3.1	1.8
		Time %	71.2	69.2	1.9	-15.3	19.2	76.7	67.5	9.1	-10.8	29.0	77.4	90.3	-12.9	-34.3	8.6
LLF	Away	Peak	35.6	37.8	-2.1	-13.4	9.1	19.9	20.7	-0.8	-7.9	6.2	10.8	12.2	-1.5	-4.4	1.4
		Mean	20.9	20.5	0.4	-6.4	7.1	12.3	12.2	0.0	-3.6	3.7	8.5	9.4	-0.9	-3.1	1.3
		Time %	81.4	76.3	5.1	-10.8	21.0	75.4	75.4	-0.1	-18.8	18.7	72.1	89.0	-16.9	-38.2	4.4
	Return	Peak	29.8	27.7	2.1	-12.5	16.7	18.6	21.8	-3.3	-13.1	6.6	9.4	11.2	-1.9	-4.9	1.2
		Mean	15.0	17.1	-2.1	-11.5	7.3	10.5	14.8	-4.3	-11.0	2.3	7.9	9.3	-1.4	-3.8	1.1
		Time %	57.7	62.8	-5.1	-25.6	15.3	71.2	69.5	1.7	-20.4	23.9	74.0	91.4	-17.4	-39.5	4.7
			RAS					RPC					RT4				
RLF	Away	Peak	43.3	41.1	2.2	-12.9	17.3	21.1	18.2	2.9	-2.0	7.8	5.7	6.8	-1.1	-2.7	0.5
		Mean	23.3	24.3	-1.0	-9.0	7.0	13.6	11.3	2.3	-1.2	5.8	6.3	5.9	0.4	-2.2	3.0
		Time %	80.9	81.2	-0.3	-16.3	15.8	77.2	82.6	-5.4	-24.9	14.2	78.4	79.1	-0.7	-19.0	17.6
	Return	Peak	35.5	33.2	2.2	-14.7	19.2	15.9	16.9	-1.0	-8.3	6.3	7.0	7.1	-0.1	-1.2	1.0
		Mean	17.1	18.1	-1.0	-11.6	9.7	9.8	10.5	-0.8	-5.7	4.2	5.7	6.9	-1.2	-3.1	0.7
		Time %	57.6	55.1	2.5	-20.4	25.4	60.1	67.5	-7.4	-32.5	17.7	76.6	76.1	0.5	-20.7	21.7
LLF	Away	Peak	8.0	14.1	-6.1	-13.0	0.8	11.4	11.1	0.3	-4.7	5.2	6.1	6.5	-0.4	-2.3	1.6
		Mean	4.5	8.3	-3.8	-7.9	0.2	7.6	7.3	0.3	-3.0	3.6	4.9	5.1	-0.2	-1.8	1.4
		Time %	31.4	28.4	3.0	-17.3	23.3	58.2	52.0	6.2	-17.7	30.1	75.2	82.7	-7.5	-26.4	11.4
	Return	Peak	25.6	28.8	-3.2	-11.7	5.2	17.4	14.2	3.2	-1.6	8.0	6.1	6.9	-0.8	-2.6	1.0
		Mean	15.4	15.7	-0.3	-5.0	4.3	12.2	9.9	2.3	-0.9	5.6	4.8	5.4	-0.6	-2.0	0.8
		Time %	71.8	73.3	-1.6	-20.4	17.2	73.2	74.8	-1.6	-21.9	18.6	78.8	83.9	-5.0	-25.9	15.9
			LSCM					LUT					LT9				
RLF	Away	Peak	8.8	14.5	-5.7	-16.2	4.8	9.6	9.2	0.3	-3.7	4.3	26.4	24.4	2.0	-2.9	6.9
		Mean	4.2	7.2	-3.0	-7.4	1.4	6.3	6.3	0.0	-3.5	3.5	20.1	18.8	1.3	-2.7	5.3
		Time %	34.5	50.9	-16.4	-40.4	7.7	29.3	63.8	-34.5	-57.9	-11.0	80.8	94.3	-13.4	-30.8	3.9

			Adjusted means					Adjusted means					Adjusted means				
			CG		MD	CI		CG		MD	CI		CG		MD	CI	
			M	M		Lower	Upper	M	M		Lower	Upper	M	M		Lower	Upper
LLF	Return	Peak	31.9	26.0	5.9	-4.6	16.4	8.0	8.2	-0.3	-4.8	4.3	28.3	26.4	1.8	-4.0	7.7
		Mean	18.4	13.7	4.7	-1.9	11.3	5.6	5.6	0.1	-3.6	3.7	22.7	20.9	1.8	-2.6	6.1
		Time %	81.7	80.9	0.7	-15.7	17.2	32.3	53.0	-20.7	-47.5	6.2	85.0	90.7	-5.7	-25.2	13.9
	Away	Peak	40.8	41.0	-0.1	-16.7	16.4	14.0	11.9	2.1	-3.4	7.6	20.7	22.4	-1.7	-5.8	2.4
		Mean	23.9	23.2	0.7	-10.1	11.5	10.0	8.2	1.9	-2.3	6.1	15.5	17.2	-1.7	-5.2	1.8
		Time %	88.1	80.6	7.5	-8.5	23.5	50.7	65.4	-14.7	-39.2	9.8	72.1	91.2	-19.2	-35.1	-3.3
	Return	Peak	29.7	37.3	-7.5	-23.6	8.5	11.1	10.1	1.0	-2.4	4.3	18.7	20.2	-1.5	-7.2	4.2
		Mean	14.4	20.5	-6.1	-16.7	4.5	8.3	7.6	0.7	-2.0	3.3	14.3	16.1	-1.8	-5.3	1.6
		Time %	72.0	59.6	12.4	-11.5	36.3	45.2	64.9	-19.7	-45.7	6.2	68.0	84.6	-16.5	-33.2	0.1
			RSCM					RUT					RT9				
RLF	Away	Peak	46.0	51.1	-5.1	-24.3	14.0	10.5	8.3	2.2	-1.8	6.1	23.8	26.5	-2.8	-9.3	3.7
		Mean	24.3	30.2	-5.9	-17.9	6.1	7.3	5.5	1.8	-0.9	4.5	18.2	20.1	-2.0	-7.0	3.1
		Time %	84.1	88.3	-4.2	-20.0	11.6	55.7	61.1	-5.5	-27.9	17.0	72.0	73.4	-1.4	-24.4	21.6
	Return	Peak	33.5	43.7	-10.2	-29.6	9.1	8.7	7.6	1.1	-1.8	4.0	22.5	25.4	-2.9	-8.7	2.9
		Mean	15.9	24.2	-8.3	-20.6	3.9	6.6	5.4	1.2	-1.1	3.5	17.0	20.1	-3.1	-7.5	1.3
		Time %	59.4	66.7	-7.3	-25.0	10.5	45.9	57.6	-11.7	-35.6	12.1	73.5	72.5	1.0	-22.8	24.8
	Away	Peak	9.2	16.5	-7.3	-16.4	1.9	7.0	5.9	1.1	-2.1	4.3	30.3	30.8	-0.5	-7.4	6.3
		Mean	4.7	8.7	-4.0	-8.8	0.8	4.9	3.8	1.1	-1.1	3.4	23.8	24.0	-0.2	-5.7	5.3
		Time %	35.1	52.6	-17.5	-38.7	3.8	25.3	35.4	-10.1	-31.8	11.6	76.3	87.4	-11.1	-34.1	11.8
Return	Peak	27.1	31.2	-4.0	-15.9	7.8	6.2	4.3	1.9	-0.9	4.6	27.9	31.6	-3.7	-10.6	3.2	
	Mean	16.9	17.1	-0.3	-7.1	6.6	4.8	3.2	1.6	-0.6	3.9	22.9	25.9	-3.1	-9.2	3.0	
	Time %	72.9	83.8	-11.0	-30.0	8.0	36.6	46.8	-10.2	-30.8	10.4	78.3	87.7	-9.4	-32.8	13.9	

(CG – control group, EG – experimental group, LF – lateral flexion, L – left, R – right, , PC – posterior cervical, AS – anterior scalene, SCM – sternocleidomastoid, UT – upper trapezius, T9 – thoracic vertebrae 9, T4 – thoracic vertebrae 4, PC – posterior cervical, M – mean, MD – mean difference, CI – confidence interval, % - percentage)

Table 7.9: Mean differences between the groups for sEMG readings during left and right rotation

			Adjusted means					Adjusted means					Adjusted means				
			CG		MD	CI		CG		MD	CI		CG		MD	CI	
			M	EG		M	M	Lower	Upper		M	M	Lower	Upper		M	M
			LAS					LPC					LT4				
Rrot	Away	Peak	22.3	25.3	-3.1	-9.4	3.3	23.3	31.1	-7.8	-21.5	5.9	12.5	13.3	-0.9	-4.6	2.9
		Mean	13.6	14.5	-0.9	-5.9	4.1	17.6	17.6	0.0	-9.5	9.6	10.5	10.2	0.3	-2.6	3.3
		Time %	60.5	64.4	-3.9	-18.7	11.0	83.1	80.1	3.1	-14.3	20.4	81.4	92.5	-11.1	-30.9	8.6
	Return	Peak	24.6	26.8	-2.3	-9.2	4.7	23.5	24.5	-1.0	-8.5	6.6	11.7	12.4	-0.6	-3.7	2.4
		Mean	16.5	16.9	-0.4	-4.5	3.7	16.1	16.8	-0.7	-6.2	4.7	9.6	10.3	-0.8	-3.3	1.8
		Time %	67.2	71.6	-4.4	-23.2	14.3	82.2	88.9	-6.7	-21.5	8.1	78.5	96.1	-17.6	-36.4	1.2
Lrot	Away	Peak	24.0	21.6	2.3	-8.4	13.0	53.8	50.4	3.4	-13.6	20.5	10.8	11.0	-0.2	-3.2	2.7
		Mean	12.3	12.7	-0.4	-4.8	4.1	28.0	29.7	-1.6	-11.1	7.9	8.5	9.4	-0.9	-3.2	1.3
		Time %	56.8	61.6	-4.7	-23.0	13.6	85.6	87.9	-2.3	-12.5	7.9	76.3	88.6	-12.4	-32.9	8.1
	Return	Peak	21.2	21.6	-0.4	-9.7	9.0	48.2	47.4	0.9	-19.6	21.3	11.9	12.3	-0.4	-4.5	3.6
		Mean	12.1	14.4	-2.3	-7.4	2.7	24.4	30.3	-5.9	-19.8	8.1	10.0	10.4	-0.4	-3.5	2.8
		Time %	52.0	53.8	-1.8	-23.3	19.8	82.4	81.3	1.1	-17.2	19.3	76.0	85.8	-9.8	-32.7	13.1
			RAS					RPC					RT4				
Rrot	Away	Peak	20.7	18.4	2.2	-6.0	10.5	54.4	50.9	3.5	-12.4	19.3	6.3	6.3	0.0	-1.9	1.9
		Mean	11.3	10.9	0.4	-3.0	3.8	32.2	29.8	2.3	-5.8	10.4	5.0	4.9	0.1	-1.7	1.8
		Time %	67.9	71.5	-3.6	-24.5	17.3	93.6	94.3	-0.7	-13.2	11.9	81.0	78.4	2.5	-15.2	20.2
	Return	Peak	18.2	19.5	-1.3	-11.0	8.4	47.7	52.1	-4.4	-24.4	15.6	6.8	7.2	-0.4	-2.9	2.0
		Mean	10.6	12.1	-1.5	-5.4	2.4	25.9	30.7	-4.8	-18.8	9.2	5.7	5.6	0.0	-1.9	2.0
		Time %	54.7	62.3	-7.6	-27.5	12.3	79.4	91.5	-12.1	-27.3	3.1	86.3	83.6	2.7	-14.2	19.7
Lrot	Away	Peak	19.4	18.8	0.6	-5.5	6.7	26.1	29.4	-3.3	-16.8	10.2	6.4	7.1	-0.7	-3.0	1.7
		Mean	10.6	10.6	0.0	-3.3	3.3	15.0	17.6	-2.6	-12.9	7.6	5.1	5.5	-0.4	-2.3	1.4
		Time %	55.5	62.0	-6.5	-27.3	14.3	72.0	76.3	-4.3	-22.7	14.2	84.4	84.2	0.3	-15.3	15.9
	Return	Peak	21.1	20.4	0.7	-6.1	7.5	25.3	24.0	1.4	-6.5	9.2	6.7	6.0	0.7	-1.6	3.0
		Mean	12.2	13.6	-1.4	-5.3	2.5	15.3	16.4	-1.1	-6.3	4.0	5.3	5.2	0.1	-1.6	1.9
		Time %	65.3	71.8	-6.4	-28.6	15.7	81.7	85.4	-3.6	-21.7	14.4	82.4	81.0	1.5	-17.2	20.1
			LSCM					LUT					LT9				
Rrot	Away	Peak	47.9	48.6	-0.7	-14.9	13.5	12.4	8.9	3.5	-0.8	7.8	25.7	21.9	3.8	-1.8	9.4
		Mean	24.3	26.0	-1.7	-10.1	6.7	8.6	6.3	2.4	-1.4	6.1	20.5	17.4	3.1	-1.7	7.9
		Time %	80.3	84.1	-3.8	-21.3	13.7	39.5	60.6	-21.1	-46.7	4.5	80.1	94.6	-14.5	-30.9	1.9

			Adjusted means					Adjusted means					Adjusted means				
			CG		MD	CI		CG		MD	CI		CG		MD	CI	
			M	EG		Lower	Upper	M	EG		Lower	Upper	M	EG		Lower	Upper
Lrot	Return	Peak	47.3	49.9	-2.6	-18.6	13.5	9.7	8.4	1.3	-2.5	5.0	24.6	22.7	1.9	-4.2	7.9
		Mean	26.3	29.2	-2.9	-14.8	9.0	7.3	6.5	0.8	-2.4	4.1	20.1	18.7	1.3	-3.1	5.7
		Time %	85.2	81.7	3.5	-13.8	20.7	37.5	53.6	-16.1	-42.7	10.4	81.4	91.9	-10.6	-27.9	6.8
	Away	Peak	17.3	21.1	-3.9	-13.7	6.0	7.5	7.9	-0.4	-4.2	3.4	20.8	19.5	1.3	-2.6	5.2
		Mean	9.1	10.4	-1.3	-7.0	4.4	4.5	5.4	-0.9	-3.3	1.6	16.2	15.2	1.0	-2.4	4.4
		Time %	70.7	71.1	-0.4	-20.0	19.1	27.7	49.2	-21.5	-44.7	1.7	77.0	85.5	-8.6	-26.9	9.7
	Return	Peak	15.5	17.0	-1.5	-9.3	6.3	7.4	7.5	-0.1	-3.6	3.4	21.7	19.1	2.6	-2.3	7.5
		Mean	8.8	10.8	-2.0	-7.0	2.9	5.1	5.4	-0.3	-3.1	2.4	17.2	16.2	1.0	-2.5	4.6
		Time %	69.4	68.3	1.1	-19.9	22.1	32.2	45.0	-12.9	-38.8	13.0	76.3	91.5	-15.2	-32.5	2.2
			RSCM					RUT					RT9				
Rrot	Away	Peak	19.0	21.6	-2.6	-13.6	8.4	6.7	5.4	1.3	-1.3	3.9	24.1	24.2	0.0	-3.8	3.7
		Mean	11.5	10.3	1.2	-4.3	6.7	4.4	3.5	1.0	-1.2	3.1	18.9	19.4	-0.5	-3.8	2.7
		Time %	66.0	80.6	-14.6	-33.7	4.4	43.4	57.8	-14.5	-37.8	8.9	74.5	76.9	-2.3	-24.9	20.3
	Return	Peak	14.7	19.5	-4.8	-13.2	3.6	7.2	4.6	2.6	-1.0	6.3	22.6	24.8	-2.1	-6.6	2.3
		Mean	9.3	12.8	-3.5	-9.7	2.8	5.1	3.1	2.1	-1.2	5.3	18.6	20.5	-1.9	-5.6	1.8
		Time %	55.6	70.2	-14.6	-35.2	6.0	44.3	44.0	0.2	-24.0	24.5	70.4	81.4	-11.0	-34.7	12.6
	Away	Peak	50.0	50.3	-0.4	-14.3	13.6	8.4	6.1	2.3	-1.7	6.2	29.0	28.6	0.4	-4.1	4.9
		Mean	22.5	24.6	-2.1	-10.0	5.9	5.9	4.4	1.5	-1.2	4.3	22.3	22.9	-0.6	-4.5	3.4
		Time %	69.8	78.7	-8.9	-23.4	5.6	42.5	46.0	-3.5	-26.7	19.7	71.5	88.4	-16.9	-39.3	5.5
Return	Peak	45.1	45.3	-0.2	-18.6	18.2	5.8	5.4	0.4	-2.5	3.2	26.2	26.2	0.0	-4.5	4.5	
	Mean	24.0	29.5	-5.4	-18.4	7.5	3.8	4.0	-0.2	-2.5	2.2	21.8	22.0	-0.2	-4.5	4.1	
	Time %	77.2	89.1	-11.8	-25.6	2.0	39.9	47.6	-7.7	-32.5	17.1	70.5	88.6	-18.1	-42.1	6.0	

(CG – control group, EG – experimental group, L – left, R – right, LF – lateral flexion, Rot – rotation, PC – posterior cervical, AS – anterior scalene, SCM – sternocleidomastoid, UT – upper trapezius, T9 – thoracic vertebrae 9, T4 – thoracic vertebrae 4, PC – posterior cervical, M – mean, MD – mean difference, CI – confidence interval, % - percentage)

time for LUT ($F(1,28) = 6.683, p = 0.015, \eta^2 = 0.187$), than the intervention group. In right lateral flexion, the LAS had greater return time percentage in the control group ($F(1,26) = 05.723, p = 0.024; \eta^2 = 0.18$), and for left lateral flexion, the control group had greater LAS away ($F(1,26) = 4.318, p = 0.048, \eta^2 = 0.142$) and return ($F(1,26) = 4.575, p = 0.042, \eta^2 = 0.042$) time percentage activation and the LPC had greater activation in away peak ($F(1,28) = 5.299, p = 0.029, \eta^2 = 0.159$) and away mean ($F(1,28) = 4.326, p = 0.049, \eta^2 = 0.134$) than the intervention group, as seen in **Table 7.10**. No differences were found between the groups for rotation motion. **Supplementary files 7.5 and 7.6** show the results of the ANCOVA analysis for sEMG at the tested time points.

Table 7.10: Significant between group difference for post-adjusted scores for muscle activation immediately following the first treatment and at the fourth visit

Motion	Muscle	Phase	Time point	Control				Intervention				MD	SE	p-value	CI		η ²
				M	SE	CI		M	SE	CI							
						Low	High			Low	High						
Flex	LPC	Return time %	P-P	94.0	5.9	82.0	94.0	70.6	5.9	5.9	82.7	23.3	8.8	0.012	5.4	41.3	0.18
Ext	LAS	Return time %	P-P	92.9	5.0	82.7	92.9	71.1	5.1	5.1	81.6	21.8	7.5	0.007	6.5	37.1	0.22
	LSCM	Return time %	P-P	96.7	4.7	87.1	96.7	79.1	4.8	4.8	88.9	17.7	7.2	0.019	3.1	32.3	0.16
RLF	LAS	Away mean	P-P	5.9	1.3	3.2	5.9	10.2	1.4	1.4	13.1	-4.3	2	0.041	-8.5	-0.2	0.13
		Away time %	P-P	23.0	8.0	6.8	23.0	49.9	8.7	8.7	67.5	-26.8	13	0.045	-53.0	-0.6	0.12
	LUT	Away time %	P-P	29.9	7.9	13.9	29.9	64.2	8.6	8.6	81.7	-34.2	12	0.008	-59.0	-9.4	0.19
	LT9	Return mean	P-P	23.5	1.3	20.8	23.5	18.9	1.5	1.5	22	4.6	2.2	0.049	0.0	9.2	0.12
LLF	RAS	Away peak	P-P	7.3	2.3	2.6	7.3	15.3	2.5	2.5	20.3	-8.0	3.5	0.029	-15.0	-0.9	0.15
		Away mean	P-P	4.1	1.4	1.3	4.1	9.0	1.5	1.5	12	-4.9	2.1	0.025	-9.1	-0.6	0.15
	LT9	Away time %	P-P	70.8	5.7	59	70.8	93.4	6.5	6.5	107	-22.6	9.1	0.019	-41.0	-4.0	0.16
RRot	RPC	Return time %	P-P	77.3	5.2	66.8	77.3	95.5	5.4	5.4	107	-18.3	7.7	0.024	-33.9	-2.6	0.15
	LT4	Return time %	P-P	76.8	6.4	63.8	76.8	100	6.9	6.9	114	-23.4	9.7	0.021	-43.1	-3.7	0.15
	RSCM	Away time %	P-P	63.9	6.3	51.0	63.9	84.6	6.7	6.7	98.2	-20.7	9.6	0.038	-40.2	-1.2	0.13
Flex	RAS	Return mean	P-V4	9.5	1.9	5.7	9.5	16.2	1.8	1.8	19.8	-6.68	2.8	0.024	-12.0	-1.0	0.18
	LT4	Return time %	P-V4	76.1	6.7	62.3	76.1	96.4	6.1	6.1	109	-20.3	9.2	0.035	-39.0	-1.5	0.15
Ext	RPC	Return peak	P-V4	10.9	1.3	8.3	10.9	6.94	1.2	1.2	9.33	3.95	1.8	0.034	0.3	7.58	0.15
		Return mean	P-V4	6.2	0.7	4.9	6.2	4.01	0.6	0.6	5.23	2.23	0.9	0.02	0.4	4.08	0.18
	LUT	Return time %	P-V4	64.8	9.7	44.9	64.8	29.7	9.2	9.2	48.6	35.1	14.0	0.015	7.3	62.9	0.19
RLF	LAS	Return time %	P-V4	80.5	8.4	63.3	80.5	53.1	7.3	7.3	68.1	27.4	11.0	0.024	3.9	50.9	0.18
LLF	LAS	Away time %	P-V4	88.7	8.4	71.4	88.7	65	7.4	7.4	80.2	23.7	11.0	0.048	0.3	47.1	0.14
		Return time %	P-V4	79.2	10.0	58.4	79.2	49.8	9.1	9.1	68.5	29.4	14	0.042	1.2	57.7	0.15
	LPC	Away peak	P-V4	23.9	2.4	19.0	23.9	16.3	2.2	2.2	20.8	7.63	3.3	0.029	0.8	14.4	0.16
		Away mean	P-V4	15.2	1.7	11.7	15.2	10.3	1.6	1.6	13.5	4.95	2.4	0.047	0.1	9.82	0.13

(Flex – flexion, Ext – extension, L – left, R – right, LF – lateral flexion, Rot – rotation, PC – posterior cervical, AS – anterior scalene, SCM – sternocleidomastoid, UT – upper trapezius, T9 – thoracic vertebrae 9, T4 – thoracic vertebrae 4, PC – posterior cervical, P-P – pre to post, P – V4 – pre to visit 4, M – mean, SE – standard error, CI – confidence interval, η^2 – partial eta squared, % - percentage)

Pearson's correlation assessed for correlations between pain, kinematics and muscle activation in the control and intervention group. In the control group moderate to strong correlations were found for away velocity average during extension was positively correlated with pain ($r(28) = 0.645$; $p = 0.09$). There were no other significant correlations found for the control group for cervical kinematics. Correlations were found in the control group during flexion there was a negative relationship between pain and muscle activation in the LAS for away peak ($r(26) = -0.61$, $p = 0.027$) and mean ($r(24) = -0.67$, $p = 0.012$) activation; RAS for away activation time percentage ($r(27) = -0.54$, $p = 0.049$); LSCM for away peak ($r(26) = -0.56$, $p = 0.046$) and mean ($r(26) = -0.64$, $p = 0.018$) activation; right lateral flexion there was a positive relationship between pain and muscle activation in the RT4 during return activation time percentage ($r(27) = 0.71$, $p = 0.004$); RSCM during away activation time percentage ($r(24) = 0.62$, $p = 0.041$); left lateral flexion there was a positive relationship between pain and muscle activation in the RT4 for away ($r(27) = 0.71$, $p = 0.002$) and return ($r(27) = 0.61$, $p = 0.022$) activation time percentage and a negative relationship between pain and muscle activation in the LPC during away mean activation ($r(27) = -0.55$, $p = 0.044$); right rotation there was a positive relationship between pain and RT4 during away ($r(27) = 0.83$, $p < 0.001$) and return ($r(27) = 0.62$, $p = 0.019$) activation time percentage and left rotation there was a positive relationship between pain and LPC during away activation time percentage ($r(28) = 0.52$, $p = 0.045$); RPC during away activation time percentage ($r(27) = 0.54$, $p = 0.045$); RT4 during away ($r(26) = 0.79$, $p = 0.001$) and return ($r(26) = 0.71$, $p = 0.004$) activation time percentage.

For the intervention group, there were no significant correlations found between pain and cervical kinematics ($p > 0.05$). The following moderate correlations were found between pain and muscle activation during flexion there was a positive relationship between pain and LUT during away ($r(32) = 0.49$, $p = 0.048$) and return ($r(32) = 0.49$, $p = 0.046$) activation time percentage; extension there was a positive relationship was found between pain and RPC during return peak ($r(36) = 0.63$, $p = 0.006$) and mean ($r(36) = 0.53$, $p = 0.027$) activation; RT4 during away peak ($r(32) = 0.67$, $p = 0.004$) and mean ($r(32) = 0.61$, $p = 0.010$) activation; RUT during away activation time percentage ($r(32) = 0.53$, $p = 0.027$); right lateral flexion a positive relationship was

found between pain and RUT for return activation time percentage ($r(32) = 0.48$; $p = 0.049$); left lateral flexion a positive relationship was found between pain and RPC during return mean ($r(32) = 0.51$, $p = 0.035$) and return activation time percentage ($r(32) = 0.54$, $p = 0.027$); RUT return activation time percentage ($r(32) = 0.57$; $p = 0.016$); and a negative relationship for the LT9 during return activation time percentage ($r(31) = -0.57$; $p = 0.023$); right rotation there was a positive relationship between pain and RPC during return peak activation ($r(32) = 0.61$; $p = 0.010$); LUT during return activation time percentage ($r(32) = 0.54$; $p = 0.026$), RT9 away ($r(32) = 0.50$; $p = 0.042$) and return peak ($r(32) = 0.54$; $p = 0.027$) and mean ($r(32) = 0.63$; $p = 0.007$) activation and left rotation there was a positive relationship between pain and RAS during away peak ($r(31) = 0.52$; $p = 0.040$), return peak ($r(31) = 0.57$; $p = 0.022$) and mean activation ($r(31) = -0.55$; $p = 0.029$); T9 during return mean activation ($r(32) = 0.49$; $p = 0.048$).

Patient global impression of change and treatment satisfaction

Figure 7.5 shows the responses per group to the PGIC assessment, no significant differences were found between the two groups ($p = 0.455$), using Fischer's Exact test. Analysis of the rating of global improvement on the line scale comparing the control (3.1 ± 1.6 , $n=15$) to the SMT group (2.0 ± 1.8 , $n=19$) found no significant between group effects using independent sample t-tests ($t(32) = -2.018$, $p = 0.052$, $d = -0.67$).

Figure 7.6 presents the results for the level of satisfaction. There were no significant differences between the groups for the level of satisfaction questionnaire for the domains of activity ($p = 0.068$), symptoms ($p = 0.724$), if they were satisfied with the change in their neck pain ($p = 0.100$), if they would choose chiropractic care ($p = 1.000$), spinal manipulation ($p = 0.426$) for future treatment or if they would return to the facility for future care ($p = 1.000$), assessed using Fischer's Exact test. Significant differences were found between the groups, with the SMT group having a greater number of participants reporting that their emotions ($p = 0.001$) and quality of life ($p = 0.025$) were better. The following comments were made by those in the intervention group ($n=4$): "I'm glad to not feel the sting of the neck pain", "I'm returning next week for my back", "No headaches since the last treatment", "the very moments and hours

after chiropractic care my neck is back to normal” and “treatment was very comfortable”. These comments were made by those in the control group (n=2): “I can feel a lot of change and the treatment was not painful” and “thank you for the much-needed help on my neck”.

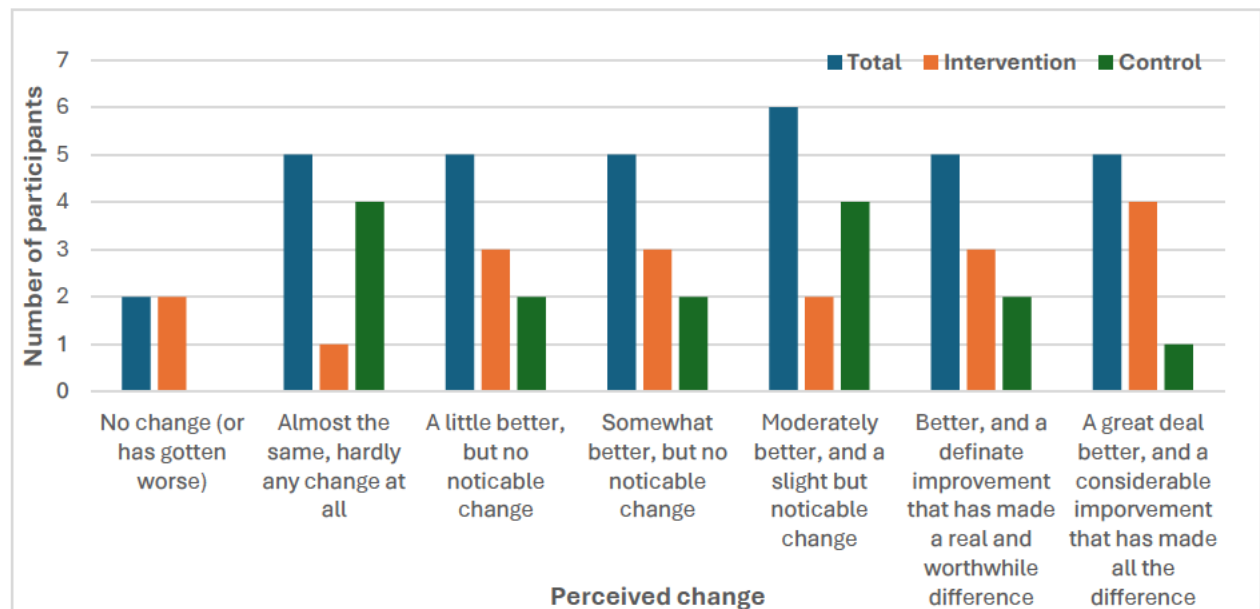


Figure 7.5: Patients global impression of change scores

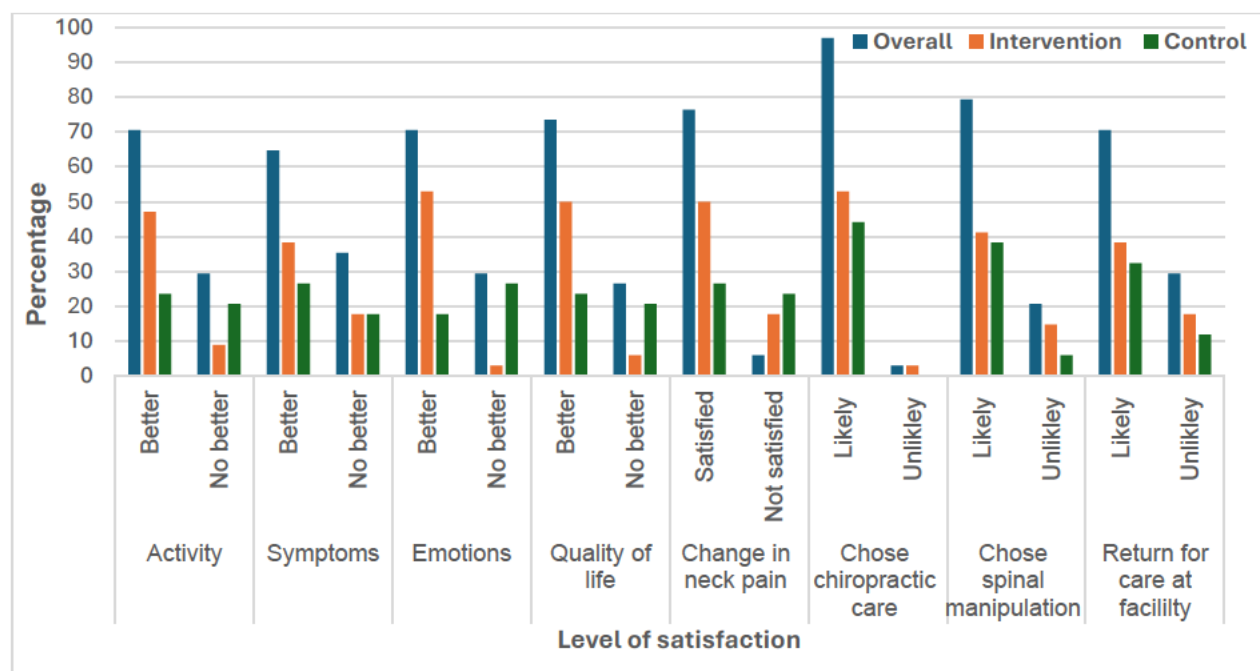


Figure 7.6: Level of satisfaction with care

Adverse events

In this study minor adverse events were defined as short-term, mild, non-serious, transient, reversible consequences of the treatment (Saavedra-Hernández *et al*, 2012). In the intervention group 7 participants complained of mild tenderness following one treatment (34%), and in the control group 4 participants experience mild tenderness (27%). All symptoms resolved within 24 hours. One participant in the control group developed shingles between the first and second appointment and was excluded from the study.

DISCUSSION

This study investigated the effect of cervical spine manipulation compared to control on cervical kinematics and muscle recruitment patterns during cervical ROM. It was found that both groups showed improvements in pain and disability, with the SMT group having greater improvements in both measures with large effect sizes, with neither measure crossing the clinically important different threshold. The groups were similar in duration to execute cervical ROM and peak displacement, with cervical kinematics differing between the groups with the SMT group having increased jerk and reduced cervical flexor and extensor muscle activity following one treatment. At the fourth visit, this pattern changed, where only flexion motion displayed increased jerk in the SMT group, and muscle activation varied between the groups' normalising function in the intervention group, with the control group showing increased activity of the AS, SCM and UT. The groups reported similar levels of perceived improvement and satisfaction with the treatment, with more participants in the SMT group reporting improved emotions and quality of life.

SMT has been associated with pain relieving effects in neck pain (Coulter *et al*. 2019; Chaibi, Stavem and Russell 2021), which was supported by the results of this study, with a large effect. Following three treatments the between group differences were close to the clinically significant threshold proposed by Young *et al* (Young *et al*. 2019) for change in pain intensity. Several mechanisms have been proposed to induce pain relief following SMT (Bialosky *et al*. 2018; Gevers-Montoro *et al*. 2021b). Therapeutic touch has been linked to pain reduction (Mancini *et al*. 2014), not only due to cognitive

processes but through tactile interaction (Harper and Hollins 2012). In both groups skin contact was made through identification of the restricted motion segment and during moving the joint to end-range, allowing the activation of the mechanoreceptors and afferent feedback to the central nervous system (Pickar 2002; Pickar and Bolton 2012). The difference between the two groups was the thrust, where the SMT group experienced tissue loading, followed by the delivery of a force to the tissues. Although the biomechanical parameters of the SMT application were not assessed in this study the delivery was in line with a HVLA thrust (Bergmann and Peterson 2010). These characteristics have been associated with vertebral displacement, muscle spindle activity, neuronal and EMG responses (Nougarou *et al.* 2016; Gyer *et al.* 2022).

Neurophysiological process occurring following SMT has been proposed to activate the descending inhibitory control mechanism, through activation of the periaqueductal grey region in the midbrain, where the noradrenergic descending system is activated resulting in reduction of nociception at the level of the spinal cord, inducing mechanical hypoalgesia (Savva, Giakas and Efstathiou 2014). Significant between group effects were only found during the course of the treatment, with both groups reporting similar pain improvement at the one week follow up. In a study using a similar treatment approach (four sessions over two weeks) but comparing SMT to two mobilisation techniques in the treatment of neck pain, reported no between group differences in pain after four sessions, with all groups having improvement in pain (Izquierdo Pérez *et al.* 2014). It has been recommended that chiropractic care for chronic musculoskeletal conditions of moderate to severe pain should consist of two to three sessions per week over two to four weeks (Hawk *et al.* 2020). It is possible that stopping the treatment at two weeks may have been too early and continued treatment may have been necessary, to elicit a more definitive between group effect.

The placebo effect may have played a part in the results of this study, as it has both physiological and psychological effects on pain (Bialosky *et al.* 2011) and may explain the improvement observed in the control group over the course of the study. In terms of pain relief, the effect of SMT is influenced by the dose and velocity of the application (Pasquier *et al.* 2019; Lardon *et al.* 2022) together with patient and provider characteristics (Bialosky *et al.* 2018). Patient expectations impact treatment outcomes

(Plank *et al.* 2021). There were no differences between the groups in terms of prior exposure to chiropractic treatment, with most participants having not received chiropractic treatment before. Thus, it is unlikely that those in the control group were aware that the technique that was used should have had a 'joint clinking' aspect to it, leading them to feel that they were not receiving an active treatment. In addition, care was taken when explaining the research that two forms of manual manipulation were being tested, with no emphasis on cavitation. When asked about the level of satisfaction with the care received and if they would select this type of treatment in the future there were no differences between the groups, supporting that it is unlikely that those receiving the control felt like it was not a 'real' treatment.

Neck pain is a leading cause of disability (Safiri *et al.* 2020; Shin *et al.* 2022) impacting a person's ability to function optimally at work (Côté *et al.* 2008) and home (Falsiroli Maistrello *et al.* 2022). The level of self-reported disability improved in both groups, with greater improvements occurring in the SMT group supporting previous research (Gross *et al.* 2015; Gevers-Montoro *et al.* 2021a). The improvements did not exceed minimal clinical detectable change scores (Vernon and Mior 1991; Young *et al.* 2019), despite large effect sizes. The SMT group reported improved emotions and quality of life ratings on the level of satisfaction questionnaire, however this survey has not been validated. At entry into the study the control group did express lower levels of physical health and social functioning when compared to the intervention group and this may have affected their response.

Clinical practice guidelines for neck pain recommend assessing cervical ROM as part of the clinical assessment (Blanpied *et al.* 2017), however, its usefulness in assessing change to treatment has been questioned (Snodgrass *et al.* 2014). In this study no difference was found for peak displacement between the groups, supporting previous research (Martínez-Segura *et al.* 2006; Izquierdo Pérez *et al.* 2014; Valera-Calero *et al.* 2019; Serra-Añó *et al.* 2023). Biomechanical theories suggest that during SMT there is releasing of entrapped synovial folds or meniscoids (Shekelle 1994; Evans 2002) which then results in an increased range. A recent review supports an increase in lumbar facet joint space and decreased spinal stiffness following SMT (Young *et al.*

2024), however, due to the mobility of the cervical spine, these changes may not lead to a gross improvement in ROM.

In an attempt to assess the neuromusculoskeletal effects of SMT in this study, we assessed cervical kinematic and muscle activation responses to single and multiple SMT treatments. Cervical kinematics were not significantly different to those in the control group except for jerk across the motions and velocity in rotation, with these effects being most prominent following one treatment. The reliability of the jerk measures is questioned based on an earlier study (chapter four), thus should be interpreted with caution. Increased velocity in the SMT group during rotation occurred with no between group differences in the muscles that execute cervical rotation. This contrasts with a study were following cervical mobilisation when compared to a control, both groups had increased cervical velocity with no between group differences (Lascurain-Aguirrebeña *et al.* 2018a). Altered neck velocity in neck pain has been associated with kinesiophobia (Meisingset *et al.* 2015) (Sarig Bahat *et al.* 2014) and fear avoidance behaviour (Vikne *et al.* 2013). Participants were screened and excluded if they displayed signs of fear avoidance behaviours and central sensitisation, therefore minimising the effect that this could have on the results. It is possible that following the initial treatment the intervention group participants may have been more cautious about moving their necks, however, no other ROMs showed altered velocity.

There is a paucity of trials assessing cervical kinematic changes following spinal manipulation. In the only other trial assessing spinal movement smoothness following SMT, Serra- Añó *et al* (Serra-Añó *et al.* 2023) reported that movement harmony (the absolute value of the correlation coefficient between the angle (Θ) and the angular acceleration ($\ddot{\Theta}$)) was reduced in the SMT group when compared to a control, following one treatment to the cervical spine. Supporting the findings of this study. The increased jerk cannot be explained due to pain, as there were no significant correlations, between jerk and pain intensity. When comparing those with and without neck pain in an earlier study O'Connor *et al* (2025)(Chapter five) found that those with neck pain differed from those without neck pain for velocity but not jerk. The increased jerk, or reduction in movement smoothness (Wolpert, Ghahramani and Jordan 1995;

Hogan and Sternad 2009), may have occurred due to afferent bombardment of the dorsal horn following the HVLA thrust manipulation, resulting in inhibition of muscle activity (Pickar 2002). This would be supported by the control group having significantly increased cervical muscle activation levels during flexion/extension, in line with normal muscle firing patterns for these motions. This pattern was not observed in the other motions where greater activity was seen in the AS when acting eccentrically during lateral flexion and in the right SCM, PC and left T4 during rotation in the SMT group. SMT has been shown to increase the activation of lower threshold motor units, suited to low force production and precise action (Robinault *et al.* 2021), this would lead to greater control, which based on these results did not occur due to the increased jerk observed in the SMT group. However as previously mentioned the jerk readings were mostly of low reliability (chapter four), warranting further exploration of this finding.

By the fourth visit, only jerk during flexion motion was higher in the SMT group, with muscle activation patterns changing between the groups. The reliability of the OptiTrack system was not assessed longitudinally, and it is possible that like the immediate reliability that the longitudinal reliability would be low. In terms of the muscle activity, over time it appears that the intervention group had a “normalising” effect on muscle function with the control group relying on faulty motor recruitment strategies, seen as increased activity of the AS, SCM and UT. Over activity in the AS, SCM and upper trapezius have been found in neck pain patients (Barton and Hayes 1996; Falla, Jull and Hodges 2004b) and are proposed to be maladaptive control strategies in neck pain (Falla and Farina 2007).

Correlation analysis of pain and cervical kinematics showed only one positive relationship and that was in the control group where pain was moderately correlated with extension away velocity, no correlations were found for the SMT group for the cervical kinematics. Few studies include correlation analysis of patient reported outcomes with ‘objective’ measures following SMT interventions for neck pain, despite calls for this to occur (Stenneberg *et al.* 2017). In a longitudinal study of neck pain participants, following physiotherapy treatment which included SMT, found weak correlations between pain and cervical ROM (Chiu, Lam and Hedley 2005), whereas

Martinez-Segura et al (2006) after one treatment of SMT found a negative relationship between pain and cervical ROM reporting that less pain was reported at rest with increased neck ROM (Martínez-Segura *et al.* 2006). Participants were not asked if they perceived that they could move better/more effectively, this is something that future studies may consider seeing if changes in the quality of motion are meaningful to patients.

Several positive correlations were found in both groups from visit one to four, for pain and muscle activation patterns for the muscle of the cervicothoracic region. In the control group as pain decreased muscle activity increased during ROM in the left and right AS, SCM, PC and RT4, whereas in the intervention group, the increased activity was found in the left and right UT, PC, T9 and right T4 and AS. Neck pain has been characterised as having increased muscle activity in the superficial neck muscles with decreased activation in the deep flexor muscles (Falla *et al.* 2003; Falla *et al.* 2004a; Falla and Farina 2007), as can be seen in this study in the control group as pain decreased, the increased activity in the neck muscles persisted, whereas in the SMT group, only the AS had increased activity and this was during left rotation motion. Motor patterns are variable (Bergin *et al.* 2014) and this variability may impact the correlations between kinematic and muscle activation outcomes and pain. There are no studies where minimally clinical important differences have been documented for muscle activity, thus although these muscles showed significant differences it cannot be quantified if those differences have clinical meaning. They do indicate that SMT alters muscle activity, supporting neurophysiological theories explaining the effects of SMT.

SMT has been associated with a barrage of afferent firing from muscle spindles, Golgi tendon organs and high threshold mechanoreceptors which elicit a cascade of neurophysiological response which changes post-synaptic response (Pickar and Bolton 2012). Some studies have shown altered alpha-motor neuron excitability (Niazi *et al.* 2015; Christiansen *et al.* 2018; Holt *et al.* 2019) and motor unit recruitment (Robinault *et al.* 2021) following SMT. Which may explain the results observed in this study. It is important to note that patterns of motor control disturbances in chronic neck pain are varied can be individualised and may not necessarily be due to pain

(Sjölander *et al.* 2008). However, changes were observed as pain levels changed. Highlighting the need for further research into understanding the impact of pain on the motor system and how therapeutic interventions impact it. In addition, the motor system has great adaptability to optimising task execution (Mulla and Keir 2023), which may compensate for and make the small changes from therapeutic interventions less noticeable.

Strength and limitations

This is one of the first studies to assess the effect of cervical spinal manipulation on cervical kinematics and muscle recruitment patterns in neck pain participants during active cervical ROM. It adds to a growing body of knowledge highlighting the neurophysiological effects of spinal manipulation and opens avenues for further investigation.

The mechanical event of SMT stimulates neurophysiological processes whereby the peripheral, spinal and supraspinal structures modulated its effects (Pickar 2002; Pickar and Bolton 2012; Gyer *et al.* 2019; Wirth *et al.* 2019; Gevers-Montoro *et al.* 2021b; Haavik *et al.* 2021). The force and velocity of the interventions in this trial were not controlled. Recent work highlights that these characteristics of the application of HVLA-SMT influence the neurophysiological responses, thereby potentially influencing treatment outcomes (Nougarou *et al.* 2016; Gyer *et al.* 2022). Future studies should include monitoring these biomechanical properties of SMT during treatment application. In addition the reliability of the motion capture system was only done for within day reliability, future studies should assess the longitudinal reliability if the system.

In this study there were more males in the control group. It has been reported that women experience more neck pain than men (Kazeminasab *et al.* 2022) and that the way females and males experience pain is different (Keogh 2025). Although the analysis controlled for age and sex, the baseline difference may could indicate that the randomisation was not optimal.

There are limitations with normalization procedures of the surface EMG amplitude (Duchateau, Semmler and Enoka 2006) and conducting between day assessments (Halaki and Ginn 2012). A standardised laboratory set up was utilised, with one person applying the electrodes, to try and minimise between day variations. However, cross talk and electrode interference may have influenced the results. Similarly, with the application of the reflective markers for capturing human movement, between day application sites may have varied. Although efforts were put in place to minimise this by using a tape measure and bony landmarks, it is possible that it may have influenced the results.

CONCLUSION

Cervical SMT resulted in improved pain and disability, with participants reporting improved emotions and quality of life. In terms of kinematics cervical SMT resulted in increased rotation velocity and jerk in flexion, lateral flexion and left rotation in the immediate term with increased jerk in flexion and left rotation in the short term. Indicating that the movement may have increased but it was less smooth than that seen in the control group. Muscle activation patterns following SMT resulted in increased activation during lateral flexion and rotation immediately after one session with greater activation occurring in the control group in the short term. This finding suggests a more normal response to neck motion. These findings add to a growing body of literature regarding the effects of cervical SMT on motor control.

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Conflict of interest

The authors declare no conflict of interest related to this research.

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CHAPTER EIGHT
MANUSCRIPT SIX:
RANDOMISED CONTROLLED TRIAL INVESTIGATING
CERVICAL SPINAL KINEMATIC AND MUSCLE
RECRUITMENT PATTERN RESPONSES DURING TWO
FUNCTIONAL UPPER LIMB TASKS FOLLOWING
CERVICAL SPINAL MANIPULATION

8.1 BACKGROUND TO THE CHATER

The upper extremity has an intimate relationship with the cervical and thoracic spine (Katsuura *et al.* 2020). It receives its neurological supply from the cervical spine (Betteridge, Taylor and Hartley 2021) with many of the stabilising muscles attaching to the cervical and thoracic spine either directly or via the scapulae (Ludewig and Reynolds 2009). Studies have shown that when moving the extremities there is feedforward activation of the stabilising neck muscles prior to this movement (Hodges and Richardson 1999; Hodges, Cresswell and Thorstensson 2001; Hodges and Tucker 2011), however in neck pain these mechanisms are delayed (Falla, Jull and Hodges 2004). Potentially leaving the cervical spine vulnerable to perturbations (Falla and Farina 2007).

A few case controlled studies have investigated the effect that neck pain has on spinal kinematics while utilising the upper extremity in various tasks such as unilateral, overhead reaching (Tsang, Szeto and Lee 2014; Snodgrass *et al.* 2016; Moghaddas, Edwards and Snodgrass 2022, chapter six), ball catching (Grip *et al.* 2008) and putting on a safety belt (Snodgrass *et al.* 2016; Moghaddas, Edwards and Snodgrass 2022). They revealed that those with neck pain have altered movement strategies during these tasks. One trial (Tsang, Szeto and Lee 2014) included the assessment of muscle activation patterns, together with spinal kinematic assessment, while participants with and without neck pain lifted a two-kilogram weight in the seated position. This study revealed that not only are kinematics altered in those with neck pain, but muscle recruitment strategies were also affected during a single arm task.

There is a growing body of literature indicating that spinal manipulation (SMT) results in neurophysiological effects that not only alter local reflexes but can impact spinal and central control systems (Pickar 2002; Bialosky *et al.* 2009; Pickar and Bolton 2012; Bialosky *et al.* 2018; Gyer *et al.* 2019; Gevers-Montoro *et al.* 2021; Haavik *et al.* 2021). Studies have shown changes in muscle activation (Lehman and McGill 2001; Bicalho *et al.* 2010), stretch reflexes (Clark *et al.* 2011; Fryer and Pearce 2012), increased afferent discharge (Pickar 2002; Pickar and Bolton 2012), muscle strength and cortical drive (Niazi *et al.* 2015; Christiansen *et al.* 2018; Holt *et al.* 2019), central motor excitability (Murphy, Dawson and Slack 1995; Dishman, Ball and Burke 2002; Dishman, Greco and Burke 2008), alterations in pain processing (Lelic *et al.* 2016) and descending inhibition (Savva, Giakas and Efstathiou 2014).

Many of these mechanistic studies investigate immediate effects without follow up, and a call has been made to increase the number of double-blind randomized controlled trials to assess the clinical significance of these neurophysiological changes (Gyer *et al.* 2019). Thus, this study was designed to determine the effect of cervical SMT, compared to a control, on cervicothoracic spinal kinematics and muscle recruitment patterns in those with chronic neck pain while undertaking two functional upper limb tasks.

8.2 MANUSCRIPT

The effect of cervical spinal manipulation on cervicothoracic spinal kinematics and muscle recruitment patterns during functional arm tasks – a randomised control trial

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ABSTRACT

Background: Neck pain is associated with disability and has a negative impact on quality of life. Spinal manipulative therapy (SMT) is commonly utilised in its treatment, yet the mechanism through which it brings about its effects is not clearly understood. This study aimed to determine the effect of cervical spine manipulation compared to a control intervention on cervicothoracic spinal kinematics and muscle recruitment patterns during two functional upper limb tasks.

Methods: Participants with chronic neck pain were randomised to either cervical SMT (n=19) or a control group (n=20). Participants executed a seated unilateral arm lifting task, followed by a bilateral standing overhead lifting task. Each task was repeated three times. Muscle activation patterns, as recorded by surface electromyography, and spinal kinematics, captured via motion capture technology, were obtained during the task. Measures were taken before and after the first treatment and repeated at the fourth visit. A total of four treatments were administered over two weeks. Pain and disability were assessed before treatment, at the fourth visit (only pain) and at a one-week follow up where the patient's perception of global change was obtained together with the level of satisfaction. Data were statistically analysed with a p -value less than 0.05 being significant.

Results: The intervention group has a greater decrease in pain at the fourth visit ($p = 0.010$, $\eta^2 = 0.22$), with no difference at the one-week follow up ($p = 0.340$, $\eta^2 = 0.03$). Disability reduction was greater in the intervention group ($p = 0.006$, $\eta^2 = 0.24$) at one week. There were no differences in spinal kinematics found during the unilateral arm task after one treatment ($p > 0.05$), with greater peak ($p = 0.038$, $\eta^2 = 0.13$) and mean ($p = 0.031$, $\eta^2 = 0.14$) muscle activity in the right paraspinal muscle in the intervention group during the lowering phase. At the fourth visit the intervention group had a greater upper thoracic spine rotation range ($p = 0.021$, $\eta^2 = 0.17$) during lifting, an increased flexion/extension range in the lower thoracic spine ($p = 0.037$, $\eta^2 = 0.141$) during

lowering. The right upper trapezius muscles had greater mean activity in the intervention group ($p = 0.026$, $\eta^2 = 0.141$) during lifting. In the bilateral arm task, greater flexion/extension jerk occurred in the lower thoracic spine ($p = 0.038$, $\eta^2 = 0.13$) during lowering in the control group, with the intervention group having greater jerk in lateral flexion ($p = 0.014$, $\eta^2 = 0.13$) and rotation ($p = 0.019$, $\eta^2 = 0.17$) and greater rotation range ($p = 0.041$, $\eta^2 = 0.13$) and velocity ($p = 0.006$, $\eta^2 = 0.22$) in the lower thoracic spine. The intervention group had less peak activity in the right posterior cervical (PC) muscle during lifting ($p = 0.049$, $\eta^2 = 0.119$), with greater peak activation in right paraspinal T4 ($p = 0.026$, $\eta^2 = 0.151$) and activation time percentage in the right SCM during lifting ($p = 0.029$, $\eta^2 = 0.148$) and lowering ($p = 0.015$, $\eta^2 = 0.186$). At the fourth visit, the intervention group had significantly greater upper thoracic spine flexion/extension jerk ($p = 0.045$, $\eta^2 = 0.14$) during lowering, with lower left PC peak muscle activation during lifting ($p = 0.029$, $\eta^2 = 0.16$) and mean activation during lowering ($p = 0.006$, $\eta^2 = 0.237$). Mean activation of the left ($p = 0.039$, $\eta^2 = 0.154$) and right ($p = 0.034$, $\eta^2 = 0.157$) SCMs during the lowering phase was greater in the intervention group. No between groups differences were found for the perceived global impression of change categories ($p=0.500$) or level of satisfaction ($p > 0.05$), except that the SMT group reported improved emotions ($p=0.001$) and quality of life ($p=0.025$).

Conclusions: Cervical SMT resulted in short-term pain reduction and improved disability. Few significant between group effects were found in spinal kinematics and muscle recruitment patterns during the functional arm tasks, warranting further investigation.

Keywords: Spinal manipulation, cervical, thoracic, neck pain, functional task, upper limb, kinematics, muscle recruitment

INTRODUCTION

Neck pain is a global problem that negatively impacts the lives of those who suffer with this condition (Kazeminasab *et al.* 2022). It is estimated that every person will

experience some form of neck pain in their lives (Carroll *et al.* 2009). The majority of cases will resolve with some persisting in an episodic manner (Irgens *et al.* 2022) and others resulting in chronic pain (Côté *et al.* 2004). Neck pain is defined as pain from the superior nuchal line to the T1 vertebrae (Fandim *et al.* 2021), most often non-specific in nature, arising from irritation of the pain-sensitive structures in the neck such as the zygapophyseal joints, ligaments and muscles (Bogduk 2003; Cohen 2015). It can be disabling impacting both personal and occupational well-being (Yang *et al.* 2015; van Randerad-van der Zee *et al.* 2016; Kazeminasab *et al.* 2022).

People with neck pain have difficulty executing activities of daily living especially when using their upper limbs (Osborn and Jull 2013). Recent clinical practice guidelines recommend the inclusion of monitoring activity limitations and physical functioning when treating neck pain patients (Blanpied *et al.* 2017). Execution of motor tasks requires processing skills, logic to carry out the steps, and modification of performance (James *et al.* 2015), with proper coordination of neurophysiological processes that control the involved body parts (Shirota *et al.* 2016). Neck pain sufferers reportedly modify their movement patterns to achieve the same functional task as individuals without neck pain (Sandlund *et al.* 2008), proposed to achieve this through adaptations of how the spine moves, and not how much it moves (Tsang, Szeto and Lee 2014).

During repetitive upper limb movement, those with neck pain showed increased activation of the superficial cervical muscles (Falla, Jull and Hodges 2004) and delayed onset of the deep cervical flexor muscles (Falla, Jull and Hodges 2004) impacting the ability of the neck to respond to perturbations (Falla and Farina 2007). Tasks involving limb movement require the trunk postural stabilisers to activate prior to limb motion (Hodges and Richardson 1999; Zambarano, Bouillon and Glaviano 2021), in pain this pattern changes (Hodges and Smeets 2015), which may be subtle and cause a redistribution of function within and/or between muscles (Hodges *et al.* 2013). This change in motor function can be assessed through task performance, as observed by Tsang *et al.* (2014) during a seated, loaded, unilateral arm task where those with neck pain were found to have decreased velocity and acceleration in sagittal spinal motion with increased neck muscle activity when compared to healthy controls (Tsang, Szeto and Lee 2014). Several other studies support altered motor

control during upper limb activities in those with neck pain (Grip *et al.* 2008; Moghaddas *et al.* 2019; Moghaddas, Edwards and Snodgrass 2022). It has been suggested that pursuing interventions that address movement impairments may result in improved treatment outcomes (Hesby *et al.* 2019).

Spinal manipulation (SMT), is a commonly utilised treatment for spinal pain (Paige *et al.* 2017; Masaracchio *et al.* 2019; Rubinstein *et al.* 2019; Gevers-Montoro *et al.* 2021), and has been recommended for neck pain (Bussi res *et al.* 2016; Blanpied *et al.* 2017) (Coulter *et al.* 2019; Chaibi, Stavem and Russell 2021), yet the mechanisms through which it brings about its effects remain elusive (Pickar and Bolton 2012; Gyer *et al.* 2019). In order to appropriately direct treatment interventions the mechanisms through which they bring out their effect need to be understood (Bialosky *et al.* 2018). The delivery of a controlled high-velocity, low-amplitude (HVLA) thrust SMT is suggested to result in the afferent bombardment of the dorsal horn which activates a series of neurophysiology responses (Pickar 2002; Gyer *et al.* 2019). These responses range from hypoalgesia to neuromuscular and autonomic effects (Bialosky *et al.* 2018; Gyer *et al.* 2019). Activation of the descending inhibitory pain mechanisms, reducing central excitability, has been shown following SMT (Savva, Giakas and Efsthathiou 2014; Chimenti, Frey-Law and Sluka 2018), with these effects being modulated by patients' perceptions, expectation and doctor-patient relationships (Bialosky *et al.* 2009; Bialosky *et al.* 2018).

Neuromuscular effects, often measured using electromyography (EMG), show activation of spinal reflexes affecting muscle hypertonicity (Lehman and McGill 2001; Lehman 2012), flexion relaxation phenomena (Lalanne, Lafond and Descarreaux 2009; Murphy, Marshall and Taylor 2010) and muscle strength (Keller and Colloca 2000; Suter and McMorland 2002; Cleland *et al.* 2004). Inhibitory effects on alpha motor neuron pool excitability, assessed using H-reflex (Fryer and Pearce 2012; Niazi *et al.* 2015; Dishman, Burke and Dougherty 2018) and alterations in somatosensory processing (Haavik and Murphy 2012) have also been documented. The clinical relevance of some of these effects is not known as many studies only measured the immediate effects of SMT (Gyer *et al.* 2019).

Few studies have investigated the effect of SMT on functional motor tasks in neck pain (Chapter 3). In the low back pain literature, a recent study assessed the sit to stand test following lumbar spinal and pelvic manual therapy, finding an improved lumbar sagittal range of motion (ROM) and decreased test time during the task when compared to a control group (Carpino *et al.* 2020). Assessing both spinal kinematics and muscle activity patterns after lumbar SMT in low back pain during repeated flexion-extension tasks, no between group changes were found for spinal kinematics but reduced paraspinal muscle activity was found in those receiving SMT. The authors suggested that either the SMT reduced sensitisation or had a fatigue resistance effect in the paraspinal muscles explaining the improved function of the paraspinal muscles (Harvey and Descarreaux 2013).

In those with neck pain, previous research involving cervical SMT has focused primarily on muscle activity changes, as opposed to kinematic changes, during upper limb functional tasks, with conflicting results. Assessing the effect of cervical SMT on sEMG of the deltoid muscle during rest, isotonic contraction for five seconds and isometric contraction for five and 30 seconds, increased deltoid muscle amplitude and fatigue resistance was found during the 30 second isometric deltoid muscle contraction following a single treatment of cervical SMT, relative to a control group, in people with neck pain (de Camargo *et al.* 2011). Whereas Bracht *et al.* (2018) assessed the sEMG of upper extremity muscles during a unilateral, loaded lifting and gripping task which was divided into feedforward (period till the object was lifted) and feedback components (period from lifting to end of the movement). No differences in the selected upper limb muscle activity were found between those receiving cervical SMT when compared to a control group during either of the phases (Bracht *et al.* 2018). In both these trials, there was no monitoring of the muscles of the head and neck relative to the activity. As previously stated, there is a protective mechanism activated by the nervous system to bring stability to the spine prior to extremity motion (Hodges and Richardson 1999; Hodges, Cresswell and Thorstensson 2001; Hodges and Tucker 2011), which may have been missed in these trials.

The assessment of the impact of treatment on functional tasks, which are closely matched to daily activities (Shirota *et al.* 2016) and include complex, multi-planar and

multi-joint activities (Carpino *et al.* 2020), relative to treatment outcomes is necessary to gain further insights into how SMT brings about its effects (Aragón-Basanta *et al.* 2024). Thus, this study aimed to determine the effect of cervical SMT, compared to a control group, on cervicothoracic spinal kinematics and muscle recruitment patterns during two upper limb tasks. Hypothesizing that those receiving cervical SMT would have improved velocity, jerk and muscle activation patterns when compared to the control group.

METHODS

Study Design and approvals

A randomised, controlled clinical trial design was utilised. The study was conducted at a university chiropractic clinic (**Appendix H**) following permission from an Institutional Research and Ethics Committee (IREC 017/20) which operates in accordance with the Declaration of Helsinki, 1975 (**Appendix I**). The trial was registered on the Pan African clinical trial registry (PACTR202006491989074)(**Appendix V**). All participants provided informed consent (**Appendix U**). The study was reported according to the CONSORT statement (**Appendix Z**).

Participants

The participants consisted of those who took part in the previous study (Chapter 7). They were recruited via pamphlets, social media adverts and word of mouth between September 2022 to December 2023 (**Appendix G**). They were adults (18 to 50 years of age) with non-specific neck pain, that had been present for more than a three-month duration or regularly over the last 12 months (Tsang, Szeto and Lee 2014). The pain severity was required to be severe enough to warrant seeking care. The participants were right-handed (to prevent differences in muscle activity due to handedness (Sainburg 2002; Amar, Cochran and Woldstad 2017)).

Participants were excluded if they suffered from any neurological/orthopaedic/rheumatic disorder, had severe trauma or surgery to the brain or spine, a history of sensory or vestibular deficits. They were required to have

no open wounds in the neck and trunk region, which would prevent electrode placement, and a skin fold thickness of less than 19mm over the upper trunk to ensure adiposity did not affect transmission of the surface sEMG signal (Baniqued *et al.* 2016). All participants were screened for central sensitisation (**Appendix Q**), using a cut off score of 40 {Neblett, 2013 #699}{Mayer, 2012 #406}, and Fear Avoidance Behaviours (FAB) {Kori, 1990 #408} (**Appendix R**), using a cut off score of 37 {Roelofs, 2004 #1313}, if scores exceeded these values they were excluded. All participants underwent a case history and orthopaedic examination, conducted by a chiropractor with more than 20 years' experience.

Sampling

An *a priori* sample size was calculated using pilot testing data with an independent student t-test, assuming an α of 0.05, and power at 0.8 (beta = 0.2), an effect size of 0.95 required a sample size of 17 per group. The sample size was calculated using G*Power (Faul *et al.* 2007). A person not involved in the study utilised the Random.org Integer website (Generator© 1998-2024 RANDOM.ORG, <https://www.random.org/integers/>) to produce a list of random numbers consisting of either one (cervical SMT) or two (control). The numbers were then put into sealed, opaque envelopes labelled consecutively starting at one. The envelopes were stored at the data collection site. When a participant met the eligibility criteria LO collected the envelop and opened it revealing the group allocation, and the appropriate intervention was then administered. Thus, the person providing the treatment (LO) was not blinded. **Figure 8.1.** shows the participation through the duration of the trial, as per the consort statement diagram.

Measurement instruments

Patient-reported outcome measures (PROMs) were:

RAND 36-Item Health Survey 1.0 to assess quality of life (**Appendix L**) in terms of physical functioning, bodily pain, role limitations due to physical health problems, role limitations due to personal or emotional problems, emotional well-being, social functioning, energy/fatigue, and general health perceptions. The domains are scored

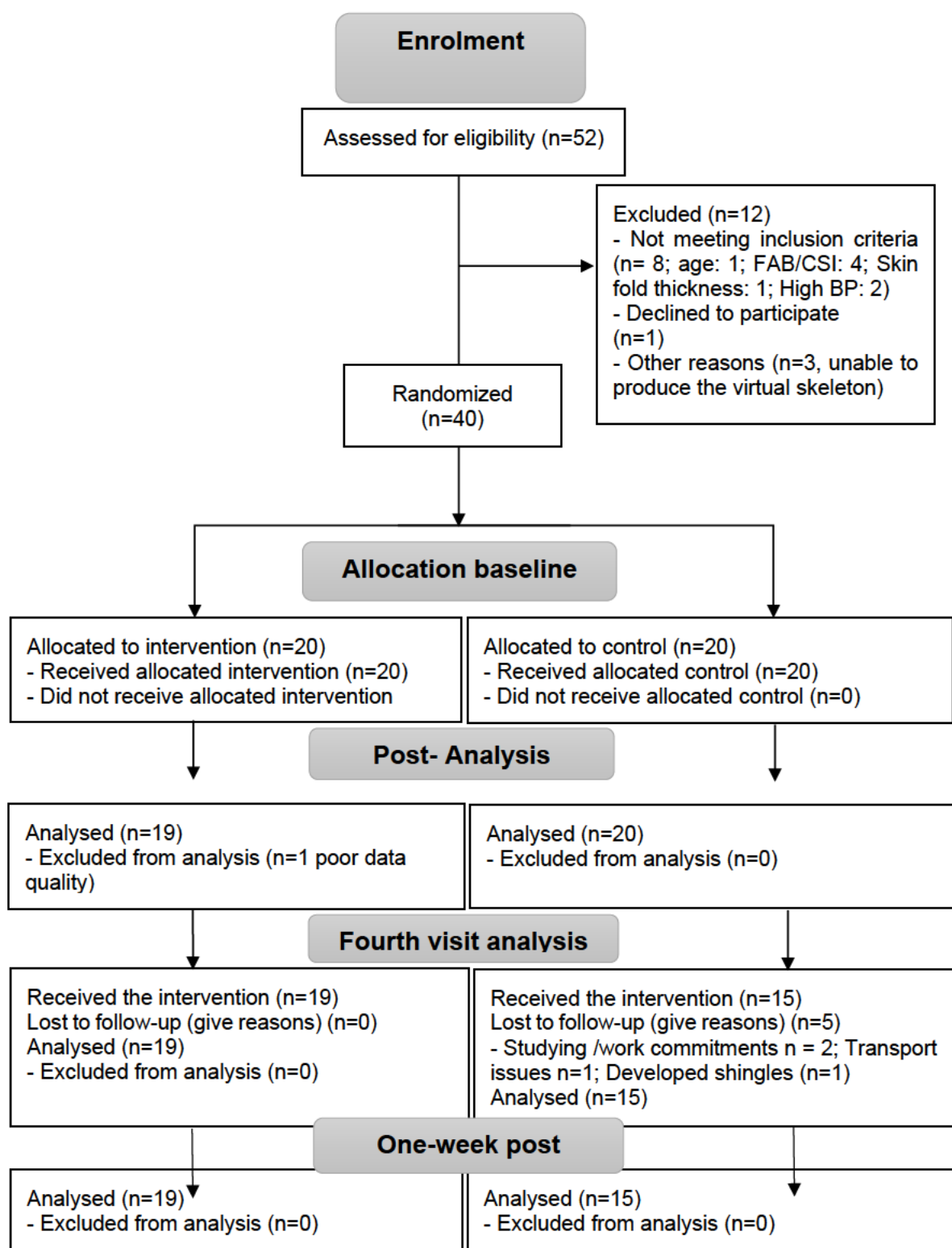


Figure 8.1: Consort flow diagram

as a percentage with the higher the percentage the more favourable the health status (RAND Corporation 2023). Neck pain intensity over the last week was assessed using the numerical pain rating scale 101, which has been found valid, reliable, and responsive (Ferreira-Valente, Pais-Ribeiro and Jensen 2011) for use in neck pain patients (Modarresi *et al.* 2022)(**Appendix M**). It is an 11-point rating scale which is easy to administer with zero being no pain and 10 being the worst pain imaginable (Pool *et al.* 2007). This was re-measured at the fourth consultation prior to the application of the last intervention and at one-week post-intervention. The NRS has been shown to be responsive within 48 hours of treatment in neck pain and a change score of 1.5 is considered clinically significant (Young *et al.* 2019).

- Self-reported, perceived level of disability due to neck pain was assessed using the neck disability Index (NDI) which has been shown to have good content validity in patients with chronic, non-traumatic neck pain (En, Clair and Edmondston 2009) (**Appendix N**). It consists of 10 items related to functional activities with each item having five options of responses ranging from zero no disability to five being total disability, resulting in a score out 50. The higher the score the more disability experienced (Pool *et al.* 2007). This was re-administered at one-week post the completion of the interventions. Responsiveness of the NDI has been demonstrated in three weeks in neck pain with a change score of 5.5 indicating clinical significance (Young *et al.* 2009).
- Patient global impression of change scale (PGICS) was administered post-intervention at one week (**Appendix W**). It is easy to understand, quick to complete and allows for self-assessment of response to treatment (Kamper, Maher and Mackay 2009). The concurrent validity of this scale with other patient reported outcomes was very good with very good-to-excellent quality between neck disability changes scores and PGICS (Bobos *et al.* 2019). Responsiveness of the NDI has been demonstrated in three weeks in neck pain (Young *et al.* 2009).

- Patient satisfaction form to assess participants' level of satisfaction with the treatment was adapted from a survey used by Haneline (2005) who assessed perceived satisfaction levels of chiropractic patients with a primary diagnosis of acute neck pain (Haneline 2006)(**Appendix Y**). Participants were asked to describe the change, if any, since beginning treatment in terms of their ability to be active, symptom character, emotions, and overall quality of life and to indicate their level of satisfaction with the change in their neck pain, whether they would choose chiropractic care or spinal manipulation in the future for neck pain and if they would return to the facility for care in the future.

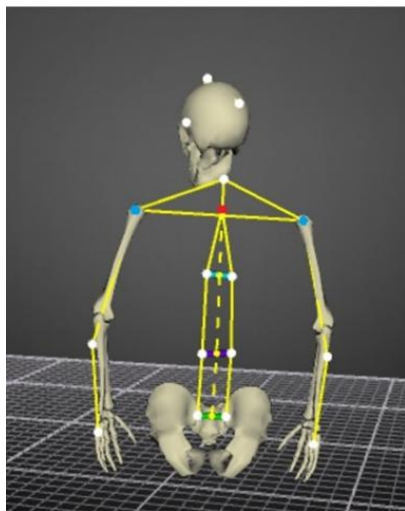
All PROMs were collected by LO or one of two trained research assistants who were registered for a Masters Degree in Chiropractic. All motion capture and sEMG data were collected by either of the trained research assistants depending on their availability on the day. Instructions for data collection were standardised (**Appendix O**).

Objective measures

Kinematics

The OptiTrack™ motion capture system (Optitrack, Natural Point, OR, USA), with eight Prime 13 cameras, with a resolution of 1.3 MP (1280 × 1024) and 240 frame rate, with a sampling frequency of 120 Hz per camera (Muyor *et al.* 2017) were used. OptiTrack motion capture system (OptiTrack, Natural Point, OR, USA) has been found to track markers accurately and reliably and is comparable to other motion capture systems (Carse *et al.* 2013). Cameras were wall or tripod mounted around the test area. Pre-capture calibration was performed and the capture volume set {NaturalPoint Corporation, 2023 #18}. Masking was used to remove any unwanted light reflections in the capture volume. Reflective markers (14 mm) were attached, using either electrodes or Velcro stickers, to anatomical sites on the head, trunk and arms using bony anatomy to guide placement as seen in **Figure 8.1**. The C7 marker had a one-centimetre extender. Unlabelled markers were streamed through motive™ to 3DMA STT-system™ to allow for movement processing (STT systems group, Spain). Each reflective marker was allocated to the appropriate anatomical site, producing a

custom-made digital human model calibrated to the participants anthropometry, syncing the position and orientation of each reflective marker to the correct body segment, to complete the matrix transformation. The model constructed cervical spinal kinematics from the reflectors from the external occipital protuberance to C7, and a kinematical estimation model was developed in STT-systems™ and provided six degrees of freedom (DOF) in three cardinal planes.



- Centre top of the head
- Forehead over glabella
- External occipital protuberance
- Spinous process (SP) of the C7 cervical vertebrae – an extender was utilised of 15mm
- T3 SP
- Bilateral acromion
- Bilateral 4cm Left and Right of T7 vertebrae in line with the spinous process
- Bilateral 4cm Left and Right of L1 vertebrae in line with the SP
- Bilateral lateral epicondyle
- Bilateral posterior superior iliac spine (PSIS)
- Bilateral ulna styloid process

Figure 8.2: Location of reflective markers

Electromyography

The Biopac Bionomadix MP150 Data Acquisition System (Biopac systems® Inc.) was utilised together with a wireless transmitter and receiver pair. The system has a differential amplifier with a common mode rejection rate (CMRR) of 110dB at 50/60 Hz, gain of 2000, input impedance of 2 MΩ with signal to noise ratio over 65dBs). Data were transmitted at 2000 Hz. The data acquisition software (Acqknowledge 4.1, BIOPAC systems Inc.) was set to a sampling frequency of 2000 Hz. Prior to placement of electrodes, the skin was lightly abraded, shaved where necessary, and cleaned with alcohol (Hermens *et al.* 2000). Disposable, rectangular, pre-gelled Ag/AgCl surface electrodes (30x25mm) (Vitatrode™ Electro Spyres, Johannesburg) were placed on the six muscles bilaterally, parallel to the muscle fibres, and in the mid-line, with an

inter-electrode distance of 20 mm (Hermens *et al.* 2000). Care was taken to accurately locate electrode placement sites through palpation of bony landmarks and the use of a tape measure, (see **Table 8.2** for details). Reference electrodes were placed on the closest bony prominence.

The kinematics and sEMG outcomes were collected before and immediately after the first intervention and re-taken at the fourth visit prior to administration of the fourth treatment (i.e. after three treatment sessions).

Research procedure

The participant stood upright, with their hands facing their thighs, while the markers were detected by the OptiTrack cameras, streamed to Motive™ tracker and onto STT Insight™ software (STT systems group, Spain). This took approximately five seconds. At the same time baseline EMG activity was recorded for 50ms. During the capture marker position and allocation were monitored. Once the calibration was complete participants were required to undertake the following upper limb tasks:

Unilateral arm task: Participants sat upright on a wooden stool (45 cm high), with no backrest, looking straight ahead to a mark on the wall, with their feet flat on the floor and arms hanging by their sides. A tripod was situated in front and to the right of the stool. It consisted of two shelves, one 70 cm off the floor and a higher shelf 70cm above it. A circular glass jar weighing two-kilogram was placed on the lower shelf and was required to be lifted by the participants from this shelf to the top shelf, where it was held for two counts, then lowered to the lower shelf. This was repeated three times and participants were encouraged to track the motion with their head and neck.

The task mimicked the everyday activity of reaching overhead (Constand and MacDermid 2013) together with weight transfer (Taylor *et al.* 2018). Both these tasks have been associated with NP (Genebra *et al.* 2017) and occur as items in disability questionnaires such as the Neck Disability Index (NDI)(Young *et al.* 2009). This task was like that used by Tsang, Szeto, and Lee (2014). The seat and tripod location were marked on the floor to ensure that they did not move during the data collection process.

Table 8.12: Electrode placement

Muscle	Placement	Reference electrode
Upper trapezius (UT)	One third from the distal edge of the acromion on a line drawn between the acromial and C7 spinous process (Farina <i>et al.</i> 2002)	Manubrium
Cervical erector spinae (PC)	2 cm lateral to the C4 spinous process bilaterally (Criswell 2011; Tsang, Szeto and Lee 2014)	
Sternocleidomastoid (SCM)	Midpoint between the mastoid process and the sternal insertion, slightly posterior to the muscle belly (Criswell 2011; Tsang, Szeto and Lee 2014)	Anterior superior iliac spine (ASIS).
Anterior Scalene (AS)	Lateral to the SCM's attachment on the clavicle, above the clavicle and anterior to the upper trapezius, placed at a slightly oblique angle (Criswell 2011)	
Thoracic erector spinae upper T4 (T4)	4 cm lateral to the T4 spinous process bilaterally (Tsang, Szeto and Lee 2014)	Ipsilateral medial epicondyle
Thoracic erector spinae lower T9 (T9)	4 cm lateral to the T9 spinous process bilaterally (Tsang, Szeto and Lee 2014)	

Bilateral arm task: Participants stood behind the stool. A box 52(l)x34(w)x35(ht) cm was placed on the stool with a two-kilogram metal bar (48cm in length) resting on top of the box. Participants grasped the bar with both hands (one on each end) and raised the bar above their head, held it there for two counts, and then lowered the bar back to rest on top of the box. Participants were encouraged to track the bar movement with their head and neck. This was repeated three times. Bilateral overhead activities are commonplace in day-to-day life such as washing hair and hanging clothes on a washing line and frequently take place in the work environments (Garosi *et al.* 2022). To prevent excessive forward flexion when reaching to pick the bar up it was placed on a box which was 80cm above the ground in line with the average height of a kitchen counter (Kishtwaria, Mathur and Rana 2007).

Prior to undertaking the two tasks, participants were given an opportunity to practice two to three times prior to the start of data collection. If they were not performing the motion correctly, such as moving their shoulders, or not reaching the end limit, their motion was corrected. The unilateral arm task took place first, followed by the bilateral arm task. Tasks were completed at the participants' self-selected pace. No attempts

were made to correct the chosen movement strategy, allowing participants to execute the motion in how they would normally do so. The research assistant guided the participant through the procedure encouraging a two count pause at maximal lifting and when returning the object to the shelf/box before lifting again, (**Appendix O**).

Interventions

A standardised musculoskeletal examination was conducted, by a chiropractor with more than 20 years' experience, who utilised motion palpation, to identify areas of intersegmental motion restriction and tenderness to palpation (Hubka and Phelan 1994; Smedmark, Wallin and Arvidsson 2000). Motion palpation of the cervical spine has been validated in detecting hyper- and hypomobile joints in the cervical spine with a high level of agreement between examiners ($K = 0.65$) and a sensitivity ranging between 55-78%, with high overall specificity (91-98%) (Humphreys, Delahaye and Peterson 2004). Each participant received four treatments over two weeks, in line with a similar study (Izquierdo Pérez *et al.* 2014). Treatment was individualized to participants and by treatment session based on the motion palpation findings. On completion of the trial, all participants were provided with a voucher to receive four free treatments at the chiropractic clinic for their participation in the study. Interventions are described according to the Template for Intervention Description and Replication (TIDieR) guide, **Table 8.2**.

Cervical spinal HVLA manipulation

The participant lay supine with their cervical spine in neutral. The clinician contacted the posterolateral articular pillar of the hypermobile cervical vertebrae, with the middle phalanx of the index finger, joint slack was removed and a high-velocity low-amplitude thrust manipulation was executed. The HVLA manipulation was performed either in rotation or lateral flexion depending on which motion was most restricted (Izquierdo Pérez *et al.* 2014). No more than two different levels were manipulated per person. When no-audible cavitation occurred on the first attempt a second attempt was performed (Puntumetakul *et al.* 2015).

Table 8.2: Interventions applied according to TIDieR

Item	Description	
Brief name	Cervical spinal manipulation HVLA technique	Control
Why	SMT has been purported to result in neurophysiological changes that affect pain rating, neuromuscular response and motor control.	This comparator was selected to allow for the activation of skin mechanoreceptors but exclude the thrust component of the HVLA.
What material	Bergman and Peterson (2011) (Bergmann and Peterson 2010) were used to direct the application of the intervention.	The procedure as detailed by Haavik Taylor and Murphy (2010) (Taylor and Murphy 2010; Blanpied <i>et al.</i> 2017) was utilised with light pressure applied of the articular pillar during the procedure.
What procedures	Participants lay supine with their cervical spine in neutral the clinician contacted the posterolateral articular pillar of the hypermobile cervical vertebrae, with her index middle phalanx of the index finger, joint slack was removed and a high-velocity low-amplitude thrust manipulation was executed. The HVLA manipulation was performed either in rotation or lateral flexion depending on which motion was most restricted (Izquierdo Pérez <i>et al.</i> 2014).	The same procedure as outlined for the HVLA manipulation was followed except that no thrust was administer, instead the clinician held the position for 2 counts and released.
Who provided	A chiropractor with more than 20 years of experience.	A chiropractor with more than 20 years of experience.
How	In person	In person
Where	Private clinic room at an institutional chiropractic teaching clinic	Private clinic room at an institutional chiropractic teaching clinic
When and how much	Treatment was administered 4 times over 2 weeks. Each treatment lasted approximately 2 minutes, including the time taken to position the patient correctly. When no-audible cavitation occurred on the first attempt a second attempt was performed (Puntumetakul <i>et al.</i> 2015).	It was administered 4 times over 2 weeks. Each treatment lasted approximately 2 minutes, including the time taken to position the patient correctly.
Tailoring	The technique was applied at the level of joint hypermobility identified for each patient with each patient receiving on average 2 HVLA thrusts, with a maximum of 3.	The technique was applied at the level of joint hypermobility identified for each patient with each patient experiencing the clinician touching their neck twice, with a maximum of 3 times.
	Treatment was individualized to participants	
Modification	No modification to the technique occurred	No modification to the technique occurred
How well (planned)	The technique was to be applied as outlined by (Bergmann and Peterson 2010).	The technique was to be applied as outlined by (Taylor and Murphy 2010) including light pressure.
	Care was taken not to mention the 'cracking/popping' sound that may occur with SMT during the informed consent stage, to not allude participants to their group allocation.	
How well (actually)	Intervention adherence or fidelity was not assessed.	Intervention adherence or fidelity was not assessed.

Control intervention

The same procedure as outlined for the HVLA manipulation was followed except that no thrust was administered, instead the clinician held the position for two counts and released, with light finger pressure over the joint that was hypermobile, allowing for sensory input without the effect of HVLA thrust (Haavik Taylor and Murphy 2010).

A summary of the research procedure is presented in **Figure 8.3**.

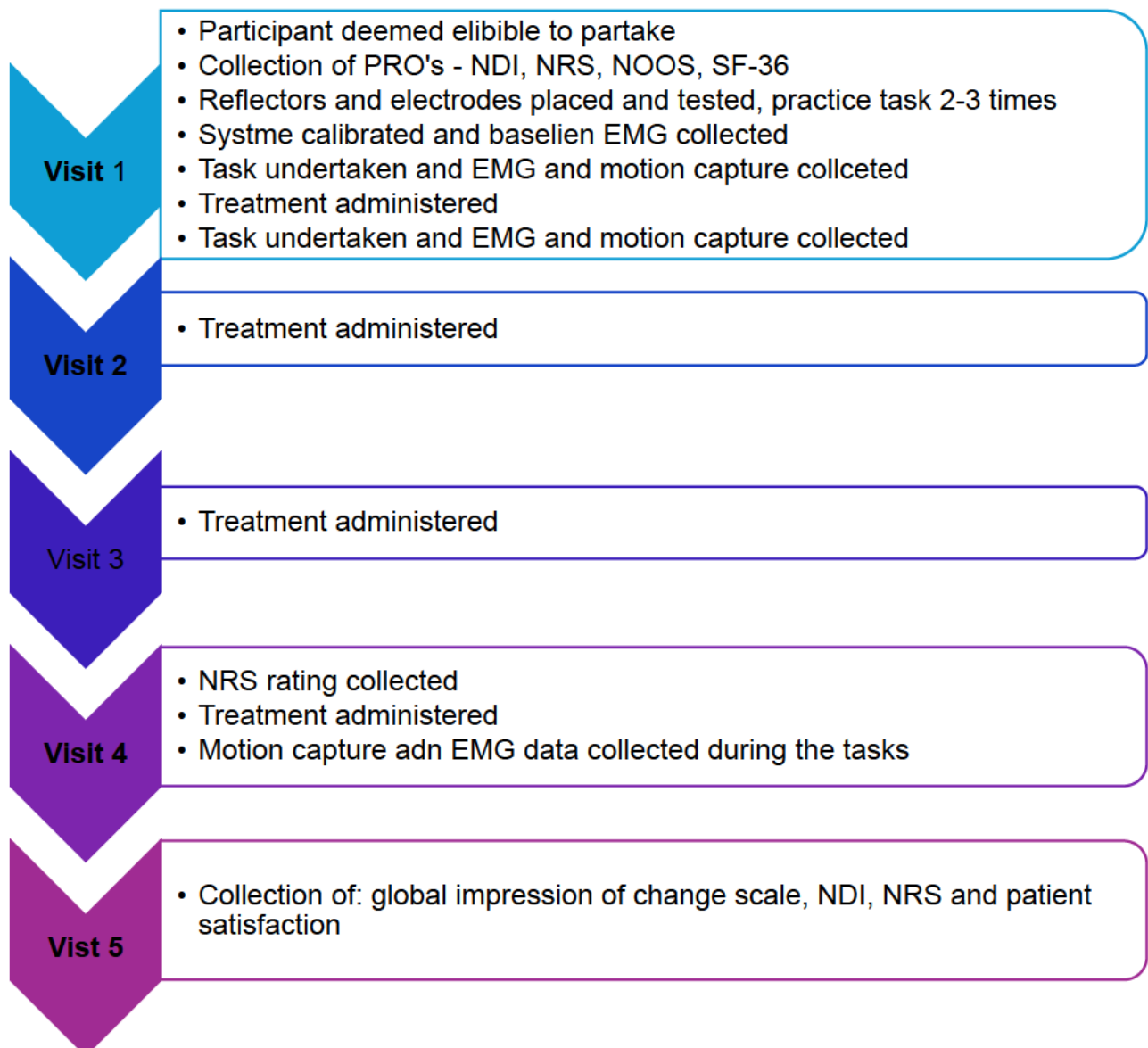


Figure 8.3: Summary of the data collection process

Data processing

Motion capture data were exported from STT Insight™ software (STT systems group, Spain) and EMG data from AcqKnowledge® software and imported into MATLAB (R2023a) (MathWorks® Inc., Natick, Massachusetts, United States) where a customised code processed the signals.

Motion capture: The signals were filtered using a 4th order low pass (5Hz) Butterworth filter (Descarreaux, Passmore and Cantin 2010). Various smoothing options between two and 10Hz were tested with the 5Hz used by Descarreaux et al (2010) being the preferable one. Data were then segmented into phases of the lifting object – away being the motion of the arm away from the body, and return being when the arm returns to the starting position. The shoulder marker was used to differentiate these stages. Thresholds to register an excursion required that the:

1. Shoulder marker needed to exceed 60°
2. Have a minimum velocity of 2 (°/s)
3. Minimum excursion time of 0.67 seconds and a maximum excursion time of 15 seconds
4. With a minimum of 2 and a maximum of 3 excursions consecutively
5. A minimum transition time of 1.0 seconds and a maximum transition time of 15 seconds
6. Neutral threshold of 45°

The maximum peak of shoulder motion is the value at the top and breaks the task into away and return phases. Spinal motion was then assessed per away and return phases based on the cardinal planes of motion and recorded as, an example of the signal is presented in **Figure 8.4**:

1. Range – the range of motion (ROM) during the away or return phase of motion,
2. Mean velocity – the speed of the spinal motion per phase (m/s), the segment was deemed to be moving when the displacement was greater than 10 degrees per second,
3. Mean jerk – the smoothness of the spinal motion per phase (m/s³).

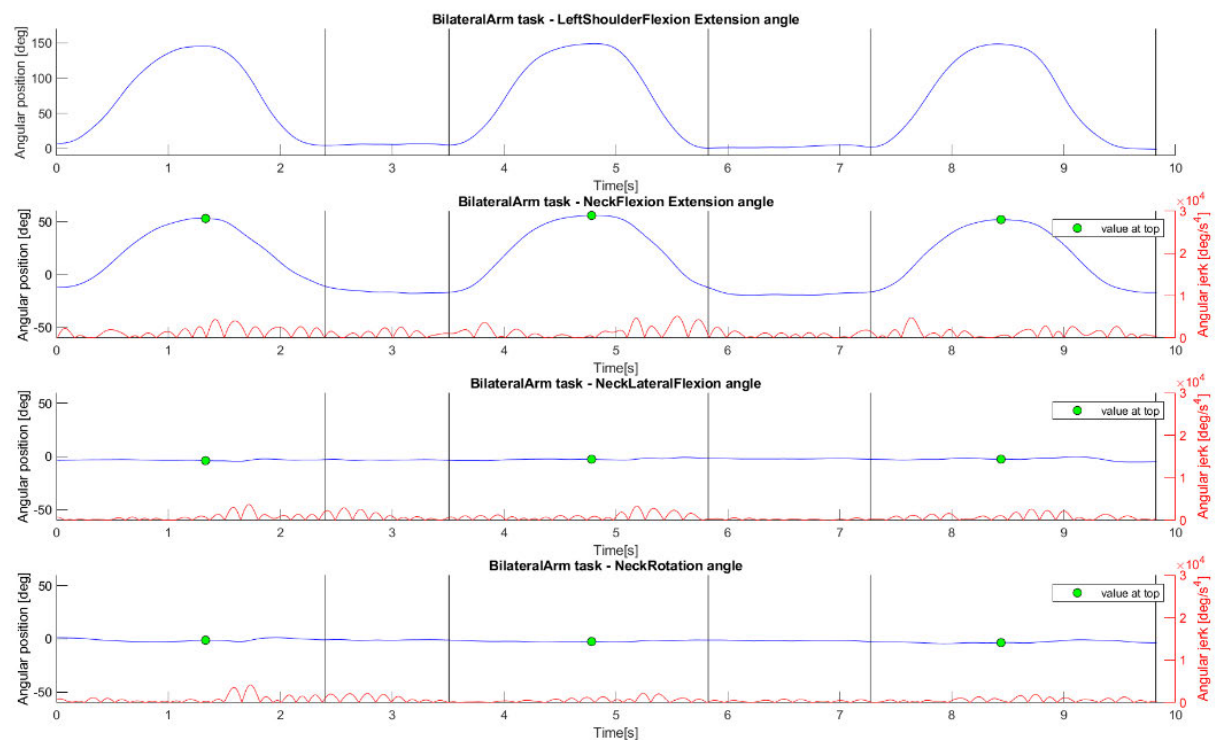


Figure 8.4: An example of the signal from the bilateral arm task of a participant from the control group (C18) showing shoulder flexion and extension and cervical displacement per ROM and jerk

sEMG: The raw sEMG signal was synced to the kinematic data, then processed using a fourth bidirectional Butterworth filter (a bandpass filter with a low pass cut off 150 hz to remove electrical noise, and a high pass cut off of 50hz to remove low frequency noise such as movement artifacts). Thereafter the signal was full wave rectified and then smoothed using a moving average over a 300ms sliding window. Following smoothing the data was normalised to the peak amplitude achieved by each muscle across the task (Halaki and Ginn 2012).

This signal was then used to determine activity onset which was detected as the data point where the magnitude of the EMG signal was three standard deviations larger than the baseline and where the duration of contraction was greater than 25 ms (Hodges and Bui 1996). The onset and offset of muscle activity during the tasks were

quantified into a percentage of muscle activation duration. Allowing for the temporal characteristics of the muscle activity to be examined during the half-cycles of cervical ROM. Data were exported as normalised percentage peak, mean and activation time per sub-phase of motion. When activity was 100% during any one phase, this indicated that the muscle was active for the entire duration of that phase. The sEMG data described in chapter six, was recorded for as:

1. Peak – the maximum normalised amplitude of the EMG signal during the phase of motion (%),
2. Mean – the mean value of the normalised signal during the motion (%), and
3. Activation time percentage – which represents the amount of time that the muscle was active during the phase. The activity of 100% during any one phase would indicate that the muscle was active for the whole time during that phase (%).

Following the segmentation of the motion capture and EMG data, event and outcome images (which visually displayed the signal, tasks and sub-phases) were produced and assessed per participant to determine the quality of the signal. When the signal was distorted and lack conformability to the tasks it was excluded, this was done in consultation with a biomechanist. Where isolated technical issues were found, for example where the marker was lost resulting in severe signal distortion or when the electrode failed to detect the signal, the data for only that measurement was excluded from the analysis for that participant. Once satisfied that the signals were acceptable the data for each of the three trials together with the calculated average of the three measures (i.e. the mean) for each of the phases were exported to an Excel spreadsheet for statistical analysis.

Data were segmented **Figure 8.5** shows an example of the sEMG signals for the unilateral and bilateral arm tasks from a participant in the intervention group taken at the post the initial treatment.

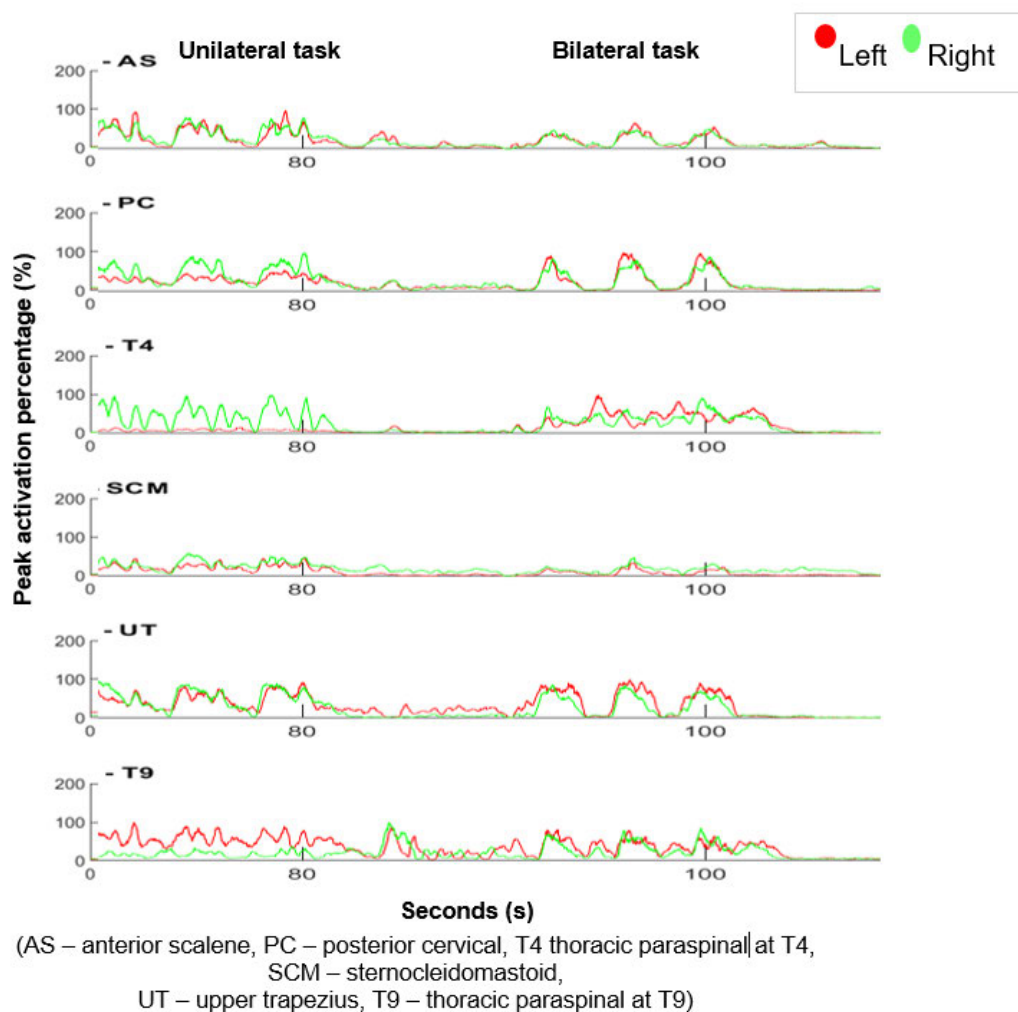


Figure 8.5: sEMG signal from the unilateral and bilateral arm tasks for the 6 pairs of muscles from a participant in the intervention group taken as pre-measure (I6)

Data analysis

Chi-square and Fischer's Exact tests were used to determine relationships between categorical variables. Independent student t-tests assessed for baseline differences between the groups for numerical variables. Analysis of Covariance (ANVOCA) was used to assess the effect of the interventions from pre- to post at visit one, and from pre-visit one to the fourth visit. The model adjustment for baseline measures, age and sex. A *p*-value of 0.05 indicated significance. Statistical analysis was conducted using SPSS (version 27, IBM Corp. Released 2020. IBM SPSS Statistics for Windows,

Armonk, NY: IBM Corp). Normality was assessed using kurtosis and skewness. Effect sizes were calculated using Partial Eta Squared (η^2), where the effect was considered small if $\eta^2 = 0.01$; medium if $\eta^2 = 0.06$ and large if $\eta^2 = 0.14$ (Yagin, Pinar and de Sousa Fernandes 2024). Pearson's correlational analysis (r) was utilised to assess the strength and direction of relationships between change in pain and the cervical kinematic and muscle activation outcomes.

RESULTS

Demographic characteristics

Demographic, anthropometric and neck pain characteristics of the participants are presented in **Table 8.3**. The intervention group had more females than males ($\chi^2(1,39) = 4.496, p=0.034$) and reported poorer physical health ($p=0.036$) and social functioning ($p=0.031$), on the SF-36, compared to the control group. The participants reported moderate pain levels, with mild disability, with the pain most often being experienced bilaterally.

Pain intensity and disability

At the fourth visit, the intervention group had a greater decrease in pain intensity compared to the control group (MD 1.4 (SE:0.5) CI: -2.4 to -0.4; $F(1, 27) = 7.718, p = 0.010; \eta^2 = 0.22$), with a large effect size. There were no between group differences at the one-week follow-up ($F(1,29) = 0.941, p = 0.340; \eta^2 = 0.03$). Both groups reported improved disability scores, with greater improvements occurring in the intervention group, with a large effect size ($F(1,29) = 8.904, p = 0.006, \eta^2 = 0.24$), **Table 8.4**.

Unilateral task:

Kinematics: Cervical kinematics outcomes for the three time points for the unilateral arm task and the analysis, using ANCOVA and controlling for baseline measures, age and sex, comparing the immediate post-measures and the measures at the fourth visit are presented in **Supplementary file 8.1, 8.2 and 8.3**. No between group effects were observed immediately following one treatment for spinal kinematics. At the fourth visit, the intervention group had a significantly increased range in rotation in the upper

thoracic rotation spine ($F(1,29) = 5.900$, $p = 0.021$, $\eta^2 = 0.17$) during lifting and increased flexion/extension range in the lower thoracic spine ($F(1,29) = 4.778$, $p = 0.037$, $\eta^2 = 0.141$) during lowering as seen in **Table 8.5**. **Figure 8.6** shows bar charts of the between group analysis.

Table 8.3: Demographic, anthropometric neck pain characteristics of the participants

Characteristic	Total (n=39)		SMT (n=19)		Control (n=20)		p-value
	M	SD	M	SD	M	SD	
Sex n(%)							
Female	22	56.4	14	73.7	8	40	0.034
Male	17	43.6	5	26.3	12	60	
Age	24.9	7.2	24.1	7.9	25.7	6.6	0.510
Height (m)	1.7	0.1	1.6	0.1	1.7	0.1	0.665
Weight (kg)	66.4	15.3	64.5	10	68.1	19.2	0.471
Health status (SF-36)							
Physical functioning	88.5	21.2	95.1	24.8	82.3	15.3	0.059
Physical health	61.1	38.2	74.1	29.9	48.8	41.7	0.036
Emotional problem	53.9	44.3	54.4	43.3	53.5	46.3	0.951
Energy/fatigue	51.1	16.3	52.7	15.8	49.6	16.9	0.558
Emotional	42.5	13.2	40.7	8.4	44.2	16.6	0.421
Social functioning	61.5	31.3	72.5	32.1	51.1	27.3	0.031
Pain	52	21.4	57.2	21.8	47.0	20.4	0.137
General Health	53.1	12.7	55	8	51.3	16	0.366
Pain intensity (NPRS)	5.3	1.8	4.9	1.8	5.7	1.8	0.168
Neck disability (NDI)	24.4	10.0	21.8	6.5	26.9	12.1	0.120
Duration (months)	26.9	22.6	24.8	18.5	29.1	26.4	0.573
Location n(%)							
Unilateral	10	25.6	6	31.6	4	20	0.500
Bilateral	29	74.4	13	68.4	16	80	
Associated with HA n(%)							
Yes	16	41	8	42.1	8	40	1.000
No	23	59	11	57.9	12	60	
Prior chiropractic treatment n(%)							
Yes	14	36	6	31.6	8	40	0.584
No	25	64	13	68.4	12	60	

(M - mean; SD - standard deviation; HA – headache; m – meters; kg – kilograms; Chi-squared test was utilised and independent samples t-test were used)

In the control group correlation analysis found negative correlations between pain and cervical flexion/extension range during lifting ($r(13) = -0.54$, $p = 0.048$) and average velocity ($r(13) = -0.62$, $p = 0.015$) during lowering; upper thoracic spine during lowering flexion/extension average velocity ($r(13) = -0.63$, $p = 0.012$) and average jerk ($r(13) =$

-0.61, $p = 0.016$); in the lower thoracic spine during lowering flexion/extension average velocity ($r(13) = -0.59$, $p = 0.022$). The intervention group had a positive correlation between pain and average jerk in cervical rotation during lifting ($r(15) = 0.60$, $p = 0.011$).

Muscle activity: Muscle activity outcomes for the three time points and the analysis, using ANCOVA and controlling for baseline measures, age and sex, comparing the immediate post-measures and the measures at the fourth visit are presented in **Supplementary files 8.4, 8.5 and 8.6**. After one treatment the peak ($F(1,32) = 4.685$, $p = 0.038$; $\eta^2 = 0.13$) and mean ($F(1,32) = 5.123$, $p = 0.031$; $\eta^2 = 0.14$) muscle activity in the right paraspinal muscle T4 was greater in the intervention group during the lowering phase of the unilateral arm task with large effect sizes. At the fourth visit, the right UT muscles had greater mean activity in the intervention group ($F(1,28) = 5.520$, $p = 0.026$; $\eta^2 = 0.17$) during lifting, with a large effect size, **Table 8.6**. There were no other significant between group differences. **Figure 8.7** shows bar charts of the between group analysis.

In the control group correlation analysis found negative correlations between pain and left PC muscle activation time during lowering ($r(12) = -0.55$; $p = 0.041$), and positive correlations for right paraspinal muscle T4 mean activation ($r(12) = 0.60$; $p = 0.024$) and left paraspinal muscle T9 activation time ($r(13) = 0.59$, $p = 0.021$) in the lifting phase. In the intervention group, a positive correlation was found between pain and right AS muscle peak activation during lifting ($r(14) = 0.506$; $p = 0.045$).

Bilateral task:

Kinematics: Cervical kinematics outcomes for the three time points for the bilateral arm task and the results of the analysis of the ANCOVA post-adjusted scores controlling for baseline, age and sex are presented in **Supplementary files 8.7, 8.8 and 8.9**. Following one treatment between group differences were found during lowering for the lower thoracic spine where the control group had significantly greater flexion/extension jerk ($F(1,31) = 0.4681$, $p = 0.038$; $\eta^2 = 0.13$), whereas the intervention group had greater rotation range ($F(1,31) = 4.548$, $p = 0.041$; $\eta^2 = 0.13$), velocity ($F(1,31) = 8.868$, $p = 0.006$; $\eta^2 = 0.22$) and jerk ($F(1,31) = 6.146$, $p = 0.019$; $\eta^2 = 0.17$)

with increased jerk in lateral flexion ($F(1,31) = 6.832$, $p = 0.014$; $\eta^2 = 0.18$), with medium to larger effects. There were no other differences between the groups. At the fourth visit, the intervention group had a significantly greater jerk in upper thoracic spine flexion/extension ($F(1,28) = 4.413$, $p = 0.045$, $\eta^2 = 0.14$), with a large effect, during lowering. These results are presented in *Table 7*. There were no other significant findings. **Figure 8.8** shows bar charts of the between group comparisons of post-adjusted scores.

Correlation analysis found that during the bilateral arm task, as pain decreased in the control group there was increased upper thoracic spine flexion/extension average jerk in the lifting ($r(13) = -0.557$; $p = 0.031$) and lowering ($r(13) = -0.559$; $p = 0.030$) phases. No correlations were found for the kinematic variables in the intervention group.

Table 8.4: Pain intensity and disability scores between the groups at visit 4 and 1-week post-treatment

Outcome		Pre-measures				Post-measures				p-value	Adjusted means				
		CG		EG		CG		EG (n=19)			CG	EG	MD	CI	
		(n=15)		(n=19)		(n=15)								Low	High
		M	SD	M	SD	M	SD	M	SD						
Pain intensity	P1-P4	5,7	1,8	4,9	1,8	3,5	1,6	1,8	1,3	0,010	3,4 (0,3)	2 (0,3)	1,4	-2,4	-0,4
	P1-1w					1,6	2,2	3,4	2,1	0,340	-	-	-	-	-
Disability	P1-1w	26,9	12,1	21,8	6,5	18,1	14,7	7,1	6,8	0,006	8,2 (1,0)	4,1 (0,9)	4,1	-6,9	-1,3

(P1 = pre-visit 1; P4 – pre-visit 4; 1w = 1 week follow up; CG – control group; EG – experimental group, M – mean, SE – standard error, CI – confidence interval)

Table 8.5: Significant results of the analysis of adjusted means between the groups at the fourth visit for the unilateral arm task

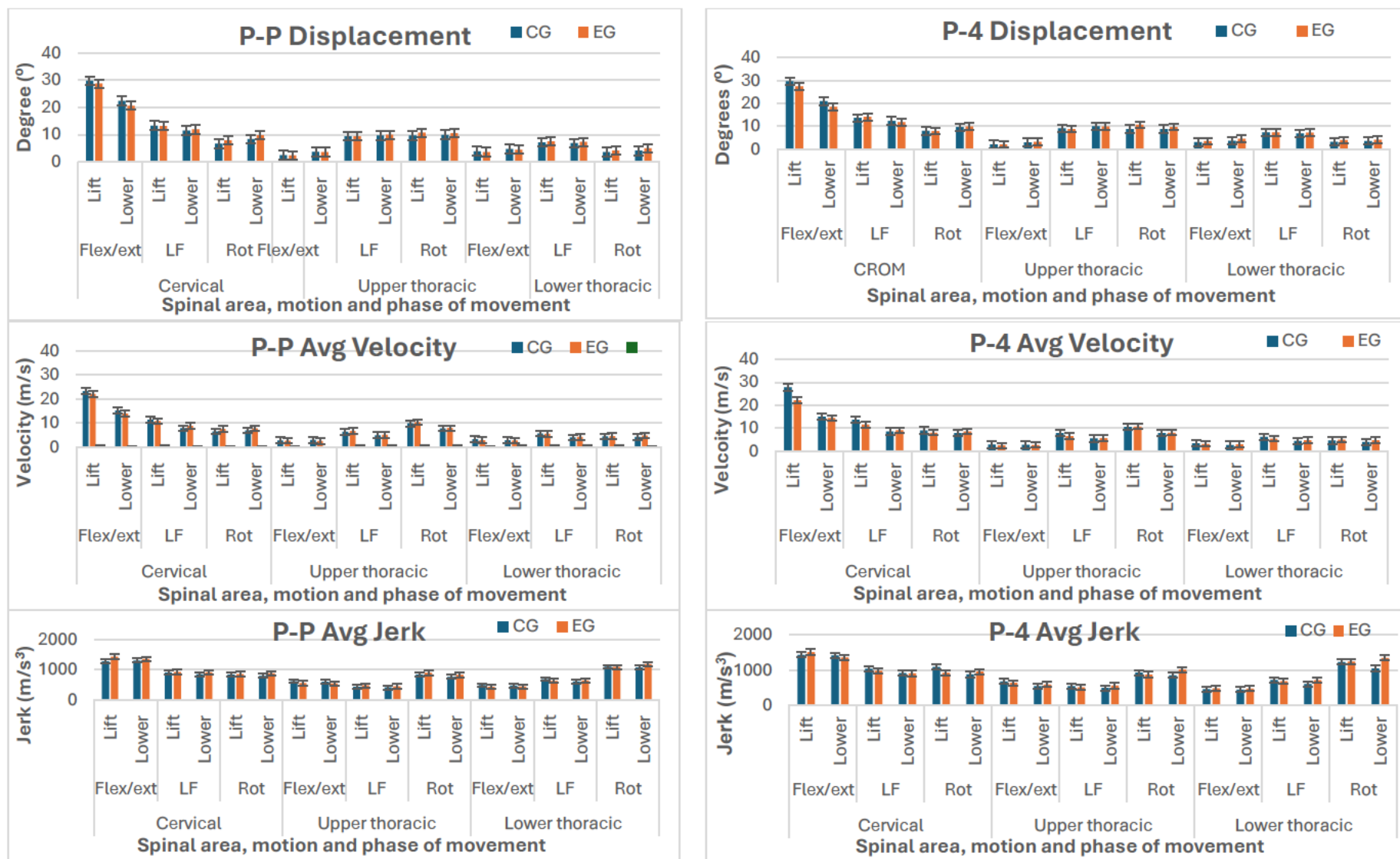
Area	ROM	Measure	Phase	CG				EG				MD	SE	p-value	CI		η²
				M	SE	CI		M	SE	CI							
						Low	High			Low	High						
Upper thoracic	Rot	Range	Lift	8.9	0.5	7.8	10.0	10.7	0.5	9.7	11.8	-1.8	0.75	0.021	-3.36	-0.29	0,17
Lower thoracic	Flex/ Ext	Range	Lower	3.6	0.3	3.0	4.3	4.6	0.3	4.0	5.2	-0.93	0.43	0.037	-1.81	-0.06	0.14

(Rot – rotation, Flex/Ext – flexion/extension, CG – control group; EG – experimental group, M – mean, SE – standard error, CI – confidence interval, η^2 – partial eta squared)

Table 8.6: Significant between group adjusted outcomes for muscle activity during the unilateral arm task immediately post the first intervention and after three treatments

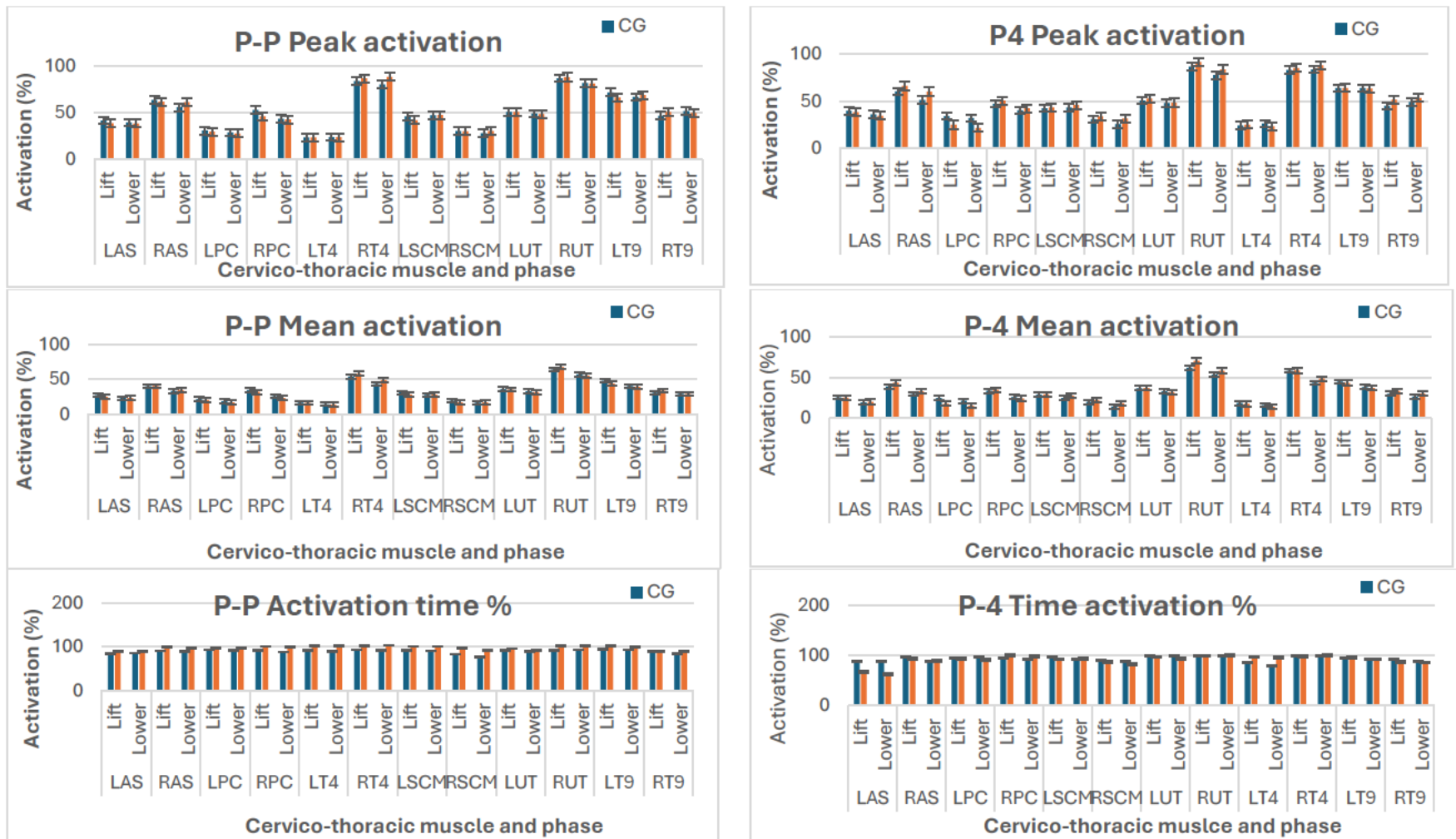
Time point	Muscle	Activation	Phase	CG				EG				MD	SE	p-value	CI		η²
				M	SE	CI		M	SE	CI							
						Low	High			Low	High						
P-P	RT4	Peak	Lower	80,1	2,5	75,0	85,3	88,3	2,6	83,0	93,5	-8.1	3,7	0,038	-15,7	-0,5	0,13
		Mean	Lower	43,0	1,6	39,7	46,3	48,6	1,7	45,2	52,0	-5.6	2,5	0,031	-10,6	-0,6	0,14
P-4	RUT	Mean	Lift	62,1	2,6	56,7	67,4	70,7	2,3	65,9	75,5	-8.6	3,7	0,026	-16,1	-1,1	0,17

(P1 = pre-visit 1; P4 – pre-visit 4; CG – control group; EG – experimental group, RT4 – right paraspinal muscle at T4, RUT – right upper trapezius muscle, M – mean, SE – standard error, CI – confidence interval, η^2 – partial eta squared)



(P-P – pretreatment one to post-treatment one; P-4 – pretreatment one to visit four; avg – average; flex/ext – flexion/extension; LF – lateral flexion; Rot – rotation)

Figure 8.6: Between group comparison of post-adjusted means for the spinal kinematic outcomes in the unilateral arm task



(P-P – pretreatment one to post-treatment one; P-4 – pretreatment one to visit four; % - percentage; avg – average; L – left, R – right; AS – anterior scalene; PC – posterior cervical; SCM – sternocleidomastoid; UT – upper trapezius; T4 – paraspinal at T4; T9 – paraspinal at T9)

Figure 8.7: Between group comparison of post-adjusted means for the sEMG for the 6 pairs of muscles during the unilateral arm task

Muscle activity: Measures taken at the three time points and the results of the ANCOVA analysis of post-adjusted scores adjusted for baseline, age and sex are shown in **Supplementary files 8.10, 8.11 and 8.12**. Following one treatment a significant difference was found between the groups with the intervention group having lower peak activity in the right PC during the lifting phase ($F(1,31) = 4.206, p = 0.049; \eta^2 = 0.119$), and greater peak activation in right paraspinal T4 ($F(1,31) = 5.494, p = 0.026, \eta^2 = 0.151$) and greater activation time percentage in the right SCM during lifting ($F(1,30) = 5.230, p = 0.029; \eta^2 = 0.148$) and lowering ($F(1,30) = 6.641, p = 0.015; \eta^2 = 0.186$) when compared to the control group, with medium to large effect sizes.

At the fourth visit, the intervention group had lower left PC peak muscle activation during the lifting phase ($F(1,28) = 5.318; p = 0.029; \eta^2 = 0.16$) and mean activation during the lowering phase ($F(1,28) = 8.678, p = 0.006, \eta^2 = 0.237$). The mean activation of the left ($F(1,26) = 1.599, p = 0.039; \eta^2 = 0.154$) and right ($F(1,27) = 915.041; p = 0.034; \eta^2 = 0.157$) SCMs during the lowering phase was greater in the intervention group. There were no other between group differences. **Figure 8.9** shows bar charts of the between group comparisons of post-adjusted scores.

In the control group negative correlations were found between pain and right PC muscle peak activation ($r(12) = -0.553, p = 0.040$) during lifting, peak ($r(12) = -0.569, p = 0.340$) and mean ($r(12) = -0.605, p = 0.0034$) activation during lowering; the right paraspinal T4 muscle peak ($r(12) = -0.664, p = 0.010$), mean ($r(12) = -0.727, p = 0.003$) and activation time ($r(12) = -0.558, p = 0.038$) in lifting. A positive correlation was found between pain and left paraspinal T4 activation time ($r(12) = 0.589, p = 0.027$) during lowering. In the intervention group, a negative correlation was found between pain and right paraspinal T9 peak ($r(15) = -0.513, p = 0.035$) activation in lifting and mean ($r(15) = -0.574, p = 0.016$) activation in lowering.

Table 8.7: Significant between group adjusted outcomes for spinal kinematics after one treatment and at the fourth visit for the bilateral arm task

Area and motion	Measure	Phase	CG				EG				MD	SE	p value	CI		η^2
			M	SE	CI		M	SE	CI					Low	High	
					Low	High			Low	High						
Pre to Post																
Lower thoracic:																
Flex/ext	Jerk avg	Lower	466,3	41,4	382,1	550,6	436,2	43,5	347,6	524,8	-154,6	71,4	0,038	-300,3	-8,9	0,13
LF	Jerk avg	Lower	606,2	41,4	522,1	690,4	636,4	43,6	547,8	725,1	-511,4	195,7	0,014	-910,4	-	0,18
															112,4	
Rot	Range	Lower	4,1	0,4	3,2	5,0	4,9	0,4	4,0	5,8	-1,7	0,8	0,041	-3,4	-0,1	0,13
	Velocity	Lower	4,2	0,3	3,6	4,9	4,8	0,3	4,1	5,5	-2,6	0,9	0,006	-4,4	-0,8	0,22
	avg															
	Jerk avg	Lower	1073,3	111,5	846,4	1300,2	1182,4	117,2	944,0	1420,8	-410,8	165,7	0,019	-748,7	-72,8	0,17
Pre to 4 TH																
Upper thoracic:																
Flex/ext	Jerk avg	Lower	368,4	47,3	271,5	465,4	507,8	45,5	414,6	601,0	-139,4	66,3	0,045	-275,3	-3,5	0,14

(P-P = pre- to post visit 1; P-4 – pre-visit 4; CG – control group; EG – experimental group, flex/ext – flexion/extension, LF – lateral flexion, Rot – rotation, avg - average, M – mean, SE – standard error, CI – confidence interval, η^2 – partial eta squared)

Table 8.8: Significant between group adjusted outcomes for muscle activation after one treatment and at the fourth visit for the bilateral arm task

Muscle	Activation	Phase	CG				EG				MD	SE	p value	CI		η²
			M	SE	CI		M	SE	CI					Low	High	
					Low	High			Low	High						
Pre to Post																
RPC	Peak	Lift	61.9	3.8	54.1	69.7	50.4	3.9	42.5	58.3	11.5	5.6	0.049	0.1	22.9	0.12
RT4	Peak	Lower	34.3	2.5	29.2	39.4	42.9	2.5	37.8	48.1	-8.6	3.7	0.026	-16.1	-1.1	0.15
RSCM	Time %	Lift	77.9	5.4	66.9	88.9	98.0	5.3	87.2	108.7	-20.1	7.8	0.029	-36.0	-4.1	0.14
	Time %	Lower	77.9	5.4	66.9	88.9	98.0	5.3	87.2	108.7	-20.1	7.8	0.015	-36.0	-4.1	0.19
Pre to 4 TH																
LPC	Peak	Lift	67.0	4.6	57.5	76.5	52.3	4.3	43.6	61.0	14.8	6.4	0.029	1.7	27.9	0.16
	Mean	Lower	31.0	2.8	25.2	36.7	19.6	2.5	14.4	24.8	11.4	3.9	0.006	3.5	19.3	0.24
LSCM	Mean	Lower	10.0	3.1	3.6	16.5	19.5	2.9	13.6	25.4	-9.4	4.3	0.039	-18.3	-0.5	0.05
RSCM	Mean	Lower	14.1	3.6	6.7	21.6	25.4	3.4	18.5	32.4	-11.3	5.0	0.034	-21.6	-0.9	0.00

(P-P = pre- to post visit 1; P-4 = pre-visit 4; CG – control group; EG – experimental group, RPC – right posterior cervical, RT4 – right paraspinal T4, RSCM – right sternocleidomastoid, LSCM – left sternocleidomastoid, % - percentage, M – mean, SE – standard error, CI – confidence interval, η^2 – partial eta squared)

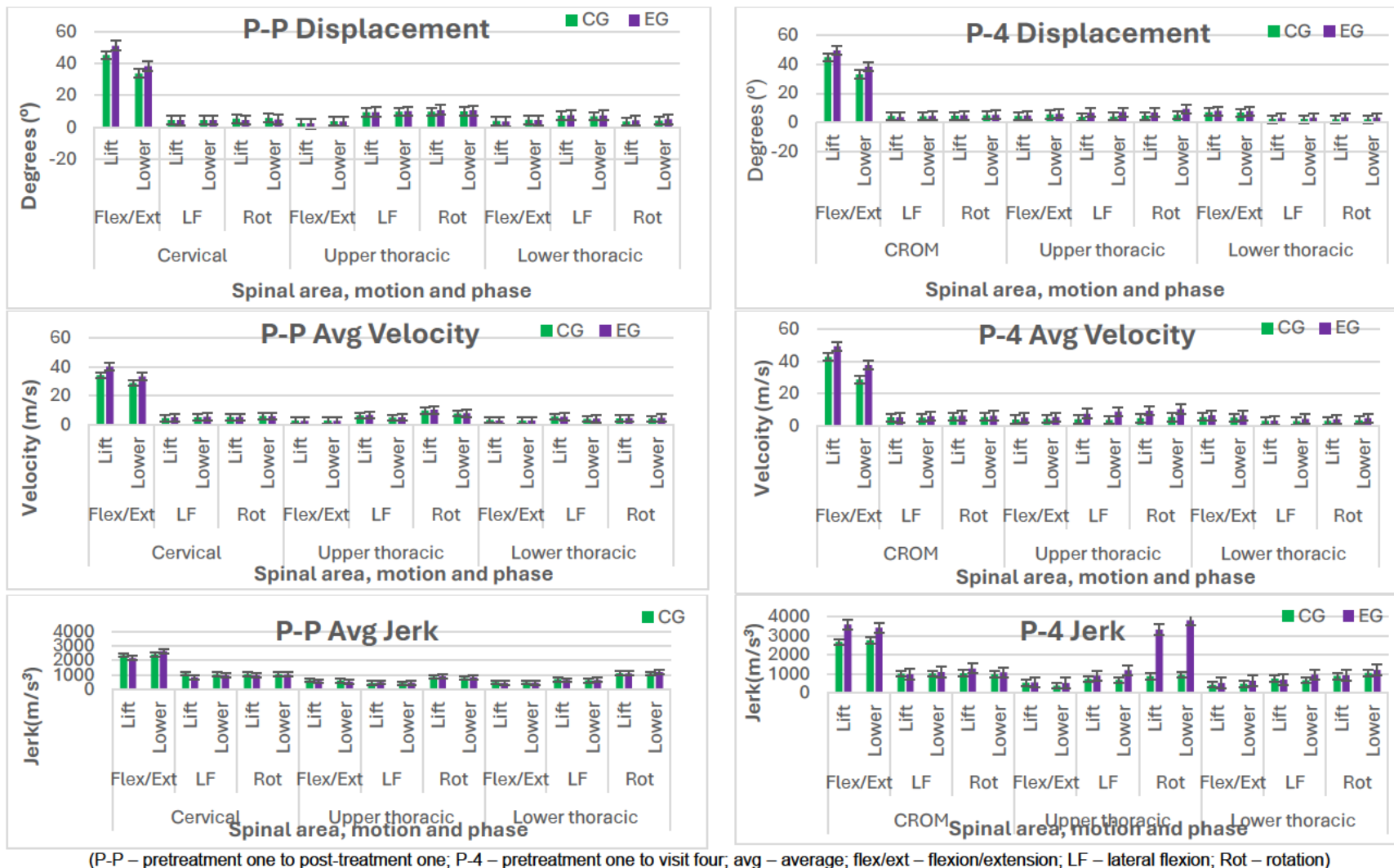
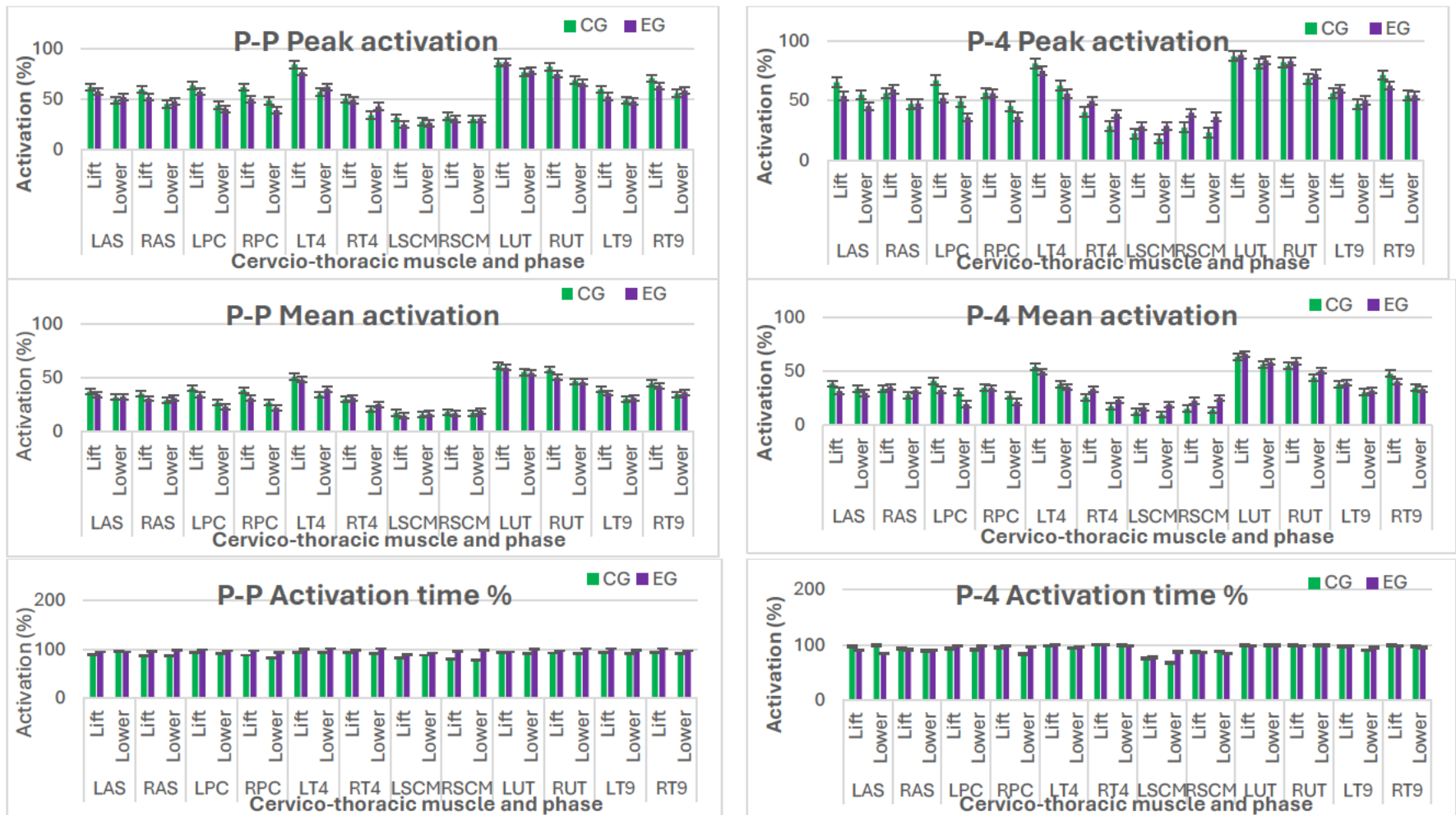


Figure 8.8: Between group comparison of adjusted post-means for the spinal kinematic outcomes in the bilateral arm task



(P-P – pretreatment one to post-treatment one; P-4 – pretreatment one to visit four; % - percentage; avg – average; L – left, R – right; AS – anterior scalene; PC – posterior cervical; SCM – sternocleidomastoid; UT – upper trapezius; T4 – paraspinal at T4; T9 – paraspinal at T9)

Figure 8.9: Between group comparison of post-adjusted means for the sEMG for the 6 pairs of muscles during the bilateral arm task

Patient global impression of change and treatment satisfaction

There were no significant differences between the two groups according to the PGIC score categories ($p=0.500$), using Fischer's Exact test, **Figure 8.10**, or the line assessment ($t(32) = -2.018, p=0.052$).

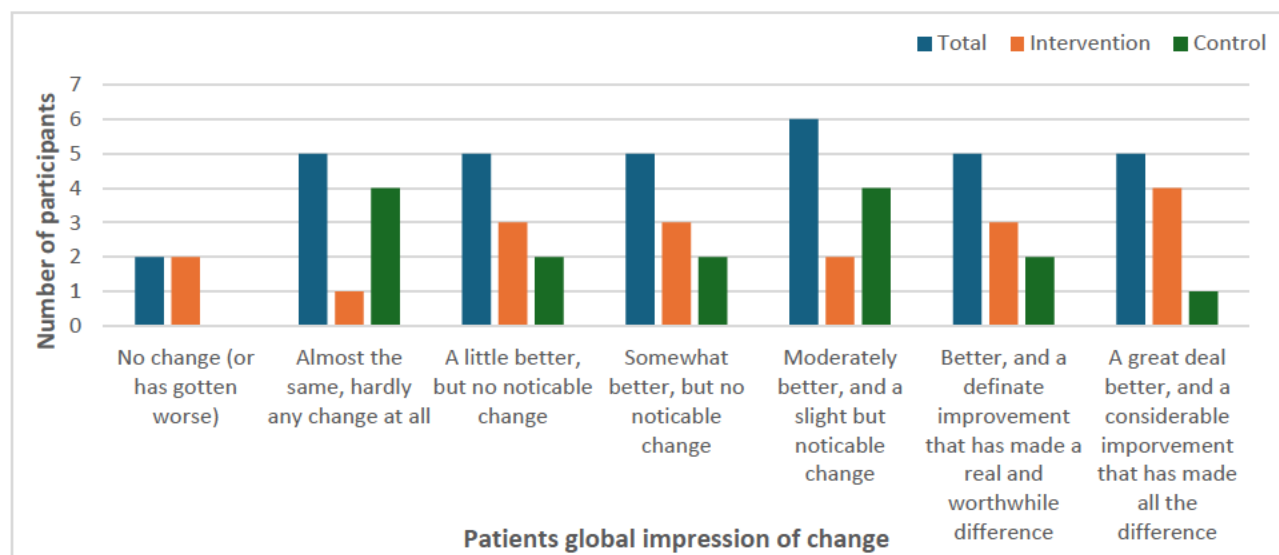


Figure 8.10: Patients global impression of change scores

There were no significant differences between the groups for level of satisfaction questionnaire, except for emotions ($p=0.001$) and quality of life ($p=0.025$), assessed using Students t-tests, with almost all the participants in the intervention group indicating better improvement in these domains ($n=18, 95\%$; $n=17, 89.5\%$), **Figure 8.10**. The following comments were made by those in the intervention group ($n=6$): “I was expecting they would give me some pills for my neck pain because my spine is good, I never felt pain in my spine”, “I’m glad to feel sting without neck pain”, “I’m returning next week for my back”, “No headaches since the last treatment”, “the very moments and hours after chiropractic care my neck is back to normal” and “treatment was very comfortable”. These comments were made by those in the control group ($n=2$): “I can feel a lot change and the treatment was not painful” and “thank you for the much-needed help on my neck”.

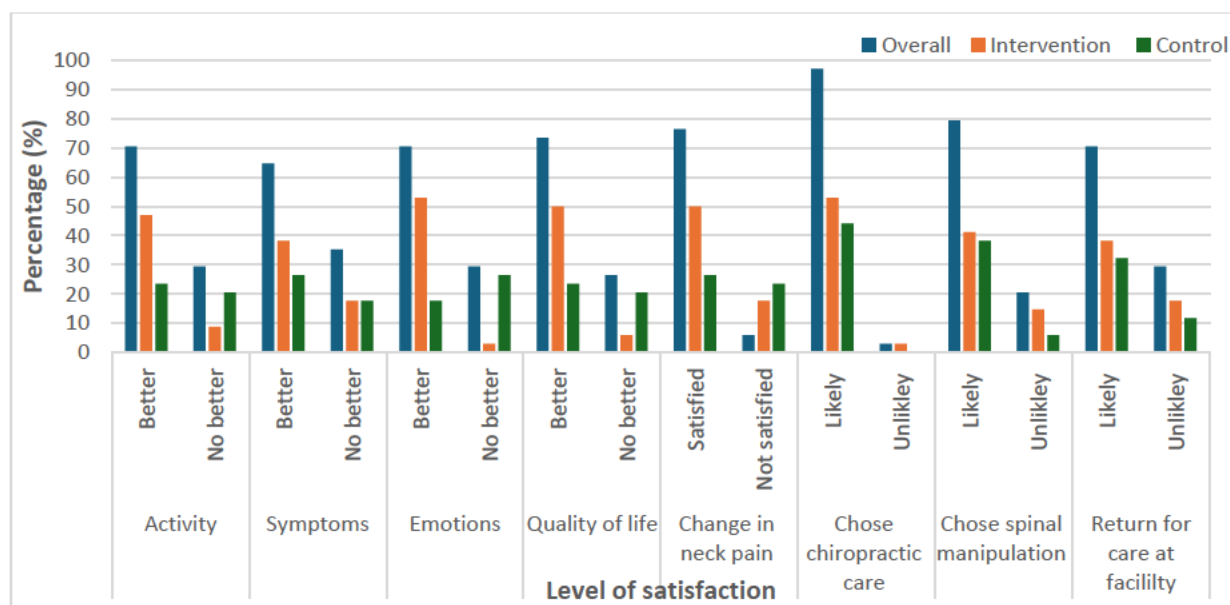


Figure 8.11: Level of satisfaction with care

Adverse events

In this study 11 participants developed minor adverse events, defined as short-term, mild, non-serious, transient, reversible consequences of the treatment (Saavedra-Hernández *et al*, 2012). In the intervention group 7 participants complained of mild tenderness following one treatment (34%), and in the control group 4 participants experience mild tenderness (27%). All symptoms resolved within 24 hours. One participant in the control group developed shingles between the first and second appointment and was excluded from the study.

DISCUSSION

The findings of this study showed that SMT resulted in pain reduction and improved disability, with few changes in spinal kinematics and muscle recruitment patterns being variable and differing between the tasks. SMT did not alter cervical spinal kinematics in either task but following treatment, there were increases in thoracic spine range, velocity

and jerk. Muscle recruitment patterns changed during both tasks with increased right upper trapezius muscle activation occurring in the unilateral lifting part of the arm task and decreased left posterior cervical muscle and increased left and right SCM activity in the bilateral arm task during lowering in the SMT group. The control group had stronger correlation relationships between pain and spinal kinematic and muscle recruitment variables than the SMT group.

Alterations in spinal kinematics have been found in those with neck pain when executing arm tasks (Grip *et al.* 2008; Tsang, Szeto and Lee 2013; Moghaddas, Edwards and Snodgrass 2022)(Chapter 6). There is a paucity of literature assessing the impact of manual treatments on spinal kinematics in neck pain, from the studies that are available they assessed the effect of manual therapy on cervical ROM kinematics. Lascrain-Aguirrebeña *et al* (2018) found that cervical mobilisation resulted in no between group differences for cervical velocity, and Serra-Añó *et al* (2023) found that cervical SMT resulted in no changes in movement harmony, both studies assessed immediate effects of one treatment. Contrasting with these studies, following one and three treatments of cervical SMT, increased velocity and jerk were found during cervical ROM (Chapter 7). In the current study cervical kinematic outcomes were not influenced by the treatment. During the tasks participants were encouraged to track the lifted object with their head and neck, to encourage neck motion, however, it is possible that the cervical motions required to perform the tasks were not sufficiently challenging to highlight temporal changes following treatment. The more challenging a task, the more the neuromuscular system has to respond and adapt.

The tasks utilised in this study are common activities of daily living, refined over many years of execution, and thus the motor system would have a wide variety of motor synergies (Bizzi and Cheung 2013), based on the principle of abundance (Latash *et al.* 2010), from which to select a strategy to execute the motion (Ting *et al.* 2015). The motor system can select a movement strategy which is 'good enough' to allow task performance, and its selection is made via preferred configurations of muscle

coordination, modulated across the motion, rather than due to biomechanical conditions (Ting *et al.* 2015).

In this study changes in thoracic spine kinematics were found during both tasks, in the unilateral arm task, increased range occurred in lifting and lowering and in the bilateral arm task increased rotation range, velocity and jerk occurred during lowering in the SMT group. The thoracic spine has an intimate relationship with the cervical spine, as part of the kinematic chain (Karandikar and Vargas 2011), and motion in the thoracic spine is necessary for the execution of shoulder flexion (Crawford and Jull 1993; Stewart *et al.* 1995) – as was needed in this study. The theory of regional interdependence (Wainner *et al.* 2007) posits that treatments applied to one area can bring about alterations in other areas distant from the original area affected.

Alternatively, these changes may have occurred due to variations in trial-to-trial testing that can occur with motor repetition (Latash *et al.* 2010; Nordin *et al.* 2017) and may not be related to the intervention. Over the duration of the study, the intervention group reported greater improvements in self-reported disability when compared to the control group, yet this change in disability was not reflected in changes in spinal kinematics, potentially indicating that the improvements in disability are more perceptual (Varela and Van Asselt 2022) than related to actual movement impairments.

People with neck pain have been found to have altered muscle activation patterns during cervical ROM (Chapter 5)(Murphy, Marshall and Taylor 2010; Pinheiro, dos Santos and Chaves 2016; Lascurain-Aguirrebeña *et al.* 2018; Nobe *et al.* 2022) and arm related activities (Falla, Bilenkij and Jull 2004; Szeto, Straker and O'Sullivan 2005, 2009; Leonard *et al.* 2010; Tsang, Szeto and Lee 2014). In an earlier study, (Chapter 6) people with neck pain were found to have increased activation time for the right UT and left paraspinal at T4 during the lifting phase and decreased left paraspinal T4 activation during lowering while executing a unilateral arm task. In the current study following one treatment of cervical SMT, the right paraspinal muscle at T4 had increased activity during lowering when compared to the control group; and after three treatments increased right UT

muscle activation during lifting. Shoulder flexion results in thoracic spine extension (Crawford and Jull 1993; Stewart *et al.* 1995), induced by the paraspinal muscles working concentrically, and on arm lowering working eccentrically, controlling thoracic spine flexion. Increased activity during this motion would indicate improved control during this phase of the activity. SMT has been found to result in EMG response in muscles distant to the site of application (Herzog, Scheele and Conway 1999; Currie *et al.* 2016; Currie *et al.* 2023). Whether these effects lead to improved task execution was not determined but the participants receiving SMT reported improved disability scores, greater than those in the control group.

Gorrell *et al.* (2022) reported in participants with mild neck disability that reflex responses were found in muscles of the neck and back (including the thoracic paraspinal muscles), with greater responses occurring locally and occurring after lower rather than upper cervical SMT (Gorrell *et al.* 2022). The proposed mechanism for reflex responses is the activation of muscle spindles and mechanoreceptors in the zygapophyseal joints (Pickar 2002; Pickar and Bolton 2012; Gorrell, Conway and Herzog 2019). Yet no between group differences were found for the cervical muscles, which may indicate that the light pressure utilised in the control group may have been sufficient to alter mechanoreceptor input locally but not distally as seen in those who received SMT.

After three treatments, those receiving cervical SMT displayed increased right UT muscle activity during the lifting phase of the unilateral arm task. This muscle contributes to both shoulder elevation and lowering (Büll, Vitti and De Freitas 1989) and in neck pain sufferers has been found to have increased activity during writing and keyboard tasks when compared to asymptomatic controls (Falla, Bilenkij and Jull 2004; Szeto, Straker and O'Sullivan 2005; Leonard *et al.* 2010). In contrast, Falla *et al.* (2004) found during a right-handed, arm task, where participants were required to move their upper limb, that right UT muscle activity was greatest in those without neck pain - compared to those with neck pain (Falla, Bilenkij and Jull 2004). Thus, increased right UT activity observed in the

current study may indicate increased efficacy in the muscle to execute the weight arm task.

During the bilateral arm task, after one treatment there was decreased right PC muscle activity, with increased right paraspinal T4 and SCM activation during lifting, whereas after three treatments there was decreased left PC and increased left and right SCM activity in lowering in those receiving SMT. There were no differences between the groups for cervical spine range during the task, thus these differences cannot be explained due to one group having great neck motion. Nobe et al (2022) comparing healthy controls to those with neck pain reported increased activity of the cervical flexors and extensors in neutral and during neck motion when returning to neutral in those with neck pain. The reduction in PC muscle activity and the increase in SCM activation, found in the current study, may indicate that following cervical SMT the ratio of flexor to extensor activation was normalised. Due to the lack of study from which to compare these findings, a comparison is made to Tsang et al (2014) who found that during a unilateral, weighted arm lifting task, asymptomatic controls had increased activation of their PC muscle during lifting and lowering (Tsang, Szeto and Lee 2014).

Bilateral arm tasks require greater co-ordination and motor control strategies (Swinnen and Wenderoth 2004) and this may explain why in the unilateral task this pattern of muscle recruitment was not observed following intervention. Besides for reflexogenic changes following SMT, alpha motor neuron pool excitation (Murphy, Dawson and Slack 1995; Dishman, Ball and Burke 2002; Bicalho *et al.* 2010; Dishman, Burke and Dougherty 2018; Haavik *et al.* 2018) and activation of supraspinal structures involved in motor control (Lelic *et al.* 2016; Haavik *et al.* 2017; Niazi *et al.* 2020) have been reported.

Pain can impact movement by making subtle changes to motor activity to complete avoidance of movement (Hodges 2011; Merkle, Sluka and Frey-Law 2020). Fear avoidance behaviours can negatively impact a person's willingness to move (Gatchel *et al.* 2016; Lundberg and Archer 2022) and for this reason, participants were screened and excluded if they showed signs of this behaviour. Both groups reported pain reduction with

those receiving cervical SMT having greater improvements by the third visit, a finding supported by previous work (Saavedra-Hernández *et al.* 2012; Serra-Añó *et al.* 2023). However, by the one week follow up there were no between group differences, with both groups having clinically significant changes in pain from the first visit. When pain was correlated with spinal kinematics stronger relationships were found in the control group. Previous research has found that following cervical SMT a strong correlation was found between decreasing pain and increased cervical ROM (Martínez-Segura *et al.* 2006), whereas in the current study, a decrease in pain was only correlated with a reduction in cervical rotational jerk on lifting in the unilateral arm task.

Three mechanisms may explain the changes in reported pain in the groups: the first is the Hawthorne effect, through being observed the participants felt improvement in their condition (Berthelot, Nizard and Maugars 2019), the second is the placebo effect, where the control intervention lead to neuro mediators that resulted in them feeling better (Dodd *et al.* 2017), and the third is that the light pressure applied during delivery of the control intervention resulted in cervical mechanoreceptors activation which may have affected sensorimotor control (Geri *et al.* 2019). Unlike previous studies where a similar control intervention was utilised (Haavik-Taylor and Murphy 2007; Murphy, Marshall and Taylor 2010) in this study light pressure was applied, this was done to try and isolate the effect of the HVLA thrust. In studies involving manual therapy, it is difficult to blind the person providing the treatment and the person receiving the intervention (D'Alessandro *et al.* 2022; Hohenschurz-Schmidt *et al.* 2023). Care was taken to inform the participants that manual techniques were being tested without mentioning 'cavitation' to reduce expectations. Although the recruitment strategy did limit inclusion to those who had no prior exposure to SMT, many of the participants were naïve to chiropractic treatment (64%), and the between group allocation was similar, which may have added to the placebo effect.

Strengths and limitations

This is one of the first studies to assess the effect of cervical SMT compared to a control group on functional upper limb tasks assessing spinal kinematics and muscle recruitment patterns. Many studies of this nature have only assessed immediate or intermediate effects following a single treatment, whereas this study assessed immediate and short terms effects. Thus, adding to a growing body of literature on the effects of SMT. This study can help researchers design future studies to further assess the effects of SMT on motor control and enlighten clinicians on the neuromuscular effects of SMT.

There are some limitations to the study with regard to the findings and their clinical relevance. In many instances, the differences between the groups were small with large confidence intervals. It is possible that some of the changes observed occurred due to crosstalk or artefacts from the motion of reflectors during task execution. In addition, there are challenges in the collection of motion capture and sEMG data on separate days. Efforts were made to minimise these effects, by utilising only one person who applied the electrodes and reflectors, and a standardised laboratory set up to minimise poor quality readings. Participants executed the tasks at their own self-selected pace, and their movement strategy was not corrected, but they were guided as to the motions and when to perform them. In addition, the seat and arm reach were not normalised to body height. This variability may have impacted the results. The array of motor synergies that the body can use to execute motion (Bizzi and Cheung 2013) may override the small changes that may have occurred due to the intervention and highlight the ability of the body to execute tasks (Bizzi and Ajemian 2020).

CONCLUSION

This study found that cervical SMT resulted in decreased pain and improved disability, with variable changes in spinal kinematics, mostly of the thoracic spine, and changes in muscle recruitment patterns during a unilateral and bilateral upper limb task immediately following one and three treatments. Patients' perceived change and satisfaction was

similar across the groups. The spinal kinematic and muscle recruitment responses may have been artefacts from differences between trial assessments of motor function thus future work will aid in determining the clinical relevance of the observed changes.

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Conflict of interest

The authors declare no conflict of interest related to this research.

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CHAPTER NINE

DISCUSSION, STUDY LIMITATIONS, RECOMMENDATIONS AND CONCLUSION

9.1 DISCUSSION

Spinal manipulative therapy dates to ancient civilisations and was utilised by Hippocrates to alleviate musculoskeletal pain (Pettman 2007). It is most frequently utilised to treat neck and back pain (Paige *et al.* 2017; Rubinstein *et al.* 2019; Gevers-Montoro *et al.* 2021a) but can be utilised in other areas of the body (Brantingham *et al.* 2011; Brantingham *et al.* 2012). Its use as a treatment for neck pain has been well documented (Coulter *et al.* 2019; Chaibi, Stavem and Russell 2021) and recommended by clinical practice guidelines (Bryans *et al.* 2014; Côté *et al.* 2016; Whalen *et al.* 2019; Hawk *et al.* 2020). Despite the popularity of this treatment approach the mechanisms through which it brings about its effects are still under investigation (Bialosky *et al.* 2018; Gyer *et al.* 2019).

A comprehensive model was proposed by Bialosky *et al.* (2018), to explain the effect of manual therapy on pain inhibition (Bialosky *et al.* 2018). The model included mediators affecting treatment outcomes that come from the patient, such as their clinical presentation, perceptions and expectations; the practitioner, their characteristics and the treatment, how it is applied and its underlying mechanism of action responsible for inducing treatment outcomes. Mechanistic studies propose that the mechanical event of the application of SMT results in a 'cascade' of neurophysiological effects (Pickar 2002; Pickar and Bolton 2012) impacting peripheral, spinal and supraspinal processes (Gyer *et al.* 2019). This in turn activates descending inhibitory pain mechanisms (Savva, Giakas and Efstathiou 2014), reflexogenic effects (Herzog *et al.* 1995; Herzog, Scheele and Conway 1999; Gorrell, Conway and Herzog 2019; Gorrell *et al.* 2022), alpha and gamma motor neuron excitability and corticospinal tract activity (Murphy, Dawson and Slack 1995; Dishman, Ball and Burke 2002; Dishman, Greco and Burke 2008; Bicalho *et al.* 2010;

Clark *et al.* 2011; Fryer and Pearce 2012; Niazi *et al.* 2015; Lelic *et al.* 2016; Gyer *et al.* 2019; Kingett *et al.* 2019; Niazi *et al.* 2020; Haavik *et al.* 2021).

The majority of trials investigating the neurophysiological effects of SMT have been conducted on either asymptomatic populations (Herzog *et al.* 1995; Symons *et al.* 2000; King, Docrat and Abdul-Rasheed 2022), those with subclinical pain (Haavik-Taylor and Murphy 2007; Haavik *et al.* 2017; Haavik *et al.* 2018) or low back pain (Colloca and Keller 2001; Lallanne, Lafond and Descarreaux 2009; Harvey and Descarreaux 2013; Currie *et al.* 2016). Studies on neck pain populations have focused on flexion-relaxation phenomena (Murphy, Marshall and Taylor 2010) and electromyographic responses (de Camargo *et al.* 2011; Pires *et al.* 2015; Bracht *et al.* 2018; Gorrell *et al.* 2022), with only one trial assessing characteristics of motion other than cervical ROM, in the form of motion smoothness (Serra-Añó *et al.* 2023) following SMT.

This was highlighted in the systematic review and meta-analysis conducted as part of this research (chapter three) that was undertaken to assess the empirical literature on the effect of spinal manipulation on muscle recruitment patterns and spinal kinematics in patients with non-specific neck pain. The review found no trials that simultaneously investigated the effect of spinal SMT on spinal kinematic and muscle recruitment patterns in those with neck pain. In addition, the use of 3D motion capture was under-utilised, with an over utilisation of cervical ROM measurement, mostly using the CROM goniometer. Little attention has been paid to other kinematics outcomes such as velocity, acceleration or jerk. The review also showed that very few trials assessed the impact of SMT on muscle activation, with those that did finding varied responses, in neck pain populations, warranting further exploration. This review will hopefully encourage researchers to seek other measures to further explore SMT and its effects on neck pain, supporting calls for clinical trials to establish the clinical relevance of the theorised neurophysiological mechanisms of SMT (Gyer *et al.* 2019).

In order to undertake this research project a purpose-built biomechanics laboratory was developed using eight Prime 13 OptiTrack motion capture cameras (Optitrack®, Natural Point, OR, USA), the Motive™ tracker and STT-system™ software (STT systems group, Spain) to allow for capturing of three-dimensional data. The Biopac Bionomadix MP150 Data Acquisition System (Biopac systems® Inc.) was utilised to record surface EMG from six cervicothoracic muscles bilaterally. A custom-made biomechanical model was developed to allow acquisition of cervical and thoracic spinal kinematics during cervical ROM and two functional upper limb tasks.

Due to the novelty of this model, the second study objective was to determine the within day, test-retest reliability of the procedures utilised to obtain cervical spinal kinematics (angular displacement, peak and mean velocity and jerk) using motion capture while performing cervical ROM in participants with and without neck pain (chapter four). The study showed that the system had good to excellent reliability, with the jerk measures being low to moderate. Mean velocity measures were more reliable than peak velocity, and jerk measures were less robust than the other kinematic outcomes. These findings were in line with previous research undertaken using electromagnetic tracking devices (Vikne *et al.* 2013b; Sarig Bahat *et al.* 2016) and the gold standard Vicon® (Lascrain-Aguirrebeña *et al.* 2018c). SEMs and MDCs were provided for the various measures. The reliability of the system did not differ between those with and without neck pain. Although this study only provided reassurance for the use of the system for within day measures, it showed that tracking of the markers was consistent over time and evidence supported the hypothesis that the ICC's would be greater than 0.5 for the kinematic measures however some jerk measures were less reliable.

The next two objectives were to compare cervical spinal kinematics (angular displacement, peak and mean velocity and jerk) and muscle recruitment patterns (peak and mean activation and activation time percentage) of selected cervicothoracic muscle in participants with and without neck pain whilst performing cervical ROM (chapters five) and two upper limb arm tasks (chapter six). Cervical ROM is commonly assessed as part

of the diagnostic examination of a patient with neck pain (Cohen 2015; Blanpied *et al.* 2017), where reduced motion is often noted (Snodgrass *et al.* 2014; Stenneberg *et al.* 2017). Cervical ROM measurement records peak displacement and does not provide information regarding the quality of the motion. Including measures such as velocity and jerk can allow quantification of the way in which the person with neck pain moves (Sjölander *et al.* 2008; Lemmers *et al.* 2018). A recent review of spinal kinematics in neck pain found a moderate level of evidence supporting changes in velocity and acceleration, with limiting to conflicted evidence for jerk outcomes being associated with neck pain (Franov *et al.* 2022).

The methodologies used in the case controlled, cross-sectional studies have been varied with only a few studies assessing all three planes of ROM (Sjölander *et al.* 2008; Guo *et al.* 2012; Tsang, Szeto and Lee 2013a; Waeyaert *et al.* 2016; Alsultan *et al.* 2019; Salehi *et al.* 2021), and only one study that included sub-phase analysis - which was limited to flexion-extension motion (Vikne *et al.* 2013a). Few trials (Vikne *et al.* 2013a; Park *et al.* 2017; Lascurain-Aguirrebeña *et al.* 2018b) combined the assessment of muscle activation patterns with a kinematic assessment during cervical ROM, with only the study by Lascurain-Aguirrebeña *et al.* (2018) including all three cardinal planes of cervical motion, with no sub-phases analysis. Sub-phase assessment allows the motion away from and back to neutral to be examined which can provide valuable information on the concentric and eccentric components of cervical ROM, which were included in the current study. These studies aimed to provide further insights into functional impairments which can aid in developing a greater understanding of the impact of neck pain (Lansade *et al.* 2009; Sarig Bahat, Weiss and Laufer 2010) and can then inform treatment recommendations (Lemmers *et al.* 2018).

The results of the case-controlled study on neck ROM (chapter five) found that the neck pain participants did not differ from those without neck pain for peak displacement, peak and mean velocity or jerk measures, supporting the null hypothesis, but they did take longer to execute lateral flexion motion, albeit a very small difference. It was anticipated

that there would be greater differences in kinematics between the two groups. In terms of muscle activation patterns between group variations were seen with those with neck pain having reduced activation time in the left posterior cervical muscle during cervical extension when acting concentrically, and the left anterior scalene muscle during right rotation when it was acting eccentrically. During lateral flexion and rotation, the thoracic paraspinal muscles showed increased activation time with lower peak and mean activation levels, rejecting the null hypothesis. These findings indicate that neck pain affected motor control, not by altering kinematics but in the way muscles were recruited. This was contrary to the hypothesis that those with neck pain would differ from asymptomatic controls for kinematic outcomes but provided evidence that people with neck pain have altered muscle activation patterns.

The second and third tasks (chapter six) involved unilateral and bilateral arm lifting tasks. These tasks were selected as upper limb motion is utilised in activities of daily living (Henmi *et al.* 2006) and in the occupational environment (Skovlund *et al.* 2022). The relationship between the cervical spine and upper extremity is intimate (Alreni *et al.* 2017) with spinal perturbations being reported during arm lifting tasks (Fayad *et al.* 2008). Pain in either the neck or in the arm can negatively impact the other area (McLean *et al.* 2010; Alreni *et al.* 2017). People with neck pain have been found to have feedforward coactivation of neck muscles during arm lifting, proposed to establish stability to the neck (Falla *et al.* 2004c). Few studies (Szeto, Straker and O'Sullivan 2005; Grip *et al.* 2008; Szeto, Straker and O'Sullivan 2009; Tsang, Szeto and Lee 2014; Moghaddas, Edwards and Snodgrass 2022) have investigated the effect of neck pain on functional task execution and its effect on altering kinematics (Moghaddas *et al.* 2019), with even fewer studies (Tsang, Szeto and Lee 2014) assessing muscle activation patterns simultaneously to spinal kinematics during functional activities. Movement occurs due to complex, multi-system processing (Mulla and Keir 2023), therefore combining kinematic and muscle activation pattern assessment would allow greater insight into the neuromuscular aspects of motor control.

The results of this study (chapter six) showed that those with neck pain differed from those without neck pain during the unilateral arm task with less peak displacement of the upper thoracic spine during rotation and greater displacement in the lower thoracic spine during lateral flexion and rotation, rejecting the null hypothesis. It was interesting that the conjoint motions were affected as opposed to the primary plane motion. During the lifting and lowering phases those with neck pain had a greater lower thoracic spine rotation range, with no differences occurring between the groups for velocity or jerk measures. This suggest that those with neck pain used their thoracic spine more to execute the desired task.

In terms of muscle activation patterns differences occurred during lifting with those with neck pain having a greater percentage activation time in the right upper trapezius and left paraspinal muscle at T4, and lower peak activation magnitude of the left paraspinal muscle at T4. Whereas during lowering the left paraspinal muscle at T4 had greater activation time percentage and lower peak and mean activation in those with neck pain, rejecting the null hypothesis. These findings indicate that those with neck pain had greater upper thoracic spine stiffness with increased lower thoracic spine motion as compensation, this was accompanied by contra-lateral paraspinal muscle activation requiring longer activation time with lower activation levels to complete the same task as those without neck pain.

For the bilateral arm task, during the lifting phase, those with neck pain had less cervical spine lateral flexion velocity with increased rotation range in the upper and lower thoracic spine. During the lowering phase, those with neck pain had lower average velocity in cervical lateral flexion and rotation. Interestingly there were no differences between the groups for muscle activation patterns during this task. These findings showed that during a sagittal plane lifting task cervical conjunct motions were slower in those with neck pain with thoracic range increasing to allow for task execution. The effects on the thoracic spine support literature that motivates to include the treatment of the thoracic spine for neck pain (Masaracchio *et al.* 2019). These findings support the hypothesis that spinal

kinematic and muscle recruitment differences are found between those with and without neck pain during the execution of two upper limb lifting tasks, however, the kinematic differences were isolated to displacement, range and velocity and there was variability in the muscle activation patterns.

These studies support previous research highlighting kinematic (Grip *et al.* 2008; Tsang, Szeto and Lee 2014; Moghaddas, Edwards and Snodgrass 2022) and muscle activation differences (Szeto, Straker and O'Sullivan 2005, 2009; Leonard *et al.* 2010; Tsang, Szeto and Lee 2014) between those with and without neck pain and that these effects extend beyond the cervical spine. In chronic neck pain changes to cervical sensorimotor control and maladaptive neural plasticity may be responsible for the motor control adaptations seen (Qu *et al.* 2022). The high adaptability of the body to execute movement is influenced by many mechanisms throughout the nervous system (Merkle, Sluka and Frey-Law 2020). Muscles can adapt by altering within and between muscles' function (Hodges and Tucker 2011). The cross-sectional nature of these investigations does not allow for cause-and-effect relationships to be established (Andrade 2022), these findings need to be verified via longitudinal studies. However, they do provide insights into possible mechanisms of persistent neck pain and that consideration of these factors should be made when designing management programmes (Tsang, Szeto and Lee 2013a; Moghaddas *et al.* 2019).

Following on from these investigations two randomised controlled trials (RCT) were undertaken with the objective to determine the effect of cervical SMT, in the form of HVLA-thrust manipulation, on patient reported outcomes (pain intensity, disability, perceived treatment effect and level of satisfaction), cervical spinal kinematic (angular displacement, peak and mean velocity and jerk) and muscle recruitment patterns (peak and mean activation and activation time percentage) of selected cervicothoracic muscle compared a control intervention while performing cervical ROM (chapter seven) and two upper limb tasks (chapter eight). SMT has been proposed to induce a sequence of neurophysiological effects that aid the symptomatic improvement associated with this

treatment approach (Pickar 2002; Pickar and Bolton 2012; Bialosky *et al.* 2018). In neck pain, most of the mechanistic studies investigating the effects of SMT on neck pain have focused on immediate short-latency changes in muscle activity and flexion-relaxation phenomena (Murphy, Marshall and Taylor 2010; de Camargo *et al.* 2011; Pires *et al.* 2015; Bracht *et al.* 2018). Despite several studies highlighting altered kinematic (Sarig Bahat, Weiss and Laufer 2010; Tsang, Szeto and Lee 2014; Franov *et al.* 2022)(Chapter five and six) and muscle recruitment patterns (Falla *et al.* 2003; Falla *et al.* 2004a; Tsang, Szeto and Lee 2014; Nobe *et al.* 2022)(chapter five) differences between those with and without neck pain few studies have attempted to assess the effect of SMT on these outcomes in neck pain. Maladaptive motor behaviours negatively impact neck pain sufferers (Harman *et al.* 2021) and require suitable treatments to reverse these effects. SMT is frequently sought as a treatment for neck pain (Davis *et al.* 2015) and understanding its effects on motor control would assist clinicians in identifying patients that would respond to this treatment.

The first RCT (chapter seven), evaluated the effect of SMT on cervical ROM. An assessment of cervical ROM is recommended as part of the diagnostic work up of the neck pain patient (Cohen 2015; Blanpied *et al.* 2017). Two reviews have assessed the effect of SMT on cervical ROM showing varied responses (Snodgrass *et al.* 2014; Stenneberg *et al.* 2017), with few studies assessing the effect of SMT on the quality of the motion i.e. velocity and jerk, to execute cervical ROM. Only one study has assessed the effect of a single, cervical SMT on movement harmony and peak displacement during cervical ROM (Serra-Añó *et al.* 2023). They reported increased peak displacement in right lateral flexion and left rotation in the SMT group, with the control group having increased movement harmony during flexion motion. Concluding that SMT had little impact on these outcomes. This trial did not include measures of muscle activation and only assessed immediate changes.

Likewise, studies assessing changes in muscle activation patterns following cervical SMT for neck pain, utilised a single treatment, with most trials assessing muscles of the arm

during arm tasks (de Camargo *et al.* 2011; Bracht *et al.* 2018). Neither of these trials included an assessment of neck musculature during the tasks nor was pain correlated with changes in these objective measures, despite recommendations for its inclusion in the analysis (Stenneberg *et al.* 2017). Thus, the effect of cervical SMT on pain, disability, cervicothoracic spinal kinematics and muscle activation patterns was undertaken, compared to a control intervention, for immediate and short-term effects.

The results of the study (chapter seven) found that cervical SMT following three treatments resulted in a significantly greater reduction in pain when compared to the control group. At the one week follow up, the pain reduction was similar across the groups with the cervical SMT group reporting greater improvements in disability. Global perceived improvement and level of satisfaction with treatment across the groups was similar at one week with the cervical SMT group reporting significantly greater improvements in emotional state and quality of life. This together with the improved disability shows how SMT can improve patients with neck pain day to day lives. In terms of spinal kinematics, those receiving SMT had a significant increase in left rotation velocity and jerk in flexion, left lateral flexion and rotation following one treatment, with increased jerk persisting at the fourth visit in flexion and left rotation. It was an unintended finding that jerk would increase following SMT. This suggests a negative effect, despite many people reporting improvement following SMT.

Muscle activation patterns differed between the groups after one treatment with the control group having greater activation in the left posterior cervical (LPC) in flexion, left anterior scalene (LAS) and left sternocleidomastoid (LSCM) in extension and the left paraspinal at T9 (LT9) during right lateral flexion, and lower activation in the LAS and the left upper trapezius (LUT) during right lateral flexion, in the right anterior scalene (RAS) and LT9 for during left lateral flexion and the RPC, LT4 and RSCM during right rotation. This pattern changed following three treatments whereby the control group had less RAS activation during flexion and greater activation of the RPC and LUT during extension, LAS in right lateral flexion and LPC during left lateral flexion, whereas the intervention group

had higher levels of activation in the left paraspinal at T4 during flexion. Correlation analysis showed positive correlations between decreasing pain and decreased muscle activity in both groups. The control group had a negative correlation with pain and activity in the ASs and left SCM during flexion and the left PC muscle during left lateral flexion, indicating as pain decreased activity in these muscles increased, whereas in the SMT group, the only negative correlation was found for left lateral flexion where the left paraspinal at LT9 had increased activity when pain decreased by the fourth visit.

These findings support the hypothesis that cervical SMT results in improved pain, disability and changes in kinematic and muscle activation patterns when compared to a control. The increased jerk observed following SMT may be explained due to afferent input from the SMT altering post-synaptic pathways (Pickar and Bolton 2012) which may have influenced the alpha motor neuron (Niazi *et al.* 2015; Christiansen *et al.* 2018; Holt *et al.* 2019), motor unit recruitment (Robinault *et al.* 2021) or cortical processing of motor responses (Haavik-Taylor and Murphy 2007; Haavik and Murphy 2012; Haavik *et al.* 2017). However, this finding requires further investigation and adds a novel contribution to the effects of SMT on motor control.

In terms of muscle activation patterns, the immediate effects seen over three treatments in those receiving SMT showed lower activation of the muscles of the head and neck. Motor impairment in neck pain has been characterised by increased activation of the superficial neck flexors, reduced activation of the deep cervical muscles (Falla *et al.* 2003; Falla *et al.* 2004a; Falla and Farina 2007) and co-activation of the cervical muscles (Nobe *et al.* 2022). A normalising of this protective pattern was seen in those who received the SMT treatment, whereas the control group, following three treatments, still presented with increased activation relative to decreased pain. In terms of perceived global improvement and level of satisfaction, both groups reported improvement and that they were satisfied with the treatment, indicating that they would select this type of treatment again in the future. This was interesting as it was anticipated that the control would be dis-satisfied with their treatment due to perceiving that they were not actually getting a treatment. Many

of the participants were new to chiropractic treatment, having never seen a chiropractor before, and that they were satisfied with their treatment indicates the effect of seeking medical care for a condition and the placebo effect that is associated with that.

The second RCT (chapter eight) investigated the effect of cervical SMT on two functional arm tasks immediately following one treatment and after three treatments to determine the effect that cervical SMT had on pain, disability, spinal kinematics and muscle recruitment patterns of cervicothoracic muscles. Although arm tasks have been utilised to assess for differences between those with and without neck pain there is a paucity of studies assessing if treatments for neck pain alter spinal motor control patterns during the execution of upper limb tasks. Previous studies assessing the effects of cervical SMT on muscle function when arm tasks were executed only assessed unilateral arm tasks, with limited observation of spinal muscles (de Camargo *et al.* 2011; Pires *et al.* 2015; Bracht *et al.* 2018).

The results of this study found that by the fourth visit, those receiving cervical SMT had significantly lower pain, which by the one week follow up showed no difference between the groups. At the one week follow up the SMT group had a greater reduction in disability, however, no between group differences were found for the global impression of change from the treatment. When asked about their level of satisfaction both groups reported being satisfied with the treatment with those receiving SMT having greater improvement in emotions and social functioning.

For the unilateral arm task, there were no immediate changes in cervical kinematics, with only the right paraspinal T4 having greater activation in those receiving SMT during the lowering phase. After three treatments increased thoracic spine displacement occurred in the accessory motions, with increased muscle activation of the right UT muscle. Pain had stronger correlations with spinal kinematics and muscle recruitment in the control group. Whereas in the bilateral arm task, immediate significant differences occurred in the lower thoracic region where the control group had increased flexion/extension jerk and the intervention group had increased lateral flexion jerk, rotation range, velocity and

jerk. Muscle activation patterns showed decreased right PC and increased right paraspinal T4 during lifting and increased right SCM activation during lifting and lowering in the SMT group. Following three treatments the SMT group had greater upper thoracic flexion/extension jerk during lowering with decreased left PC activity in lifting and lowering and increased left and right SCM activity during lowering. Similar to the unilateral arm task, stronger correlations occurred between pain and spinal kinematics and muscle recruitment patterns in the control group.

The intervention did not lead to changes in cervical kinematics, like what was observed in Chapter seven but rather brought about effects in thoracic spinal kinematics. There is a close relationship between the cervical and thoracic spine with people who suffer from neck pain having altered kinematics and coordination between these two areas (Tsang, Szeto and Lee 2013a). The increase in the thoracic range observed during the unilateral arm task and the kinematic changes seen during the bilateral arm task could be a result of the kinematic chain, where alterations to the cervical spine resulted in mechanical changes in the thoracic spine (Karandikar and Vargas 2011). The theory of regional interdependence may also be at play, where treatments applied in one area of the body can bring about changes in another region (Wainner *et al.* 2007).

When assessing changes in muscle activation the increased right thoracic paraspinal T4 muscle activity in the unilateral arm task immediately following treatment and increased right UT muscle activity at the fourth visit support improved movement patterns in those who received SMT. During shoulder flexion, which was required by the tasks, the thoracic spine undergoes extension (Crawford and Jull 1993; Stewart *et al.* 1995). During right sided arm lifting the right paraspinal muscle T4 would act eccentrically during weight lowering, controlling spinal flexion, thus increased activation would be considered normal. In terms of the UT, reduced UT muscle activity has been seen as a feature of neck pain when performing raised arm lifts (Falla, Bilenkij and Jull 2004), thus the increased activity relative to the control group would indicate an improved pattern of activity.

During the bilateral arm task, effects were found where those who received SMT had a reduction in PC activation and an increase in SCM activation. Neck pain sufferers have been found to have increased flexor–extensor muscle activation when compared to asymptomatic controls during the performance of cervical ROM (Nobe *et al.* 2022), thus these changes may represent the normalising of movement patterns during loaded tasks. It was anticipated that greater differences would have been seen between the groups based on the biomechanical (Evans 2002) and neurophysiological (Pickar 2002; Pickar and Bolton 2012; Gyer *et al.* 2019) effects that SMT is purported to induce. The null hypothesis was rejected as changes in kinematics and muscle activation occurred during the two upper limb task following SMT.

The activities undertaken in these functional tasks are common activities of daily living. The motor system would have an abundance of motor strategies from which to select, for execution of these tasks (Latash *et al.* 2010; Bizzi and Cheung 2013; Ting *et al.* 2015). Although previous studies comparing those with and without neck pain have reported differences between the groups while performing similar tasks (Tsang, Szeto and Lee 2014; Moghaddas, Edwards and Snodgrass 2022), the neurophysiological effect that cervical SMT may have induced, may not have been large enough to be expressed where the body could select a movement strategy which would have been ‘good enough’ to execute the task (Ting *et al.* 2015). Meaning that the changes that may have occurred were not detected by the employed methodology. Alternatively, the changes observed in this study may be due to natural variations in trial-to-trial testing that can occur with motor repetition (Latash *et al.* 2010; Nordin *et al.* 2017).

9.2 CONCLUSION

This study provided novel insights into the nuanced effects of cervical SMT on neck pain and movement, extending beyond traditional pain relief measures. While effectively alleviating pain, and disability, and improving quality of life, the findings revealed a

fascinating interplay of physiological changes. The intriguing alterations in cervical kinematics, characterized by an initial increase in movement jerk, suggest a temporary shift in movement control. This is a new contribution to the literature and warrants further research to confirm this finding. This study showed a complex interplay of muscle activation patterns, that changed over the duration of the study. Notably, we observed reduced activity in specific cervical muscles, while other muscles, particularly in the cervicothoracic region, exhibited increased activation.

These findings suggest that SMT may not solely attenuate pain but rather exert a profound influence on the underlying neuromuscular mechanisms. This may involve a series of neurophysiological effects ranging from the modulation of spinal reflexes and altered muscle recruitment patterns, which may optimise sensorimotor function.

These findings have significant implications for our understanding of SMT mechanisms and may inform future research on optimising treatment protocols for individuals with neck pain.

9.3 THESIS LIMITATIONS

The findings of this thesis need to be taken in the context of the following limitations:

This thesis aimed to assess responses to cervical SMT immediately following one treatment and over several treatments. This methodology required the re-application of the electrodes and reflective markers at the re-assessment visit. This was performed by a single person, a chiropractor with over 20 years of experience, it is possible that minor variations in placement occurred, which may have impacted the outcomes observed. To minimise this a measurement ruler and a tape measure were utilised, together with bony landmark identification.

The methodology employed did not collect kinematic and muscle recruitment data at the one week follow up. Difficulties in patient retention and the risk of dropout motivated this

choice. However, it prevented a correlation of the spinal kinematics and muscle recruitment data with the disability data, as the latter was only collected at the one week follow up.

There are inherent difficulties associated with repeated measures of muscle activity using surface EMG between days (Duchateau, Semmler and Enoka 2006). Normalisation procedures assist in allowing these comparisons (Halaki and Ginn 2012). Extrinsic factors may have influenced the follow up measurement of muscle activity impacting the comparability to the baseline assessments. In addition, cross talk from surrounding and underlying muscles can influence the signal. In an attempt to minimise cross talk, electrodes were placed in positions reported in the literature (Tsang, Szeto and Lee 2014), however, given the complex arrangement of neck musculature, cross talk cannot be ruled out and may have influenced the comparability of the results.

This study took place on a university campus, and although advertisements were placed in communal gathering sites outside the campus and on social media platforms, the majority of the participants were students. This resulted in the mean age of the participants being relatively young. This has several implications: firstly, this impacts the ability to extrapolate these findings to an older neck pain population; and secondly, although they suffered from chronic neck pain, their relatively young age may have had some protective effect on the musculoskeletal manifestations of chronic neck pain seen in older populations.

This study utilised a standardised experimental set up, which was not adjusted to the anthropometric characteristics of the participants. This standardisation may have influenced the normal movement patterns of the participants particularly in the seated one arm task.

The use of motion capture technology and the placement of reflective markers along the spine prevented the use of a chair with a backrest. Thus the participants were required to support themselves in upright sitting and were encouraged to not move their shoulders

when executing cervical ROM. Motion in the thoracic spinal may have contributed to the cervical ROM measures, making comparison to studies where the thoracic spine was anchored, difficult. As mentioned previously the aim of the study was to capture normal movement patterns and thus this can be seen as a contribution of this study.

Given the nature of the musculoskeletal system and its adaptability, some of the findings may be due to transient manifestations occurring during motor control. The array of motor synergies that the body can use to execute motion (Bizzi and Cheung 2013) may override the modest changes that may have occurred due to the intervention and highlight the ability of the body to allow task execution (Bizzi and Ajemian 2020). Thus, it is necessary for these findings to be further explored.

There is a growing body of knowledge with regard to the impact that the force and velocity of SMT have on clinical outcomes (Nougarou *et al.* 2013; Pagé *et al.* 2014; Nougarou *et al.* 2016). In this study, these aspects were not controlled. In an attempt to standardise the application of the interventions, one chiropractor with 20 years of experience applied all interventions, according to predefined guidelines. However, bias may have affected the outcomes as it was not possible to blind the care provider, which is a drawback of manual therapy studies.

9.4 RECOMMENDATIONS

9.4.1 Recommendations for future research

Due to the relative paucity of literature in this area, it is necessary for future studies to include these outcomes in their assessment to elucidate the effect of SMT and to verify if the changes observed in this study are consistent.

The finding of increased jerk following SMT and the mechanism that underlie this presentation requires further investigation, to add to the body of knowledge of how SMT brings about its therapeutic effects.

It is recommended that when assessing the effect of SMT on functional tasks the participants are asked to self-rate their ability to execute the tasks prior to and following interventions. This can then be correlated with changes in kinematics and muscle recruitment patterns to further understand the impact of pain on movement.

This study should be repeated in a neck pain population consisting of older adults to establish if the manifestations of neck pain differ or are similar to those seen in this study and to assess if the response to SMT would be different in an older population.

Future studies of this nature should include measures of time-force profiles in the application of SMT to see if these characteristics alter the effects of SMT on spinal kinematics and muscle recruitment patterns.

9.4.2 Recommendations for practice

Cervical SMT in people with neck pain can be utilised to reduce pain improve self-reported disability and improve quality of life. It is premature to make suggestions regarding the impact of cervical SMT on functional task execution however the results of this study suggest that spinal kinematics and muscle recruitment patterns change following SMT. The clinical benefit of these changes requires further investigation.

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APPENDICES

APPENDIX A: CASE CONTROLLED STUDIES ASSESSING SPINAL KINEMATIC DIFFERENCES BETWEEN THOSE WITH AND WITHOUT NECK PAIN

Author	Sample	Task and measurement tool	Task specifics	Result	Discussion
Descarreaux 2010	Canada CNP = 19 HP = 20	Fitts task Tool: Motion analysis system (Optotrak Northern Digital, Waterloo, ON, Canada).	Speed: move their head as quickly, and precisely as possible to a target under 4 conditions.	NP increased movement time ($p = 0.034$) and deceleration phase duration ($p = 0.012$) for the small target/large movement amplitude condition. No grp difference for movement time variability, acceleration phase duration and absolute positioning errors ($p > 0.05$)	Motor performance was affected in chronic neck pain patients, especially during the most challenging tasks
Alsultan 2019	United Kingdom CNP = 18 HP = 18	Cervical ROM Optoelectronic system (BTS Bioengineering, Milan, Italy)	Seated upright posture Flexion-extension, bilateral lateral flexion and rotation during natural, slow and fast motion helical axis (HA) for mean distance (MD) - the distance between all intersection points between the HA and a transversal plane from their barycenter, mean angle of each axis and the total average (MA) RoM was quantified by calculating the mean difference between the maximal flexion and extension movements	NP smaller MD was observed in during flexion-extension ($p = 0.019$) and rotation movements ($p = 0.007$). Smaller values for MA during rotation with different speeds ($p = 0.01$). No difference in the mean angle was observed between grps for flexion-extension and lateral flexion.	Those with NP had less variable movement than asymptomatic participants.

Yang 2014	Taiwan NP = 18 (duration unspecified) HP = 18	Seated cervical circumduction electromagnetic tracking system (LIBERTY™, Polhemus Inc, USA) using spectral entropy to determine movement smoothness	Seated active maximum cervical circumduction spectral entropy of time-series linear acceleration and other speed dependent parameters	NP longer movement time, higher value in the spectral entropy and wider band response in frequency spectrum than healthy volunteers ($p = 0.01$)	Neck pain presents with less smooth motion during circumduction.
Sarig Bahat 2015	Israel CNP = 33 HP = 22	Virtual reality through head mounted display with a built-in motion tracker (Wrap™ 1200VR by Vuzix, New York, www.vuzix.com), equipped with gyroscopes, accelerometers and magnetometers.	Peak (maximum velocity) and mean (overall speed of the head motion) velocity (°/sec), smoothness (represented by the number of velocity peaks (NVP)), symmetry (represented by time to peak velocity percentage (TTPP)), and accuracy of cervical motion.	NP had significantly decreased flexion, extension and bilateral rotation excluding TTPP in left rotation ($p = 0.25$). Accuracy measures – 5/8 showed lower values in neck pain ($p < 0.05$).	Neck pain decreases movement speed and smoothness.
Sarig Bahat 2010	Israel CNP = 25 HP = 42	Virtual reality through head mounted display with electromagnetic tracker	Kinematic measures (response time, peak and mean velocity, number of velocity peaks, time to peak velocity percentage) were sampled while participants were engaged in the virtual game.	NP had lower peak and mean velocities than the asymptomatic participants ($p < 0.001$), with the greater number of velocity peaks, indicating impaired motion smoothness ($p = 0.004$). No group differences for response time or time to peak velocity percentage. Cervical rotations were faster and smoother than flexion and extension movements ($p < 0.05$). Overall impairment percentage in velocity and smoothness of cervical	Velocity and smoothness of cervical motion were more restricted in patients with chronic neck pain than found previously. Unlike ROM and other static measurements, these dynamic variables reflect functional cervical motion and therefore contribute to a better

				motion in NP ranged from 22% to 44% compared with HC.	understanding of the impairment associated with neck pain. Because the ability to move quickly in response to external stimuli is a commonly occurring phenomenon, this deficit is highly relevant to clinical assessment and management.
Röijezon 2010	Sweden, females only NP = 118 HC = 49	Electromagnetic tracking system	Seated fast, self-paced, axial head rotations while eyes were closed, pain was assessed using the NPRS-101	Peak speed and conjunct movements had a sensitivity of 76% and a specificity of 78% in discriminating between NP and HC ($p < 0.01$) Peak speed was slower in NP compared to HC and even slower in NP with comorbidity of low-back pain. Associations were found between reduced peak speed and self-rated difficulties with running, performing head movements, car driving, sleeping and pain. Peak speed showed reasonably high reliability, while the reliability for conjunct movements was poor	Cervical axial rotation speed is reduced in females with NP
Tsang 2013	Hong Kong CNP = 34 HP = 34	Cervical ROM Electromagnetic tracking device (Fastrak, Polhemus Inc., Colchester, VT, USA)	Seated active neck ROM, in 3 planes, at a self-pace assessing angular displacement, velocity, and acceleration of cervical, upper and lower thoracic	No differences for angular displacement in any direction ($p < 0.05$); NP lower velocities and accelerations in all directions for cervical ($p < 0.01$); NP decreased velocity of the upper thoracic spine	Neck pain did not affect gross motion but presented with lower speed and acceleration, affecting not only the

				in cervical flexion and extension and acceleration in RLF ($p < 0.05$); NP decrease velocity and acceleration in the lower thoracic spine for cervical flexion and extension and acceleration on LLF ($p < 0.05$). Inter-regional co-ordination was lower in NP in all movements except LROT and RROT in angular displacement ($p < 0.001$) and for velocity and acceleration in the cervical and upper thoracic spines ($p < 0.05$).	cervical spine but the thoracic spine too.
Waeyaert 2016	Belgium CNP = 41 HP = 156	Used winBIRD software (Shelburne, VT). Subgroups were symmetrical and asymmetrical pain. Measurements: ROM of the main and coupled motions; the cross-correlation (CC) between the main and coupled motion; the ratio = SD (axial rotation (AR)/ side bending (SD) (lateral bending (LB); The Euclidean norm representing global 3D motion = $(\sqrt{AR^2+LB^2+FE^2})$ sta	Rot – NP symmetrical grp had poorer quality motion with more jerkiness, NP asymmetrical grp had less ROM in the conjunct motions with a higher AR:LB ratio ($p < 0.05$); LF – greater mobility in the HP; NP symmetrical grp had smoother motion than the NP asymmetrical grp; CC differed between controls and NP symmetrical grp ($p < 0.05$) FE – NP asymmetrical grp had smoother movement than symmetrical grp ($p < 0.05$)	Differences were mostly found between the “symmetrical” and “asymmetrical” pain grps on average, the symmetrical grp had significantly less harmonic movement patterns, compared to the “asymmetrical” grp and controls. The “asymmetrical” grp had significantly lower scores on quantitative parameters than the “symmetrical” grp and controls. The degree of functional disability correlated moderately with changes in qualitative parameters.	A symmetrical neck pain pattern had poorer movement quality with those with asymmetrical pain patterns having reduced quantitative measures. Subgrouping of neck patients based on pain location may be of help for further research and clinics.

		standard error of measurement on the deviation of the original data and a sixth polynomial function; and jerk index (the root mean square of the jerk)			
Guo 2012	Taiwan NP = 27 HC = 13	Electromagnetic motion tracking device	Seated active CROM, coupling motion, and calculation of the upper cervical rotation ratio	NP had decreased ROM in right rotation ($p < 0.05$) and extension ($p < 0.05$) movements compared to the HC. Increased coupling motion ($p < 0.05$) in the rotation plane during cervical flexion in the NP grp. For rotations in neutral or flexion positions, rotation to the right showed a smaller range of motion compared to rotation to the left.	NP was associated with altered cervical movement patterns with increases in coupling motion.
Sjölander 2008	Sweden NP = 8 WAD = 7 HP = 16	Cervical ROM Electromagnetic tracking system (FASTRAKTM, Polhemus Inc, USA)	Standing cervical rotations were defined as outright/left and in right/left: Voluntary head motions ROM, ROM-Variability, peak velocity, and smoothness of movement (jerk index). Repositioning acuity after cervical rotations was evaluated by analysing constant and variable error.	No diff for ROM and peak velocity, Repositioning bias – no diff between grps ($p = 0.08$), there was increased jerk index in those with NP and WAD ($p < 0.01$), Variable error (VE) – in right rot differed between control and neck pain grps; in left differences between control and WAD; ROM variability – out right ($p < 0.01$) and out left ($p < 0.01$) were sig between control and WAD only	NP had a larger jerk index, ROM-Variability and VE. No differences were found between insidious neck pain and WAD. Jerky and irregular cervical movements and poor position sense acuity are characteristic sensorimotor symptoms in chronic neck pain.
Cattrysse 2020	Belgium NP = 171 HP = 413	Cervical ROM Polhemus Liberty system (Polhemus	Seated cervical ROM took place at self-pace	FE – all measures, except MA, were smaller in the NP grp ($p < 0.05$)	NP participants had reduced variability in their motion

		Liberty, Colchester Vermont, USA), and a Flock of Birds system (Ascension Technologies Corporation, USA). Measures to determine cervical helical axis: minimal convex hull(CH), the mean Angle (MA) the path length (PL) and the finite helical rotation angle (FH Angle).		LF and Rot – all measures were smaller in the NP grp except the helical rotation angle	
Lascrain-Aguirrebeña 2018 <i>*only reporting kinematic data</i>	United Kingdom NP = 40 HP = 40	Cervical ROM in all directions Vicon motion capture system (Vicon Systems Ltd., Oxford, UK)	Standing active cervical ROM at the usual speed	No significant between grp differences for RoM ($p < 0.05$), except for secondary transverse plane movement during flexion where HP rotated to the right 1.52° (SD6.18°) and NP rotated to the left 2.48° (SD5.9°)($p = 0.048$; $d = 0.44$). The pain increased as NP approximated the end of ROM. No differences in movement speed around the primary axis were seen.	There was no evidence of restricted ROM in participants with neck pain.
Rutledge 2013	USA NP = 19 HP = 22	Cervical ROM Qualysis motion tracking system (Qualysis, Gothenburg, Sweden) Measures: displacement and angular velocity for	Participants were assessed for seated active and passive cervical ROM	Active motions had higher angular velocities ($p < 0.001$) and larger ROMs, with greater lateral flexions ($p < 0.05$). The HP grp had a greater average LF of 7.9° at an average angular velocity of 2 deg/s greater than the NP grp. Trends for grp assignments were the same for active and passive motions.	NP presented with decreased LF displacement and velocity

		cervical LF ROM, coupled axial Rot, and the angular velocity of LF			
Salehi 2021	Iran NP = 20 HC = 20	Qualisys Motion capture technology	Standing, with arms across the chest, eyes closed performing cervical ROM at self-paced speed. Cervical ROM, peak velocity (Peak-V), duration of movement (t), jerk index (j), NDI	NP had lower peak velocities in flexion ($p = 0.01$) and right rotation ($p = 0.02$), higher jerk index during extension ($p < 0.001$), flexion ($p = 0.001$), and left rotation ($p = 0.005$). Longer duration of movement in right rotation ($p = 0.01$) Pain intensity was significantly associated with duration of movement, range of motion, peak velocity, and smoothness predominantly in extension (r range = 0.4 to 0.6, $p < 0.05$).	Cervical kinematic assessment should be undertaken in people with neck pain.
Lemmers 2018	Brussels NP = 35 HC = 100	Flock of Birds electromagnetic tracking system (Ascension Technologies, Shelburne, USA©).	Seated upright posture with sacrum and thorax against chair. The upper thoracic motion was allowed. Cervical lateral bending and flexion-extension motions were captured and ratio of whole motion trajectory was obtained plus root mean square of jerk.	No statistically significant differences in qualitative and quantitative parameters. Analysis of the effect of age showed that the ROM decreases significantly ($p < 0.01$) with increasing age. In lateral bending, the ratio between axial rotation and lateral bending increases significantly ($p < 0.01$) among older subjects. Differences in acceleration, jerk and polynomial fit are seen between the age categories, but are not significant.	No kinematic differences were found between those with and without neck pain.

(NP – neck pain, HP – healthy participants, WAD – whiplash associated disorder, ROM – range of motion, FE – flexion/extension, LF – lateral flexion, Rot – rotation, USA – United States of America, HN – head-neck, FH – forward head)

APPENDIX B: CASE-CONTROLLED STUDIES ASSESSING DIFFERENCES BETWEEN PEOPLE WITH AND WITHOUT NECK PAIN DURING FUNCTIONAL TASKS

Author	Sample	Task and measurement tool	Task specifics	Result	Discussion
Xie 2018	China NP = 19 HP = 18 (young adults who were right-hand dominant And smartphone users)	Typing tasks Inertial measurement unit (IMU) motion sensors (MyoMotion Clinical, Noraxon U.S.A. Inc.) performed task from texting and typing apps named 'tap typing' (Flairify LLC, version 3.4.5, USA) and 'typing master' (version 10.1.1.837, Typing Master, Inc) displayed on a smartphone and the desktop computer. Participants perform all three text-entry tasks at their usual speed, as accurately as possible, and without text entry error correction.	Unilateral and bilateral smartphone typing task and computer task	Speed and accuracy - no grp differences for task on a computer, smartphone unilaterally or bilaterally; Angular displacement between grp difference for cervical side flexion being greater in the NP grp during bilateral and unilateral texting with no difference between the grps during computer typing ($p < 0.05$). NP grp had greater angular displacement ranges and a trend of higher frequency of posture changes in cervical rotation compared with HP while performing the three tasks ($p < 0.05$).	NP influences head posture during smartphone typing tasks.
Szeto 2005	China NP = 23 HP = 20 (only females)	Computer typing task Vicon 370, Version 3.1 (Oxford Metrics, UK) an adjustable workstation was used and the typing task continuously executed at normal pace for 1h	Office workers performing monotonous keyboard tasks for 1 hour	NP had a greater mean head flexion range than HP, which was maintained throughout the 1-hour task. NP had more right-side flexion and right rotation ($p < 0.05$). No difference was found for thoracic postures and movements between the grps.	NP subjects had altered head posture with an increased range in flexion and less right lateral flexion and rotation than HP. Differences were maintained throughout the 1-hour

				Shoulder flexion and abduction differed by side but not grp.	task. The shoulder posture had a strong side effect for flexion angles and ranges of shoulder flexion and abduction, but not for grps, showing mouse use leads to imbalances.
Grip 2008	Sweden NP = 19 WAD = 17 HP = 24	Head rotation and ball catching task Optical motion capture system (Qualisys Medical ABs, Gothenburg, Sweden) Head and upper arm movements were defined as the helical angle of rotation relative to the upper body, and upper body movement as the helical angle of rotation relative to the lab coordinate frame. Velocity and acceleration were calculated.	Seated head rotation task moving their head as fast as possible to a target and seated ball catch delivered through a tube to the participant's left/right shoulder.	ROM and velocity: between grp difference for flexion, extension and rotation ($p < 0.05$) Catch ROM between grp differences for head ($p = 0.03$) and body ($p = 0.03$) not arm ($p = 0.08$). Head motion was greater in the NP grp. Body motion was less in the WAD grp. Catch velocity grp differences for body ($p = 0.02$), with WAD having less velocity; but not head and arm ($p = 0.25$; $p = 0.06$) The number of crossings per second of the helical axis during head movements and catching: of direction vectors: difference between the grps ($p < 0.001$), with WAD having greater variability across measures and NP for rotation and catch position vectors: difference between the grps ($p < 0.001$), with WAD and NP differing to	A general increase in axis irregularity that correlated to pain intensity was found in WAD. Superior displacement of the rotation centre occurred in NP and WAD during side rotation. During ball catching, anterior displacement of the centre of rotation and slower and more restricted upper body movements implied a changed movement strategy in neck pain, possibly to stabilize the cervical spine during head movement.

				the controls with increased variability, no difference between the grps was reported for the catch.	
Moghaddas 2022	Australia NP = 33 HP = 30	Four tasks: standing overhead reaching forward, right and left, using a 500g weight, and putting on a seatbelt Qualysis Oqus 300 (v2, Qualysis AB, Gothenburg, Sweden).	Kinematic variables included joint angles, ROM, velocity and percentage of movement phase for joint angles (head-neck [HN joint], head+neck-upper trunk [HNT], and thoracolumbar) and segments (head, neck, head+neck [HN segment], upper trunk, and trunk.	Forward overhead – no between grp differences for angles or timing. Overhead reach right ($p = 0.022$) and left ($p = 0.023$) NP had more flexed HN segment compared to HP. Total sagittal ROM – NP had decreased measures across tasks ($p = 0.010$). No differences were found for the thoracolumbar range and peak joint angles for the tasks. Velocity – increased peak velocity of flexion/extension components of the tasks: right and left reach and seatbelt task ($p = 0.004$); NP has higher HN segment peak flexion velocity for left reach ($p = 0.035$) and lower HN segment peak velocity for forward reach ($p = 0.045$). HN joint peak velocity in flexion was lower in the NP grp for forward reach ($p = 0.008$) and higher in the seatbelt task ($p = 0.036$), for HN joint peak extension velocity NP grp had a higher peak velocity for right reach ($p = 0.003$), neck segment peak flexion velocity showed NP had higher velocities across tasks ($p =$	Neck pain sufferers had more flexed postures of their head and neck when performing the overhead reach to the side and putting on a seatbelt task. Higher velocity peaks were also found which may suggest reduced smoothness of movement. In tasks requiring over-head reaching and possibly looking up neck pain sufferers do not extend their head and neck as much as healthy controls.

				0.004) with right reach ($p = 0.041$) and seatbelt ($p = 0.42$) tasks having higher peak velocities in the NP grp.	
Constand 2013	Canada NP = 7 HP = 12	Standing and reading task Canon PowerShot SD1200 IS Digital ELPH camera with Dartfish ProSuite 5.5 Video Software Solutions	Standing one arm lifting task of a 0.9kg weight to a shelf 63.5cm above the participant's navel and a seated reading task for 2 minutes	No differences found in arc of motion ($p = 0.500$) during the lifting task and neck flexion angle change in reading ($p = 0.502$)	Although mean differences in arcs of motion during reading were 10° different for people with neck pain in comparison to controls this finding was not significant. Larger sample sizes will be needed to obtain statistical significance.
Falla 2017	Australia NP = 14 HP = 14	Motion-analysis system (Oqus 300; Qualisys AB, Gothenburg, Sweden)	Neck and trunk rotations and variability, stride cadence, ROM of the hip, knee and ankle	No difference between grps for speed, stride cadence, ROM of the hip, knee or ankle, neck rotation and trunk variability. NP had a shorter stride length ($p < 0.001$) and less trunk rotation ($p < 0.001$), trunk rotation increased more in the NP when the head was rotated	Reduced trunk rotation occurred in neck pain while walking especially with the head rotated.
Hsu 2019	Taiwan NP = 25 HP = 25		The postural sway, muscle onset time, and activation level of the erector spinae, rectus abdominal, semispinalis capitis (SSC), and sternocleidomastoid (SCM) muscles were assessed during shoulder flexion	NP had increased body sway, muscle activation of the SCM and SSC, longer onset time for the cervical flexors (SCM), trend of an effect for greater sway and shorter onset times with eyes closed. After fatigue After muscle fatigue, the CNP grp further exhibited (1) greater body sway during the eyes-open condition but decreased body sway during the eyes-	NP resulted in reduced postural control and altered neck muscle control. Under fatigue conditions decreased balance stability and provoked protective neck muscle control strategy occurred during the shoulder flexion movement

				closed condition, (2) higher activation of the neck flexor (SCM) and lower activation of the trunk extensor (erector spinae), and (3) early onset of the neck muscles (SCM and SSC).	
Tsang 2014	Hong Kong NP = 30 HP = 30	Synchronized measurements of the three-dimensional spinal kinematics and electromyographic activities of cervical and thoracic spine	Seated one arm lifting task – cervical and thoracic kinematics: displacement, velocity and acceleration, sEMG bilateral upper trapezius, posterior cervical (PC), sternocleidomastoid, anterior scalene and thoracic paraspinal	No differences between cervical and thoracic displacement. NP had lower cervical flexion ($p = 0.048$) and extension ($p = 0.033$) velocity with decreased acceleration in cervical flexion ($p = 0.024$) and extension ($p = 0.008$). NP had higher number of people activating nearly all their muscles compared to HC. The right PC and left paraspinal at T9 had lower activity. NP had a high activation % in all neck muscle except right PC, with higher activation in right T4 throughout all three phases of the task. Raising phase - higher % activation duration in NP for bilateral UT ($p = 0.02$ for right and left); left PC ($p = 0.01$); left SCM ($p = 0.01$); bilateral T4 ($p = 0.002$ for right; $p = 0.03$ for left); and right T9 ($p = 0.006$). Release phase - only right T4 in NP had longer activation duration ($p = 0.01$). Lowering phase - NP longer activation in	NP during a unilateral arm task results in decreased cervical velocity and acceleration while performing the task. Predominantly prolonged coactivation of cervical and thoracic muscles throughout the task cycle.

				right UT ($p = 0.05$); bilateral SCM ($p = 0.02$; $p = 0.025$); and right T4 ($p = 0.01$).	
Snodgrass (2016)	Australia NP = 10 HP = 10	Three-dimensional kinematics were measured using six Oqus 300 cameras (Qualisys, Sweden) during overhead reach to the right, and putting on a seatbelt	Kinematic variables calculated during each phase were: peak joint angle and range of motion for right rotation and flexion-extension joint angles ($^{\circ}$, head segment relative to neck segment [head-neck joint]; and head/neck segment relative to upper thoracic segment [head/neck-trunk joint]), peak and mean resultant head rotation velocity (mm/s), time from start to time of peak right rotation joint angle and resultant head rotation velocity (%), and mean hand segment velocity (mm/s). Self-reported pain intensity (VAS) Neck disability using the Neck Disability Index (NDI)	VAS = 45.2mm (SD 16.3, 95% CI 33.5-56.90), NDI = 14.2 (SD 3.6) Overhead reach to the right, the peak head rotation velocity was less (MD 24.0 mm/s, 95% CI 2.1-46.0, $p = 0.034$), and the time of peak right rotation head-neck joint angle was earlier in those with neck pain (20.3%, 4.2- 36.5, $p = 0.018$). No other kinematic variables for the reach or seatbelt task were significantly different between grps. For right overhead reach, higher neck disability was significantly correlated with lower peak ($r = .788$, $p = 0.007$) and mean head rotation velocity ($r = .651$, $p = 0.041$). Other variables for reach and for the seatbelt task were not significantly correlated with pain or disability.	Chronic idiopathic neck pain resulted in slower velocity and altered coordination of movement when compared to healthy individuals during functional movement.

(NP – neck pain, HP – healthy participants, WAD – whiplash associated disorder, grp – group, ROM – range of motion, FE – flexion/extension, LF – lateral flexion, Rot – rotation, USA – United States of America, HN – head-neck, FH – forward head, SCM – sternocleidomastoid, AS – anterior scalene, UT – upper trapezius, LT – lower trapezius, T4 – thoracic paraspinal at T4, T9 – thoracic paraspinal at T9, PC – posterior cervical)

APPENDIX C: CASE-CONTROLLED STUDIES ASSESSING MUSCLE RECRUITMENT DIFFERENCES IN THOSE WITH AND WITHOUT NECK PAIN

Author	Sample	Task and measurement tool	Task specifics	Results	Discussion
Falla (Falla and Farina 2005) (2005)	Australia CNP = 19 HP = 9	Compare average muscle fibre conduction velocity (CV) and its changes over time in the bilateral upper trapezius (UT) muscle during a repetitive upper limb task. sEMG CV and instantaneous mean power spectral frequency were estimated for each cycle at the time instant corresponding to 90° of shoulder flexion.	Subjects tapped their hands in a cyclic manner between targets positioned mid-thigh and 120° of shoulder flexion, to the beat of a metronome set at 88 beats/min for up to 5 min.	Average muscle fibre CV was higher in CNP ($M \pm SE$, 4.8 ± 0.1 m/s) than HP (4.4 ± 0.1 m/s; $p < 0.05$). The CNP had decreased CV over time ($p < 0.05$).	Membrane muscle fibre properties in the UT occur over time during dynamic contraction of the upper limb in people with CNP
Jiménez-Grande (Jiménez-Grande <i>et al.</i> 2021)(2021)	United Kingdom CNP = 20 HP = 20	sEMG obtained from the SCM, splenius capitis (SC), and UT muscles bilaterally in terms of frequency-domain and time-domain features including intermuscular coherence between grps of neck muscles.	Rectilinear and curvilinear gait	The best classification performance corresponds to the SC during curvilinear gait: accuracy of 70%, a specificity of 78%, the sensitivity of 60%, followed by SCM with an accuracy of 65%, a specificity of 3.63% and a sensitivity of 66.67%. Compared to the other trajectories, the performance difference between muscles is easily noticeable in curvilinear	EMG measures of neck muscle activity, especially in SCM and SC, can be used to classify people with and without CNP, these differences were exaggerated in curvilinear gait, suggesting that more simple tasks such as normal rectilinear gait is not sufficient to reveal these differences

				gait where SCM and SC muscles achieved higher performance than UT muscle and at the same time, higher than the other trajectories	
Bech (2017) (Bech <i>et al.</i> 2017)	Denmark Neck/shoulder pain (NSP) = 10 Hp = 10	UT thickness measured using ultrasonography and pain intensity was measured on a visual analogue scale (VAS). Superimposed stimuli were delivered to the accessory nerve at peak force and during a 2% MVC following the maximal contraction	Voluntary activation (VA) was calculated from five maximal muscle activation attempts.	Presented as mean $\pm$ SD for NSP and HP: VAS; 16.0 ± 14.4 mm and 2.1 ± 4.1 mm ($p = 0.004$), MVC; 545 ± 161 N and 664 ± 195 N ($p = 0.016$), UT thickness; 10.9 ± 1.9 mm and 10.4 ± 1.5 mm ($p = 0.20$), VA; $93.6 \pm 14.2\%$ and $96.3 \pm 6.0\%$ ($p = 0.29$).	There was an eight-fold higher pain intensity and 20% lower MVC for NSP compared to HP, no differences were found for voluntary activation.
Pinheiro (2016) (Pinheiro, dos Santos and Chaves 2016)	Brazil Computer users with: CNP = 20 HP = 20 Individuals who did not use computers for work and use them less than 4 h/day for other purposes CG = 20	Flexion-relaxation phenomenon (FRP) and flexion-relaxation ratios (FR-ratios) and reference FR-ratio (flexion relaxation ratio [FRR], defined as the maximum activity in 1 s of the re-extension/full flexion sEMG activity) were obtained using sEMG of the cervical extensor muscles	Seated full flexion of the neck and returning to initial position (extension) resulted in the phases of: flexion, full flexion and re-extension lasting 3 seconds, counted using a metronome repeated three times, with an interval of 30 s.	FR-ratios showed smaller values in the semispinalis capitis muscles of the two grps of workers compared to the control grp. FRR was significantly higher in the computer workers with neck pain compared to the CG (CPG: 3.10, 95% confidence interval [CI95%] 2.50–3.70; CNP: 2.33, CI95% 1.93–2.74; CG: 1.99, CI95% 1.81–2.17; $p < 0.001$).	The FR-ratios and FRR suggest that computer use increases recruitment of the semispinalis capitis during neck extension (concentric and eccentric phases).

Leonard (2010) (Leonard <i>et al.</i> 2010)	Malaysia NP = 25 HP = 25	Writing task while recording UT sEMG	The subjects wrote for 30 minutes under standardized experimental conditions during which the activity of the UT was recorded using surface electromyography (EMG).	Mean EMG activity of UT was significantly higher in the NP ($p < 0.05$).	Prolong and continuous writing tasks resulted in overuse of UT and altered motor control patterns in NP
Nobe 2022 (Nobe <i>et al.</i> 2022)	Japan NP = 24 HP = 24	sEMG of the cervical extensors and flexors recorded during neck flex, ext, bilateral LF, bilateral Rot, and at the neutral position in Phase I (the neck from the neutral position to the maximum range of motion), Phase II (at the maximum range of motion), and Phase III (from the maximum range of motion to the neutral position), yielding a total of 42 phases.	A percentage of maximum voluntary contraction to normalize muscle activity in each phase was calculated to obtain the ratio of muscle activities in the extensors and flexors in each of 36 phases of the motions to the neutral position and the ratio of the flexors to extensors in activity for 21 phases.	In 28 of 36 phases of the motions, the ratios of muscle activity in the extensors and flexors to the neutral position in NP were significantly larger than HP ($p < 0.05$). In 6 of 21 phases, the ratios of the flexors to extensors in activity in the NP were significantly larger than HP ($p < 0.05$).	The activity of the cervical extensors and flexors associated with neck motion increased with an imbalance in activity between these muscles compared to their activity in healthy adults.
Murphy (2010)(Murphy, Marshall and Taylor 2010)	New Zealand CNP = 14 HP = 14	The cervical flexion-relaxation ratio (FRR) were obtained using sEMG	Seated cervical flexion-extension was performed for phases: flexion, relaxation, and re-extension each phase was 3 seconds. Measurements were taken at baseline and 4 weeks later	ICC for NP grp was 0.83 (95% CI: 0.67–0.92). ICC for HP 0.89 (95% CI: 0.76–0.95). A significant difference in the baseline FRR data between the control grp and the neck pain grp ($p < 0.001$)	Consistent FRP in HP and is reproducible for both HP and CNP. The FRR in neck pain patients is significantly higher than in control subjects suggesting that this measure may be a useful marker of altered neuromuscular function.

Voerman (2007) (Voerman, Vollenbroek-Hutten and Hermens 2007)	The Netherlands WAD with neck and shoulder pain = 20 WMSD = 21 HP = 20	Computer task where muscle activity was recorded as root mean square (RMS) and relative rest time (RRT) for muscle relaxation. sEMG was used. of the print of each colour-word.	Computer task with arms straight and horizontally abducted to 90° with no additional weight and the hands were relaxed with the palms pointing downwards. The typing task involved bilateral arm motion when coping with text and a stress task involving dominant arm mouse work – each task was 10 min. Measures were taken during four reference contractions of 15 s each, the two tasks, before and after rest measures.	Similarities were found between muscle activation patterns of WMSD and WAD, with no significant differences when compared to healthy controls. There were slightly higher activity levels and lower relaxation levels in WAD and WMSD, with larger variability.	Similar muscle activity in HP, WMSD and WAD with a tendency of higher activity during computer tasks in the patient grps, although these were small.
Szeto (2009)(Szeto, Straker and O'Sullivan 2009)	Hong Kong Female office workers NP = 39 HP = 34	UT muscle activity during two computer work postures using sEMG	Seated computer task where the hands were rested on a keyboard or typing.	Resting hands on the keyboard elicited significantly increased muscle activity in the right UT of subjects with high discomforts rating, similar to that observed during actual typing. In contrast, the asymptomatic controls showed no difference in muscle activity between the resting postures. When resting hands on lap there were similar outcomes per grp with the exception of the high discomfort grp which had a trend of increased right UT muscle activity.	Altered muscle activation patterns in NP occurred, they were task-specific and related to reporting of high discomfort during the subsequent typing tasks. This may represent an anticipatory motor response triggered by the memory or anticipation of pain related to typing.
Szeto (2005)(Szeto,	Hong Kong	sEMG was obtained during a monotonous keyboard	Seated computer task with adjustable chair and keyboard	Higher activity in the right UT was found in the NP	Altered muscle recruitment

Straker and O'Sullivan (2005)	Female office workers NP = 23 HP = 23	typing task while assessing four neck–shoulder muscles	was used where participants copied text from a display screen using both hands. They worked at their own pace and ignored typing errors while sEMG was obtained bilaterally from the cervical erector spinae (CES), UT, lower trapezii (LT) and anterior deltoids (AD)	with the HP having more symmetrical muscle activity The High discomfort NP grp had significantly higher right UT activity compared to the low discomfort and HP grps.	patterns observed in the symptomatic subjects preceded the onset of task discomfort.
Falla (2003) (Falla <i>et al.</i> 2003)	Australia CNP = 10 HP = 10 Myoelectric manifestations of sternocleidomastoid and anterior scalene muscle fatigue in chronic neck pain patients D	Muscle fatigue was assessed in the sternocleidomastoid (SCM) and (AS) muscles during a neck flexion task using sEMG	Participants lay in the crooked lying position head strapped to a customised cervical flexion force measuring device anchored to a plinth. sEMG was recorded from the sternal head of SCM and anterior scalene (AS) muscles bilaterally during submaximal isometric cervical flexion contractions at 25 and 50% of the maximum voluntary contraction (MVC). The mean frequency, average rectified value and conduction velocity of the sEMG signal were calculated to quantify muscle fatigue.	For both the SCM and AS muscles the initial value and slope of the mean frequency in NP was greater ($p < 0,05$) at both the 25 and 50% MVC.	These results suggest a predominance of type-II fibres and greater fatigability of the superficial cervical flexors in NP.
Falla (2004b)(Falla, Jull and Hodges 2004b)	Australia NP = 10 HP = 10	sEMG was used to assess the activity of deep and superficial cervical flexor muscles during the craniocervical flexion test.	Customised electrodes obtained signals from the deep cervical flexor and sEMG electrodes from the SCM and AS obtained root mean square EMG amplitude during the craniocervical flexion test measured at five incremental levels in supine.	A strong linear relation was found for the deep cervical flexor muscles and the incremental stages of the craniocervical flexion test for control and NP ($p = 0.002$), with lower amplitudes occurring in those with NP, significant	Reduced performance of the craniocervical flexion test is associated with dysfunction of the deep cervical flexor muscles in NP.

				at the higher increments of the task ($p < 0.05$). A trend of greater SCM and AS muscle activity occurred for those with neck pain.	
Falla (2004)(Falla, Bilenkij and Jull 2004)	Australia NP = 10 WAD = 10 HP = 10	sEMG recorded from SCM, AS and UT muscle during and on completion of a functional repetitive upper limb task	A desk task with height-adjustable office chair and feet flat on the ground involved dotting pencil marks in 3 circles in an anticlockwise direction using the right hand. The task was performed to the beat of a metronome set at 88 beats/minute. The patient's left forearm rested motionless on the table. The task was performed for 2.5 minutes. Myoelectric signals were recorded for 5 seconds epochs prior to (baseline), at 10 seconds, 60 seconds, and 120 seconds into the performance of the task and at 10 seconds after completion of the task. Disability was assessed using the NDI.	A trend of greater sEMG amplitude in the SCM, AS and left UT muscle for WAD, then NP with the lowest values seen in the HP. A reverse effect was apparent for the right UT muscle. The level of perceived disability had a significant effect on the sEMG amplitude recorded between neck pain patients.	Greater activation of accessory neck muscles during a repetitive upper limb task occurred in NP, representing an altered motor control pattern to compensate for reduced activation of painful muscles. Perceived disability influenced sEMG amplitudes of the superficial cervical muscle activity during performance of the functional task.
Falla (2004c)(Falla <i>et al.</i> 2004a)	Australia CNP = 20 HP = 20	Neuromuscular efficiency (NME) of the SCM and AS muscles was assessed during submaximal isometric cervical flexion contractions.	Sub-maximal isometric cervical flexion contractions at 25 and 50% of the maximum voluntary contraction (MVC) were obtained and the NME was calculated as the ratio between MVC and the corresponding average rectified value of the EMG signal. Ultrasonography was used to measure	Both the SCM and AS muscles had reduced NME in NP at 25% MVC ($p < 0.05$). No differences were found for the subcutaneous tissue thickness for each muscle and grp.	NP patients required greater muscle activity to produce an equivalent amount of force compared to HP, especially during low-load conditions, this may be attributed to

			subcutaneous tissue thickness over the SCM and AS to ensure that differences did not exist between grps.		(1) greater excitability of the motoneuronal pool, (2) modification of neural activation patterns accommodating for weakness or inhibition of another muscle, or (3) a combination of these mechanisms.
Falla (2004a) (Falla, Jull and Hodges 2004a)	Australia CNP = 10 HP = 12	sEMG was used to assess the onset of deep and superficial cervical flexor muscle activity during rapid, unilateral arm movements	Deep cervical flexor (DCF) EMG was recorded with custom electrodes and sEMG electrodes were placed over the SCM and AS muscle activity was recorded during standing, flexion and extension of the right arm in response to a visual stimulus.	HP had activation of DCF, SCM and AS muscles occurred less than 50 ms after the onset of deltoid activity, which is consistent with feedforward control of the neck during arm flexion and extension. NP on flexing the arm, the onsets of DCF and contralateral SCM and AS muscles were significantly delayed ($p < 0.05$)	Delayed neck muscle activity associated with movement of the arm in patients with NP indicates a significant deficit in the automatic feedforward control of the cervical spine, this may leave the cervical spine vulnerable to reactive forces from arm movement.
Woolf (2022)	USA NP = 18 HP = 18	Grip strength, and cervical ROM were measured with a goniometer and three tasks: unilateral forward reach, bilateral forward reach, and unilateral upward reach, each motion was held at the top of each reaching	sEMG and ultrasound shear wave elastography were collected from the SCM and UT muscles	NP had lower UT activation during bilateral reaches ($p = 0.004$) without corresponding changes in stiffness during similar trials, and decreased SCM stiffness during forward unilateral ($p =$	People with NP adapt their movement strategies, possibly to avoid pain. The changes in muscle stiffness independent of changes in muscle

		movement for data to be collected bilaterally		0.023) and bilateral ($p = 0.038$) reaching, without corresponding activation changes during unilateral or bilateral reaching ($p > 0.577$). Unilateral reaching had no effect of the grp on UT EMG amplitudes or shear wave velocity ($p > 0.175$). Women demonstrated consistently higher SCM activation and stiffness when compared to men ($p < 0.05$) in the tasks, with no differences for the UT during the tasks ($p > 0.41$).	activity indicates the importance of assessing both these characteristics in NP.
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(NP – neck pain, HP – healthy participants, NSP – neck-shoulder pain, WAD – whiplash associated disorder, grp – group, ROM – range of motion, FE – flexion/extension, LF – lateral flexion, Rot – rotation, USA – United States of America, CV – conduction velocity, HN – head-neck, FH – forward head, SCM – sternocleidomastoid, AS – anterior scalene, UT – upper trapezius, LT – lower trapezius, T4 – thoracic paraspinal at T4, T9 – thoracic paraspinal at T9, PC – posterior cervical, DCF - Deep cervical flexor, CES – cervical erector spinae, AD – anterior deltoid, NDI – neck disability index, NME – neuromuscular efficiency, RMS - root mean square, RRT - relative rest time, FRR – flexion relaxation ratio, MVC – maximal voluntary contraction, FRP - flexion–relaxation phenomenon, FR-ratio - flexion–relaxation ratios)

APPENDIX D: CASE-CONTROLLED STUDIES ASSESSING DIFFERENCES IN MUSCLE ACTIVITY AND SPINAL KINEMATICS IN THOSE WITH AND WITHOUT NECK PAIN

Author	Sample	Task and measurement tool	Task specifics	Results	Conclusion
Tsang (2014)(Tsang, Szeto and Lee 2014)	Hong Kong NP = 30 HP = 30	Synchronized measurements of the three-dimensional spinal kinematics using electromagnetic tracking device (Fastrak, Polhemus Inc. Colchester, VT, USA) and sEMG using Noraxon System 9000 (Noraxon, USA Inc.) to assess muscle activity of the cervical and thoracic spine	Seated one arm lifting task where sEMG was obtained from the UT, SCM, AS, T4 and T9 paraspinal muscles and cervical and thoracic kinematics were obtained in the form of peak displacement, velocity and acceleration.	Neck pain grp showed a significantly decreased cervical velocity and acceleration while performing the task ($p < 0.05$). NP had predominantly prolonged coactivation of cervical and thoracic muscles throughout the task cycle.	CNP presents with compromised level of movement velocity and acceleration during functional tasks involving light weight transfer. The prolonged co-activation of muscles in CNP supports motor changes that were not only confined to the neck but included the thoracic spine
Lascurain-Aguirrebeña (2018) (Lascurain-Aguirrebeña <i>et al.</i> 2018b)	United Kingdom NP = 20 HP = 20	Three dimensional movement of the participants' head and thorax was captured using a Vicon motion capture system (Vicon Systems Ltd., Oxford, UK) with sEMG (Biopac Systems Inc., California, USA) determining bilateral muscle activity of the scalene (SA), SCM, erector spinae (ES) and UT muscle.	Standing cervical ROM to obtain neck kinematics and sEMG were recorded continuously and analysed in 10° increments during cervical forward and side flexion, extension and rotation. The point of pain occurrence in the movement was recorded.	NP had lower activity of scalene during flexion and extension ($p < 0.05$), and a non-significant higher activity in SCM during rotation. No differences in neck kinematics were observed ($p > 0.05$). 65% of NP reported pain during at least one neck movement. Pain was reported in the last ≈20–40% of the range of movement.	Neck muscle activity was modulated by the neck position in the RoM, supporting the need for the differentiated sEMG analysis presented in the current study. Decreased SA activity during both flexion and extension in NP, thus exercises aiming to minimise SA activity may not be appropriate treatment strategies for all patients with neck pain.

Park (2017) (Park <i>et al.</i> 2017)	Korea Unilateral NP = 20 HP = 20	A three-dimensional ultrasonic motion analysis system (Zebris System, Medizintechnik, Tübingen, Germany) with Noraxon TELEmyo system (Noraxon US, Scottsdale, AZ, USA) to detect sEMG were utilised to assess cervical extension, combined rotation and lateral bending during prone neck extension and seated CROM, and cervical paraspinal muscle activation	Prone subjects with a pillow under their chest and upper thoracic region stabilized to the table performed neck extension and seated cervical ROM with the thoracic spine anchored to the back rest.	Earlier combined neck rot to the painful side and LF toward the non-painful side were greater in the NP grp ($p < 0.05$); the extent of combined neck rot and LF were greater in the NP grp ($p < 0.05$). Delayed onset occurred on the painful side in the NP grp ($p < 0.05$), and no difference occurred in onset time between the non-painful side in the NP grp and the corresponding side in the HP grp during prone neck extension ($p = 0.13$). Neck flexion, extension, axial rotation and lateral bending toward the painful side were significantly lower in the NP grp ($p < 0.05$)	Unilateral NP significantly altered neck motion and muscle activation patterns of the cervical extensors during prone active neck extension, and restricted pain-free cervical ROM of the neck while sitting.
Vikne (2013) (Vikne <i>et al.</i> 2013a)	Norway WAD = 15 HP = 15	Unconstrained head movements were assessed using an electromagnetic motion tracker (Liberty, Polhemus Inc.) to obtain kinematics, smoothness and symmetry. sEMG was used to obtain bilateral SCM and splenius muscle activity where RMS amplitude for the accelerative and declarative phases of movement were analysed.	Seated sagittal cervical motion from neutral to maximal flexion (FFN), then back to neutral (EBN), from neutral to extension (EFN) then back to neutral (FBN), these motions took place at 3 speeds: slow (S), preferred (P) and maximum (M)	WAD movement velocity, acceleration, displacement, smoothness and RMS sEMG amplitude in agonist and antagonist muscles for a series of comparisons across the test conditions (range 17 – 121%, $p < 0.05$) differed from controls. After controlling for movement displacement, peak movement velocity and	Simple, unconstrained head movements in WAD occur with reduced velocity and displacement, but with normal muscle activation levels and movement patterns for a given velocity and displacement.

				acceleration persisted, whereas when controlling for peak displacement no differences in movement smoothness and RMS sEMG amplitude were found.	
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(NP – neck pain, HP – healthy participants, WAD – whiplash associated disorder, grp – group, ROM – range of motion, FE – flexion/extension, LF – lateral flexion, Rot – rotation, RMS – root mean squared; FFN - neutral to maximal flexion; EBN – extension back to neutral; EFN - neutral to extension; FBN – flexion back to neutral; S – slow; P – preferred; M - maximum)

APPENDIX E: PRISMA CHECKLIST FOR SYSTEMATIC REIEWS FOR MANUSCRIPT ONE

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	PG 89
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	Done
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Background
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	pg 94 objective
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Pg 95 study selection and participants
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Pg 96 search methods and identification of studies
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Table 3.1 and supplementary file 3.1
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Pg 97 data collection – study selection and data extraction
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Pg 97 data collection – study selection and data extraction
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Pg 97 data collection – study selection and data extraction
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Pg 97 data collection – study selection and data extraction

Section and Topic	Item #	Checklist item	Location where item is reported
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Pg 98 risk of bias assessment
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	Pg 98 data analysis
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Pg 98 data analysis
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	Pg 98 data analysis
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	Pg 98 data analysis
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Pg 98 data analysis
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	Pg 98 data analysis
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	Pg 98 data analysis
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	PG 98 Risk of bias
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	Pg 99 GRADE
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Fig 3.2
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Suppl file 3.2
Study characteristics	17	Cite each included study and present its characteristics.	Table 3.2
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Table 3.3
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Fig 3.3 – 3.5

Section and Topic	Item #	Checklist item	Location where item is reported
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Pg 121 - 127
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	Pg 121-127
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	Pg 121-127
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	Pg 121-127
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	Pg 121-127
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	Pg 121-127
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Pg 127-131
	23b	Discuss any limitations of the evidence included in the review.	Pg 131
	23c	Discuss any limitations of the review processes used.	Pg 131
	23d	Discuss implications of the results for practice, policy, and future research.	Pg 133
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	Pg 94
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	Pg 94
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	Pg 94
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Pg 133
Competing interests	26	Declare any competing interests of review authors.	Pg 133
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Pg 133

APPENDIX F: PROSPERO REGISTRATION

The effect of spinal manipulative therapy on muscle recruitment patterns and spinal kinematics in patients with non-specific neck pain

Laura O'Connor, Julian Pillay, Bernadette Murphy, Kesari Padayachy, Grant Matkovich

Citation

Laura O'Connor, Julian Pillay, Bernadette Murphy, Kesari Padayachy, Grant Matkovich. The effect of spinal manipulative therapy on muscle recruitment patterns and spinal kinematics in patients with non-specific neck pain. PROSPERO 2024 Available from https://www.crd.york.ac.uk/prospERO/display_record.php?ID=CRD42021170235

REVIEW TITLE AND BASIC DETAILS

Review title

The effect of spinal manipulative therapy on muscle recruitment patterns and spinal kinematics in patients with non-specific neck pain

Review objectives

What effect does spinal manipulation have on muscle recruitment patterns and spinal kinematics in patients with non-specific neck pain?

Keywords

kinematics, muscle recruitment, neck pain, spinal manipulation

APPENDIX G: ADVERTISEMENTS

PAMPHLET:

Do you suffer with ***NECK PAIN?***



Would you like a free
assessment and/or
treatment?

Research is being conducted at the
Durban University of Technology
Contact

Dr O'Connor M. Tech Chiropractic
031 373 2923 / 2055

SOCIAL MEDIA:

Do you suffer with ***NECK PAIN?***

You may be eligible for free
treatment.

Research is being conducted at the
Durban University of Technology
Criteria are required for enrollement in the
study.

Contact: Dr L. O'Connor (M. Tech Chiropractic)
Telephone: 031 373 2055 / 072 752 5012
Email: lauraw@dut.ac.za

APPENDIX H: CLINIC DIRECTOR PERMISSION

MEMORANDUM

To : Prof Adam Chair: IREC
From : Dr Aadil Docrat per procurationem: Acting Head of Department: Chiropractic
Dr Desiree Varatharajullu Clinic Director: Chiropractic Day Clinic: Chiropractic
Date : 23.06.2020
Re : Request for permission to use the Chiropractic Day Clinic for research purposes

Permission is hereby granted to: Dr Laura O'Connor (Student Number: 19500653)

Research title: "Cervical spine manipulation for neck pain- effect on muscle recruitment patterns, spinal kinematics, pain and disability in participants in KwaZulu-Natal".

Dr O'Connor, is requested to submit a copy of her FRC/IREC approved proposal along with proof of her PhD: Health Sciences registration to the Clinic Administrator/s before she starts with her research in order that any special procedures with regards to her research can be implemented prior to the commencement of her seeing patients.

Thank you for your time.

Kind regards,



Dr Aadil Docrat
per procurationem:
Acting Head of Department: Chiropractic
Cc: Mrs Linda Twiggs: Chiropractic Day Clinic
Prof Julian Pillay: Supervisor
Prof Bernadette Murphy: Co-supervisor



Dr D Varatharajullu
Clinic Director: Chiropractic Day
Clinic: Chiropractic

APPENDIX I: APPROVAL FROM THE INSTITUTIONAL RESEARCH ETHICS COMMITTEE



*Directorate for Research and Postgraduate Support
Durban University of Technology
Tromso Annexe, Steve Biko Campus
P.O. Box 1334, Durban 4000
Tel.: 031-3732576/7
Fax: 031-3732946*

22nd June 2020
Dr Laura O'Connor
c/o Department of Chiropractic and Somatology
Faculty of Health Sciences
Durban University of Technology

Dear Dr O'Connor

PERMISSION TO CONDUCT RESEARCH AT THE DUT

Your email correspondence in respect of the above refers. I am pleased to inform you that the Institutional Research and Innovation Committee (IRIC) has granted **Full Permission** for you to conduct your research "Cervical spinal manipulation for neck pain - effect on muscle recruitment patterns, spinal kinematics, pain and disability in participants in KwaZulu-Natal" at the Durban University of Technology.

The DUT may impose any other condition it deems appropriate in the circumstances having regard to nature and extent of access to and use of information requested.

We would be grateful if a summary of your key research findings can be submitted to the IRIC on completion of your studies.

Kindest regards.
Yours sincerely

A handwritten signature in black ink, appearing to read 'L. Liganiso'.

DR LINDA ZIKHONA LIGANISO
DIRECTOR: RESEARCH AND POSTGRADUATE SUPPORT DIRECTORATE

APPENDIX J: INFORMATION AND INFORMED CONSENT – CHAPTER FOUR (RELIABILITY STUDY)



LETTER OF INFORMATION

Dear Sir/Madam

Thank you for taking the time to respond to take part in the testing of this software programme. This letter aims to provide you with the necessary details for you to make an informed decision about partaking. Please read through it carefully and should you require clarification please ask.

Title of the Research Study: Cervical spinal manipulation for neck pain - effect on muscle recruitment patterns, spinal kinematics, pain and disability in participants in KwaZulu-Natal

Principal researcher: Dr L. O'Connor M. Tech: Chiropractic

Supervisor/s: Prof J. Pillay PhD: Physiology

Prof B. Murphy PhD

Brief Introduction and Purpose of the Study:

This reliability study is being conducted as part of a doctoral investigation into cervical spinal manipulation therapy as a treatment for neck pain. This study will enable the researcher to determine the reliability i.e. the consistency of the software to determine changes in human movement.

Outline of the Procedures:

To partake you will be required to change into tight fitting clothes (leggings/cycling shorts and a tight vest/sports bra). Reflective markers will then be placed on your body. Three on the head, two on the shoulders, two on both arms and seven along the spine. The reflective markers allow for the capture of motion of the body parts. Once this is complete you will be asked to preform two tasks three times, twice during your visit, while being recorded by the motion capture cameras. The visit should take approximately 40 minutes.

Risks or Discomforts to the Participant:

The procedures used in this study should not result in any discomfort.

Benefits:

The results of this study will establish the reliability of this software for use in human movement studies.

Reason/s why the Participant May Be Withdrawn from the Study: Should it be determined that you have a condition which would influence the outcomes you will be withdrawn from the study. Examples include spinal surgery or un-united shoulder one fracture. You are also free to withdraw from the study at any time, without any adverse consequence for you.

Remuneration:

There is no monetary remuneration for you partaking in this study.

Costs of the Study:

There is no cost you to partake in this study, except your travelling cost to the DUT chiropractic clinic.

Confidentiality:

All your personal information will be kept confidential. When reporting the results of this study coding will be used to ensure that your name is not associated with any of the reported research results.

Research-related Injury:

There is no treatment being administered, thus it is unlikely that you will sustain an injury as a result of your participation however should you feel that you have please contact the researcher immediately.

COVID-19 precautions: All necessary precautions to prevent the transmission of COVID-19 will be put in place. The research equipment will be sanitized before and after each visit. Masks will be worn at all times and you will be screened on arrival at the chiropractic clinic for symptoms of COVID-19. Should you display any symptoms of COVID-19 please let the researcher know via telephone. Do not come to the clinic but seek medical attention.

Persons to Contact in the Event of Any Problems or Queries:

Please contact the researcher on 031 373 2923/lauraw@dut.ac.za or the supervisor Prof Pillay on 031 373 2398 julianp@dut.ac.za. Alternatively, the Institutional Research Ethics Administrator can be contacted on 031 373 2375. Complaints can be reported to the DVC: Research, Innovation and Engagement Prof Moyo on 031 373 2576 or moyos@dut.ac.za



CONSENT

Statement of Agreement to Participate in the Research Study:

- I hereby confirm that I have been informed by the researcher, Laura O'Connor/representative of, about the nature, conduct, benefits and risks of this study - Research Ethics Clearance Number: IREC 017/20,
- I have also received, read and understood the above written information (Participant Letter of Information) regarding the study.
- I am aware that the results of the study, including personal details regarding my sex, age, date of birth, initials and diagnosis will be anonymously processed into a study report.
- In view of the requirements of research, I agree that the data collected during this study can be processed in a computerised system by the researcher.
- I may, at any stage, without prejudice, withdraw my consent and participation in the study.
- I have had sufficient opportunity to ask questions and (of my own free will) declare myself prepared to participate in the study.
- I understand that significant new findings developed during the course of this research which may relate to my participation will be made available to me.

_____	_____	_____	_____
Full Name of Participant	Date	Time	Signature/Right Thumbprint

I, Laura O'Connor/representative of herewith confirm that the above participant has been fully informed about the nature, conduct and risks of the above study.

Laura O'Connor

_____	_____	_____
Full Name of Researcher	Date	Signature

_____	_____	_____
Full Name of Witness (If applicable)	Date	Signature

APPENDIX K: GRRAS CHECKLIST FOR REPORTING RELIABILITY AND AGREEMENT FOR MANUSCRIPT TWO

Section	Item #	Checklist item	Reported on page #
TITLE AND ABSTRACT	Identify in title or abstract that interrater/intrarater reliability or agreement was investigated.	√	Pg 149
INTRODUCTION	Name and describe the diagnostic or measurement device of interest explicitly.	√	Pg 151-152
	Specify the subject population of interest.	√	Pg 153 study design, [participants and approval
	Specify the rater population of interest (if applicable)	√	na
	Describe what is already known about reliability and agreement and provide a rationale for the study (if applicable)	√	Pg 151-152
Methods	Explain how the sample size was chosen. State the determined number of raters, subjects/objects, and replicate observations.	√	Pg 153 sampling
	Describe the sampling method.	√	Pg 153 sampling
	Describe the measurement/rating process (e.g. time interval between the repeated measurements, availability of clinical information, blinding).	√	Pg 155 experimental procedure
	State whether measurements/ratings were conducted independently.	√	Pg 155 experimental procedure
	Describe the statistical analysis.	√	Pg 156 data reduction and analysis
RESULTS	State the actual number of rates and subjects/objects which were included and the number of replicate observations which were conducted.	√	Pg 158
	Describe the sample characteristics of rates and subjects (e.g. training, experience).	√	Table 4.1
	Report estimates of reliability and agreement including measures of uncertainty.	√	Pg 159-166
DISCUSSION	Discuss the practical relevance of results.	√	Pg 166
AUXILIARY MATERIAL	Provide detailed results if possible (e.g. online).	In the manuscript	n/a

Version based on Table I in: Kottner J, Audigé L, Brorson S, Donner A, Gajewski BJ, Hróbjartsson A, Robersts C, Shoukri M, Streiner DL. Guidelines for reporting reliability and agreement studies (GRRAS) were proposed. Journal of Clinical Epidemiology. 2011;64(1):96-106

APPENDIX L: RAND 36-ITEM HEALTH SURVEY 1.0

General health: RAND 36-Short Form survey (Copyright © 1994-2016 RAND Corporation)

Choose one option for each questionnaire item by placing a tick (✓) or a cross (X) in the appropriate box.

Excellent	Very good	Good	Fair	Poor
-----------	-----------	------	------	------

1. In general, would you say your health is:

2. Compared to one year ago, how would you rate your health in general now?	X/✓
1 Much better now than one year ago	
2 Somewhat better now than one year ago	
3 About the same	
4 Somewhat worse now than one year ago	
5 Much worse now than one year ago	

HEALTH: The following items are about activities you might do during a typical day.

Does your health now limit you in these activities? If so, how much?	Yes, limited a lot	Yes, limited a little	No, not limited at all
3 Vigorous activities , such as running, lifting heavy objects, participating in strenuous sports			
4 Moderate activities , such as moving a table, pushing a vacuum cleaner, bowling, or playing golf			
5 Lifting or carrying groceries			
6 Climbing several flights of stairs			
7 Climbing one flight of stairs			
8 Bending, kneeling, or stooping			
9 Walking more than a mile			
10 Walking several blocks			
11 Walking one block			
12 Bathing or dressing yourself			

During the **past 4 weeks**, have you had any of the following problems with your work or other regular daily activities **as a result of your physical health**?

	Yes	No
12 Cut down the amount of time you spent on work or other activities		
14 Accomplished less than you would like		
15 Were limited in the kind of work or other activities		
16 Had difficulty performing the work or other activities (for example, it took extra effort)		

During the **past 4 weeks**, have you had any of the following problems with your work or other regular daily activities **as a result of any emotional problems** (such as feeling depressed or anxious)?

	Yes	No
17 Cut down the amount of time you spent on work or other activities		
18 Accomplished less than you would like		
19 Didn't do work or other activities as carefully as usual		

Answer the following questions by placing a X/✓ in the appropriate box:							
20	During the past 4 weeks , to what extent has your physical health or emotional problems interfered with your normal social activities with family, friends, neighbours, or groups?	Not at all	Slightly	Moderately	Quite a bit	Extremely	
21	How much bodily pain have you had during the past 4 weeks ?	None	Very mild	Mild	Moderate	Severe	Very severe
22	During the past 4 weeks , how much did pain interfere with your normal work (including both work outside the home and housework)?	Not at all	A little bit	Moderately	Quite a bit	Extremely	

These questions are about how you feel and how things have been with you **during the past 4 weeks**. For each question, please give the one answer that comes closest to the way you have been feeling.

How much of the time during the past 4 weeks ...		All of the time	Most of the time	A good bit of the time	Some of the time	A little of the time	None of the time
23	Did you feel full of pep?						
24	Have you been a very nervous person?						
25	Have you felt so down in the dumps that nothing could cheer you up?						
26	Have you felt calm and peaceful?						
27	Did you have a lot of energy?						
28	Have you felt downhearted and blue?						
29	Did you feel worn out?						
30	Have you been a happy person?						
31	Did you feel tired?						

32. During the **past 4 weeks**, how much of the time has **your physical health or emotional problems** interfered with your social activities (like visiting with friends, relatives, etc.)?

How TRUE or FALSE is each of the following statements for you. (circle one)							
All of the time		Most of the time	Some of the time	A little of the time	None of the time		
How TRUE or FALSE is each of the following statements for you.			Definitely true	Mostly true	Don't know	Mostly false	Definitely false
33	I seem to get sick a little easier than other people						
34	I am as healthy as anybody I know						
35	I expect my health to get worse						
36	My health is excellent						

APPENDIX M: THE NUMERICAL PAIN RATING SCALE

Numerical Rating Scale - 101

Questionnaire Date:

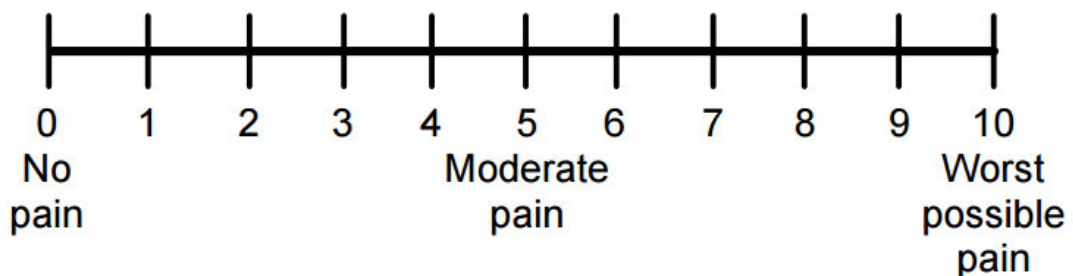
File no:

Visit no:

Patient name:

Please indicate on the line below, the number between 0 and 10 that best describes the pain you experience. A zero (0) would mean “no pain at all”, and one hundred (100) would mean “pain as bad as it could be”. Please write only **one** number.

0–10 Numeric Pain Rating Scale



APPENDIX N: NECK DISABILITY INDEX

Neck Disability Index

This questionnaire has been designed to give us information as to how your neck pain has affected your ability to manage in everyday life. Please answer every section and **mark in each section only the one box that applies to you**. We realise you may consider that two or more statements in any one section relate to you, but please just mark the box that most closely describes your problem.

Office Use Only

Name _____

Date _____

Section 1: Pain Intensity

- ☐ I have no pain at the moment
- ☐ The pain is very mild at the moment
- ☐ The pain is moderate at the moment
- ☐ The pain is fairly severe at the moment
- ☐ The pain is very severe at the moment
- ☐ The pain is the worst imaginable at the moment

Section 2: Personal Care (Washing, Dressing, etc.)

- ☐ I can look after myself normally without causing extra pain
- ☐ I can look after myself normally but it causes extra pain
- ☐ It is painful to look after myself and I am slow and careful
- ☐ I need some help but can manage most of my personal care
- ☐ I need help every day in most aspects of self care
- ☐ I do not get dressed, I wash with difficulty and stay in bed

Section 3: Lifting

- ☐ I can lift heavy weights without extra pain
- ☐ I can lift heavy weights but it gives extra pain
- ☐ Pain prevents me lifting heavy weights off the floor, but I can manage if they are conveniently placed, for example on a table
- ☐ Pain prevents me from lifting heavy weights but I can manage light to medium weights if they are conveniently positioned
- ☐ I can only lift very light weights

Section 7: Work

- ☐ I can do as much work as I want to
- ☐ I can only do my usual work, but no more
- ☐ I can do most of my usual work, but no more
- ☐ I cannot do my usual work
- ☐ I can hardly do any work at all
- ☐ I can't do any work at all

Section 8: Driving

- ☐ I can drive my car without any neck pain
- ☐ I can drive my car as long as I want with slight pain in my neck
- ☐ I can drive my car as long as I want with moderate pain in my neck
- ☐ I can't drive my car as long as I want because of moderate pain in my neck
- ☐ I can hardly drive at all because of severe pain in my neck
- ☐ I can't drive my car at all

- ☐ I cannot lift or carry anything

Section 4: Reading

- ☐ I can read as much as I want to with no pain in my neck
- ☐ I can read as much as I want to with slight pain in my neck
- ☐ I can read as much as I want with moderate pain in my neck
- ☐ I can't read as much as I want because of moderate pain in my neck
- ☐ I can hardly read at all because of severe pain in my neck
- ☐ I cannot read at all

Section 5: Headaches

- ☐ I have no headaches at all
- ☐ I have slight headaches, which come infrequently
- ☐ I have moderate headaches, which come infrequently
- ☐ I have moderate headaches, which come frequently
- ☐ I have severe headaches, which come frequently
- ☐ I have headaches almost all the time

Section 6: Concentration

- ☐ I can concentrate fully when I want to with no difficulty
- ☐ I can concentrate fully when I want to with slight difficulty
- ☐ I have a fair degree of difficulty in concentrating when I want to
- ☐ I have a lot of difficulty in concentrating when I want to
- ☐ I have a great deal of difficulty in concentrating when I want to
- ☐ I cannot concentrate at all

Section 9: Sleeping

- ☐ I have no trouble sleeping
- ☐ My sleep is slightly disturbed (less than 1 hr sleepless)
- ☐ My sleep is mildly disturbed (1-2 hrs sleepless)
- ☐ My sleep is moderately disturbed (2-3 hrs sleepless)
- ☐ My sleep is greatly disturbed (3-5 hrs sleepless)
- ☐ My sleep is completely disturbed (5-7 hrs sleepless)

Section 10: Recreation

- ☐ I am able to engage in all my recreation activities with no neck pain at all
- ☐ I am able to engage in all my recreation activities, with some pain in my neck
- ☐ I am able to engage in most, but not all of my usual recreation activities because of pain in my neck
- ☐ I am able to engage in a few of my usual recreation activities because of pain in my neck
- ☐ I can hardly do any recreation activities because of pain in my neck
- ☐ I can't do any recreation activities at all

Score: ____/50 Transform to percentage score x 100 = %points

Scoring: For each section the total possible score is 5: if the first statement is marked the section score = 0, if the last statement is marked it = 5. If all ten sections are completed the score is calculated as follows:

Example: 16 (total scored)
50 (total possible score) x 100 = 32%
If one section is missed or not applicable the score is calculated: 16 (total scored)
45 (total possible score) x 100 = 35.5%

Minimum Detectable Change (90% confidence): 5 points or 10 %points

NDI developed by: Vernon, H. & Mior, S. (1991). The Neck Disability Index: A study of reliability and validity. Journal of Manipulative and Physiological Therapeutics. 14, 409-415

APPENDIX O: DATA COLLECTION SCRIPT

Participant name:

Date:

Data capturer:

PRE

POST

Check all leads attached to correct muscle?	Y	N
Pre-check to ensure no markers are lost?	Y	N
Pre-check to check leads can reach?	Y	N

EMG CHECK

L AS

R AS

L SCM

L UT

R UT

L PC

R PC

L T4 ES

R T4 ES

L T9 ES

R T9 ES

EMG CHECK

L AS

R AS

L SCM

L UT

R UT

L PC

R PC

L T4 ES

R T4 ES

L T9 ES

R T9 ES

MVICs

1

2

3

Left UT

Right UT

SCM + AS

PC + ES

Explain the process then **Hold 5 sec, rest 15 sec

Lie supine secure head band

Line prone secure head band

MVICs

1

2

3

Left UT

Right UT

SCM + AS

PC + ES

Participant to stand in upright relaxed position until calibrations is complete – do not sway or look around, then sit on the stool, feet resting on the floor arms relaxed at sides, looking straight ahead. Start with flexion, then extension, left then right rotation, then left then right lateral flexion. Pause briefly at the end range, do not move shoulders.

Pre measures*pause end ROM				Post measures *pause end ROM				Post measures Tx 4*pause end ROM			
CROM	1	2	3	CROM	1	2	3	CROM	1	2	3
Flex				Flex				Flex			
Extension				Extension				Extension			
L ROT				L ROT				L ROT			
R ROT				R ROT				R ROT			
L LF				L LF				L LF			
R LF				R LF				R LF			

Sit up right on stool, tracking glass container with head and eyes, start with right hand in the lap and reach for jar and move to top shelf, pause briefly then lower to bottom shelf, pause and lift again – repeat three times

One arm*pause end ROM				One arm*pause end ROM				One arm*pause end ROM			
1				1				1			
2				2				2			
3				3				3			

Stand behind the chair facing forward, lift bar with both arms and raise above head, tracking with head and eyes, repeat three times ending with putting bar on the box.

Bilat arm*pause end ROM				Bilat arm*pause end ROM				Bilat arm*pause end ROM			
1				1				1			
2				2				2			
3				3				3			

Checked capture to ensure all markers are seen? Y N

Saved capture correctly? Y N

APPENDIX P: LETTER OF INFORMATION AND INFORMED CONSENT CHAPTER FIVE AND SIX (CASE-CONTROLLED STUDY)



LETTER OF INFORMATION

Dear Sir/Madam

Thank you for taking the time to respond to the advert for this research study. This letter aims to provide you with the necessary details for you to make an informed decision about partaking in this research project. Please read through it carefully and should you require clarification please ask.

Title of the Research Study: Cervical spinal manipulation for neck pain - effect on muscle recruitment patterns, spinal kinematics, pain and disability in participants in KwaZulu-Natal

Principal researcher: Dr L. O'Connor M. Tech: Chiropractic

Supervisor/s: Prof J. Pillay PhD: Physiology

Prof B. Murphy PhD

Brief Introduction and Purpose of the Study:

This study is investigating the effect that a form of treatment for neck pain, call spinal manipulation, has on spinal motion, muscle recruitment patterns (the way in which your body recruits different muscles during movement), pain and disability in people with neck pain. In order to investigate this this study consists of two parts. Part one is where people with neck pain will be compared to people without neck pain in terms of cervical and thoracic spine motion and muscle recruitment patterns to determine if people with neck pain use different muscle recruitment strategies when moving their arm. On completion of part one if you suffer with neck pain you will be invited to partake in the second part of this study participant where

you will be treated with cervical spinal manipulation to see how this treatment alters your body's ability to recruit muscles when moving your arm. This study will contribute the literature in terms of our understanding of how spinal manipulation begins about its therapeutic effect.

Outline of the Procedures:

The first stage of this study requires volunteers between the ages of 18 and 50, with and without neck pain to undergo an assessment of their movement patterns while performing two everyday tasks. People with neck pain will be required to be diagnosed by the researcher as having non-specific neck pain, of greater than three months duration. Those without neck pain will be required to have no pain in their neck, trunk or arm. All participants must not have had spinal surgery, serve trauma, sensory or vestibular deficits, bony abnormalities, deformities of the trunk, be suffering from rheumatic disease, experience problems with their temporomandibular joint or has a pacemaker.

Once meeting these criteria there are various forms that require completion. These forms document your health status, pain and disability. Once complete this study requires that you change into tight fitting clothes (leggings/cycling shorts and a tight vest/sports bra). The electrodes and reflected markers will then be placed on your skin. The electrodes will record muscle activity, via surface electromyography which is a machine which is able to detect the electrical activity that your muscles produce. The reflective markers allow for the capture of motion of the body parts.

In order to ensure good contact the area will need to be cleaned with alcohol and lightly abraded. If you are particularly hairy in these areas they may be shaved with a disposable razor. Once the electrodes are placed you will be required to perform a maximum contraction of the muscles being tested (this means contracting the muscle as hard as possible against resistance). This will occur three times. Following this you will be required to perform the two tasks while being recorded. On completion of the task the electrodes will be removed and you will be free to leave. This part is anticipated to take approximately one and half hours.

If you suffer with neck pain you will be invited to participate in the second phase of the project. The second phase entails receiving either cervical spinal manipulation or a control

intervention. There will be a 50% chance of receiving either the control or intervention. Should you be available to partake in this phase henna will be utilized to mark the exact location of the electrode and marker placement so that at your next visit these are placed in the same position. Following the initial conducting of the functional tasks you will then receive the intervention and will thereafter have to complete the functional tasks again. This should take approximately an additional 15 minutes.

You will be required to return to the clinic for an additional three treatments within the next two weeks. Should you be unable to commit to this you will be excluded from partaking in this phase of the project. Should you be available, you will then receive the necessary treatment (each treatment will take approximately 15 minutes) and on the fourth treatment a final set of measurements will be taken (this session will take approximately 45 minutes). Thereafter you will no longer be required to come to the clinic for treatment. The researcher/research assistant will telephone you in one week to ask you about your neck pain. Thereafter your involvement in the study will be complete.

During the study you are requested to refrain from changing your normal habits i.e. exercise, work and activities. You will be required to document all pain and non-steroidal anti-inflammatory medication you take.

Risks or Discomforts to the Participant:

The procedures used in this study are commonly utilized. Following cervical spinal manipulation, you may experience mild discomfort which may last 24 hours. This can be managed by having a shower and letting the warm water run over the area.

Benefits:

The results of this study will contribute to our understanding of how spinal manipulation brings about its therapeutic effect. In addition, all participants with neck pain will receive cervical spinal manipulation as a treatment either during the study or after (a total of four treatments), depending which group you are allocated to.

Reason/s why the Participant May Be Withdrawn from the Study: Should you become ill during the study or develop pain in the trunk or arm or if you are non-compliant

with the treatment schedule you will be withdrawn from the study. You are also free to withdraw from the study at any time, without any adverse consequence for you.

Remuneration:

There is no monetary remuneration for you partaking in this study. However, all treatments administered will be free of charge.

Costs of the Study:

There is no cost you to partake in this study, except your travelling cost to the DUT chiropractic clinic.

Confidentiality:

All your personal information will be kept confidential. When reporting the results of this study coding will be used to ensure that your name is not associated with any of the reported research results.

Research-related Injury:

Should you sustain an injury while being enrolled in this study please advise the researcher immediately.

COVID-19 precautions: All necessary precautions to prevent the transmission of COVID-19 will be put in place. The research equipment will be sanitized before and after each visit. Masks will be worn at all times and you will be screened on arrival at the chiropractic clinic for symptoms of COVID-19. Should you display any symptoms of COVID-19 please let the researcher know via telephone. Do not come to the clinic but seek medical attention.

Persons to Contact in the Event of Any Problems or Queries:

Please contact the researcher on 031 373 2923/lauraw@dut.ac.za or the supervisor Prof Pillay on 031 373 2398 julianp@dut.ac.za. Alternatively the Institutional Research Ethics Administrator can be contacted on 031 373 2375. Complaints can be reported to the DVC: Research, Innovation and Engagement Prof Moyo on 031 373 2576 or moyos@dut.ac.za



CONSENT

Statement of Agreement to Participate in the Research Study:

- I hereby confirm that I have been informed by the researcher, Laura O'Connor/representative of, about the nature, conduct, benefits and risks of this study - Research Ethics Clearance Number: IREC 017/20,
- I have also received, read and understood the above written information (Participant Letter of Information) regarding the study.
- I am aware that the results of the study, including personal details regarding my sex, age, date of birth, initials and diagnosis will be anonymously processed into a study report.
- In view of the requirements of research, I agree that the data collected during this study can be processed in a computerised system by the researcher.
- I may, at any stage, without prejudice, withdraw my consent and participation in the study.
- I have had sufficient opportunity to ask questions and (of my own free will) declare myself prepared to participate in the study.
- I understand that significant new findings developed during the course of this research which may relate to my participation will be made available to me.

Full Name of Participant Date Time Signature/Right Thumbprint

I, Laura O'Connor/representative of herewith confirm that the above participant has been fully informed about the nature, conduct and risks of the above study.

Laura O'Connor

Full Name of Researcher Date Signature

Full Name of Witness (If applicable) Date Signature

APPENDIX Q: STROBE CHECKLIST FOR MANUSCRIPT THREE

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No.	Recommendation	Page No.	Relevant text from the manuscript
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	180	Participants with chronic, non-specific neck pain were age and sex matched to asymptomatic control (n=46) in a case-controlled design
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	180-181	Abstract
Introduction				
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	181-184	Introduction
Objectives	3	State specific objectives, including any prespecified hypotheses	184	Thus this study aimed to compare cervical spine kinematics and muscle recruitment patterns of selected cervical and thoracic spinal muscles during active cervical ROM in participants with and without neck pain. It was hypothesised that those with neck pain would differ from the healthy controls in cervical spine kinematics and/or cervicothoracic muscle recruitment patterns.
Methods				

Study design	4	Present key elements of study design early in the paper	184	Under methods
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	184	Chiropractic clinic on a university campus; November 2022 and August 2023
Participants	6	(a) <i>Cohort study</i> —Give the eligibility criteria and the sources and methods of selection of participants. Describe methods of follow-up <i>Case-control study</i> —Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls <i>Cross-sectional study</i> —Give the eligibility criteria, and the sources and methods of selection of participants	184-185	
		(b) <i>Cohort study</i> —For matched studies, give matching criteria and number of exposed and unexposed <i>Case-control study</i> —For matched studies, give matching criteria and the number of controls per case	184-185	See section participants
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	185-186 and 188-189	See measurement tools and Data processing and analysis
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	185-185	See measurement tools
Bias	9	Describe any efforts to address potential sources of bias	185	An independent person collected the data
Study size	10	Explain how the study size was arrived at	185	See sampling
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	188-190	See Data processing and analysis

Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	190	See Data processing and analysis
		(b) Describe any methods used to examine subgroups and interactions		
		(c) Explain how missing data were addressed		
		(d) <i>Cohort study</i> —If applicable, explain how loss to follow-up was addressed		
		<i>Case-control study</i> —If applicable, explain how the matching of cases and controls was addressed <i>Cross-sectional study</i> —If applicable, describe analytical methods taking account of the sampling strategy		
		(e) Describe any sensitivity analyses		
Results				
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	190	A total of 46 participants joined the study, 23 in each group.
		(b) Give reasons for non-participation at each stage		
		(c) Consider use of a flow diagram		
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	191	Table 5.2: Results
		(b) Indicate number of participants with missing data for each variable of interest		
		(c) <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)		
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time	192	N/A See figures 5.3-5.11
		<i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure		

		<i>Cross-sectional study</i> —Report numbers of outcome events or summary measures		N/A
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	191-195	Results
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses		na
Discussion				
Key results	18	Summarise key results with reference to study objectives	195,198-202	Discussion section
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	202	Strengths and limitations section
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	202	Conclusion
Generalisability	21	Discuss the generalisability (external validity) of the study results	195,198-202	Discussion
Other information				
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	203	Funding section

CENTRAL SENSITIZATION INVENTORY: PART A

Date: _____

1	I feel tired and unrefreshed when I wake from sleeping.	Never	Rarely	Sometimes	Often	Always
2	My muscles feel stiff and achy.	Never	Rarely	Sometimes	Often	Always
3	I have anxiety attacks.	Never	Rarely	Sometimes	Often	Always
4	I grind or clench my teeth.	Never	Rarely	Sometimes	Often	Always
5	I have problems with diarrhea and/or constipation.	Never	Rarely	Sometimes	Often	Always
6	I need help in performing my daily activities.	Never	Rarely	Sometimes	Often	Always
7	I am sensitive to bright lights.	Never	Rarely	Sometimes	Often	Always
8	I get tired very easily when I am physically active.	Never	Rarely	Sometimes	Often	Always
9	I feel pain all over my body.	Never	Rarely	Sometimes	Often	Always
10	I have headaches.	Never	Rarely	Sometimes	Often	Always
11	I feel discomfort in my bladder and/or burning when I urinate.	Never	Rarely	Sometimes	Often	Always
12	I do not sleep well.	Never	Rarely	Sometimes	Often	Always
13	I have difficulty concentrating.	Never	Rarely	Sometimes	Often	Always
14	I have skin problems such as dryness, itchiness, or rashes.	Never	Rarely	Sometimes	Often	Always
15	Stress makes my physical symptoms get worse.	Never	Rarely	Sometimes	Often	Always
16	I feel sad or depressed.	Never	Rarely	Sometimes	Often	Always
17	I have low energy.	Never	Rarely	Sometimes	Often	Always
18	I have muscle tension in my neck and shoulders.	Never	Rarely	Sometimes	Often	Always
19	I have pain in my jaw.	Never	Rarely	Sometimes	Often	Always
20	Certain smells, such as perfumes, make me feel dizzy and nauseated.	Never	Rarely	Sometimes	Often	Always
21	I have to urinate frequently.	Never	Rarely	Sometimes	Often	Always
22	My legs feel uncomfortable and restless when I am trying to go to sleep at night.	Never	Rarely	Sometimes	Often	Always
23	I have difficulty remembering things.	Never	Rarely	Sometimes	Often	Always
24	I suffered trauma as a child.	Never	Rarely	Sometimes	Often	Always
25	I have pain in my pelvic area.	Never	Rarely	Sometimes	Often	Always
				Total=		

544

CENTRAL SENSITIZATION INVENTORY: PART B

Name: _____

Date: _____

Have you been diagnosed by a doctor with any of the following disorders?

Please check the box to the right for each diagnosis and write the year of the diagnosis.

		NO	YES	Year Diagnosed
1	Restless Leg Syndrome			
2	Chronic Fatigue Syndrome			
3	Fibromyalgia			
4	Temporomandibular Joint Disorder (TMJ)			
5	Migraine or tension headaches			
6	Irritable Bowel Syndrome			
7	Multiple Chemical Sensitivities			
8	Neck Injury (including whiplash)			
9	Anxiety or Panic Attacks			
10	Depression			

APPENDIX S: TAMPA SCALE OF KINESIOPHOBIA

Tampa Scale for Kinesiophobia (Miller, Kori and Todd 1991)

1 = strongly disagree
2 = disagree
3 = agree
4 = strongly agree

1. I'm afraid that I might injury myself if I exercise	1	2	3	4
2. If I were to try to overcome it, my pain would increase	1	2	3	4
3. My body is telling me I have something dangerously wrong	1	2	3	4
4. My pain would probably be relieved if I were to exercise	1	2	3	4
5. People aren't taking my medical condition seriously enough	1	2	3	4
6. My accident has put my body at risk for the rest of my life	1	2	3	4
7. Pain always means I have injured my body	1	2	3	4
8. Just because something aggravates my pain does not mean it is dangerous	1	2	3	4
9. I am afraid that I might injure myself accidentally	1	2	3	4
10. Simply being careful that I do not make any unnecessary movements is the safest thing I can do to prevent my pain from worsening	1	2	3	4
11. I wouldn't have this much pain if there weren't something potentially dangerous going on in my body	1	2	3	4
12. Although my condition is painful, I would be better off if I were physically active	1	2	3	4
13. Pain lets me know when to stop exercising so that I don't injure myself	1	2	3	4
14. It's really not safe for a person with a condition like mine to be physically active	1	2	3	4
15. I can't do all the things normal people do because it's too easy for me to get injured	1	2	3	4
16. Even though something is causing me a lot of pain, I don't think it's actually dangerous	1	2	3	4
17. No one should have to exercise when he/she is in pain	1	2	3	4

Reprinted from:
Pain, Fear of movement(re) injury in chronic low back pain and its relation to behavioral performance, 62, Vlaeyen, J., Kole-Snijders A., Boeren R., van Eek H., 371.
Copyright (1995) with permission from International Association for the Study of Pain.

Scoring Information Tampa Scale for Kinesiophobia (Miller et al 1991)

A total score is calculated after inversion of the individual scores of items 4, 8, 12 and 16.

APPENDIX T: STROBE CHECKLIST FOR MANUSCRIPT FOUR

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No.	Recommendation	Page No.	Relevant text from the manuscript
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	218	Participants with chronic, non-specific neck pain were age and sex matched to asymptomatic control (n=46) in a case-controlled design
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	218-219	Abstract
Introduction				
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	219-222	Introduction
Objectives	3	State specific objectives, including any prespecified hypotheses	222	Thus this study aimed to compare cervical spine kinematics and muscle recruitment patterns of selected cervical and thoracic spinal muscles during active cervical ROM in participants with and without neck pain. It was hypothesised that those with neck pain would differ from the healthy controls in cervical spine kinematics and/or cervicothoracic muscle recruitment patterns.
Methods				

Study design	4	Present key elements of study design early in the paper	222	
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	222	Chiropractic clinic on a university campus; November 2022 and August 2023
Participants	6	(a) <i>Cohort study</i>—Give the eligibility criteria and the sources and methods of selection of participants. Describe methods of follow-up <i>Case-control study</i>—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls <i>Cross-sectional study</i>—Give the eligibility criteria, and the sources and methods of selection of participants		
		(b) <i>Cohort study</i>—For matched studies, give matching criteria and number of exposed and unexposed <i>Case-control study</i>—For matched studies, give matching criteria and the number of controls per case	222-223	See section participants
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable		See Data processing and analysis
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	223-225	See <i>measurement tools</i>
Bias	9	Describe any efforts to address potential sources of bias		An independent person collected the data
Study size	10	Explain how the study size was arrived at	223	See sampling
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	227-228	See Data processing and analysis
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	229	See Data processing and analysis

		(b) Describe any methods used to examine subgroups and interactions		
		(c) Explain how missing data were addressed	229	There were no missing data
		(d) <i>Cohort study</i> —If applicable, explain how loss to follow-up was addressed	222	
		<i>Case-control study</i> —If applicable, explain how the matching of cases and controls was addressed		
		<i>Cross-sectional study</i> —If applicable, describe analytical methods taking account of the sampling strategy		
		(e) Describe any sensitivity analyses		
Results				
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	229-230	A total of 46 participants joined the study, 23 in each group.
		(b) Give reasons for non-participation at each stage		N/A
		(c) Consider use of a flow diagram		
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	230	Table 5.2:
		(b) Indicate number of participants with missing data for each variable of interest	231-236	Results
		(c) <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)		N/A
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time		N/A
		<i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure	233+237	See figures 5.3-5.11
		<i>Cross-sectional study</i> —Report numbers of outcome events or summary measures		N/A

Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	229-236	Results
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses		na
Discussion				
Key results	18	Summarise key results with reference to study objectives	236-241	Discussion section
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	241	Strengths and limitations section
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	243	Conclusion
Generalisability	21	Discuss the generalisability (external validity) of the study results	236-241	Discussion
Other information				
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	243	Funding section

APPENDIX U: LETTER OF INFORMATION AND INFORM CONSET FOR CHAPTER SEVEN AND EIGHT (RCT)



LETTER OF INFORMATION (RCT)

Dear Sir/Madam

Thank you for taking the time to respond to the advert for this research study. This letter aims to provide you with the necessary details for you to make an informed decision about partaking in this research project. Please read through it carefully and should you require clarification please ask.

Title of the Research Study: Cervical spinal manipulation for neck pain - effect on muscle recruitment patterns, spinal kinematics, pain and disability in participants in KwaZulu-Natal

Principal researcher: Dr L. O'Connor M. Tech: Chiropractic

Supervisor/s: Prof J. Pillay PhD: Physiology

Prof B. Murphy PhD

Brief Introduction and Purpose of the Study:

This study is investigating the effect that a common treatment for back and neck pain - spinal manipulation - has on spinal motion, muscle recruitment patterns (the way in which your body recruits different muscles during movement), pain and disability in people with neck pain. In order to investigate this people with neck pain will be treated with cervical spinal manipulation to see how the manipulation alters your body's ability to recruit muscles when moving your arm. This study will contribute the literature in terms of our understanding of how spinal manipulation begins about its therapeutic effect.

Outline of the Procedures:

This study requires volunteers between the ages of 18 and 50, with neck pain will be required to be diagnosed by the researcher as being non-specific in nature and of a duration greater than three months. Participants must not have had spinal surgery, serve trauma, sensory or vestibular deficits, bony abnormalities, deformities of the trunk, be suffering from rheumatic disease, experience problems with their temporomandibular joint or has a pacemaker.

Once meeting these criteria there are various forms that require completion. These forms document your health status, pain and disability. Once complete this study requires that you change into tight fitting clothes (leggings/cycling shorts and a tight vest/sports bra). The electrodes and reflected markers will then be placed on your skin. The electrodes will record muscle activity, via surface electromyography which is a machine which is able to detect the electrical activity that your muscles produce. The reflective markers allow for the capture of motion of the body parts.

In order to ensure good contact the area will need to be cleaned with alcohol and lightly abraded. If you are particularly hairy in these areas they may be shaved with a disposable razor. Once the electrodes are placed you will be required to perform a maximum contraction of each of the involved muscles (this means contracting the muscle as hard as possible against resistance). This will occur three times. Following this you will be required to perform the two tasks while the surface electromyography machine records your muscle activity. On completion you will be allocated to one of two treatment groups. There will be a 50% chance of receiving either the control or intervention. Henna will be utilized to mark the exact location of the electrode placement so that each when the electrodes will be used again they are placed in the right position. Following the initial conducting of the functional task – this entails sitting and moving an object from a desk to a shelf then standing and placing the same object from a desk onto a shelf. Following the task you will then receive the treatment and will thereafter have to complete the functional tasks again. This should take approximately an additional one hour and 45 minutes. You will be required to return to the clinic for an additional three treatments within the next two weeks. Should you be unable to commit to this you will be excluded from partaking in this phase of the project. Should you be available you will then receive the necessary treatment (each treatment will take approximately 15 minutes) and on the fourth treatment a final set of measurements will be taken (this session will take approximately 45 minutes). Thereafter you will no longer be required to

come to the clinic for treatment. The researcher/research assistant will telephone you in one week to ask you about your neck pain. Thereafter your involvement in the study will be complete.

During the study you are requested to refrain from changing your normal habits i.e. exercise, work and activities. You will be required to document all pain and non-steroidal anti-inflammatory medication you take.

Risks or Discomforts to the Participant: The procedures used in this study are commonly utilized. Following cervical spinal manipulation you may experience mild discomfort which may last 24 hours. This can be managed by having a shower and letting the warm water run over the area.

Benefits: The results of this study will contribute to our understanding of how spinal manipulation brings about its therapeutic effect. In addition all participants with neck pain will receive cervical spinal manipulation as a treatment either during the study or after (a total of four treatments), depending which group you are allocated to.

Reason/s why the Participant May Be Withdrawn from the Study: Should you become ill during the study or develop pain in the trunk or arm or if you are non-compliant with the treatment schedule you will be withdrawn from the study. You are also free to withdraw from the study at any time, without any adverse consequence for you.

Remuneration: There is no monetary remuneration for you partaking in this study. However all treatments administered will be free of charge.

Costs of the Study: There is no cost to you to partake in this study, except your travelling cost to the DUT chiropractic clinic.

Confidentiality: All your personal information will be kept confidential. When reporting the results of this study coding will be used to ensure that your name is not associated with any of the reported research results.

Research-related Injury: Should you sustain an injury while being enrolled in this study please advise the researcher immediately.

COVID-19 precautions: All necessary precautions to prevent the transmission of COVID-19 will be put in place. The research equipment will be sanitized before and after each visit. Masks will be worn at

all times and you will be screened on arrival at the chiropractic clinic for symptoms of COVID-19. Should you display any symptoms of COVID-19 please let the researcher know via telephone. Do not come to the clinic but seek medical attention.

Persons to Contact in the Event of Any Problems or Queries:

Please contact the researcher on 031 373 2923/lauraw@dut.ac.za or the supervisor Prof Pillay on 031 373 2398/ julianp@dut.ac.za. Alternatively the Institutional Research Ethics Administrator can be contacted on 031 373 2375. Complaints can be reported to the DVC: Research, Innovation and Engagement Prof Moyo on 031 373 2576 or moyos@dut.ac.za



Statement of Agreement to Participate in the Research Study:

- I hereby confirm that I have been informed by the researcher, Laura O'Connor/representative of, about the nature, conduct, benefits and risks of this study - Research Ethics Clearance Number: IREC 017/20,
- I have also received, read and understood the above written information (Participant Letter of Information) regarding the study.
- I am aware that the results of the study, including personal details regarding my sex, age, date of birth, initials and diagnosis will be anonymously processed into a study report.
- In view of the requirements of research, I agree that the data collected during this study can be processed in a computerised system by the researcher.
- I may, at any stage, without prejudice, withdraw my consent and participation in the study.
- I have had sufficient opportunity to ask questions and (of my own free will) declare myself prepared to participate in the study.
- I understand that significant new findings developed during the course of this research which may relate to my participation will be made available to me.

Full Name of Participant	Date	Time	Signature/Right Thumbprint
---------------------------------	-------------	-------------	-----------------------------------

I, Laura O'Connor/representative of herewith confirm that the above participant has been fully informed about the nature, conduct and risks of the above study.

Laura O'Connor

_____	_____	_____
Full Name of Researcher	Date	Signature

_____	_____	_____
Full Name of Witness (If applicable)	Date	Signature

APPENDIX V: CLINICAL TRIAL REGISTRATION

Pan African Clinical Trials Registry

South African Medical Research Council, South African Cochrane Centre
PO Box 19070, Tygerberg, 7505, South Africa
Telephone: +27 21 938 0506 / +27 21 938 0834 Fax: +27 21 938 0836
Email: pactradmin@mrc.ac.za Website: pactr.samrc.ac.za

Trial no.:	PACTR202006491989074	Date of Approval:	18/06/2020
Trial Status:	Registered in accordance with WHO and ICMJE standards		
TRIAL DESCRIPTION			
Public title	Cervical spinal manipulation for neck pain - effect on muscle recruitment patterns, spinal kinematics, pain and disability in participants in KwaZulu-Natal		
Official scientific title	Cervical spinal manipulation for neck pain - effect on muscle recruitment patterns, spinal kinematics, pain and disability in participants in KwaZulu-Natal		
Brief summary describing the background and objectives of the trial	Spinal manipulation (SMT) is a commonly used therapeutic modality in the treatment of neck and back pain. In the context of this research, SMT is the application of a high velocity, low amplitude thrust applied to the joint/s of the spine to induce healing, resulting in decreased pain and disability. Although well utilised, the specific mechanism through which it exerts its reported clinical effects are not well understood. Patients with neck pain (NP) patients have been shown to have altered cervico-thoracic kinematic and muscle activity patterns during a sitting functional task (Tsang, Szeto and Lee, 2014) when compared to healthy controls. The particular task investigated is more often performed in a standing position. By changing the task from sitting to standing, the motor recruitment and the cervical and thoracic spine kinematic pattern may be altered. This requires further investigation. In addition it is not clear if the application of cervical SMT in NP patients would alter the cervico-thoracic kinematic and muscle activity patterns observed during this functional task and if these changes are associated with changes in pain and disability. Thus this study aims to determine the effect of cervical spine manipulation compared to a control intervention in participants with non-specific neck pain in terms of both objective and subjective measures: Objective measures: - Cervical spine range of motion (ROM), - Cervico-thoracic muscle recruitment patterns (timing onset relative to phase of movement and percentage activation), and - Kinematics for the cervical and thoracic spine (angular displacement, velocity and acceleration) during two functional tasks. Subjective measures: - Pain, - Disability, and - Global impression of change - Level of satisfaction		
Type of trial	RCT		
Acronym (If the trial has an acronym then please provide)			
Disease(s) or condition(s) being studied	Musculoskeletal Diseases		
Sub-Disease(s) or condition(s) being studied			
Purpose of the trial	Treatment: Other		

APPENDIX W: CONSORT CHECKLIST FOR MANUSCRIPT FIVE



CONSORT 2010 checklist of information to include when reporting a randomised trial*

Section/Topic	Item No	Checklist item	Reported on page No
Title and abstract			
	1a	Identification as a randomised trial in the title	261
	1b	Structured summary of trial design, methods, results, and conclusions (for specific guidance see CONSORT for abstracts)	262-263
Introduction			
Background and objectives	2a	Scientific background and explanation of rationale	264-267
	2b	Specific objectives or hypotheses	267
Methods			
Trial design	3a	Description of trial design (such as parallel, factorial) including allocation ratio	267
	3b	Important changes to methods after trial commencement (such as eligibility criteria), with reasons	n/a
Participants	4a	Eligibility criteria for participants	268
	4b	Settings and locations where the data were collected	268
Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were actually administered	274,276
Outcomes	6a	Completely defined pre-specified primary and secondary outcome measures, including how and when they were assessed	270-273
	6b	Any changes to trial outcomes after the trial commenced, with reasons	n/a
Sample size	7a	How sample size was determined	268
	7b	When applicable, explanation of any interim analyses and stopping guidelines	n/a
Randomisation:			
	8a	Method used to generate the random allocation sequence	268,270

Sequence generation	8b	Type of randomisation; details of any restriction (such as blocking and block size)	268,270
Allocation concealment mechanism	9	Mechanism used to implement the random allocation sequence (such as sequentially numbered containers), describing any steps taken to conceal the sequence until interventions were assigned	268,270
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions	268,270
Blinding	11a	If done, who was blinded after assignment to interventions (for example, participants, care providers, those assessing outcomes) and how	271
	11b	If relevant, description of the similarity of interventions	276
Statistical methods	12a	Statistical methods used to compare groups for primary and secondary outcomes	277-278
	12b	Methods for additional analyses, such as subgroup analyses and adjusted analyses	277-278
Results			
Participant flow (a diagram is strongly recommended)	13a	For each group, the numbers of participants who were randomly assigned, received intended treatment, and were analysed for the primary outcome	269
	13b	For each group, losses and exclusions after randomisation, together with reasons	269
Recruitment	14a	Dates defining the periods of recruitment and follow-up	268
	14b	Why the trial ended or was stopped	na
Baseline data	15	A table showing baseline demographic and clinical characteristics for each group	279
Numbers analysed	16	For each group, number of participants (denominator) included in each analysis and whether the analysis was by original assigned groups	269

Outcomes and estimation	17 a	For each primary and secondary outcome, results for each group, and the estimated effect size and its precision (such as 95% confidence interval)	280-289 + suppl material
	17 b	For binary outcomes, presentation of both absolute and relative effect sizes is recommended	280-289 + suppl material
Ancillary analyses	18	Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing pre-specified from exploratory	280-289 + suppl material
Harms	19	All important harms or unintended effects in each group (for specific guidance see CONSORT for harms)	289
Discussion			
Limitations	20	Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses	295
Generalisability	21	Generalisability (external validity, applicability) of the trial findings	289-294
Interpretation	22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence	289-294
Other information			
Registration	23	Registration number and name of trial registry	267
Protocol	24	Where the full trial protocol can be accessed, if available	267
Funding	25	Sources of funding and other support (such as supply of drugs), role of funders	296

Citation: Schulz KF, Altman DG, Moher D, for the CONSORT Group. CONSORT 2010 Statement: updated guidelines for reporting parallel group randomised trials. BMC Medicine. 2010;8:18.

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*We strongly recommend reading this statement in conjunction with the CONSORT 2010 Explanation and Elaboration for important clarifications on all the items. If relevant, we also recommend reading CONSORT extensions for cluster randomised trials, non-inferiority and equivalence trials, non-pharmacological treatments, herbal interventions, and pragmatic trials. Additional extensions are forthcoming: for those and for up-to-date references relevant to this checklist, see www.consort-statement.org.

APPENDIX X: PATIENT GLOBAL IMPRESSION OF CHANGE SCALE (PGICS)

Patients' Global Impression of Change (PGIC) scale.

Name: _____ Date: _____ DOB: _____

Chief Complaint: _____

Since beginning treatment at this clinic, how would you describe the change (if any) in
ACTIVITY LIMITATIONS, SYMPTOMS, EMOTIONS and OVERALL QUALITY OF LIFE,
related to your painful condition? (tick ONE box).

- | | |
|--|----------------------------|
| No change (or condition has got worse) | ☐ 1 |
| Almost the same, hardly any change at all | ☐ 2 |
| A little better, but no noticeable change | ☐ 3 |
| Somewhat better, but the change has not made any real difference | ☐ 4 |
| Moderately better, and a slight but noticeable change | ☐ 5 |
| Better, and a definite improvement that has made a real and worthwhile difference | ☐ 6 |
| A great deal better, and a considerable improvement that has made all the difference | ☐ 7 |

In a similar way, please circle the number below, that matches your degree of change since
beginning care at this clinic:

Much Better	No Change										Much Worse
0	1	2	3	4	5	6	7	8	9	10	

APPENDIX Y: LEVEL OF SATISFACTION

Name: _____

File number: _____

Please answer the following questions related to the treatment you received while taking part in this research project:

1.1 For each row select one option from the columns that most describes the change, if any since beginning treatment at this facility for neck pain?

Item:	No change/got worse (1)	Almost the same, hardly any change at all (2)	A little better, but no noticeable change (3)	Somewhat better, but the change has not made any real difference (4)	Moderately better, and a slight but noticeable change (5)	Better and a definite improvement that has made a real and worthwhile difference (6)	A great deal better and a considerable improvement that has made all the difference (7)
Ability to be active							
Symptom character							
Emotions							
Overall quality of life							

1.2 Were you satisfied with the change in your neck pain?

Not at all satisfied	Moderately dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	Moderately satisfied	Extremely satisfied
----------------------	-------------------------	-----------------------	---------	--------------------	----------------------	---------------------

1.3 How likely are you to choose chiropractic care for a similar problem in the future?

Very unlikely	Unlikely	Neutral	Likely	Very likely
---------------	----------	---------	--------	-------------

1.4 How likely are you to choose spinal manipulation for a similar problem in the future?

Very unlikely	Unlikely	Neutral	Likely	Very likely
---------------	----------	---------	--------	-------------

1.5 How likely would you return for care at this facility?

Very unlikely	Unlikely	Neutral	Likely	Very likely
---------------	----------	---------	--------	-------------

APPENDIX Z: CONSORT CHECKLIST FOR MANUSCRIPT SIX



CONSORT 2010 checklist of information to include when reporting a randomised trial*

Section/Topic	Item No	Checklist item	Reported on page No
Title and abstract			
	1a	Identification as a randomised trial in the title	319
	1b	Structured summary of trial design, methods, results, and conclusions (for specific guidance see CONSORT for abstracts)	320-321
Introduction			
Background and objectives	2a	Scientific background and explanation of rationale	321-325
	2b	Specific objectives or hypotheses	325
Methods			
Trial design	3a	Description of trial design (such as parallel, factorial) including allocation ratio	325
	3b	Important changes to methods after trial commencement (such as eligibility criteria), with reasons	325-326
Participants	4a	Eligibility criteria for participants	325-326
	4b	Settings and locations where the data were collected	325
Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were actually administered	332-333
Outcomes	6a	Completely defined pre-specified primary and secondary outcome measures, including how and when they were assessed	326,329-331
	6b	Any changes to trial outcomes after the trial commenced, with reasons	n/a
Sample size	7a	How sample size was determined	326
	7b	When applicable, explanation of any interim analyses and stopping guidelines	n/a
Randomisation:			
	8a	Method used to generate the random allocation sequence	326

Sequence generation	8b	Type of randomisation; details of any restriction (such as blocking and block size)	326
Allocation concealment mechanism	9	Mechanism used to implement the random allocation sequence (such as sequentially numbered containers), describing any steps taken to conceal the sequence until interventions were assigned	326
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions	326
Blinding	11a	If done, who was blinded after assignment to interventions (for example, participants, care providers, those assessing outcomes) and how	332
	11b	If relevant, description of the similarity of interventions	334
Statistical methods	12a	Statistical methods used to compare groups for primary and secondary outcomes	333-336
	12b	Methods for additional analyses, such as subgroup analyses and adjusted analyses	
Results			
Participant flow (a diagram is strongly recommended)	13a	For each group, the numbers of participants who were randomly assigned, received intended treatment, and were analysed for the primary outcome	328
	13b	For each group, losses and exclusions after randomisation, together with reasons	328
Recruitment	14a	Dates defining the periods of recruitment and follow-up	325
	14b	Why the trial ended or was stopped	n/a
Baseline data	15	A table showing baseline demographic and clinical characteristics for each group	337-338
Numbers analysed	16	For each group, number of participants (denominator) included in each analysis and whether the analysis was by original assigned groups	328

Outcomes and estimation	17 a	For each primary and secondary outcome, results for each group, and the estimated effect size and its precision (such as 95% confidence interval)	338-350+suppl material
	17 b	For binary outcomes, presentation of both absolute and relative effect sizes is recommended	338-350+suppl material
Ancillary analyses	18	Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing pre-specified from exploratory	338-350+suppl material
Harms	19	All important harms or unintended effects in each group (for specific guidance see CONSORT for harms)	350
Discussion			
Limitations	20	Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses	335
Generalisability	21	Generalisability (external validity, applicability) of the trial findings	350-355
Interpretation	22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence	356
Other information			
Registration	23	Registration number and name of trial registry	325
Protocol	24	Where the full trial protocol can be accessed, if available	325
Funding	25	Sources of funding and other support (such as supply of drugs), role of funders	356

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*We strongly recommend reading this statement in conjunction with the CONSORT 2010 Explanation and Elaboration for important clarifications on all the items. If relevant, we also recommend reading CONSORT extensions for cluster randomised trials, non-inferiority and equivalence trials, non-pharmacological treatments, herbal interventions, and pragmatic trials. Additional extensions are forthcoming: for those and for up-to-date references relevant to this checklist, see www.consort-statement.org.

SUPPLEMENTARY MATERIALS

SUPPLEMENTARY FILE 3.1: LITERATURE SEARCH STRATEGY USED EXCLUDING PUBMED

Database	Search strategy
Scopus	neck pain* OR cervicalgia* OR cervicodynia* OR cervical pain* AND spinal manipulative OR spinal adjustment OR chiropractic OR chiropractic adjustment OR cervical manipulation OR high-velocity low amplitude OR manual therapy OR thrust OR spinal manipulation OR chiropractic manipulation OR orthopedic manipulation OR Musculoskeletal Manipulations OR Osteopathic Manipulation AND kinesiology OR kinematic* OR motor control OR biomechanical phenomena OR head movement OR spinal movement OR motor pattern OR movement coordination OR range of motion OR motor variability OR muscle activity OR muscle recruitment OR muscle recruitment pattern OR muscle pattern OR myoelectric* OR neuromuscular function OR spinal reflex OR muscle function OR electromyograph* OR neural responses OR reflex responses OR neurophysiolog*
Web of Science	“neck pain” OR cervicalgia OR cervicodynia OR “cervical pain”) AND “spinal manipulative” OR “spinal adjustment” OR chiropractic OR “chiropractic adjustment” OR “cervical manipulation” OR “high-velocity low-amplitude” OR “manual therapy” OR thrust OR “spinal manipulation” OR “chiropractic manipulation” OR “orthopedic manipulation” OR "Musculoskeletal Manipulations" OR " Osteopathic Manipulation" AND kinesiology OR kinematic* OR “motor control” OR “biomechanical phenomena” OR “head movement” OR “spinal movement” OR “motor pattern” OR “movement coordination” OR “range of motion” OR “motor variability” OR “muscle activity” OR “muscle recruitment” OR “muscle recruitment pattern” OR “muscle pattern” OR myoelectric* OR “neuromuscular function” OR “spinal reflex” OR “muscle function” OR electromyograph* OR “neural responses” OR “reflex responses” OR neurophysiolog*
CINHAL	“neck pain*” OR cervicalgia* OR cervicodynia* OR “cervical pain*” AND “spinal manipulative” OR “spinal adjustment” OR chiropractic OR “chiropractic adjustment” OR “cervical manipulation” OR “high-velocity low-amplitude” OR “manual therapy” OR thrust OR “spinal manipulation” OR “chiropractic manipulation” OR “orthopedic manipulation” OR "Musculoskeletal Manipulations" OR " Osteopathic Manipulation" AND kinesiology OR kinematic* OR “motor control” OR “biomechanical phenomena” OR “head movement” OR “spinal movement” OR “motor pattern” OR “movement coordination” OR “range of motion” OR “motor variability” OR “muscle activity” OR “muscle recruitment” OR “muscle recruitment pattern” OR “muscle pattern” OR myoelectric* OR “neuromuscular function” OR “spinal reflex” OR “muscle function” OR electromyograph* OR “neural responses” OR “reflex responses” OR neurophysiolog*
ClinicalTrial s.gov	“neck pain*” OR cervicalgia* OR cervicodynia* OR “cervical pain*” OR “spinal manipulation” OR “spinal manipulative” OR “spinal adjustment” OR “chiropractic” OR “chiropractic adjustment” OR “cervical manipulation” OR “chiropractic manipulation” OR “high-velocity low-amplitude” OR “manual therapy” OR “osteopathic manipulation
ISRCTN Register	Neck pain or cervical pain AND manual therapy OR spinal manipulation OR manipulation OR adjustment OR high-velocity low-amplitude
Cochrane Central Register for	“neck pain” OR cervicalgia OR cervicodynia OR “cervical pain” in Title Abstract Keyword AND “spinal manipulation” OR “spinal manipulative” OR “spinal adjustment” OR “chiropractic adjustment” OR “cervical manipulation” OR “chiropractic

Controlled Trials	manipulation" OR "high-velocity low-amplitude" OR "manual therapy" OR "osteopathic manipulation" in Title Abstract Keyword AND kinesiology OR kinematic OR "motor control" OR "biomechanical phenomena" OR "head movement" OR "spinal movement" OR "motor pattern" OR "movement coordination" OR "range of motion" OR "motor variability" OR "muscle activity" OR "muscle recruitment" OR "muscle recruitment pattern" OR "muscle pattern" OR myoelectric OR "neuromuscular function" OR "spinal reflex" OR "muscle function" OR electromyography OR "neural responses" OR "reflex responses" OR neurophysiology
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SUPPLEMENTARY FILE 3.2: LIST OF EXCLUDED TRIALS

Study	Reason for exclusion
Gorrell, L.M., Conway, P.J., Onasch, F. and Herzog, W. 2022. Electromyographic responses of neck, back, and limb outlet muscles associated with high-velocity, low-amplitude manual cervical and upper thoracic spinal manipulation of individuals with mild neck disability: a descriptive observational investigation. <i>Journal of Manipulative and Physiological Therapeutics</i> , 45(1):33-44. doi: 10.1016/j.jmpt.2022.03.018.	No comparative group
Smith, D.L., Dainoff, M.J. and Smith, J.P. 2006. The effect of chiropractic adjustments on movement time: a pilot study using Fitts Law. <i>Journal of Manipulative and Physiological Therapeutics</i> , 29(4):257-66. doi: 10.1016/j.jmpt.2006.03.009. PMID: 16690379.(Smith, Dainoff and Smith 2006)	No spinal kinematic or muscle activity outcome
Palmgren, P.J., Sandström, P.J., Lundqvist, F.J. and Heikkilä, H. 2006. Improvement after chiropractic care in cervicocephalic kinesthetic sensibility and subjective pain intensity in patients with nontraumatic chronic neck pain. <i>Journal of Manipulative and Physiological Therapeutics</i> , 29(2):100-6. doi: 10.1016/j.jmpt.2005.12.002.	No spinal kinematic or muscle activity outcome
Saavedra-Hernández, M., Arroyo-Morales, M., Cantarero-Villanueva, I., Fernández-Lao, C., Castro-Sánchez, A.M. and Puente-dura, E.J., Fernández-de-las-Peñas, C. 2013. Short-term effects of spinal thrust joint manipulation in patients with chronic neck pain: a randomized clinical trial. <i>Clinical Rehabilitation</i> . 27(6):504-12. doi: 10.1177/0269215512464501.	No spinal kinematic or muscle activity outcome
Moodley, M. and Brantingham, J.W. 2002. The relative effectiveness of spinal manipulation and ultrasound in mechanical pain: pilot study. <i>Journal of Chiropractic Medicine</i> . 2002 Autumn;1(4):184-8. doi: 10.1016/S0899-3467(07)60034-2. PMID: 19674582; PMCID: PMC2646945.	HVLA not in isolation
Anderst, W.J., Gale, T., LeVasseur, C., Raj, S., Gongaware, K. and Schneider, M. 2018. Intervertebral kinematics of the cervical spine before, during, and after high-velocity low-amplitude manipulation. <i>The Spine Journal</i> , 18(12): 2333 - 2342	No comparative group
Bautista-Aguirre, F., Oliva-Pascual-Vaca, A., Heredia-Rizo, A.M., Boscá-Gandía, J.J., Ricard, F. and Rodríguez-Blanco, C. 2017. Effect of cervical vs. thoracic spinal manipulation on peripheral neural features and grip strength in subjects with chronic mechanical neck pain: a randomized controlled trial. <i>European Journal of Physical Rehabilitation and Medicine</i> , 53(3):333-341. doi: 10.23736/S1973-9087.17.04431-8.	No spinal kinematic or muscle activity outcome
Cleland, J.A., Childs, M.J.D., McRae, M., Palmer, J.A. and Stowell, T. 2005. Immediate effects of thoracic manipulation in patients with neck pain: a randomized clinical trial. <i>Manual Therapy</i> , 10(2): 127-135, ISSN 1356-689X, doi: 10.1016/j.math.2004.08.005.	No spinal kinematic or muscle activity outcome
Mansilla-Ferragut, P., Fernández-de-las Peñas, C., Alburquerque-Sendín, F., Cleland, J.A. and Boscá-Gandía, J.J. 2009. Immediate effects of atlanto-occipital joint manipulation on active mouth opening and pressure pain sensitivity in women with mechanical neck pain. <i>Journal of Manipulative and Physiological Therapeutics</i> , 32(2): 101 - 106	No spinal kinematic or muscle activity outcome
Salom-Moreno, J., Ortega-Santiago, R., Cleland, J.A., Palacios-Ceña, M., Truyols-Domínguez, S. and Fernández-de-las-Peñas, C. 2014. Immediate changes in neck pain intensity and widespread pressure pain sensitivity in patients with bilateral chronic mechanical neck pain: a randomized controlled trial of thoracic thrust manipulation vs non-thrust mobilization. <i>Journal of Manipulative and Physiological Therapeutics</i> . 2014 Jun;37(5):312-9. doi: 10.1016/j.jmpt.2014.03.003.	No spinal kinematic or muscle activity outcome

Rogers R.G. 1997. The effects of spinal manipulation on cervical kinesthesia in patients with chronic neck pain: a pilot study. <i>Journal of Manipulative and Physiological Therapeutics</i> , 20(2):80-5.	No spinal kinematic or muscle activity outcome
García-Pérez-Juana, D., Fernández-de-las-Peñas, C., Arias-Burúa, J.L., Cleland, J.A., Plaza-Manzano, G. and Ortega-Santiago, R. 2018. Changes in cervicocephalic kinesthetic sensibility, widespread pressure pain sensitivity, and neck pain after cervical thrust manipulation in patients with chronic mechanical neck pain: a randomized clinical trial. <i>Journal of Manipulative & Physiological Therapeutics</i> , 41(7): 551 – 560	No spinal kinematic or muscle activity outcome
Evans, R., Bronfort, G., Nelson, B. and Goldsmith, C.H. 2002. Two-year follow-up of a randomized clinical trial of spinal manipulation and two types of exercise for patients with chronic neck pain. <i>Spine (Phila Pa 1976)</i> , 1;27(21):2383-9. doi: 10.1097/00007632-200211010-00013.	No spinal kinematic or muscle activity outcome
Fisher, A.R., Bacon, C.J. and Mannion, J.V.H. 2014. The effect of cervical spine manipulation on postural sway in patients with nonpecific neck pain. Jan;38(1):65-73. doi: 10.1016/j.jmpt.2014.10.014. Epub 2014 Nov 18.	No spinal kinematic or muscle activity outcome
Galindez-Ibarbengoetxea, X., Setuain, I., Ramírez-Velez, R., Andersen, L.L., González-Izal, M., Jauregi, A. and Izquierdo, M. 2018. Immediate effects of osteopathic treatment versus therapeutic exercise on patients with chronic cervical pain. <i>Alternative Therapies in Health and Medicine</i> , 24(3):24-32.	HVLA not in isolation
Galindez-Ibarbengoetxea, X., Setuain, I., Ramírez-Velez, R., Andersen, L.L., González-Izal, M., Jauregi, A. and Izquierdo, M. Short-term effects of manipulative treatment versus a therapeutic home exercise protocol for chronic cervical pain: a randomized clinical trial. <i>Journal of Back and Musculoskeletal Rehabilitation</i> , 6;31(1):133-145. doi: 10.3233/BMR-169723.	HVLA not in isolation
Greenstein, J., McNamara, T., Bishop, B., Etnoyer-Slaski, J. and Topp, R. 2017. The Effect of Kinesiology Tape on Pain and Neck Range of Motion After Cervical Manipulation. <i>Journal of Performance Health Research</i> , 1(1): 18–25 DOI: 10.25036/jphr.2017.1.1.	HVLA not in isolation
Griswold, D., Learman, K., O'Halloran, B. and Cleland, J. 2015. A preliminary study comparing the use of cervical/upper thoracic mobilization and manipulation for individuals with mechanical neck pain. <i>Journal of Manual and Manipulative Therapies</i> . 23(2):75-83. doi: 10.1179/2042618614Y.00000000095.	HVLA not in isolation
Krauss, J., Creighton, D., Elym J.D. and Podlowska-Ely, J. The immediate effects of upper thoracic translocator spinal manipulation on cervical pain and range of motion: a randomized clinical trial. <i>Journal of Manual and Manipulative Therapeutics</i> . 2008;16(2):93-9. doi: 10.1179/106698108790818530. PMID: 19119394; PMCID: PMC2565124. (Krauss <i>et al.</i> 2008)	Treatment not HVLA
Lau, H., Cheung, M., Chiu, W., Tai, T. and Tai-Hing, L. 2011. The effectiveness of thoracic manipulation on patients with chronic mechanical neck pain – a randomized controlled trial. <i>Manual Therapy</i> , 16(2): 141-147 doi.org/10.1016/j.math.2010.08.003	HVLA not in isolation
Branney, J., Breen, A.C. 2014. Does inter-vertebral range of motion increase after spinal manipulation? A prospective cohort study. <i>Chiropractic and Manual Therapies</i> , 1;22:24. doi: 10.1186/s12998-014-0024-9.	HVLA not in isolation
Leaver, A.M., Maher, C.G., Herbert, R.D., Latimer, J., McAuley, J.H., Jull, G. and Refshauge, K.M. 2010. A randomized controlled trial comparing manipulation with mobilization for recent onset neck pain. <i>Archives of Physical Medicine and Rehabilitation</i> , 91(9):1313-8. doi: 10.1016/j.apmr.2010.06.006.	No spinal kinematic or muscle activity outcome

Strunk, R.G. and Hondras, M.A. 2008. A feasibility study assessing manual therapies to different regions of the spine for patients with subacute or chronic neck pain. <i>Journal of Chiropractic Medicine</i> , 7(1):1-8. doi: 10.1016/j.jcme.2007.10.004.	No spinal kinematic or muscle activity outcome
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SUPPLEMENTARY FILE 3.3: MEASUREMENT TOOLS AND RANGES OF MOTION ASSESSED IN THE INCLUDED TRIALS (N=17)

Variable	n(%)	Method
Tool utilised:		
	1(6)	Video-photogrammetry (Kinescan-IBV, Valencia, Spain) (Serra-Añó <i>et al.</i> 2023)
	15(88)	CROM measuring device (Cassidy, Lopes and Yong-Hing 1993; Pikula 1999; Martínez-Segura <i>et al.</i> 2006; Saayman, Hay and Abrahamse 2011; Dunning <i>et al.</i> 2012; Saavedra-Hernández <i>et al.</i> 2012; Suvarnnato <i>et al.</i> 2013; Izquierdo Pérez <i>et al.</i> 2014; Lopez-Lopez <i>et al.</i> 2015; Puntumetakul <i>et al.</i> 2015; Valera-Calero <i>et al.</i> 2019; Aki <i>et al.</i> 2020; Joshi, Balthillaya and Neelapala 2020; Brück, Jacobi and Schmidt 2021; Erdem <i>et al.</i> 2021; Akgüller, Coşkun and Analay Akbaba 2023; Serra-Añó <i>et al.</i> 2023)
	1(6)	CROM measuring device while performing the flexion rotation test (Dunning <i>et al.</i> 2012)
Ranges of motion assessed:		
	10(59)	Flexion, extension, left and right lateral flexion and rotation (Martínez-Segura <i>et al.</i> 2006; Saavedra-Hernández <i>et al.</i> 2012; Suvarnnato <i>et al.</i> 2013; Puntumetakul <i>et al.</i> 2015; Valera-Calero <i>et al.</i> 2019; Joshi, Balthillaya and Neelapala 2020; Brück, Jacobi and Schmidt 2021; Erdem <i>et al.</i> 2021; Akgüller, Coşkun and Analay Akbaba 2023; Serra-Añó <i>et al.</i> 2023)
	2(12)	Flexion, extension, ipsilateral and contra-lateral were used for lateral flexion and rotation, relative to the side that was treated (Cassidy, Lopes and Yong-Hing 1993; Pikula 1999)
	2(12)	Flexion, extension, combined left and right lateral flexion and rotation (Saayman, Hay and Abrahamse 2011)
	2(12)	Flexion-extension, left-right lateral flexion, and left-right rotation (Izquierdo Pérez <i>et al.</i> 2014; Lopez-Lopez <i>et al.</i> 2015)
	1(5)	Passive left and right rotation (Dunning <i>et al.</i> 2012)

**SUPPLEMENTARY FILE 5.1: COMPARISON OF MUSCLE ACTIVATION BETWEEN THOSE WITH
AND WITHOUT NECK PAIN DURING FLEXION/EXTENSION CROM**

Mvt Direction	Muscle activity	NP				NNP				p value	NP				NNP				p value
		n	Mdn	25	IQR 75	n	Mdn	25	IQR 75		n	Mdn	25	IQR 75	n	Mdn	25	IQR 75	
LAS Flexion											RAS Flexion								
Away	Peak	23	26.2	14.6	43.5	23	24.3	12.8	39.4	0.546	23	20.4	15.6	27.1	23	19.5	9.0	39.3	0.818
	Mean	23	11.7	9.1	20.9	23	11.6	7.4	23.4	0.869	23	10.6	7.5	12.3	23	10.7	6.2	20.3	0.410
	Time %	23	66.9	45.4	89.3	23	70.3	33.3	86.2	0.834	23	66.7	43.2	89.7	23	65.9	26.1	99.2	0.921
Return	Peak	23	20.2	10.8	41.6	23	21.8	10.8	39.3	0.991	23	16.6	9.2	32.6	23	18.4	8.3	53.0	0.784
	Mean	23	11.8	8.3	18.7	23	13.6	8.1	22.5	0.684	23	8.7	5.5	16.2	23	8.9	5.7	29.9	0.637
	Time %	23	69.4	29.1	98.7	23	82.9	26.7	100.0	0.458	23	85.5	36.2	98.2	23	99.2	9.9	100.0	0.577
LAS Extension											LAS Extension								
Away	Peak	23	13.8	7.7	24.0	23	19.0	12.2	30.7	0.199	23	12.4	6.2	24.4	23	19.4	5.9	26.3	0.767
	Mean	23	8.7	5.0	13.3	23	12.2	7.3	20.2	0.223	23	6.6	5.0	14.0	23	8.9	4.3	16.5	0.921
	Time %	23	72.4	0.9	97.2	23	64.0	17.2	100.0	0.707	23	79.5	63.6	98.4	23	94.7	0.0	100.0	0.911
Return	Peak	23	24.7	15.0	58.6	23	38.5	32.0	54.7	0.093	23	21.4	10.7	36.1	23	24.8	16.8	44.2	0.503
	Mean	23	16.6	11.2	32.0	23	22.6	20.0	34.4	0.24	23	15.0	8.0	24.3	23	15.5	8.9	28.1	0.517
	Time %	23	90.1	66.4	100.0	23	89.7	66.7	100.0	0.831	23	90.3	66.7	99.6	23	96.1	49.4	100.0	0.973
LPC Flexion											RPC Flexion								
Away	Peak	22	7.8	7.0	15.9	22	9.1	5.9	16.6	0.869	23	8.4	4.6	14.1	23	10.9	5.1	17.9	0.423
	Mean	22	5.6	4.4	9.6	22	5.9	3.8	10.7	1	23	5.5	3.2	8.9	23	6.6	3.4	12.1	0.339
	Time %	22	46.2	6.8	68.8	22	43.1	13.3	69.8	0.742	23	36.5	0.0	66.9	23	38.7	24.9	72.1	0.428
Return	Peak	22	28.6	18.0	43.6	22	31.6	19.7	55.0	0.639	23	38.4	19.3	51.7	23	32.5	23.9	53.9	0.733
	Mean	22	17.7	12.6	23.3	22	17.7	12.0	40.8	0.557	23	18.8	12.0	32.0	23	19.8	12.7	41.1	0.339

	Time %	22	96.9	79.2	100.0	22	99.1	72.5	100.0	0.677	23	87.4	61.3	100.0	23	100.0	63.4	100.0	0.146
LPC Extension										RPC Extension									
Away	Peak	22	27.6	11.7	38.7	22	26.4	17.6	38.2	0.925	23	27.7	12.2	41.8	23	33.5	18.4	47.4	0.318
	Mean	22	13.7	8.8	17.5	22	14.1	8.1	21.8	0.557	23	12.6	6.1	20.5	23	16.4	7.4	25.8	0.258
	Time %	22	69.3	51.1	92.0	22	100.0	67.2	100.0	0.026	23	66.7	47.7	95.4	23	99.6	58.7	100.0	0.05
Return	Peak	22	7.5	4.4	10.9	22	8.6	4.2	16.7	0.425	23	6.5	5.0	10.0	23	8.3	4.7	20.4	0.215
	Mean	22	4.3	2.6	6.1	22	5.2	3.3	9.8	0.231	23	4.2	3.0	5.9	23	5.6	3.6	12.9	0.085
	Time %	22	15.2	5.5	51.5	22	38.5	1.5	94.4	0.358	23	17.9	0.0	58.6	23	52.4	10.7	73.8	0.188
LT4 Flexion										RT4 Flexion									
Away	Peak	23	10.8	6.1	14.4	23	15.4	9.3	25.2	0.116	23	5.2	4.5	9.9	23	7.5	5.3	13.3	0.106
	Mean	23	8.5	4.4	12.6	23	11.8	7.6	20.5	0.085	23	4.1	3.3	7.4	23	5.5	3.7	10.2	0.15
	Time %	23	100.0	100.0	100.0	23	100.0	98.9	100.0	0.157	23	100.0	66.7	100.0	23	100.0	97.1	100.0	0.183
Return	Peak	23	11.8	8.2	17.5	23	19.0	11.6	28.6	0.067	23	6.9	5.9	10.9	23	7.7	5.7	13.7	0.575
	Mean	23	9.9	6.7	14.3	23	14.8	8.8	22.8	0.132	23	5.5	4.3	8.3	23	5.9	3.9	11.4	0.475
	Time %	23	100.0	100.0	100.0	23	100.0	100.0	100.0	0.165	23	100.0	100.0	100.0	23	100.0	100.0	100.0	0.868
LT4 Extension										RT4 Extension									
Away	Peak	23	9.7	6.9	18.8	23	17.7	10.1	27.9	0.097	23	5.8	4.6	7.8	23	7.1	4.1	18.4	0.41
	Mean	23	7.7	4.6	14.5	23	12.5	8.0	24.0	0.093	23	4.2	3.2	5.6	23	5.2	3.0	13.3	0.277
	Time %	23	100.0	100.0	100.0	23	100.0	88.2	100.0	0.3	23	98.6	53.1	100.0	23	100.0	96.9	100.0	0.094
Return	Peak	23	8.8	4.6	17.8	23	16.0	7.9	28.6	0.063	23	4.9	3.9	8.2	23	7.0	4.4	13.8	0.199
	Mean	23	7.1	3.3	14.2	23	11.7	6.6	21.1	0.081	23	3.8	2.8	6.6	23	5.1	3.2	10.7	0.267
	Time %	23	100.0	93.4	100.0	23	100.0	79.6	100.0	0.406	23	100.0	33.9	100.0	23	100.0	96.3	100.0	0.2
LSCM Flexion										RSCM Flexion									
Away	Peak	23	18.6	9.5	28.8	23	14.7	9.3	24.3	0.423	23	17.2	12.2	28.2	23	20.2	10.1	31.5	0.852
	Mean	23	6.4	5.0	17.1	23	7.8	4.0	15.6	0.835	23	8.5	5.4	12.1	23	10.4	5.2	18.5	0.374

Return	Time %	23	71.5	48.7	95.6	23	70.1	18.6	86.6	0.198	23	71.2	33.9	87.8	23	78.2	31.2	90.7	0.684
	Peak	23	14.6	5.4	30.8	23	11.5	6.8	18.6	0.701	23	13.0	8.4	22.9	23	15.4	8.9	34.7	0.621
	Mean	23	7.5	4.0	11.0	23	6.8	4.3	13.2	0.974	23	7.7	5.4	13.2	23	9.3	5.3	20.5	0.462
	Time %	23	92.8	28.0	100.0	23	100.0	42.4	100.0	0.696	23	99.2	9.4	100.0	23	97.1	59.5	100.0	0.617
LSCM Extension										RSCM Extension									
Away	Peak	23	10.7	4.4	16.5	23	7.8	3.2	22.9	0.818	23	8.8	5.6	18.3	23	12.6	6.9	20.9	0.621
	Mean	23	5.5	3.2	8.1	23	5.7	2.9	11.7	0.886	23	6.5	3.7	10.8	23	7.2	3.9	12.0	0.59
	Time %	23	76.3	18.5	97.7	23	88.6	43.4	100.0	0.191	23	75.4	64.8	100.0	23	97.3	41.1	100.0	0.415
Return	Peak	23	24.6	12.9	42.5	23	20.0	11.9	34.6	0.684	23	25.8	12.6	44.9	23	25.2	15.0	37.6	0.921
	Mean	23	14.2	7.9	23.1	23	12.3	7.7	22.9	0.531	23	14.4	9.2	21.0	23	16.9	8.6	20.3	0.717
	Time %	23	95.8	75.3	100.0	23	94.2	89.2	100.0	0.535	23	87.3	74.0	100.0	23	91.1	77.5	100.0	0.697
LUT Flexion										RUT Flexion									
Away	Peak	22	4.6	1.8	15.2	22	3.9	1.3	12.7	0.398	23	2.6	1.4	9.0	23	2.4	1.3	6.3	0.575
	Mean	22	3.7	1.3	11.0	22	2.6	1.1	9.4	0.425	23	1.8	1.1	7.0	23	1.6	1.0	4.9	0.668
	Time %	22	26.4	0.0	78.1	22	12.2	0.0	69.6	0.632	23	6.2	0.0	71.6	23	6.6	0.0	53.5	0.973
Return	Peak	22	6.1	2.6	12.1	22	4.3	1.5	8.4	0.159	23	4.2	1.6	10.2	23	3.2	1.7	8.3	0.869
	Mean	22	4.1	2.0	9.3	22	3.5	1.2	5.9	0.231	23	2.8	1.3	7.7	23	2.4	1.3	6.7	0.835
	Time %	22	63.6	0.0	99.7	22	21.2	0.0	97.3	0.45	23	10.6	0.0	98.2	23	17.6	0.0	83.3	0.955
LUT Extension										RUT Extension									
Away	Peak	22	4.0	1.8	13.6	22	4.1	1.6	8.9	0.481	23	2.2	1.5	8.8	23	2.6	2.0	7.6	0.684
	Mean	22	3.1	1.3	8.5	22	3.4	1.2	7.2	0.606	23	1.6	1.2	6.7	23	1.7	1.2	5.6	0.818
	Time %	22	31.7	3.6	78.6	22	4.0	0.0	96.5	0.329	23	5.1	0.0	85.0	23	2.3	0.0	95.7	0.982
Return	Peak	22	4.2	1.7	10.9	22	3.2	1.8	10.3	0.511	23	2.8	1.2	7.6	23	2.7	1.1	6.5	0.75
	Mean	22	3.0	1.4	8.9	22	2.5	1.1	5.5	0.372	23	2.0	0.9	5.9	23	1.8	0.9	4.0	0.767
	Time %	22	4.8	0.0	82.1	22	6.7	0.0	53.5	0.865	23	4.8	0.0	85.7	23	0.0	0.0	89.3	0.713
LT9 Flexion										RT9 Flexion									

Away	Peak	23	25.5	19.3	32.2	23	26.7	16.9	39.3	0.852	23	30.1	14.2	37.9	23	27.1	14.3	33.6	0.207
	Mean	23	20.0	16.2	26.0	23	21.9	11.6	34.6	0.869	23	23.9	11.1	30.1	23	18.8	12.0	24.9	0.116
	Time %	23	100.0	100.0	100.0	23	100.0	73.3	100.0	0.073	23	100.0	100.0	100.0	23	100.0	86.8	100.0	0.241
Return	Peak	23	25.8	17.4	35.0	23	26.8	20.4	41.7	0.575	23	30.7	13.0	40.7	23	24.3	15.7	38.5	0.448
	Mean	23	21.2	15.2	28.1	23	21.9	15.7	32.5	0.475	23	26.5	10.9	32.1	23	18.6	11.7	30.3	0.386
	Time %	23	100.0	100.0	100.0	23	100.0	97.8	100.0	0.11	23	100.0	100.0	100.0	23	100.0	99.4	100.0	0.826
LT9 Extension										RT9 Extension									
Away	Peak	23	19.0	15.4	29.1	23	25.9	15.6	39.4	0.177	23	24.6	15.9	32.7	23	19.2	11.7	31.7	0.249
	Mean	23	15.1	10.1	24.0	23	21.0	11.5	30.0	0.156	23	18.3	10.0	26.4	23	15.2	8.6	26.4	0.517
	Time %	23	100.0	95.8	100.0	23	100.0	73.2	100.0	0.885	23	99.7	70.7	100.0	23	100.0	70.1	100.0	0.814
Return	Peak	23	20.8	16.1	28.2	23	21.9	13.0	35.0	0.956	23	25.0	14.4	30.7	23	16.5	12.2	28.4	0.184
	Mean	23	15.8	13.2	22.1	23	14.7	8.4	27.8	0.974	23	19.8	9.0	23.0	23	12.5	7.6	21.1	0.215
	Time %	23	100.0	79.6	100.0	23	100.0	16.0	100.0	0.636	23	94.0	66.5	100.0	23	97.4	38.5	100.0	0.991

(NP – neck pain; NNP – no neck pain; mvt – movement; % – percentage; IQR – interquartile range; mdn – median; n – sample, LAS – left anterior scalene; RAS – right anterior scalene; LPC – left posterior cervical; RPC – right posterior cervical; LSCM – left sternocleidomastoid; RSCM – right sternocleidomastoid; LUT – left upper trapezius; RUT – right upper trapezius; LT4 – left paraspinal at T4; RT4 – right paraspinal at T4; LT9 – left paraspinal at T9; RT9 – right paraspinal at T9)

SUPPLEMENTARY FILE 5.2: COMPARISON OF MUSCLE ACTIVATION BETWEEN THOSE WITH AND WITHOUT NECK PAIN DURING LATERAL FLEXION CROM

Mvt Direction	Muscle activity	Neck pain				No neck pain				p value	Neck pain				No neck pain				p value
		n	Mdn	IQR		n	Mdn	IQR			n	Mdn	IQR		n	Mdn	IQR		
				25	75			25.0	75.0				25	75			25	75	
LAS right lateral flexion										LAS left lateral flexion									
Away	Peak	23	10.1	5.9	18.0	23	9.2	5.7	22.1	0.717	23	33.2	20.5	50.3	23	45.1	31.3	57.5	0.121
	Mean	23	5.1	3.5	8.7	23	5.1	3.7	10.7	0.852	23	18.2	12.3	29.4	23	25.3	15.2	33.6	0.089
	Time %	23	9.2	0.0	54.6	23	14.7	0.0	47.1	0.833	23	90.1	61.0	98.3	23	87.7	56.6	100.0	0.947
Return	Peak	23	31.2	17.8	44.3	23	26.8	21.0	45.9	0.818	23	20.7	14.7	49.4	23	33.2	18.3	49.5	0.41
	Mean	23	20.7	10.6	26.1	23	15.7	14.2	30.2	0.904	23	11.8	6.7	23.0	23	16.2	9.2	25.9	0.475
	Time %	23	67.6	48.0	100.0	23	83.8	42.6	100.0	0.973	23	63.1	32.7	99.0	23	78.1	23.4	100.0	0.732
RAS right lateral flexion										RAS left lateral flexion									
Away	Peak	23	30.7	20.3	49.5	23	46.9	29.0	62.6	0.111	23	6.3	3.1	10.4	23	8.2	5.0	11.4	0.24
	Mean	23	20.7	9.9	30.6	23	21.4	14.9	33.7	0.267	23	3.9	2.3	5.8	23	4.7	3.2	7.8	0.215
	Time %	23	100.0	95.6	100.0	23	100.0	67.9	100.0	0.33	23	46.8	6.6	91.9	23	13.1	0.0	76.5	0.336
Return	Peak	23	19.7	9.5	44.2	23	32.5	14.7	53.7	0.374	23	19.5	14.3	30.6	23	23.7	13.9	36.8	0.575
	Mean	23	10.5	6.0	19.0	23	13.5	5.3	21.9	0.684	23	12.5	9.0	17.4	23	12.9	7.7	23.1	0.575
	Time %	23	86.3	64.4	100.0	23	57.1	17.9	100.0	0.159	23	97.9	71.7	100.0	23	88.2	36.7	100.0	0.206
LPC right lateral flexion										LPC left lateral flexion									
Away	Peak	21	12.1	9.8	17.1	21	12.2	6.3	18.8	0.792	21	18.7	14.4	25.7	21	15.1	12.6	27.1	0.624
	Mean	21	8.1	6.4	10.4	21	8.8	4.2	12.4	0.990	21	12.8	8.5	16.6	21	10.9	7.1	15.9	0.624
	Time %	21	73.5	15.9	100.0	21	62.8	25.9	93.0	0.771	21	89.8	59.0	100.0	21	84.6	69.0	100.0	0.71
Return	Peak	21	16.8	10.5	23.2	21	15.7	7.6	24.3	0.538	21	14.5	10.0	23.5	21	13.4	10.9	20.8	0.89
	Mean	21	11.5	7.3	17.9	21	11.3	6.3	15.8	0.642	21	9.9	6.6	15.6	21	9.6	7.0	13.5	0.94

	Time %	21	94.8	47.1	100.0	21	95.3	73.5	100.0	0.836	21	73.8	38.4	100.0	21	82.0	50.7	100.0	0.365
RPC right lateral flexion										RPC left lateral flexion									
Away	Peak	23	20.0	12.0	23.3	23	22.1	11.5	30.9	0.215	23	12.6	5.1	17.5	23	10.9	7.1	21.7	0.249
	Mean	23	12.6	8.4	17.1	23	16.0	7.0	18.7	0.475	23	8.8	3.6	10.6	23	7.7	5.3	13.2	0.267
	Time %	23	100.0	53.9	100.0	23	98.8	89.2	100.0	0.796	23	34.4	0.0	91.3	23	62.9	26.2	88.9	0.39
Return	Peak	23	13.6	7.9	18.8	23	15.5	8.3	25.8	0.374	23	15.2	10.1	20.5	23	17.2	10.9	27.9	0.215
	Mean	23	8.2	5.3	11.0	23	9.2	5.9	20.1	0.374	23	11.2	5.9	14.8	23	11.4	7.9	22.3	0.297
	Time %	23	61.1	33.3	96.3	23	80.8	49.5	100.0	0.34	23	100.0	35.7	100.0	23	100.0	91.8	100.0	0.29
LT4 right lateral flexion										LT4 left lateral flexion									
Away	Peak	23	7.4	5.7	13.8	23	16.6	7.3	22.5	0.03	23	7.9	5.3	17.9	23	14.3	7.6	22.0	0.085
	Mean	23	6.1	4.8	12.5	23	13.1	6.1	16.2	0.073	23	6.0	4.0	13.1	23	11.3	6.6	16.9	0.047
	Time %	23	100.0	100.0	100.0	23	100.0	83.7	100.0	0.016	23	100.0	100.0	100.0	23	100.0	74.6	100.0	0.165
Return	Peak	23	7.3	6.2	13.3	23	15.5	7.5	20.5	0.049	23	7.5	5.7	14.2	23	13.5	7.1	22.0	0.089
	Mean	23	6.0	4.9	11.9	23	11.8	5.4	17.9	0.063	23	6.6	4.6	12.3	23	11.1	6.1	19.6	0.085
	Time %	23	100.0	100.0	100.0	23	100.0	90.0	100.0	0.394	23	100.0	100.0	100.0	23	100.0	81.5	100.0	0.117
RT4 right lateral flexion										RT4 left lateral flexion									
Away	Peak	23	5.2	3.5	8.8	23	4.9	3.6	11.2	0.939	23	5.0	3.4	6.9	23	5.8	3.4	9.4	0.637
	Mean	23	4.1	2.9	7.2	23	4.0	3.1	8.2	0.818	23	4.0	2.8	5.8	23	4.4	2.6	7.6	0.75
	Time %	23	100.0	31.6	100.0	23	100.0	61.9	100.0	0.943	23	100.0	29.9	100.0	23	100.0	57.0	100.0	0.731
Return	Peak	23	5.4	3.5	6.6	23	4.7	4.0	10.4	0.801	23	4.6	3.5	7.4	23	5.1	4.0	8.8	0.621
	Mean	23	4.2	2.9	5.7	23	3.8	3.1	8.0	0.939	23	4.0	3.0	5.4	23	4.2	3.0	7.8	0.56
	Time %	23	100.0	34.4	100.0	23	100.0	34.2	100.0	0.822	23	100.0	61.1	100.0	23	100.0	67.8	100.0	0.635
LSCM right lateral flexion										LSCM left lateral flexion									
Away	Peak	23	5.6	2.6	8.7	23	6.0	3.3	20.2	0.362	23	44.2	23.7	55.5	23	47.8	19.1	63.1	0.974
	Mean	23	2.7	2.0	3.7	23	4.9	2.0	9.3	0.163	23	23.9	9.8	33.2	23	21.4	9.2	37.5	0.886
	Time %	23	8.0	0.0	81.8	23	13.5	3.4	56.4	0.626	23	93.1	83.2	100.0	23	85.8	70.8	100.0	0.307

Return	Peak	23	29.9	20.2	36.4	23	18.4	9.6	37.1	0.138	23	24.3	5.3	65.7	23	25.9	14.3	50.1	0.717
	Mean	23	15.9	9.4	23.5	23	9.8	5.2	22.1	0.144	23	10.6	3.8	31.0	23	11.4	6.8	18.6	0.784
	Time %	23	100.0	67.9	100.0	23	93.7	60.7	100.0	0.341	23	84.3	43.5	100.0	23	58.8	12.8	100.0	0.313
RSCM right lateral flexion										RSCM left lateral flexion									
Away	Peak	23	49.5	29.6	62.5	23	56.9	32.9	73.4	0.258	23	4.5	2.9	9.6	23	7.3	4.5	14.7	0.127
	Mean	23	28.8	18.6	35.1	23	31.6	18.3	43.8	0.606	23	3.0	2.1	5.3	23	5.1	2.8	8.7	0.097
	Time %	23	100.0	91.9	100.0	23	100.0	###	100.0	0.417	23	14.0	0.0	70.3	23	31.2	5.5	79.7	0.438
Return	Peak	23	38.1	15.5	52.8	23	34.0	21.8	45.9	0.75	23	27.2	19.6	40.8	23	25.0	13.0	46.9	0.575
	Mean	23	14.0	7.2	24.9	23	13.5	8.0	21.6	0.991	23	15.5	8.1	25.9	23	12.9	6.8	26.4	0.637
	Time %	23	83.6	28.7	100.0	23	79.9	41.4	100.0	0.894	23	100.0	63.8	100.0	23	97.8	78.9	100.0	0.88
LUT right lateral flexion										LUT left lateral flexion									
Away	Peak	22	10.5	2.6	21.9	22	4.5	1.4	14.4	0.116	22	10.7	3.3	24.7	22	6.8	3.5	21.7	0.496
	Mean	22	6.7	1.3	15.3	22	3.0	1.1	9.3	0.159	22	7.8	2.2	16.0	22	3.7	2.2	14.1	0.372
	Time %	22	43.3	0.8	97.3	22	25.2	0.0	92.7	0.592	22	75.0	9.3	97.5	22	62.9	0.0	100.0	0.721
Return	Peak	22	6.9	3.5	13.6	22	4.6	1.9	10.0	0.348	22	13.3	3.6	24.3	22	5.8	3.3	20.0	0.222
	Mean	22	4.0	2.5	10.7	22	2.9	1.3	7.9	0.348	22	11.1	2.5	16.1	22	4.3	2.0	16.5	0.336
	Time %	22	55.3	0.0	98.6	22	40.2	0.0	99.7	0.8	22	45.7	1.8	100.0	22	72.3	0.0	100.0	0.828
RUT right lateral flexion										RUT left lateral flexion									
Away	Peak	23	4.1	1.9	21.8	23	5.8	2.3	10.2	0.974	23	3.5	1.1	14.9	23	2.9	1.5	7.6	0.701
	Mean	23	2.8	1.4	14.2	23	3.4	1.5	6.2	0.869	23	2.1	0.8	10.4	23	1.9	0.9	6.2	0.818
	Time %	23	33.3	7.8	75.7	23	23.1	0.0	100.0	0.797	23	8.1	0.0	65.2	23	11.6	0.0	66.7	0.919
Return	Peak	23	6.1	1.6	21.2	23	4.7	2.5	8.5	0.939	23	3.1	1.8	8.1	23	2.7	1.8	5.7	0.362
	Mean	23	4.5	1.2	16.3	23	3.2	1.8	6.9	0.921	23	2.1	1.2	5.1	23	1.6	1.1	4.4	0.287
	Time %	23	33.3	0.0	92.8	23	27.5	0.0	100.0	0.814	23	23.1	0.0	64.9	23	13.6	0.0	70.0	0.865
LT9 right lateral flexion										LT9 left lateral flexion									
Away	Peak	23	21.2	16.5	28.5	23	20.7	13.0	37.3	0.818	23	16.7	12.9	25.9	23	20.0	11.9	32.7	0.974

Return	Mean	23	17.6	13.9	24.6	23	16.1	10.9	30.5	0.652	23	14.8	8.7	21.6	23	15.3	9.9	25.6	0.904
	Time %	23	100. 0	100. 0	100.0	23	100.0	30.4	100. 0	0.042	23	100. 0	97.7	100.0	23	100. 0	19.4	100.0	0.251
	Peak	23	21.0	18.0	31.9	23	21.5	13.1	36.4	0.668	23	15.4	11.4	24.3	23	15.1	10.5	31.1	0.991
	Mean	23	17.1	15.5	25.1	23	17.1	10.7	29.2	0.41	23	13.2	8.4	18.9	23	10.5	9.4	27.4	0.869
	Time %	23	100. 0	100. 0	100.0	23	100.0	83.5	100. 0	0.026	23	100. 0	77.3	100.0	23	100. 0	2.9	100.0	0.284
RT9 right lateral flexion										RT9 left lateral flexion									
Away	Peak	23	22.5	13.6	28.5	23	17.6	10.7	23.3	0.184	23	30.7	16.5	36.1	23	17.7	14.2	25.8	0.036
	Mean	23	16.7	6.9	23.2	23	12.2	8.4	19.0	0.223	23	23.4	13.6	28.4	23	14.2	10.5	19.4	0.047
	Time %	23	100. 0	64.1	100.0	23	100.0	43.2	100. 0	0.649	23	100. 0	97.7	100.0	23	100. 0	46.5	100.0	0.341
Return	Peak	23	19.1	11.0	29.2	23	14.4	10.6	23.4	0.223	23	30.7	17.3	38.5	23	19.4	13.7	28.5	0.081
	Mean	23	14.8	6.8	23.5	23	12.2	8.5	18.8	0.318	23	23.9	12.7	31.1	23	15.8	11.1	23.5	0.063
	Time %	23	100. 0	47.3	100.0	23	100.0	18.8	100. 0	0.803	23	100. 0	100. 0	100.0	23	100. 0	75.5	100.0	0.541

(NP – neck pain; NNP – no neck pain; mvt – movement; % - percentage; IQR – interquartile range; mdn – median; n – sample, LAS – left anterior scalene; RAS – right anterior scalene; LPC – left posterior cervical; RPC – right posterior cervical; LSCM – left sternocleidomastoid; RSCM – right sternocleidomastoid; LUT – left upper trapezius; RUT – right upper trapezius; LT4 – left paraspinal at T4; RT4 – right paraspinal at T4; LT9 – left paraspinal at T9; RT9 - right paraspinal at T9)

SUPPLEMENTARY FILE 5.3: COMPARISON OF MUSCLE ACTIVATION BETWEEN THOSE WITH AND WITHOUT NECK PAIN DURING ROTATION CROM

Mvt direction	Muscle activity	Neck pain				No neck pain				p value	Neck pain				No neck pain				p value
		n	Mdn	IQR		n	Mdn	IQR			n	Mdn	IQR		n	Mdn	IQR		
				25	75			25	75				25	75			25	75	
LAS right rotation										LAS left rotation									
Away	Peak	23	17.4	9.8	29.1	23	25.5	17.5	39.1	0.049	23	15.8	9.9	26.5	23	17.3	10.1	27.4	0.668
	Mean	23	9.1	6.0	17.1	23	14.1	10.2	17.5	0.111	23	9.6	6.0	16.9	23	9.8	7.8	12.6	0.733
	Time %	23	66.3	23.4	92.8	23	64.1	23.7	99.1	0.851	23	75.2	15.8	92.8	23	59.0	15.0	87.6	0.628
Return	Peak	23	24.3	10.2	34.3	23	26.6	15.7	42.3	0.215	23	13.3	8.7	27.3	23	14.2	6.8	18.3	0.503
	Mean	23	16.5	7.5	20.0	23	17.0	9.3	34.7	0.297	23	8.4	6.5	20.8	23	8.7	5.1	12.2	0.575
	Time %	23	92.4	56.6	100.0	23	85.0	32.4	100.0	0.779	23	62.4	6.1	84.0	23	60.6	0.0	100.0	0.851
RAS right rotation										RAS left rotation									
Away	Peak	23	13.2	8.1	19.9	23	14.2	8.6	26.3	0.35	23	15.9	7.4	20.1	23	16.4	9.2	31.2	0.59
	Mean	23	8.2	5.4	10.6	23	9.9	5.8	15.9	0.132	23	8.1	5.5	11.5	23	9.6	6.3	16.4	0.362
	Time %	23	81.5	46.3	100.0	23	86.0	10.1	100.0	0.689	23	89.1	47.0	99.4	23	73.7	17.1	100.0	0.61
Return	Peak	23	13.0	5.6	16.4	23	12.4	6.7	18.6	0.801	23	17.4	11.2	33.5	23	19.5	9.2	29.5	0.733
	Mean	23	7.1	4.0	11.8	23	7.2	3.9	12.8	0.869	23	10.0	7.6	22.5	23	12.9	5.8	19.6	0.869
	Time %	23	71.8	20.7	100.0	23	57.4	0.0	100.0	0.52	23	100.0	65.5	100.0	23	86.3	22.2	100.0	0.136
PLC right rotation										LPC left rotation									
Away	Peak	21	21.5	13.9	31.7	21	21.1	13.4	33.8	0.93	21	47.3	37.7	65.0	21	46.9	21.0	74.7	0.697
	Mean	21	11.5	8.3	18.0	21	14.4	8.3	20.7	0.505	21	25.3	19.5	31.0	21	27.0	14.1	43.7	0.93

Return	Time %	21	94.7	68.3	100.0	21	100.0	78.5	100.0	0.402	21	95.4	88.8	100.0	21	97.4	88.1	100.0	0.866
	Peak	21	25.0	13.8	34.9	21	19.3	16.7	35.8	0.97	21	49.9	28.3	75.2	21	47.6	16.7	73.3	0.473
	Mean	21	14.9	8.5	26.6	21	14.9	12.1	23.3	0.85	21	25.5	13.7	44.0	21	23.0	10.2	41.8	0.538
	Time %	21	100.0	72.0	100.0	21	100.0	91.6	100.0	0.472	21	97.4	74.7	100.0	21	100.0	97.4	100.0	0.143
PRC right rotation										RPC left rotation									
Away	Peak	23	57.8	33.7	70.1	23	62.7	47.2	73.2	0.733	23	17.3	13.4	25.0	23	16.3	11.1	26.6	0.939
	Mean	23	30.5	19.7	41.2	23	38.5	24.7	49.6	0.089	23	9.0	7.4	11.8	23	9.4	7.5	17.3	0.41
	Time %	23	100.0	97.9	100.0	23	100.0	100.0	100.0	0.349	23	79.9	34.8	97.3	23	70.1	60.1	96.7	0.725
Return	Peak	23	56.5	29.0	70.2	23	50.1	26.3	76.2	0.852	23	25.4	15.1	31.0	23	20.8	16.6	32.1	0.974
	Mean	23	24.4	16.4	38.7	23	24.1	12.9	51.2	0.818	23	13.1	11.8	22.2	23	16.1	10.0	24.9	0.921
	Time %	23	96.2	84.7	100.0	23	99.4	80.6	100.0	0.758	23	100.0	75.0	100.0	23	100.0	82.3	100.0	0.58
LT4 right rotation										LT4 left rotation									
Away	Peak	23	12.7	5.4	19.4	23	15.7	7.3	21.6	0.41	23	12.1	5.4	24.1	23	14.0	9.2	22.5	0.35
	Mean	23	7.4	4.8	15.5	23	11.5	6.5	16.3	0.287	23	7.5	4.3	11.9	23	11.0	7.0	18.0	0.163
	Time %	23	100.0	100.0	100.0	23	100.0	77.6	100.0	0.062	23	100.0	100.0	100.0	23	100.0	83.6	100.0	0.191
Return	Peak	23	8.7	6.2	19.1	23	14.5	6.8	22.1	0.328	23	11.5	5.8	26.7	23	12.5	6.4	21.7	0.904
	Mean	23	7.7	5.3	15.1	23	12.1	5.9	18.6	0.297	23	9.5	4.2	21.0	23	11.0	5.1	17.9	0.668
	Time %	23	100.0	100.0	100.0	23	100.0	87.9	100.0	0.185	23	100.0	100.0	100.0	23	100.0	54.0	100.0	0.081
RT4 right rotation										RT4 left rotation									
Away	Peak	23	5.9	3.5	9.9	23	6.1	3.9	10.4	0.668	23	5.5	4.2	9.0	23	6.0	3.8	10.9	0.801
	Mean	23	4.0	3.0	7.6	23	4.6	3.2	8.1	0.701	23	4.1	3.3	7.4	23	4.6	2.9	8.3	0.991
	Time %	23	100.0	69.0	100.0	23	100.0	68.8	100.0	0.787	23	100.0	68.2	100.0	23	100.0	84.4	100.0	0.913
Return	Peak	23	5.9	3.7	11.5	23	6.2	3.1	10.1	0.701	23	4.6	3.9	11.4	23	5.6	3.8	9.6	0.956
	Mean	23	5.1	3.1	9.8	23	5.0	2.4	8.3	0.784	23	3.9	3.1	8.5	23	4.7	3.3	8.5	0.652

	Time %	23	100.0	92.0	100.0	23	100.0	76.5	100.0	0.826	23	100.0	69.1	100.0	23	100.0	82.5	100.0	0.903
LSCM right rotation										LSCM left rotation									
Away	Peak	23	54.4	27.1	77.5	23	49.2	38.6	71.3	0.921	23	9.3	5.9	17.1	23	10.3	5.9	20.6	0.818
	Mean	23	19.6	11.2	38.7	23	22.6	12.9	31.3	0.869	23	5.5	3.4	10.0	23	5.4	3.2	11.4	0.701
	Time %	23	93.7	68.7	100.0	23	81.2	69.9	98.0	0.414	23	74.4	26.2	100.0	23	69.8	1.3	91.9	0.433
Return	Peak	23	67.2	22.9	77.8	23	36.5	27.9	75.9	0.869	23	9.3	5.1	23.7	23	7.7	5.2	10.0	0.144
	Mean	23	25.5	14.6	39.0	23	21.0	13.8	33.6	0.531	23	5.3	3.8	11.7	23	4.4	2.8	7.1	0.191
	Time %	23	100.0	86.2	100.0	23	95.7	77.1	100.0	0.534	23	78.7	33.5	100.0	23	67.4	5.2	95.9	0.277
RSCM right rotation										RSCM left rotation									
Away	Peak	23	11.7	7.0	21.9	23	14.9	10.2	27.3	0.41	23	44.3	19.4	69.0	23	44.2	29.5	69.9	0.637
	Mean	23	6.3	4.7	10.8	23	7.9	5.0	15.2	0.24	23	19.6	8.2	33.0	23	23.5	11.9	36.7	0.475
	Time %	23	91.8	42.8	100.0	23	98.9	73.2	100.0	0.399	23	89.9	54.3	100.0	23	95.4	80.8	100.0	0.456
Return	Peak	23	10.4	6.6	19.3	23	10.1	6.0	17.3	0.448	23	41.2	22.2	72.9	23	41.0	18.0	72.8	0.991
	Mean	23	6.8	3.9	12.6	23	7.7	3.9	10.6	0.818	23	20.9	13.4	38.8	23	22.9	12.0	32.5	0.886
	Time %	23	80.8	15.8	100.0	23	82.2	6.7	100.0	0.956	23	100.0	77.0	100.0	23	99.5	81.1	100.0	0.675
LUT right rotation										LUT left rotation									
Away	Peak	22	9.6	4.4	26.1	22	8.4	4.3	17.7	0.656	22	6.9	3.1	15.1	22	4.5	2.3	8.6	0.197
	Mean	22	5.7	3.0	17.1	22	5.7	3.4	10.6	0.778	22	3.6	2.0	9.9	22	2.7	1.6	5.4	0.213
	Time %	22	49.4	2.3	100.0	22	61.5	4.1	92.9	0.934	22	22.6	0.0	90.7	22	10.3	0.0	93.0	0.792
Return	Peak	22	7.8	2.1	15.9	22	4.9	2.4	10.3	0.372	22	6.3	3.4	15.5	22	4.6	3.1	7.7	0.313
	Mean	22	5.2	1.6	12.8	22	4.1	1.5	8.1	0.348	22	3.8	2.0	11.2	22	3.3	1.8	4.7	0.453
	Time %	22	15.8	0.0	92.3	22	44.5	0.0	97.3	0.565	22	21.9	0.0	85.6	22	29.3	0.0	81.8	0.962
RUT right rotation										RUT left rotation									
Away	Peak	23	4.3	2.7	9.9	23	3.7	2.1	7.9	0.852	23	4.9	2.0	13.5	23	5.4	1.6	9.9	0.462
	Mean	23	2.4	1.7	4.7	23	2.5	1.3	4.5	0.835	23	3.0	1.3	10.5	23	3.4	1.2	6.9	0.606

Return	Time %	23	18.6	0.0	62.3	23	26.5	0.0	82.7	0.79	23	32.6	0.0	77.7	23	21.1	0.0	93.5	0.947
	Peak	23	4.0	1.8	9.4	23	3.4	1.9	6.1	0.398	23	3.4	2.1	11.0	23	3.5	1.8	8.6	0.637
	Mean	23	1.7	1.3	4.9	23	2.8	1.3	4.1	0.637	23	2.7	1.4	8.9	23	2.7	1.3	7.2	0.59
	Time %	23	7.3	0.0	81.5	23	18.0	0.0	74.3	0.973	23	9.3	0.0	100.0	23	35.0	0.0	89.5	0.604
LT9 right rotation										LT9 left rotation									
Away	Peak	23	20.5	16.8	29.9	23	21.2	13.0	31.3	0.652	23	19.4	15.5	27.8	23	23.0	11.5	28.9	0.818
	Mean	23	17.2	12.7	24.5	23	17.4	10.6	26.4	0.801	23	14.6	11.3	20.6	23	16.8	9.1	24.2	0.835
	Time %	23	100.0	100.0	100.0	23	100.0	15.9	100.0	0.041	23	100.0	98.0	100.0	23	100.0	9.9	100.0	0.148
Return	Peak	23	20.6	16.7	29.5	23	20.0	12.8	31.2	0.517	23	18.8	12.6	27.5	23	17.2	10.7	26.8	0.398
	Mean	23	17.0	14.8	24.4	23	17.2	10.2	26.0	0.546	23	17.0	10.8	24.9	23	13.7	9.1	23.9	0.398
	Time %	23	100.0	100.0	100.0	23	100.0	48.2	100.0	0.002	23	100.0	99.4	100.0	23	100.0	12.4	100.0	0.215
RT9 right rotation										RT9 left rotation									
Away	Peak	23	24.3	15.9	28.5	23	15.1	9.3	24.2	0.093	23	28.1	18.7	34.5	23	15.9	10.7	26.2	0.04
	Mean	23	20.0	13.2	23.6	23	12.1	7.4	20.8	0.093	23	22.0	15.0	25.7	23	13.0	9.2	19.6	0.04
	Time %	23	100.0	83.5	100.0	23	100.0	16.6	100.0	0.319	23	100.0	96.7	100.0	23	100.0	27.9	100.0	0.159
Return	Peak	23	22.6	13.2	31.2	23	13.2	9.2	23.7	0.07	23	27.7	16.6	33.9	23	16.3	10.8	23.5	0.023
	Mean	23	18.0	11.7	26.6	23	11.6	8.0	20.0	0.102	23	23.7	12.6	27.2	23	14.2	9.6	21.1	0.026
	Time %	23	100.0	94.9	100.0	23	100.0	24.9	100.0	0.362	23	100.0	100.0	100.0	23	100.0	63.2	100.0	0.297

(NP – neck pain; NNP – no neck pain; mvt – movement; % - percentage; IQR – interquartile range; mdn – median; n – sample, LAS – left anterior scalene; RAS – right anterior scalene; LPC – left posterior cervical; RPC – right posterior cervical; LSCM – left sternocleidomastoid; RSCM – right sternocleidomastoid; LUT – left upper trapezius; RUT – right upper trapezius; LT4 – left paraspinal at T4; RT4 – right paraspinal at T4; LT9 – left paraspinal at T9; RT9 – right paraspinal at T9)

**SUPPLEMENTARY FILE 6.1: MUSCLE ACTIVATION TIME
PERCENTAGE (%) DURING THE LIFTING AND LOWERING
PHASES OF THE BILATERAL ARM TASK**

Muscle	Lifting					Lowering				
	NP		NNP		<i>p</i> value	NP		NNP		<i>p</i> value
	Mdn	IQR	Mdn	IQR		Mdn	IQR	Mdn	IQR	
LAS	99.7	9.3	100.0	8.5	0.197	100.0	9.2	100.0	2.0	0.684
RAS	100.0	2.7	100.0	8.2	0.445	100.0	0.0	100.0	10.9	0.079
LPC	100.0	0.4	100.0	0.1	0.762	100.0	12.6	100.0	1.6	0.739
RPC	100.0	2.0	100.0	2.2	0.799	100.0	15.7	100.0	5.9	0.521
LT4	100.0	0.0	100.0	0.0	1,000	100.0	0.0	100.0	0.0	1,000
RT4	100.0	0.0	100.0	0.0	0.153	100.0	0.0	100.0	0.0	1,000
LSCM	94.2	22.2	94.8	32.1	0.933	100.0	15.0	99.1	63.1	0.432
RSCM	99.7	28.1	99.5	9.0	0.784	98.8	27.7	100.0	41.0	0.673
LUT	100.0	0.8	100.0	2.2	0.641	100.0	0.3	100.0	0.2	0.853
RUT	100.0	0.0	100.0	3.3	0.443	100.0	0.6	100.0	0.0	0.617
LT9	100.0	0.0	100.0	0.0	0.409	100.0	0.3	100.0	1.6	0.621
RT9	100.0	0.0	100.0	0.0	0.740	100.0	0.3	100.0	0.0	0.617

(NP – neck pain; NNP – no neck pain; mvt – movement; mdn – median; IQR – interquartile range; LAS – left anterior scalene; RAS – right anterior scalene; LPC – left posterior cervical; RPC – right posterior cervical; LSCM – left sternocleidomastoid; RSCM – right sternocleidomastoid; LUT – left upper trapezius; RUT – right upper trapezius; LT4 – left paraspinal at T4; RT4 – right paraspinal at T4; LT9 – left paraspinal at T9; RT9 – right paraspinal at T9)

SUPPLEMENTARY FILE 7.1: MEASUREMENTS TAKEN PRE-, POST- AND AT THE FOURTH VISIT FOR DURATION AND THE CERVICAL KINEMATICS

Motion		CG						EG					
		Pre (n=20)		Post (n=20)		4th visit (n=15)		Baseline (n=19)		Post (n=19)		4th visit (n=19)	
		M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Flex													
Duration		2.1	1	1.7	0.7	1.4	0.4	1.8	0.7	1.4	0.5	1.3	0.4
Peak		41.9	6.7	42.4	6.2	39.3	8.1	39.2	9.3	38.9	8.9	38.2	8.9
Velocity	Away peak	84.1	31.1	90.7	31.1	102.6	36.2	95.7	34.3	105.8	36.2	107.6	33.6
	Return peak	93.5	33.3	98	21.7	113.2	36.8	112.1	39.5	121.2	37	122.4	39
	Away ave	39.2	12.5	42.6	10.9	47.2	16.3	43.5	14.2	50.4	15.2	52.3	15
	Return ave	60.7	20	67.4	13.6	75	23.9	74.1	28.6	79.9	24.2	81.1	23.2
Jerk	Away peak	4885.5	2921	4431	2507.5	5235.2	2999.7	4365.2	2442.9	5296.7	2448.8	5265	2015.5
	Return peak	47.5	73.6	31.3	30.2	56.2	71.9	109.1	176.1	68	59.8	111.1	105.8
	Away ave	1597.5	1033	1443.8	723.4	1692.6	843.2	1525.3	941.8	1858.7	1032.5	1889.7	829.7
	Return ave	1954.3	1847	1629.9	963.6	2273.7	1450.9	2784.6	2579.6	2787.2	1969.2	2993.9	2027.8
Ext													
Duration		2.1	1.1	1.6	0.6	1.5	0.5	1.9	0.7	1.5	0.5	1.4	0.3
Peak		39	4.9	36.9	5.7	39.9	5.7	43.7	6.1	41.9	6.5	40	9.2
Velocity	Away peak	79.1	25.8	85	22.2	102.9	32	96	29.8	106.1	33.5	106.8	39.4
	Return peak	84.9	25.9	91	27.6	105.6	27.5	105.1	34.5	112.2	38.3	112.5	34.8
	Away ave	43.3	13.2	47	11.9	55.7	16.4	50	13.9	55.7	15.5	55.3	18.9
	Return ave	50.9	14.2	56.2	14.2	57.5	14.6	65.4	21.5	70.3	24.6	68.5	22.1
Jerk	Away peak	24.9	24	30	30.9	42.2	56.4	21.6	16.3	31.8	26.8	37.5	49.3
	Return peak	4729.1	2534	4619.4	2394.3	5894.2	2684.3	4757.1	1634.1	5532.2	2057.6	6028.3	2394.4
	Away ave	1276.3	600.5	1544.8	1094.4	1901.3	981.3	1513.2	838.4	1597.3	779.6	1584.8	803.7
	Return ave	1681.3	780.7	1691.3	789.4	1997.2	821.9	1885.4	752.8	2382.9	1256.1	2438.8	1136.4

RLF													
Duration		1.6	0.6	1.3	0.5	1.2	0.4	1.5	0.4	1.4	0.4	1.2	0.3
Peak		38.2	8.6	38.2	8.1	38.3	7.3	40.9	8.4	41.5	7	39.8	7.3
Velocity	Away peak	75.1	19.4	88	20.5	95.6	18.9	94.9	32.1	98.2	31.9	107.7	32.2
	Return peak	77.5	15.8	83	14.2	97	20.8	90.9	21.6	102.2	36.5	104.8	25.5
	Away ave	41.2	11.5	46.3	10.5	49.6	9.5	46.6	11.8	49.6	14.8	55.9	14.5
	Return ave	53	10.7	58.4	11.1	66.5	11.2	64.3	16.7	69.9	23.7	71.4	16.9
Jerk	Away peak	3561	1203	3878.5	1124	4268	953.3	3973.6	1839.7	3683.6	1365.4	4196.2	1562.8
	Return peak	33.1	26.6	31.6	21	45.6	48.5	42.6	43.4	67.2	104.5	61.8	65.1
	Away ave	1321.8	515.2	1537.7	500.1	1728.7	487.4	1454.4	741.2	1472.7	610.9	1778.5	796.1
	Return ave	1479	566.9	1402.8	389.1	1854.3	775.9	1580.9	804.6	2070.3	1370	1972.7	928.6
LLF													
Duration		1.7	0.7	1.4	0.5	1.3	0.4	1.5	0.5	1.3	0.3	1.2	0.3
Peak		38.1	7.3	36.8	6.1	40.5	6.2	39	7.4	39.3	5.1	38.8	6.2
Velocity	Away peak	68.5	16.1	74.6	16.1	89.7	23.9	78.5	22.2	86.7	29.8	94.2	29.6
	Return peak	80.9	19.2	91.3	21.5	103.1	19.7	103.5	34.7	104.6	37.3	116.4	33.6
	Away ave	35.3	8.4	40.4	10.4	44.1	9.7	41	10.9	45	14.3	49.5	13.8
	Return ave	57.8	13.3	63.8	15.1	72.9	14.8	69.8	21.8	73.4	26.4	78.4	18.9
Jerk	Away peak	16.3	13.1	23.4	29.6	26.2	19.2	25.8	27.2	28.9	28.9	21.4	21
	Return peak	3336.2	884.3	3834.9	1089	4151.9	1443.1	4422.5	2336.1	4325.1	2544.1	4870.2	1965.8
	Away ave	1349.7	585.4	1395.8	495.7	1868.8	640.3	1262.3	551.2	1666.4	747.9	1811.2	1012.8
	Return ave	1370.7	513.8	1620.2	614.2	1922.6	810.1	1994.8	1172.7	1992.3	1400	2287	1139.1
Rrot													
Duration		1.8	0.8	1.5	0.5	1.4	0.4	1.7	0.6	1.4	0.4	1.3	0.3
Peak		58.4	8.4	55.5	9.7	55.3	7.7	59.5	6.4	58.2	6.9	57.9	9.7
Velocity	Away peak	157.1	49.8	157.1	46.3	180.3	49	177.9	70	201.2	70.8	198.2	65.1
	Return peak	158.3	41.7	162.2	43.4	178.3	35.9	180	59.1	194.9	55.2	198.9	53.6
	Away ave	64.9	17	67.6	18.6	77.6	18.3	73.8	29	83	28.1	80.2	26.8
	Return ave	102.2	27.3	107.1	28.1	114.5	23.4	116.8	36.2	127.4	36.2	129	33.3
Jerk	Away peak	5237	2559	4803.9	2737.7	5072.1	1756.4	5510.3	2646.8	6377.9	2923.5	5363.2	2127.4

	Return peak	97.6	87.7	82.3	64.2	107.2	84	161.6	141.4	172.9	151.9	169.5	126.1
	Away ave	1872.5	1136	1714.2	917.4	1951.1	826.8	1983.6	1108.7	2441.1	1299.4	2147.1	1169.1
	Return ave	2994.1	1524	3207.2	1367.4	3671.7	1836.1	3920.5	2328.3	4498	2473	4672.7	2657.3
Lrot													
Duration		2	0.7	1.7	0.5	1.6	0.4	1.8	0.5	1.5	0.4	1.5	0.3
Peak		64.1	8.3	64.3	9.5	64.9	7.9	64.3	7.4	66.4	9	65.2	9.9
Velocity	Away peak	139.1	40.5	145.1	39.5	163.2	33.2	157	56.8	183.4	53.3	180.3	55.8
	Return peak	171.6	51.9	182.9	48	202.8	45.2	195.7	68.7	225	67.5	217.2	64.9
	Away ave	58.7	15.4	64	14.7	74.6	17.6	66.7	24.5	78.3	23.6	74.5	19.8
	Return ave	109.8	33.5	118.6	32.8	131.3	29.2	123.1	42.9	140.9	48.3	141.6	38.2
Jerk	Away peak	20.1	19.7	20	14.1	34.1	37.2	29.9	57.3	49.1	46	30.3	35.1
	Return peak	6466.6	2892	6929.9	2834.3	7672.8	3138.8	7595.7	3310.1	9720.3	3970.4	8632.8	3874.6
	Away ave	1709.7	695.2	1648.8	536.8	2133.7	830.4	1860.4	1094.7	2447.1	1284.2	2367.2	1119.7
	Return ave	3109.5	1807	3366.4	1770.5	4138.2	2093.6	3915	2058.6	5167.2	2784.9	4869	2613.7

(CG – control group; EG – experimental group; M – mean; SD – standard deviation; ave – average; Flex – flexion; Ext – extension; LLF – left lateral flexion; RLF – right lateral flexion; Lrot – left rotation; Rrot – right rotation)

**SUPPLEMENTARY FILE 7.2: BETWEEN GROUP COMPARISON OF ADJUSTED MEANS FOR
DURATION AND CERVICAL KINEMATIC OUTCOMES FOR CHANGE FROM PRE- TO POST-
TREATMENT AT VISIT ONE**

Measure	CG		EG		MD	SE	p value	CI		η2
	M	SE	M	SE				Low	High	
Flex										
Time	1.6	0.1	1.5	0.1	0.1	0.2	0.338	-0.2	0.5	0.03
Peak	41.4	1.2	39.9	1.3	1.5	1.8	0.422	-2.2	5.1	0.02
Velocity:										
Away peak	95.8	5.2	99.6	5.6	-3.9	7.9	0.625	-19.9	12.2	0.01
Return peak	104.3	4.3	114.3	4.6	9.9	6.6	0.141	-3.5	23.4	0.06
Away ave	44.1	1.8	48.9	1.9	-4.7	2.7	0.086	-10.1	0.7	0.08
Return ave	71.6	3.0	75.4	3.2	3.9	4.6	0.405	-5.5	13.2	0.02
Jerk:										
Away peak	4340.2	446.0	5289.9	480.2	-949.7	674.8	0.168	-2321.1	421.7	0.06
Return peak	37.9	7.5	62.0	8.1	-24.1	11.5	0.044	-47.5	-0.7	0.11
Away ave	1425.1	147.7	1871.6	158.9	-446.5	222.7	0.053	-899.2	6.2	0.11
Return ave	1863.2	168.4	2573.5	181.5	-710.2	256.6	0.009	-1231.7	-188.7	0.18
Ext										
Time	1.6	0.1	1.5	0.1	0.0	0.2	0.899	-0.3	0.3	0.00
Peak	38.7	0.9	40.3	1.0	1.7	1.4	0.245	-1.2	4.6	0.04
Velocity:										
Away peak	91.7	4.9	-97.9	5.2	6.2	7.5	0.414	-9.0	21.4	0.02
Return peak	100.2	5.1	101.3	5.5	-1.1	8.0	0.891	-17.3	15.1	0.00
Away ave	49.3	2.5	53.1	2.6	3.8	3.7	0.311	-3.8	11.4	0.03
Return ave	62.7	3.1	63.0	3.4	-0.4	4.9	0.944	-10.4	9.7	0.00

Jerk:										
Away peak	29.0	4.9	31.8	5.3	-2.8	7.4	0.708	-17.8	12.2	0.00
Return peak	4751.7	422.3	5215.6	453.9	-463.9	636.1	0.471	-1756.6	828.7	0.02
Away ave	1673.6	153.5	1434.0	164.6	239.7	230.9	0.307	-229.6	708.9	0.03
Return ave	1816.4	189.5	2181.8	204.3	-365.4	288.0	0.213	-950.7	219.9	0.05
RLF										
Time	1.4	0.1	1.3	0.1	0.0	0.1	0.854	-0.2	0.2	0.00
Peak	39.7	0.7	39.8	0.7	-0.1	1.0	0.925	-2.2	2.0	0.00
Velocity:										
Away peak	95.5	3.8	89.4	4.2	6.2	6.1	0.315	-6.1	18.5	0.03
Return peak	89.6	4.3	94.2	4.7	4.6	6.8	0.500	-9.1	18.4	0.01
Away ave	47.9	1.8	47.8	2.0	0.2	2.8	0.950	-5.4	5.8	0.00
Return ave	63.5	3.1	63.8	3.4	0.3	4.9	0.950	-9.7	10.4	0.00
Jerk:										
Away peak	4008.9	237.8	3504.0	259.0	504.9	364.5	0.175	-236.7	1246.5	0.06
Return peak	34.5	14.8	62.6	16.1	-28.1	22.5	0.221	-73.9	17.7	0.05
Away ave	1574.6	99.3	1432.7	108.1	141.9	151.6	0.356	-166.6	450.3	0.03
Return ave	1389.2	190.9	2085.8	208.3	-696.7	291.2	0.023	-1289.0	-104.3	0.15
LLF										
Time	1.4	0.1	1.3	0.1	0.1	0.1	0.452	-0.1	0.3	0.02
Peak	37.5	0.6	38.6	0.7	1.2	0.9	0.200	-0.7	3.0	0.05
Velocity:										
Away peak	79.4	3.2	80.6	3.5	1.2	4.9	0.808	-8.9	11.3	0.00
Return peak	101.0	4.2	93.5	4.6	7.4	6.6	0.267	-6.0	20.9	0.04
Away ave	42.6	1.9	42.5	2.1	-0.1	2.9	0.969	-6.1	5.9	0.00
Return ave	68.3	3.4	68.4	3.7	-0.1	5.3	0.988	-10.9	10.7	0.00
Jerk:										
Away peak	23.3	6.5	29.1	7.1	-5.9	10.1	0.564	-26.4	14.6	0.01
Return peak	4170.7	399.7	3941.1	436.9	229.6	623.0	0.715	-1037.8	1497.0	0.00
Away ave	1351.8	102.0	1718.1	111.4	-366.3	155.6	0.025	-682.8	-49.8	0.14
Return ave	1800.8	224.9	1790.4	245.8	10.4	352.0	0.977	-705.7	726.5	0.00

Rrot										
Time	1.5	0.1	1.4	0.1	0.1	0.1	0.453	-0.1	0.3	0.02
Peak	56.1	0.9	57.8	1.0	-1.7	1.4	0.216	-4.5	1.1	0.05
Velocity:										
Away peak	165.7	8.8	191.3	9.5	-25.6	13.6	0.067	-53.1	1.9	0.10
Return peak	170.4	8.0	186.0	8.8	15.6	12.5	0.221	-9.8	41.0	0.04
Away ave	71.7	3.3	78.2	3.6	-6.5	5.1	0.207	-16.8	3.8	0.05
Return ave	111.9	5.2	123.2	5.6	11.3	8.0	0.168	-5.0	27.6	0.06
Jerk:										
Away peak	4967.0	474.8	6171.6	514.7	-1204.6	724.1	0.105	-2676.1	266.9	0.08
Return peak	98.4	22.8	158.7	24.9	-60.2	35.8	0.102	-132.9	12.5	0.08
Away ave	1779.1	186.6	2346.0	201.9	-566.9	283.9	0.054	-1143.8	10.0	0.11
Return ave	3509.4	341.9	4205.6	374.0	-696.2	535.7	0.203	-1784.9	392.5	0.05
Lrot										
Time	1.7	0.1	1.5	0.1	0.1	0.1	0.243	-0.1	0.3	0.04
Peak	64.6	1.0	66.0	1.1	1.4	1.5	0.369	-1.7	4.5	0.02
Velocity:										
Away peak	151.7	7.5	176.4	8.1	24.67	11.5	0.040	1.2	48.1	0.12
Return peak	192.2	8.3	215.1	9.1	-22.9	12.9	0.086	-49.1	3.4	0.08
Away ave	66.8	3.1	75.1	3.3	8.2	4.7	0.091	-1.4	17.8	0.08
Return ave	122.8	6.9	137.2	7.5	-14.3	10.6	0.187	-36.0	7.3	0.05
Jerk:										
Away peak	22.8	6.6	44.4	7.2	-21.6	10.3	0.043	-42.5	-0.7	0.12
Return peak	8189.7	603.9	8395.1	582.1	-205.4	864.7	0.814	-1973.8	1563.0	0.00
Away ave	2161.9	214.7	2449.2	205.8	-287.3	303.7	0.352	-908.5	334.0	0.03
Return ave	3669.4	384.0	4877.1	420.6	-1207.7	601.2	0.053	-2429.5	14.1	0.11

(CG – control group; EG – experimental group; M – mean; SE – standard error; MD – mean difference; CI – confidence interval; η^2 – partial eta squared; ave – average; Flex – flexion; Ext – extension; LLF – left lateral flexion; RLF – right lateral flexion; Lrot – left rotation; Rrot – right rotation)

**SUPPLEMENTARY FILE 7.3: BETWEEN GROUP COMPARISON OF ADJUSTED MEANS FOR
DURATION AND CERVICAL KINEMATIC OUTCOMES FOR CHANGE FROM PRE- TO FOURTH
VISIT**

Measure	CG		EG		MD	SE	p value	CI		η2
	M	SE	M	SE				Low	High	
Flex										
Time	1.4	0.1	1.3	0.1	0.0	0.1	0.783	-0.2	0.3	0.00
Peak	38.5	1.6	38.2	1.5	0.3	2.2	0.900	-4.3	4.8	0.00
Velocity:										
Away peak	107.4	6.2	105.7	5.9	1.6	8.8	0.855	-16.3	19.5	0.00
Return peak	119.8	6.6	118.3	6.3	-1.4	9.4	0.879	-20.6	17.8	0.08
Away ave	49.1	2.9	51.9	2.7	-2.8	4.0	0.493	-11.0	5.4	0.02
Return ave	79.0	4.7	78.6	4.5	-0.4	6.7	0.958	-14.0	13.3	0.00
Jerk:										
Away peak	4962.7	507.3	5615.7	482.6	-653.1	709.6	0.365	-2104.4	798.3	0.03
Return peak	58.3	20.4	122.0	19.4	-63.7	28.6	0.034	-122.3	-5.1	0.15
Away ave	1636.1	170.3	2002.3	161.9	-366.2	237.2	0.133	-851.4	119.0	0.08
Return ave	2346.3	418.6	3029.4	398.8	-683.1	587.0	0.254	-1883.8	517.5	0.05
Ext										
Time	1.5	0.1	1.4	0.1	0.1	0.1	0.536	-0.2	0.4	0.01
Peak	42.1	1.9	38.9	1.7	-3.2	2.7	0.247	-8.7	2.3	0.05
Velocity:										
Away peak	111.0	5.9	103.5	5.5	-7.5	8.3	0.369	-24.4	9.4	0.03
Return peak	115.6	4.7	106.0	4.4	9.6	6.7	0.164	-4.2	23.3	0.009
Away ave	57.6	3.9	54.7	3.7	-3.0	5.4	0.588	-14.1	8.1	0.01
Return ave	65.6	3.2	63.1	3.0	2.5	4.7	0.597	-7.1	12.1	0.01
Jerk:										
Away peak	40.0	13.6	39.9	13.1	0.2	19.2	0.993	-39.0	39.4	0.00
Return peak	5775.5	515.4	6045.2	489.0	-269.7	716.2	0.709	-1734.6	1195.1	0.01
Away ave	1939.3	199.6	1573.6	188.8	365.7	276.5	0.196	-199.7	931.2	0.06

Return ave	2086.6	205.9	2322.3	195.5	-235.7	287.8	0.419	-824.3	352.9	0.02
RLF										
Time	1.2	0.1	1.2	0.1	0.0	0.1	0.829	-0.2	0.2	0.00
Peak	39.7	1.2	38.7	1.2	0.9	1.7	0.586	-2.6	4.5	0.01
<i>Velocity:</i>										
Away peak	101.4	5.2	104.9	4.8	-3.5	7.3	0.636	-18.5	11.5	0.01
Return peak	100.5	5.3	103.5	4.9	3.0	7.4	0.691	-12.2	18.1	0.023
Away ave	50.7	2.6	55.8	2.4	-5.1	3.6	0.173	-12.5	2.3	0.06
Return ave	68.8	3.6	70.0	3.4	1.3	5.1	0.808	-9.3	11.8	0.00
<i>Jerk:</i>										
Away peak	4289.4	314.6	4316.7	297.1	-27.3	436.9	0.951	-921.0	866.3	0.00
Return peak	47.7	11.7	63.3	11.1	-15.6	16.3	0.346	-48.9	17.7	0.03
Away ave	1743.6	148.3	1829.3	140.3	-85.6	205.6	0.680	-506.2	334.9	0.01
Return ave	1827.0	181.3	2127.5	172.2	-300.5	251.9	0.242	-815.7	214.6	0.05
LLF										
Time	1.3	0.1	1.3	0.1	0.0	0.1	0.731	-0.2	0.2	0.00
Peak	40.8	1.2	38.9	1.1	-1.9	1.7	0.278	-5.3	1.6	0.04
<i>Velocity:</i>										
Away peak	92.7	5.9	93.1	5.6	0.4	8.3	0.965	-16.7	17.4	0.00
Return peak	109.7	5.4	113.2	5.1	-3.4	7.7	0.659	-19.1	12.3	
Away ave	45.5	2.8	49.0	2.7	3.5	4.0	0.383	-4.6	11.7	0.03
Return ave	76.2	3.6	76.7	3.4	-0.5	5.1	0.929	-10.8	9.9	0.00
<i>Jerk:</i>										
Away peak	27.0	5.1	21.5	4.8	5.6	7.1	0.442	-9.0	20.2	0.02
Return peak	4447.0	385.8	4714.1	362.2	-267.2	543.4	0.627	-1378.6	844.3	0.01
Away ave	1824.0	173.3	1880.0	164.5	-55.7	240.9	0.819	-548.4	437.0	0.00
Return ave	2121.1	219.7	2156.5	205.8	-35.4	310.1	0.910	-669.7	598.8	0.00
Rrot										
Time	1.4	0.1	1.3	0.1	0.1	0.1	0.361	-0.1	0.3	0.03
Peak	56.5	1.8	57.3	1.7	-0.8	2.6	0.751	-6.1	4.4	0.00
<i>Velocity:</i>										
Away peak	185.3	11.4	197.1	10.9	-11.7	16.1	0.472	-44.7	21.2	0.02
Return peak	184.7	7.8	196.6	7.6	11.9	11.2	0.295	-11.0	34.8	
Away ave	78.5	4.5	81.4	4.3	-2.9	6.3	0.649	-15.9	10.1	0.01

Return ave	118.8	5.2	126.0	5.0	7.2	7.5	0.341	-8.1	22.5	0.03
<i>Jerk:</i>										
Away peak	5234.6	394.4	5398.5	377.5	-163.8	557.3	0.771	-1303.7	976.0	0.00
Return peak	122.8	25.6	157.0	24.8	-34.2	36.9	0.362	-109.7	41.3	0.03
Away ave	2014.7	217.6	2197.0	208.1	-182.3	307.2	0.558	-810.6	446.0	0.01
Return ave	4104.2	374.0	4240.8	362.5	-136.6	537.1	0.801	-1235.1	961.9	0.00
Lrot										
Time	1.6	0.1	1.5	0.1	0.1	0.1	0.323	-0.1	0.2	0.03
Peak	65.3	1.7	65.5	1.6	0.2	2.4	0.919	-4.6	5.1	0.00
<i>Velocity:</i>										
Away peak	168.4	8.6	180.0	8.2	11.6	12.2	0.351	-13.4	36.5	0.03
Return peak	209.3	10.2	215.9	9.8	-6.6	14.5	0.653	-36.3	23.1	
Away ave	75.9	4.1	73.5	3.9	-2.4	5.8	0.676	-14.2	9.3	0.01
Return ave	134.4	6.4	142.1	6.1	-7.7	9.1	0.402	-26.3	10.8	0.02
<i>Jerk:</i>										
Away peak	31.7	9.4	35.8	9.0	-4.1	13.3	0.760	-31.3	23.1	0.00
Return peak	7381.2	523.6	9246.8	572.1	-1865.6	814.7	0.028	-3521.3	-209.9	0.13
Away ave	1697.3	156.6	2377.5	170.3	-680.1	240.3	0.008	-1168.6	-191.7	0.19
Return ave	4507.3	424.1	4640.4	410.7	-133.0	610.9	0.829	-1382.5	1116.4	0.00

(CG – control group; EG – experimental group; M – mean; SE – standard error; MD – mean difference; CI – confidence interval; η^2 – partial eta squared; ave – average; Flex – flexion; Ext – extension; LLF – left lateral flexion; RLF – right lateral flexion; Lrot – left rotation; Rrot – right rotation)

SUPPLEMENTARY FILE 7.4: MEASUREMENTS TAKEN PRE-, POST- AND AT THE FOURTH VISIT FOR THE MUSCLE RECRUITMENT PATTERNS

ROM	Sub-phase	CG									EG								
		Baseline			Post			4th visit			Baseline			Post			4th visit		
		n	M	SD	n	M	SD	n	M	SD	n	M	SD	n	M	SD	n	M	SD
Flex/ext																			
LAS	Flex	19	24.5	16.3	18	29.2	26.2	13	28.0	20.7	18	35.3	16.7	18	30.7	17.0	18	30.4	11.6
	Away mean	19	13.3	8.9	18	14.6	12.0	13	16.0	11.7	18	18.2	11.3	18	17.1	10.7	18	14.0	5.7
	Away time	19	66.5	33.6	18	66.3	34.3	13	71.0	33.8	18	58.2	31.6	18	62.2	29.6	18	51.1	29.1
	Return peak	19	24.6	17.7	18	28.1	28.0	13	21.5	11.9	18	27.7	20.4	18	24.1	19.7	18	25.5	13.7
	Return mean	19	12.9	7.7	18	14.4	13.2	13	11.8	5.9	18	15.1	10.5	18	14.8	11.9	18	14.2	7.8
	Return time	19	65.9	39.4	18	63.3	37.4	13	76.0	34.3	18	51.2	34.5	18	63.5	37.2	18	58.3	34.3
	Ext	19	13.7	6.4	18	20.9	18.4	13	14.1	9.2	18	22.3	12.8	18	22.0	15.0	18	17.9	10.8
	Away mean	19	9.6	4.3	18	12.9	9.8	13	8.8	4.0	18	13.3	8.0	18	14.0	10.1	18	10.9	6.2
	Away time	19	64.2	38.6	18	66.3	38.6	13	67.1	38.4	18	56.3	37.6	18	59.7	35.1	18	51.1	38.1
	Return peak	19	28.4	18.5	18	29.5	17.9	13	32.1	18.3	18	41.4	22.6	18	38.8	25.4	18	37.7	21.8
	Return mean	19	18.5	10.3	18	19.1	10.5	13	18.7	10.0	18	29.6	18.0	18	26.2	17.1	18	26.8	16.4
	Return time	19	77.7	32.9	18	88.6	18.4	13	84.2	19.0	18	84.0	25.1	18	76.5	32.1	18	71.0	39.5
RAS	Flex	19	20.6	11.8	18	21.8	14.0	14	26.6	16.7	18	30.0	18.8	18	34.3	26.9	18	32.7	18.9
	Away mean	19	9.7	5.9	18	10.6	7.3	14	13.7	9.0	18	15.7	12.2	18	16.8	13.3	18	15.1	7.0
	Away time	19	66.0	28.0	18	56.3	32.2	14	68.3	29.6	18	59.6	34.5	18	56.5	30.1	18	67.8	28.8
	Return peak	19	19.2	11.7	18	20.3	13.1	14	19.1	9.6	18	26.5	21.3	18	26.1	20.1	18	27.5	18.3
	Return mean	19	10.1	6.4	18	10.5	6.9	14	9.7	4.0	18	15.0	11.4	18	14.8	10.7	18	15.3	8.8
	Return time	19	74.5	35.5	18	63.8	39.1	14	66.7	34.2	18	62.1	38.0	18	63.8	39.0	18	73.0	37.9

	Ext																		
	Away peak	19	13.9	9.2	18	19.4	17.3	14	12.7	6.0	18	21.3	12.8	18	21.6	15.0	18	15.7	8.9
	Away mean	19	9.0	5.4	18	12.1	10.2	14	8.4	3.8	18	12.2	7.3	18	13.5	10.3	18	9.4	4.7
	Away time	18	68.9	34.2	17	64.3	38.9	13	65.4	38.5	18	70.6	33.2	18	63.9	28.9	18	70.7	28.5
	Return peak	19	21.5	14.3	18	23.0	14.9	14	25.1	12.3	18	33.8	19.1	18	34.9	23.2	18	36.5	24.5
	Return mean	19	13.5	7.6	18	14.4	8.9	14	15.0	7.4	18	24.1	14.4	18	22.8	14.9	18	25.2	17.0
	Return time	19	77.8	28.8	18	75.8	31.4	14	75.6	29.0	18	85.1	18.6	18	74.8	33.2	18	86.7	24.7
LPC	Flex																		
	Away peak	20	14.0	11.1	18	10.1	7.8	15	12.5	12.8	19	10.5	7.0	19	13.3	13.9	19	8.8	9.3
	Away mean	20	7.8	5.1	18	6.5	4.7	15	8.0	7.3	19	6.6	3.5	19	8.1	6.9	19	6.0	6.0
	Away time	20	45.1	34.6	18	55.0	39.6	15	44.2	31.9	19	35.6	32.5	19	30.3	29.2	19	45.7	38.3
	Return peak	20	32.0	20.4	18	30.3	19.9	15	38.6	26.0	19	32.1	16.2	19	33.5	24.9	19	29.3	18.6
	Return mean	20	20.9	12.1	18	21.6	15.0	15	23.9	15.6	19	18.5	9.3	19	20.8	14.4	19	18.4	13.8
	Return time	20	84.5	30.2	18	93.2	16.9	15	85.8	26.5	19	71.9	36.0	19	72.7	31.4	19	80.3	29.5
	Ext																		
	Away peak	20	27.3	18.5	18	22.4	10.5	15	35.9	24.9	19	27.5	17.0	19	31.2	24.8	19	29.7	14.8
	Away mean	20	14.2	9.8	18	10.9	5.5	15	17.0	12.8	19	13.1	8.5	19	16.5	14.4	19	14.9	8.9
	Away time	20	77.5	27.3	18	81.4	23.6	15	74.0	29.5	19	60.6	29.0	19	61.3	32.2	19	81.8	21.4
	Return peak	20	10.3	9.0	18	9.2	5.5	15	10.0	5.5	19	9.3	7.7	19	13.7	13.7	19	7.7	6.4
	Return mean	20	5.8	4.3	18	5.1	2.7	15	6.0	3.5	19	5.8	4.6	19	9.6	9.5	19	5.0	4.0
	Return time	20	35.9	32.1	19	41.5	37.6	15	38.5	35.1	19	31.5	35.0	19	24.3	32.5	19	40.7	39.8
RPC	Flex																		
	Away peak	19	12.5	10.2	18	11.1	10.5	14	10.2	8.2	19	7.9	4.9	19	10.8	12.0	19	8.3	6.1
	Away mean	19	6.6	4.5	18	6.2	4.1	14	6.8	4.9	19	5.1	2.4	19	6.2	5.1	19	5.3	3.3
	Away time	19	48.8	28.5	18	49.8	35.5	14	44.0	30.8	19	29.7	36.0	19	39.6	35.6	19	49.0	35.4
	Return peak	19	33.6	21.9	18	33.9	24.3	14	40.0	24.9	19	32.4	16.5	19	31.9	28.9	19	33.3	18.1
	Return mean	19	23.0	16.7	18	24.1	19.0	14	24.1	13.9	19	18.1	10.2	19	17.6	12.7	19	20.4	13.8
	Return time	19	88.5	19.0	18	91.1	19.4	14	87.8	18.2	19	68.6	35.0	19	70.4	31.1	19	79.5	29.0
	Ext																		
	Away peak	19	27.7	14.9	18	27.4	17.7	14	37.9	25.9	19	25.7	14.5	19	27.2	15.1	19	31.7	14.9

	Away mean	19	12.8	6.2	18	12.9	8.7	14	19.3	13.3	19	11.7	6.3	19	13.4	7.2	19	16.0	8.8
	Away time	19	75.2	26.2	18	80.6	22.2	14	77.3	25.6	19	59.5	34.4	19	70.1	25.1	19	82.1	22.6
	Return peak	19	7.9	5.0	18	9.0	7.1	14	10.9	5.8	19	9.8	8.5	19	12.1	9.2	19	7.1	3.5
	Return mean	19	4.7	2.9	18	5.1	3.7	14	6.2	3.0	19	5.8	4.8	19	7.9	7.1	19	4.2	1.8
	Return time	18	44.1	39.1	18	36.9	37.0	13	43.0	38.5	19	27.7	32.7	19	35.5	31.2	19	42.7	39.3
LT4	Flex																		
	Away peak	20	17.0	14.6	19	14.2	11.4	14	18.1	17.1	19	15.8	10.6	19	14.4	9.2	19	17.5	14.0
	Away mean	20	12.0	10.1	19	10.6	8.6	14	13.9	13.1	19	12.5	8.8	19	11.1	7.2	19	13.6	10.2
	Away time	20	98.2	8.1	19	88.8	27.5	14	71.5	42.2	19	93.5	20.5	19	92.4	21.6	19	89.9	28.9
	Return peak	20	18.4	15.2	19	15.1	10.9	14	20.6	16.9	19	15.8	8.3	19	16.4	11.8	19	17.4	10.6
	Return mean	20	14.8	11.6	19	12.1	8.8	14	16.9	14.0	19	12.9	7.4	19	13.1	8.6	19	14.8	9.3
	Return time	20	99.9	0.6	19	94.5	21.7	14	79.8	36.2	19	93.5	19.4	19	97.5	10.8	19	93.0	21.4
	Ext																		
	Away peak	20	18.7	17.5	19	13.9	11.0	14	20.9	22.1	19	14.4	8.5	19	15.9	13.2	19	15.5	11.4
	Away mean	20	14.1	12.4	19	10.5	8.7	14	16.1	17.0	19	11.1	7.5	19	12.3	10.9	19	12.0	9.8
	Away time	20	96.0	8.9	19	91.6	23.4	14	70.9	37.5	19	91.2	24.0	19	93.0	15.5	19	82.5	33.9
	Return peak	20	18.6	19.9	19	12.0	9.5	14	18.7	20.6	19	15.9	15.0	19	15.4	21.3	19	14.9	15.1
	Return mean	20	13.4	13.3	19	9.2	7.1	14	14.0	14.8	19	11.1	9.1	19	10.9	11.6	19	10.8	9.9
	Return time	20	93.3	20.0	19	87.2	31.0	14	59.2	42.1	19	84.9	30.5	19	83.2	28.7	19	78.7	34.5
RT4	Flex																		
	Away peak	19	9.0	9.4	18	9.0	10.1	14	7.8	5.2	19	6.4	2.9	19	8.0	4.2	19	7.8	3.9
	Away mean	19	6.7	7.3	18	7.0	8.0	14	6.0	3.7	19	4.9	2.2	19	6.1	3.3	19	5.9	2.7
	Away time	19	83.9	31.1	18	93.0	16.9	14	94.3	9.0	19	93.8	15.5	19	90.3	15.6	19	86.7	30.9
	Return peak	19	10.8	11.7	18	8.9	9.4	14	8.3	4.7	19	6.8	2.3	19	8.5	3.5	19	9.0	4.0
	Return mean	19	8.5	9.1	18	6.8	6.4	14	6.8	3.8	19	5.4	2.0	19	7.1	3.2	19	7.3	3.0
	Return time	19	93.1	20.7	18	92.1	13.2	14	97.7	6.9	19	92.2	23.7	19	94.7	17.1	19	89.8	24.9
	Ext																		
	Away peak	19	8.9	7.8	18	7.1	4.4	14	8.3	4.8	19	5.9	2.8	19	7.6	4.1	19	7.9	4.7
	Away mean	19	6.1	4.1	18	5.4	3.2	14	6.3	3.7	19	4.2	2.1	19	6.0	3.4	19	5.7	3.6
	Away time	19	83.1	26.8	18	86.9	27.8	14	93.6	13.1	19	86.8	25.3	19	83.6	24.7	19	81.8	35.4

	Return peak	19	8.5	7.6	18	6.8	5.9	14	7.0	4.1	19	6.0	4.2	19	7.2	5.3	19	6.4	3.9
	Return mean	19	5.8	4.2	18	5.1	4.1	14	5.3	3.2	19	4.2	2.2	19	5.2	3.5	19	4.7	2.9
	Return time	19	79.2	36.2	18	83.7	27.1	14	85.2	25.7	19	85.0	21.4	19	79.0	30.4	19	80.7	37.1
LSCM	Flex																		
	Away peak	19	19.4	15.5	18	21.7	24.1	13	20.6	12.5	18	27.1	18.6	18	25.7	17.1	18	24.5	17.5
	Away mean	19	9.4	8.3	18	10.3	10.2	13	11.3	7.0	18	13.5	11.6	18	12.8	10.8	18	10.9	7.7
	Away time	19	69.7	31.3	18	69.2	28.4	13	63.8	38.6	18	71.5	24.2	18	72.4	25.7	18	61.3	35.1
	Return peak	19	18.7	14.0	18	23.6	26.4	13	16.4	7.7	18	19.5	21.4	18	15.0	12.9	18	18.0	13.3
	Return mean	19	9.7	6.6	18	12.1	12.9	13	8.4	3.5	18	11.1	13.2	18	8.3	4.8	18	10.2	6.9
	Return time	19	74.7	35.5	18	80.3	34.5	13	61.8	41.2	18	70.0	34.6	18	75.0	33.4	18	67.4	38.3
	Ext																		
	Away peak	19	10.9	8.6	18	17.3	18.1	13	12.5	10.9	18	15.9	14.9	18	15.6	14.2	18	11.8	8.3
	Away mean	19	6.7	4.8	18	9.9	9.6	13	6.9	4.1	18	7.8	6.1	18	9.5	9.8	18	7.1	5.1
	Away time	19	61.8	41.7	18	78.6	28.8	13	62.7	39.6	18	69.4	32.7	18	74.5	31.9	18	55.5	42.1
	Return peak	19	26.3	21.4	18	25.5	18.9	13	33.7	23.8	18	35.5	24.9	18	31.4	22.8	18	34.2	24.5
	Return mean	19	16.1	12.2	18	15.2	11.1	13	19.9	16.1	18	23.4	17.9	18	21.1	17.5	18	23.7	18.7
	Return time	19	78.6	30.4	18	91.1	16.2	13	79.4	29.4	18	94.5	9.1	18	85.2	27.6	18	82.2	24.3
RSCM	Flex																		
	Away peak	19	16.5	7.5	18	16.6	7.2	14	22.4	16.0	18	30.4	18.5	18	34.0	28.7	18	29.7	15.9
	Away mean	19	7.9	3.5	18	7.5	3.2	14	11.7	8.4	18	15.7	12.5	18	16.6	14.8	18	12.9	6.5
	Away time	19	62.4	32.2	18	58.0	32.2	14	75.7	26.2	18	75.3	28.5	18	73.8	31.7	18	65.2	30.0
	Return peak	19	16.0	9.5	18	16.5	9.9	14	18.9	13.1	18	24.8	21.3	18	24.8	17.9	18	25.8	21.2
	Return mean	19	8.9	4.4	18	9.3	6.1	14	10.1	5.6	18	13.7	11.6	18	14.5	10.3	18	14.1	9.0
	Return time	19	69.3	41.2	18	73.9	34.2	14	76.6	38.4	18	80.3	34.1	18	81.0	32.3	18	80.1	25.9
	Ext																		
	Away peak	19	12.6	10.2	18	15.6	14.8	14	13.5	10.0	18	19.5	13.6	18	20.9	15.1	18	15.7	14.4
	Away mean	19	8.2	6.2	18	10.0	8.4	14	8.4	5.5	18	11.3	7.5	18	13.2	10.2	18	9.8	8.9
	Away time	19	70.3	31.1	18	67.8	33.9	14	81.5	34.9	18	86.5	25.0	18	79.5	31.5	18	72.4	36.8
	Return peak	19	28.1	23.5	18	25.1	20.7	14	37.5	29.6	18	38.1	23.9	18	36.0	25.4	18	39.3	26.7
	Return mean	19	17.1	13.9	18	14.8	11.6	14	21.7	18.6	18	25.8	17.9	18	23.9	18.4	18	26.4	19.0

	Return time	19	78.1	30.9	18	82.2	25.8	14	76.8	33.0	18	88.0	24.2	18	80.6	27.7	18	84.3	31.6
LUT	Flex																		
	Away peak	20	5.1	7.3	19	5.4	8.3	15	5.5	7.6	19	8.1	8.1	19	9.6	8.3	19	9.4	12.3
	Away mean	20	4.0	5.8	19	3.9	6.5	15	4.2	6.0	19	5.7	5.7	19	6.8	6.4	19	7.3	9.9
	Away time	20	49.3	47.5	19	28.7	41.8	15	56.3	37.5	19	32.5	34.5	19	44.1	39.4	19	31.6	38.4
	Return peak	20	6.4	8.6	19	6.3	9.0	15	6.3	8.2	19	7.9	8.1	19	9.1	9.1	19	9.5	13.7
	Return mean	20	5.1	6.8	19	5.0	7.6	15	5.0	6.9	19	5.7	6.3	19	7.2	7.6	19	7.3	9.5
	Return time	20	65.4	44.3	19	38.1	47.2	15	70.3	40.1	19	40.3	37.9	19	52.2	41.8	19	40.3	39.4
	Ext																		
	Away peak	20	5.3	6.9	19	5.3	8.8	15	6.2	7.2	19	8.5	9.7	19	9.8	11.4	19	10.8	14.9
	Away mean	20	4.0	5.2	19	4.0	6.9	15	4.7	5.8	19	5.8	6.9	19	7.1	8.6	19	8.1	11.1
	Away time	20	56.6	43.0	19	31.2	43.6	15	60.5	43.4	19	36.2	38.4	19	43.5	41.6	19	35.5	40.9
	Return peak	20	5.0	5.7	19	5.0	6.8	15	7.0	7.6	19	7.2	7.3	19	8.8	9.8	19	8.6	12.1
	Return mean	20	3.8	4.5	19	3.7	5.5	15	4.7	5.5	19	5.3	5.4	19	6.8	7.6	19	6.4	9.3
	Return time	20	47.9	44.5	19	27.4	40.4	15	66.0	38.8	19	38.1	43.3	19	44.0	45.0	19	28.9	39.8
RUT	Flex																		
	Away peak	19	3.2	2.7	18	4.7	6.4	14	4.1	6.3	19	5.3	4.9	19	5.1	5.2	19	3.5	2.8
	Away mean	19	2.3	2.2	18	3.1	4.1	14	3.0	4.7	19	3.8	3.7	19	3.8	4.3	19	2.7	2.4
	Away time	19	44.4	41.7	18	35.2	38.5	14	56.5	34.7	19	37.4	41.0	19	32.6	39.0	19	35.8	40.8
	Return peak	19	5.1	5.1	18	5.9	8.2	14	5.3	6.2	19	5.4	5.2	19	5.2	4.6	19	4.1	2.9
	Return mean	19	3.8	3.4	18	4.2	5.5	14	3.9	5.3	19	4.0	4.0	19	4.1	3.9	19	3.1	2.4
	Return time	19	54.3	44.8	18	51.4	47.3	14	74.6	35.0	19	43.1	45.7	19	48.2	41.0	19	51.1	40.4
	Ext																		
	Away peak	19	4.6	5.1	18	5.2	7.4	14	5.7	6.3	19	5.4	5.6	19	5.9	6.0	19	4.6	3.7
	Away mean	19	3.1	3.4	18	3.7	5.5	14	4.2	5.3	19	3.8	4.1	19	4.3	4.8	19	3.3	2.7
	Away time	19	50.8	44.6	18	49.5	45.5	14	67.9	36.5	19	37.2	44.2	19	39.4	42.3	19	44.7	43.7
	Return peak	19	4.2	4.5	18	5.3	7.0	14	6.7	8.6	19	4.5	5.4	19	5.0	5.3	19	3.5	3.3
	Return mean	19	2.7	2.5	18	3.3	4.5	14	4.4	5.8	19	3.6	4.3	19	3.8	4.1	19	2.7	2.5
	Return time	19	46.1	43.8	18	42.9	44.9	14	64.0	37.2	18	38.2	42.3	18	35.6	40.2	18	43.4	43.5
LT9	Flex																		

	Away peak	20	28.5	14.6	19	29.9	17.6	15	34.2	22.4	19	30.3	11.8	18	31.8	17.6	18	32.6	11.5
	Away mean	20	22.2	12.0	19	23.0	13.3	15	28.0	18.7	19	24.9	10.3	18	24.9	15.7	18	25.6	8.4
	Away time	20	97.2	6.4	19	86.9	28.5	15	92.7	15.8	19	94.4	15.4	18	92.8	18.7	18	94.3	23.5
	Return peak	20	27.0	11.7	19	27.0	13.4	15	32.1	19.0	19	30.6	11.5	18	30.3	12.6	18	32.3	12.2
	Return mean	20	20.9	9.0	19	21.0	10.6	15	25.5	14.6	19	24.1	9.5	18	24.2	9.6	18	26.9	10.8
	Return time	20	96.5	13.2	19	89.6	25.2	15	80.3	32.6	19	96.8	8.9	18	97.3	11.5	18	91.5	25.6
	Ext																		
	Away peak	20	20.9	12.7	19	20.6	11.3	15	24.3	15.8	19	24.2	9.9	18	26.8	15.0	18	26.3	12.9
	Away mean	20	15.5	9.7	19	15.8	8.9	15	19.3	13.6	19	18.8	8.6	18	20.8	12.0	18	20.1	9.8
	Away time	20	86.0	26.1	19	79.7	34.9	15	67.2	41.8	19	86.9	24.2	18	92.4	21.4	18	86.1	31.6
	Return peak	20	22.6	10.6	19	21.8	11.1	15	27.4	19.7	19	25.2	9.2	18	27.0	22.8	18	27.3	12.8
	Return mean	20	17.2	9.0	19	16.7	8.6	15	21.9	17.3	19	19.2	8.0	18	19.8	12.8	18	20.2	10.5
	Return time	20	85.5	22.9	19	80.1	38.5	15	72.5	36.4	19	85.7	24.3	18	85.1	26.5	18	87.6	28.7
RT9	Flex																		
	Away peak	19	30.9	15.8	18	30.8	17.0	14	37.7	16.2	19	33.8	17.7	19	36.3	20.5	19	34.0	10.3
	Away mean	19	23.9	12.1	18	24.2	13.3	14	30.4	12.8	19	26.6	14.1	19	28.7	17.6	19	27.4	8.6
	Away time	19	93.1	22.9	18	87.1	26.4	14	97.9	6.4	19	95.2	15.7	19	89.8	25.5	19	92.1	24.3
	Return peak	19	29.3	12.9	18	27.8	14.6	14	36.6	15.3	19	30.8	14.6	19	34.5	15.9	19	33.6	12.4
	Return mean	19	23.1	10.6	18	21.9	11.8	14	29.9	13.6	19	24.3	12.0	19	27.3	11.5	19	27.0	10.3
	Return time	19	90.8	26.1	18	80.5	34.1	14	92.0	19.0	19	89.0	23.4	19	92.5	20.0	19	95.5	12.6
	Ext																		
	Away peak	19	24.8	14.3	18	23.7	14.4	14	31.2	15.0	19	23.3	10.1	19	29.0	13.1	19	26.2	13.4
	Away mean	19	18.7	11.7	18	18.1	11.7	14	23.9	11.8	19	17.0	7.9	19	21.9	9.8	19	19.9	10.4
	Away time	19	81.1	30.0	18	75.7	38.2	14	85.3	30.5	19	82.9	29.7	19	82.5	30.6	19	84.5	31.2
	Return peak	19	24.6	13.3	18	23.0	13.7	14	29.6	15.0	19	26.2	11.0	19	29.7	16.9	19	28.4	12.6
	Return mean	19	19.0	11.4	18	17.8	11.1	14	21.8	12.6	19	19.1	7.9	19	22.7	13.3	19	21.6	11.2
	Return time	19	80.0	30.6	18	71.1	40.6	14	79.1	32.3	19	87.5	16.8	19	85.7	27.0	19	85.1	32.2
Lateral flexion																			
LAS	RLF																		
	Away peak	19	13.0	10.6	19	12.7	11.8	13	8.4	4.9	18	9.8	8.6	17	15.5	14.9	18	8.8	4.8

	Away mean	19	8.4	7.5	19	6.6	3.4	13	5.4	3.3	18	6.5	5.6	17	9.1	7.5	18	5.6	3.1
	Away time	19	46.0	36.4	19	37.2	41.4	13	32.3	31.7	18	16.5	26.0	17	33.1	38.5	18	20.8	33.2
	Return peak	19	34.2	19.2	19	35.2	18.4	13	39.8	24.1	18	32.7	23.8	17	32.2	22.7	18	30.9	18.3
	Return mean	19	23.0	13.0	19	20.9	10.7	13	22.9	14.7	18	19.0	13.3	17	17.5	10.6	18	16.3	8.7
	Return time	19	81.3	34.0	19	76.9	33.3	13	81.0	22.7	18	58.3	33.8	17	62.8	29.2	18	51.8	35.1
	LLFT																		
	Away peak	19	38.7	20.5	19	36.1	18.4	13	43.0	17.3	18	35.8	18.6	17	37.2	19.9	18	36.8	18.5
	Away mean	19	21.3	11.0	19	21.1	12.0	13	24.0	8.8	18	19.9	9.7	17	20.2	11.6	18	20.5	9.6
	Away time	19	82.2	30.5	19	84.2	23.2	13	88.7	12.9	18	68.0	24.0	17	73.1	29.2	18	64.0	35.1
	Return peak	19	32.0	21.1	19	30.6	20.6	13	30.5	16.6	18	24.3	21.7	17	26.8	22.1	18	31.2	22.0
	Return mean	19	16.4	14.5	19	15.7	12.1	13	15.2	9.2	18	13.3	10.3	17	16.4	16.1	18	17.7	12.0
	Return time	19	62.9	35.5	19	62.6	35.5	13	79.6	24.3	18	48.5	38.2	17	57.4	36.3	18	52.6	42.7
RAS	RLF																		
	Away peak	19	39.3	22.8	19	43.4	31.2	14	41.8	16.9	18	37.6	27.1	17	40.9	25.8	18	40.7	22.0
	Away mean	19	24.8	16.4	19	23.8	17.0	14	25.9	11.2	18	22.6	17.9	17	23.8	16.2	18	23.7	12.9
	Away time	19	90.7	20.9	19	85.1	31.2	14	97.3	8.9	18	77.7	33.7	17	76.5	32.0	18	82.2	33.1
	Return peak	19	33.8	23.4	19	38.0	31.6	14	28.0	15.8	18	23.2	22.8	17	30.4	20.9	18	32.3	24.3
	Return mean	19	15.0	11.6	19	18.3	18.6	14	12.7	7.9	18	11.5	8.8	17	16.8	14.9	18	16.9	14.4
	Return time	19	71.7	28.3	19	58.9	36.2	14	69.8	31.5	18	67.0	39.5	17	53.7	34.9	18	60.1	40.3
	LLF																		
	Away peak	19	10.2	13.5	19	8.0	5.1	14	7.0	3.8	18	7.9	4.4	17	14.0	13.4	18	8.4	5.7
	Away mean	19	6.5	8.1	19	4.6	2.2	14	4.3	2.4	18	4.6	2.1	17	8.1	8.2	18	5.3	3.3
	Away time	19	44.0	41.6	19	32.8	37.0	14	29.0	31.3	18	37.2	33.0	17	26.8	30.2	18	30.8	33.0
	Return peak	19	25.3	13.6	19	25.1	16.5	14	28.2	14.7	18	25.5	21.8	17	29.4	21.8	18	33.4	20.9
	Return mean	19	16.0	8.7	19	15.8	10.8	14	16.1	8.3	18	14.4	11.2	17	15.3	9.7	18	18.1	12.7
	Return time	19	85.7	23.1	19	75.5	36.8	14	77.1	25.0	18	70.4	38.6	17	69.1	30.8	18	77.4	26.6
LPC	RLF																		
	Away peak	20	13.8	8.8	19	12.3	7.3	14	14.7	11.7	19	13.3	8.0	18	13.9	7.7	19	11.6	11.6
	Away mean	20	8.8	5.1	19	7.9	4.8	14	10.8	9.9	19	8.9	5.1	18	8.9	4.2	19	7.5	6.7
	Away time	20	60.6	39.9	19	67.3	39.7	14	71.8	27.9	19	62.4	38.6	18	60.8	37.1	19	65.2	35.6

	Return peak	20	15.2	8.4	19	14.9	9.8	14	20.8	14.3	19	16.5	12.6	18	15.0	10.9	19	16.3	10.9
	Return mean	20	10.3	4.9	19	10.6	6.8	14	15.8	11.4	19	10.8	6.2	18	10.4	7.2	19	11.8	9.8
	Return time	20	74.6	34.7	19	78.2	35.1	14	87.7	26.2	19	65.4	41.1	18	66.0	37.6	19	85.5	22.9
	LLF																		
	Away peak	20	19.7	8.5	19	20.1	13.3	14	23.3	11.6	19	18.8	9.3	18	20.5	11.1	19	18.2	8.7
	Away mean	20	12.5	6.0	19	12.0	8.5	14	14.7	9.1	19	12.8	7.2	18	12.5	7.1	19	11.5	6.1
	Away time	20	85.1	16.8	19	78.0	32.1	14	85.7	15.4	19	72.5	33.5	18	72.7	27.4	19	83.7	23.4
	Return peak	20	16.7	10.3	19	20.3	15.0	14	17.3	11.5	19	15.1	10.5	18	20.0	21.5	19	14.8	8.2
	Return mean	20	11.1	7.6	19	11.3	8.0	14	12.1	9.9	19	10.7	8.6	18	14.0	16.1	19	10.2	5.7
	Return time	20	72.3	29.2	19	73.3	37.1	14	78.8	24.5	19	65.1	38.6	18	67.3	35.5	19	77.3	34.0
RPC	RLF																		
	Away peak	19	17.9	11.3	19	19.8	10.8	14	20.9	9.2	19	20.6	7.0	18	19.5	11.5	19	19.0	8.5
	Away mean	19	11.3	6.8	19	12.5	6.7	14	14.5	6.9	19	14.2	6.1	18	12.5	7.6	19	12.8	5.3
	Away time	19	84.2	28.4	19	77.6	34.7	14	89.2	26.1	19	79.0	33.5	18	82.1	22.9	19	90.8	25.7
	Return peak	19	13.2	7.7	19	15.4	9.6	14	15.9	8.9	19	15.4	8.9	18	17.4	13.9	19	14.5	7.6
	Return mean	19	7.6	4.9	19	9.0	6.9	14	9.9	6.0	19	10.8	7.8	18	11.3	9.1	19	9.4	4.7
	Return time	19	66.5	28.3	19	61.3	40.6	14	75.1	31.1	19	62.2	38.8	18	66.3	37.2	19	74.0	38.2
	LLF																		
	Away peak	19	9.9	6.9	19	10.8	8.2	14	10.4	6.7	19	14.6	9.9	18	11.7	6.4	19	9.7	5.7
	Away mean	19	6.4	4.4	19	7.3	5.4	14	7.0	4.4	19	9.7	8.0	18	7.6	4.2	19	6.0	2.7
	Away time	19	52.5	39.8	19	58.0	39.7	14	55.7	32.2	19	54.1	41.7	18	52.2	33.3	19	56.9	39.1
	Return peak	19	15.9	12.3	19	16.8	12.7	14	19.9	10.9	19	17.1	10.0	18	14.8	8.0	19	17.4	8.3
	Return mean	19	12.0	9.6	19	12.2	9.2	14	14.1	7.9	19	11.9	6.9	18	10.0	4.9	19	11.8	5.1
	Return time	19	79.6	33.6	19	75.6	38.4	14	80.8	33.7	19	68.1	37.8	18	72.3	28.2	19	88.0	21.9
LT4	RLF																		
	Away peak	20	11.3	9.9	20	10.6	10.9	14	13.8	13.7	19	11.6	7.5	18	11.7	8.4	19	10.9	7.9
	Away mean	20	8.9	7.9	20	8.6	8.8	14	11.3	11.5	19	9.7	6.6	18	9.4	7.0	19	9.2	6.8
	Away time	20	95.3	10.7	20	77.0	40.0	14	76.2	36.3	19	90.4	26.1	18	88.5	28.7	19	80.9	33.9
	Return peak	20	10.2	8.6	20	9.9	9.7	14	12.5	11.5	19	12.4	8.3	18	12.7	9.5	19	11.2	7.9
	Return mean	20	8.5	7.8	20	8.1	7.9	14	10.3	9.3	19	10.1	7.1	18	10.5	8.0	19	9.4	6.6

	Return time	20	90.8	18.9	20	77.9	40.1	14	68.7	37.9	19	89.7	25.1	18	89.7	27.8	19	81.3	34.6
	LLT																		
	Away peak	20	12.6	11.4	20	11.0	9.9	14	15.2	14.1	19	11.7	7.0	18	11.9	7.8	19	11.5	7.7
	Away mean	20	9.6	8.5	20	8.5	8.1	14	11.4	11.2	19	9.4	6.3	18	9.4	6.7	19	9.1	6.7
	Away time	20	90.8	17.1	20	73.1	41.5	14	66.4	38.9	19	88.7	25.4	18	88.0	28.1	19	81.0	33.0
	Return peak	20	11.9	10.2	20	9.6	8.2	14	13.4	11.8	19	11.1	6.3	18	11.0	7.1	19	10.8	8.5
	Return mean	20	9.5	7.8	20	7.9	6.9	14	10.7	9.4	19	9.4	5.7	18	9.3	6.4	19	8.8	7.4
	Return time	20	92.9	13.7	20	74.7	41.6	14	65.3	42.0	19	91.0	22.3	18	90.7	24.9	19	77.5	37.3
RT4	RLF																		
	Away peak	19	7.2	6.7	19	5.8	4.2	14	6.4	4.3	19	6.9	3.9	18	6.7	3.7	19	5.8	2.9
	Away mean	19	5.4	4.6	14	6.4	4.3	14	4.8	3.2	19	5.2	3.3	19	5.8	2.9	19	4.5	2.2
	Away time	19	74.1	36.6	19	75.3	36.5	14	81.8	34.3	19	86.5	28.1	18	82.3	26.1	19	82.1	37.0
	Return peak	19	7.1	7.0	19	7.2	6.7	14	6.2	3.8	19	6.6	5.9	19	6.9	3.9	19	6.4	3.8
	Return mean	19	5.5	5.2	19	5.8	4.2	14	5.0	3.3	19	5.2	4.2	18	6.7	3.7	19	4.9	2.5
	Return time	19	73.5	34.5	19	73.9	38.4	14	76.7	40.1	19	84.0	30.6	18	79.1	34.8	19	83.4	35.5
	LLF																		
	Away peak	19	7.5	8.4	19	6.7	8.1	14	6.5	4.1	19	6.0	4.4	18	5.9	2.8	19	5.9	2.6
	Away mean	19	6.0	6.6	19	5.3	5.9	14	5.2	3.4	19	4.9	3.7	18	4.7	2.3	19	4.6	1.9
	Away time	19	82.2	32.8	19	75.7	38.9	14	84.6	29.3	19	81.4	37.0	18	82.2	28.5	19	83.7	36.3
	Return peak	19	8.0	10.0	19	6.7	8.5	14	6.0	4.0	19	6.2	4.1	18	6.2	2.8	19	5.7	2.9
	Return mean	19	6.6	8.2	19	5.3	6.1	14	4.9	3.2	19	5.0	3.6	18	4.9	2.3	19	4.6	2.3
	Return time	19	82.1	30.2	19	77.9	37.6	14	83.2	30.7	19	87.0	28.6	18	84.9	29.3	19	81.5	34.3
LSCM	RLF																		
	Away peak	19	10.1	14.1	19	9.0	14.3	13	4.7	2.0	18	7.6	9.9	17	14.3	15.7	18	6.6	5.6
	Away mean	19	6.2	9.7	19	4.1	3.4	13	3.4	1.7	18	4.9	6.8	17	7.2	8.5	18	4.0	3.0
	Away time	19	41.6	39.9	19	35.9	31.9	13	32.4	38.4	18	34.1	43.6	17	49.4	40.4	18	32.5	41.1
	Return peak	19	31.1	17.7	19	32.0	18.1	13	37.7	24.1	18	29.0	22.1	17	25.8	17.2	18	36.8	24.4
	Return mean	19	19.9	13.1	19	18.8	12.6	13	21.3	14.0	18	16.7	15.9	17	13.2	9.1	18	19.7	16.4
	Return time	19	86.6	25.4	19	83.4	27.4	13	79.9	24.8	18	73.8	29.3	17	79.0	23.1	18	69.7	28.2
	LLF																		

RSCM	Away peak	19	42.4	22.6	19	41.7	24.4	13	41.2	24.4	18	36.9	22.4	17	40.0	26.7	18	49.1	19.2
	Away mean	19	23.2	14.8	19	24.2	15.0	13	22.4	14.6	18	20.8	15.6	17	22.7	19.8	18	26.8	11.1
	Away time	19	89.3	11.7	19	87.9	23.3	13	76.1	27.4	18	82.1	20.3	17	80.7	22.4	18	85.3	16.3
	Return peak	19	31.4	21.5	19	31.3	19.3	13	30.8	22.2	18	25.8	26.3	17	35.5	32.8	18	38.2	23.1
	Return mean	19	13.6	13.1	19	14.9	17.0	13	13.2	10.3	18	13.6	13.8	17	20.0	20.4	18	19.3	12.3
	Return time	19	65.8	34.4	19	72.1	30.9	13	60.4	35.3	18	64.2	35.6	17	59.5	38.4	18	66.3	36.4
	RLF																		
	Away peak	19	43.5	21.9	19	46.0	25.2	14	50.0	18.5	18	44.1	21.1	17	51.1	30.5	18	51.0	20.7
	Away mean	19	24.7	13.2	19	24.2	11.8	14	30.9	13.8	18	27.2	14.4	17	30.3	22.0	18	31.6	12.3
	Away time	19	88.6	26.5	19	85.3	31.5	14	97.3	8.9	18	81.8	33.4	17	87.0	24.7	18	93.2	17.7
	Return peak	19	35.7	24.1	19	34.7	22.0	14	27.3	16.3	18	30.9	25.1	17	42.4	37.9	18	43.1	28.6
	Return mean	19	14.8	12.3	19	15.8	17.2	14	12.3	9.6	18	15.7	12.9	17	24.2	24.6	18	20.3	14.7
	Return time	19	65.6	31.0	19	59.5	36.3	14	68.9	34.3	18	67.2	40.0	17	66.6	38.9	18	61.6	32.1
	LLF																		
	Away peak	19	13.2	20.3	19	9.4	10.6	14	5.6	3.0	18	8.3	6.2	17	16.4	15.3	18	5.8	2.9
	Away mean	19	7.9	12.6	19	4.8	3.6	14	3.7	2.2	18	4.9	3.6	17	8.6	9.3	18	3.5	1.6
	Away time	19	44.5	37.9	19	33.6	38.4	14	45.1	32.9	18	50.7	37.0	17	54.3	35.9	18	21.4	27.1
	Return peak	19	27.5	17.8	19	25.0	20.1	14	33.2	17.3	18	32.4	22.3	17	33.6	23.8	18	36.7	18.2
	Return mean	19	17.8	11.7	19	16.3	13.1	14	17.5	9.2	18	18.7	14.1	17	17.7	12.9	18	19.3	13.0
	Return time	19	80.0	32.5	19	73.0	35.5	14	82.0	29.3	18	75.0	36.5	17	83.7	25.9	18	73.8	30.9
LUT	RLF																		
	Away peak	20	9.4	9.2	20	8.1	8.5	15	8.1	10.4	19	13.4	11.9	18	10.9	11.8	19	10.3	10.6
	Away mean	20	5.7	6.6	20	5.1	5.0	15	5.6	7.7	19	9.5	8.4	18	7.7	9.6	19	7.3	7.2
	Away time	20	61.8	42.1	20	34.4	38.7	15	52.8	45.4	19	38.7	43.2	18	58.2	42.1	19	32.9	38.4
	Return peak	20	6.7	7.3	20	6.9	7.8	15	5.8	6.4	19	9.9	9.9	18	9.4	11.0	19	8.2	9.3
	Return mean	20	4.8	5.9	20	4.9	5.5	15	4.2	4.6	19	7.3	7.5	18	6.4	8.2	19	5.2	5.0
	Return time	20	64.1	44.6	20	35.7	44.2	15	54.0	42.5	19	42.2	43.1	18	49.3	40.0	19	36.0	44.4
	LLF																		
	Away peak	20	11.8	12.5	20	12.5	13.0	15	11.3	12.1	19	15.8	16.0	18	13.6	14.1	19	14.4	14.8
	Away mean	20	8.1	9.3	20	8.9	9.6	15	7.3	8.4	19	11.0	10.9	18	9.5	11.0	19	9.7	10.0

RUT	Away time	20	72.7	39.7	20	54.5	38.6	15	78.4	27.1	19	52.8	42.2	18	61.2	42.5	19	45.5	43.0
	Return peak	20	11.2	9.4	20	10.5	9.3	15	9.9	10.4	19	12.8	10.5	18	10.8	9.7	19	12.0	11.1
	Return mean	20	8.6	7.3	20	7.9	7.0	15	7.3	8.0	19	9.8	8.4	18	8.1	8.0	19	9.0	8.6
	Return time	20	76.6	38.8	20	50.7	39.7	15	70.9	36.6	19	49.5	46.0	18	58.8	44.9	19	43.9	42.5
	RLF																		
	Away peak	19	8.3	11.1	19	9.4	10.5	14	8.4	9.4	19	10.6	14.4	18	9.4	12.4	19	7.2	6.6
	Away mean	19	5.6	7.4	19	6.4	8.0	14	5.7	7.2	19	7.6	10.4	18	6.5	8.7	19	5.2	4.9
	Away time	19	59.0	41.9	19	58.7	43.1	14	86.7	22.0	19	45.7	44.3	18	58.0	39.0	19	55.3	45.3
	Return peak	19	7.8	8.8	19	8.3	7.0	14	7.8	10.1	19	8.7	11.6	18	8.0	9.0	19	7.5	6.4
	Return mean	19	5.4	5.9	19	6.0	5.5	14	5.6	7.8	19	6.7	9.3	18	6.0	7.8	19	5.5	4.7
	Return time	19	59.4	38.6	19	49.4	44.4	14	83.8	23.6	19	44.5	47.3	18	53.9	41.3	19	56.2	41.8
	LLF																		
	Away peak	19	5.4	5.3	19	5.8	6.0	14	4.8	6.9	19	8.8	11.2	18	7.1	8.7	19	6.2	5.8
	Away mean	19	3.4	3.4	19	4.0	4.2	14	3.1	4.8	19	5.7	7.5	18	4.7	6.7	19	4.0	3.9
	Away time	19	39.1	42.5	19	25.4	38.7	14	39.3	37.5	19	36.6	43.4	18	35.3	39.5	19	38.8	39.5
	Return peak	19	4.4	4.4	19	5.4	6.5	14	4.5	5.8	19	6.4	8.3	18	5.2	6.2	19	4.4	3.3
	Return mean	19	3.0	3.0	19	4.1	5.2	14	2.9	3.3	19	4.7	6.1	18	3.9	4.8	19	2.8	1.9
	Return time	19	45.1	38.8	19	37.2	43.6	14	62.4	37.1	19	41.2	45.2	18	46.2	43.9	19	39.6	42.0
LT9	RLF																		
	Away peak	20	22.5	8.6	20	24.2	13.0	15	30.5	20.5	19	29.0	12.3	17	27.0	9.6	18	25.9	8.7
	Away mean	20	17.8	7.0	20	18.4	9.4	15	24.1	17.4	19	23.3	10.4	17	20.8	8.0	18	20.5	7.2
	Away time	20	94.6	14.6	20	80.6	34.4	15	77.9	39.6	19	95.5	14.5	17	94.5	12.6	18	90.4	24.0
	Return peak	20	24.4	10.0	20	25.7	12.3	15	30.5	18.3	19	31.7	12.4	17	29.4	11.3	18	28.7	9.0
	Return mean	20	19.1	8.0	20	20.2	9.9	15	24.4	14.5	19	25.8	10.0	17	23.8	9.1	18	23.7	7.2
	Return time	20	90.2	23.7	20	82.5	34.0	15	76.3	35.8	19	99.2	1.9	17	93.7	24.0	18	91.7	23.9
	LLF																		
	Away peak	20	19.0	8.8	20	18.6	9.3	15	22.4	13.1	19	25.5	10.7	17	24.8	9.5	18	22.8	7.9
	Away mean	20	14.7	7.9	20	14.2	7.8	15	17.4	11.7	19	19.5	9.1	17	18.8	7.6	18	17.1	6.5
	Away time	20	82.6	28.6	20	70.8	40.2	15	66.9	41.8	19	86.9	26.6	17	92.8	14.2	18	78.3	32.0
	Return peak	20	17.3	6.7	20	17.2	8.3	15	21.9	14.8	19	23.7	9.8	17	21.9	11.0	18	19.1	8.9

RT9	Return mean	20	13.6	5.5	20	13.1	5.8	15	17.2	12.2	19	18.6	8.8	17	17.5	8.4	18	15.0	7.5
	Return time	20	82.6	24.7	20	68.0	42.7	15	64.1	44.2	19	84.5	28.7	17	84.6	28.4	18	71.1	39.1
	RLF																		
	Away peak	19	20.7	12.0	19	20.8	12.5	14	24.2	12.7	19	28.4	11.0	18	29.7	13.5	19	26.6	10.7
	Away mean	19	15.6	10.1	19	16.0	9.9	14	16.9	9.5	19	21.2	8.7	18	22.5	11.6	19	19.7	8.5
	Away time	19	67.4	39.2	19	63.7	41.3	14	68.3	40.3	19	92.8	14.1	18	82.2	32.4	19	85.3	31.9
	Return peak	19	17.7	9.8	19	18.9	10.7	14	20.7	10.2	19	27.4	10.5	18	29.1	12.0	19	24.0	11.5
	Return mean	19	14.0	8.5	19	14.7	8.6	14	15.0	8.1	19	20.4	9.0	18	22.6	10.3	19	17.7	9.0
	Return time	19	60.7	41.7	19	60.1	47.2	14	63.5	43.6	19	94.7	9.2	18	86.6	29.0	19	81.6	34.1
	LLF																		
	Away peak	19	24.2	13.3	19	26.7	14.5	14	31.9	16.3	19	33.6	14.3	18	34.6	14.7	19	30.0	11.1
	Away mean	19	18.5	10.1	19	20.6	12.0	14	23.9	11.4	19	26.1	10.6	18	27.4	11.5	19	23.3	9.0
	Away time	19	76.8	38.0	19	72.8	39.4	14	82.5	34.0	19	98.6	5.0	18	91.1	23.2	19	89.0	26.5
	Return peak	19	26.5	13.2	19	25.8	13.0	14	31.1	17.5	19	31.8	12.9	18	33.8	14.4	19	32.7	10.7
	Return mean	19	20.8	10.7	19	20.8	11.0	14	24.6	14.1	19	26.5	11.0	18	28.0	11.7	19	27.0	9.2
	Return time	19	84.3	31.0	19	77.0	38.4	14	75.9	35.3	19	97.2	8.6	18	89.1	27.3	19	91.4	23.6
Rotation																			
LAS	Rrot																		
	Away peak	19	20.6	11.3	19	21.1	14.2	13	14.3	5.2	18	22.8	17.0	18	26.6	20.6	18	15.7	9.0
	Away mean	19	11.2	5.0	19	11.9	8.0	13	8.2	3.5	18	15.4	12.6	18	16.3	12.9	18	9.6	5.0
	Away time	19	69.3	39.9	19	64.2	36.7	13	62.0	30.3	18	59.8	36.0	18	60.6	37.1	18	46.6	38.9
	Return peak	19	25.7	14.1	19	25.2	16.0	13	17.9	5.4	18	24.3	18.8	18	26.2	19.8	18	22.3	16.1
	Return mean	19	16.6	10.4	19	16.1	10.7	13	11.5	4.7	18	17.7	13.8	18	17.4	14.2	18	17.0	11.6
	Return time	19	70.1	36.2	19	68.2	38.2	13	72.3	28.8	18	66.3	41.2	18	70.6	30.5	18	64.1	44.8
	Lrot																		
	Away peak	19	24.4	17.2	19	26.7	26.9	13	22.0	10.9	18	18.6	12.7	18	18.7	13.4	18	19.0	8.8
	Away mean	19	13.4	9.5	19	13.3	11.7	13	11.7	5.9	18	11.1	8.3	18	11.6	9.5	18	11.3	6.3
	Away time	19	66.9	39.6	19	60.8	34.8	13	75.7	28.0	18	52.8	38.6	18	57.4	35.0	18	48.9	38.4
	Return peak	19	23.9	20.6	19	25.0	27.9	13	16.9	8.2	18	17.2	10.9	18	17.6	17.6	18	16.8	9.1
	Return mean	19	13.9	11.6	19	13.7	13.2	13	9.2	4.3	18	11.1	6.6	18	12.7	14.0	18	11.8	7.3

RAS	Return time	19	59.4	41.6	19	55.9	42.1	13	63.8	33.0	18	47.6	38.9	18	49.8	40.5	18	52.2	46.6
	Rrot																		
	Away peak	19	17.5	8.7	19	21.2	18.5	14	21.5	16.5	18	16.4	11.3	18	17.8	13.4	18	16.5	5.6
	Away mean	19	9.8	5.3	19	11.0	6.2	14	11.2	6.1	18	10.6	8.2	18	11.3	10.6	18	9.5	3.2
	Away time	19	75.4	32.2	19	70.0	37.9	14	76.3	30.9	18	68.4	35.5	18	69.3	35.8	18	69.8	36.9
	Return peak	19	20.2	17.2	19	22.6	28.5	14	18.9	17.7	18	12.8	7.7	18	14.8	9.7	18	15.0	7.6
	Return mean	19	11.6	9.0	19	12.7	12.6	14	9.2	4.9	18	8.2	4.7	18	10.0	8.0	18	9.9	5.8
	Return time	19	70.5	35.5	19	60.1	37.4	14	67.7	36.9	18	53.2	41.8	18	56.5	38.7	18	61.5	40.5
	Lrot																		
	Away peak	19	20.5	16.0	19	21.9	18.1	14	14.3	7.0	18	14.8	6.5	18	16.1	9.3	18	17.8	9.7
	Away mean	19	10.9	7.0	19	11.7	9.8	14	8.2	4.4	18	8.9	4.1	18	9.4	5.6	18	9.5	4.8
	Away time	19	72.7	33.4	19	56.7	36.8	14	65.3	26.9	18	68.4	36.8	18	60.7	36.1	18	57.2	32.5
	Return peak	19	23.3	18.9	19	23.0	13.9	14	14.0	5.6	18	17.2	9.6	18	18.4	13.6	18	21.8	13.5
	Return mean	19	14.3	10.7	19	12.8	7.4	14	9.1	4.1	18	12.7	7.2	18	13.0	10.0	18	16.0	10.1
	Return time	19	75.8	34.8	19	66.8	38.1	14	63.7	34.5	18	68.8	41.3	18	70.2	34.6	18	77.9	34.1
LPC	Rrot																		
	Away peak	20	28.1	22.0	19	23.9	19.0	15	20.2	12.2	19	26.1	20.3	19	30.5	27.8	19	23.2	14.5
	Away mean	20	14.2	6.8	19	16.1	15.0	15	13.5	9.3	19	17.1	14.1	19	19.0	19.9	19	12.6	8.8
	Away time	20	81.5	27.9	19	81.7	34.4	15	84.3	28.4	19	87.7	23.2	19	81.5	25.0	19	92.1	18.9
	Return peak	20	23.8	13.9	19	22.9	12.5	15	25.6	12.7	19	26.9	14.4	19	25.0	12.8	19	21.6	12.5
	Return mean	20	15.4	10.1	19	15.5	8.6	15	16.3	10.7	19	19.0	11.5	19	17.4	9.1	19	15.4	10.7
	Return time	20	82.5	30.7	19	83.4	32.9	15	89.1	25.7	19	81.6	29.9	19	87.7	18.8	19	94.2	18.3
	Lrot																		
	Away peak	20	55.3	21.4	19	55.3	32.5	15	51.3	21.1	19	50.4	23.2	19	48.9	26.2	19	54.1	20.9
	Away mean	20	31.3	15.9	19	28.6	16.1	15	30.7	11.0	19	29.4	15.4	19	29.1	18.4	19	29.0	14.2
	Away time	20	92.0	14.3	19	86.2	23.5	15	91.4	13.3	19	91.0	14.4	19	87.3	15.2	19	90.2	13.2
	Return peak	20	44.9	27.1	19	46.7	30.4	15	45.4	24.6	19	49.4	26.1	19	48.8	37.2	19	57.7	22.3
	Return mean	20	26.3	23.9	19	23.0	19.3	15	24.7	14.7	19	30.8	19.1	19	31.6	27.5	19	35.8	18.4
	Return time	20	85.9	21.4	19	83.3	31.7	15	85.0	21.2	19	81.4	33.0	19	80.5	27.0	19	94.6	16.0
RPC	Rrot																		

	Away peak	19	55.8	22.6	19	54.0	27.5	14	59.4	18.1	19	57.4	21.7	19	51.3	25.4	19	59.7	23.9
	Away mean	19	30.1	12.4	19	30.7	12.0	14	37.9	15.0	19	36.9	15.4	19	31.3	14.2	19	36.5	14.8
	Away time	19	97.8	6.4	19	93.9	22.9	14	98.9	3.9	19	87.1	30.4	19	94.0	11.8	19	97.0	7.9
	Return peak	19	44.4	25.5	19	45.4	28.7	14	47.6	21.7	19	51.5	22.8	19	54.4	37.8	19	61.0	25.9
	Return mean	19	21.9	15.6	19	22.9	17.1	14	24.2	11.8	19	31.0	15.7	19	33.8	27.1	19	36.7	20.7
	Return time	19	87.3	18.7	19	80.3	29.3	14	86.3	14.9	19	80.9	34.4	19	90.7	16.4	19	85.8	30.6
	Lrot																		
	Away peak	19	22.6	15.3	19	26.2	14.3	14	23.5	12.4	19	22.2	14.7	19	29.3	28.0	19	22.6	11.7
	Away mean	19	12.4	8.8	19	15.0	11.0	14	13.3	5.5	19	12.3	9.6	19	17.6	22.2	19	10.3	3.6
	Away time	19	77.1	27.5	19	74.1	31.6	14	74.6	24.3	19	62.1	37.5	19	74.2	24.9	19	71.3	29.8
	Return peak	19	23.9	12.5	19	24.0	13.5	14	29.3	16.2	19	29.5	16.3	19	25.4	13.7	19	29.4	17.3
	Return mean	19	15.3	7.7	19	14.6	7.9	14	16.5	7.4	19	19.2	11.4	19	17.1	8.7	19	19.0	11.0
	Return time	19	85.2	28.3	19	82.6	31.3	14	88.8	23.0	19	80.4	33.2	19	84.4	27.3	19	87.3	29.2
LT4	Rrot																		
	Away peak	20	15.0	12.6	20	12.9	12.1	14	15.0	12.4	19	13.9	8.6	19	12.9	8.6	19	12.9	12.3
	Away mean	20	11.3	9.6	20	10.5	10.1	14	12.5	10.1	19	11.3	7.6	19	10.2	7.1	19	10.7	10.9
	Away time	20	96.1	12.5	20	81.2	37.9	14	73.3	39.9	19	96.5	10.1	19	92.7	22.6	19	88.4	28.3
	Return peak	20	15.5	15.9	20	12.5	11.5	14	14.9	12.1	19	13.1	8.4	19	11.5	7.5	19	13.5	13.7
	Return mean	20	12.3	12.1	20	10.0	9.2	14	12.3	9.7	19	11.1	7.6	19	9.9	6.6	19	11.2	10.1
	Return time	20	94.1	18.8	20	78.8	39.9	14	75.0	40.1	19	92.8	18.7	19	95.8	12.5	19	89.2	26.1
	Lrot																		
	Away peak	20	13.4	12.6	20	10.8	9.6	14	13.5	10.6	19	13.2	8.3	19	11.0	7.2	19	13.8	13.7
	Away mean	20	10.9	10.4	20	8.7	7.9	14	10.6	8.6	19	10.4	6.9	19	9.2	6.4	19	10.8	10.7
	Away time	20	94.1	16.2	20	76.4	38.3	14	69.3	39.3	19	93.7	16.5	19	88.5	25.9	19	86.5	26.3
	Return peak	20	13.9	12.1	20	11.9	11.1	14	13.0	10.3	19	13.8	9.1	19	12.3	8.3	19	13.8	14.5
	Return mean	20	11.6	9.9	20	9.9	9.1	14	10.9	8.8	19	11.8	7.8	19	10.4	7.0	19	11.2	11.4
	Return time	20	95.6	12.6	20	75.8	42.7	14	64.3	41.7	19	95.9	11.6	19	86.0	33.6	19	86.8	26.6
RT4	Rrot																		
	Away peak	19	8.2	7.4	19	6.5	5.8	14	6.1	4.3	19	7.7	8.4	19	6.2	3.4	19	6.2	3.0
	Away mean	19	6.2	5.6	19	5.0	4.5	14	5.0	3.5	19	6.2	7.4	19	4.9	2.7	19	5.0	2.5

Away time	19	85.0	28.0	19	80.0	29.5	14	86.2	28.0	19	87.9	28.9	19	79.4	35.4	19	83.6	36.7
Return peak	19	8.2	7.4	19	6.9	7.1	14	5.8	4.2	19	8.0	8.7	19	7.2	5.2	19	7.1	5.5
Return mean	19	6.7	6.1	19	5.7	5.9	14	4.8	3.4	19	6.7	7.1	19	5.6	3.7	19	5.6	3.6
Return time	19	89.8	24.1	19	86.5	31.7	14	82.1	33.6	19	89.2	23.4	19	83.4	28.6	19	83.8	35.1
Lrot																		
Away peak	19	8.3	7.8	19	6.9	7.4	14	6.5	3.6	19	6.9	4.8	19	6.6	4.1	19	6.8	3.9
Away mean	19	6.5	6.1	19	5.5	5.6	14	5.1	3.0	19	5.5	4.1	19	5.2	3.1	19	5.1	2.3
Away time	19	89.8	23.5	19	83.7	28.3	14	87.9	24.3	19	92.4	21.0	19	84.9	24.8	19	87.6	29.6
Return peak	19	8.3	8.7	19	7.1	7.3	14	5.9	3.2	19	6.8	7.1	19	5.6	3.0	19	6.0	3.0
Return mean	19	6.9	7.2	19	5.7	5.7	14	5.0	2.8	19	5.6	5.2	19	4.8	2.6	19	5.0	2.3
Return time	19	87.1	26.5	19	81.6	31.9	14	86.6	31.8	19	89.6	21.8	19	81.7	31.5	19	85.2	34.8
LSCM Rrot																		
Away peak	19	54.8	30.1	19	51.2	28.9	13	51.8	19.5	18	44.9	23.8	18	45.1	26.6	18	54.0	15.8
Away mean	19	27.9	16.6	19	26.1	18.2	13	23.8	12.5	18	23.3	14.8	18	24.1	16.8	18	25.3	8.8
Away time	19	86.4	16.5	19	80.8	29.6	13	76.6	24.8	18	84.0	26.0	18	83.5	24.8	18	80.5	27.0
Return peak	19	49.7	27.5	19	47.7	26.5	13	51.5	22.3	18	48.8	29.5	18	49.5	37.9	18	59.5	17.8
Return mean	19	24.4	15.9	19	24.3	16.7	13	27.8	18.7	18	29.4	19.2	18	31.3	27.3	18	36.1	16.8
Return time	19	84.6	24.1	19	84.9	23.5	13	81.1	21.5	18	86.2	25.7	18	82.0	30.6	18	88.2	23.7
Lrot																		
Away peak	19	17.8	16.5	19	18.0	13.7	13	15.6	9.5	18	14.7	13.8	18	20.4	18.2	18	18.0	14.3
Away mean	19	9.5	10.0	19	9.6	9.5	13	7.6	4.1	18	7.7	8.5	18	9.9	10.0	18	8.2	7.8
Away time	19	69.9	34.7	19	71.9	29.4	13	52.5	36.6	18	61.8	37.2	18	69.9	31.9	18	48.7	37.9
Return peak	19	14.0	9.8	19	16.7	15.3	13	10.4	5.9	18	11.6	10.3	18	15.8	15.2	18	9.9	5.6
Return mean	19	8.0	6.1	19	9.2	8.4	13	5.8	3.1	18	7.3	6.6	18	10.5	11.1	18	6.7	4.0
Return time	19	60.6	37.3	19	68.5	32.6	13	47.5	41.4	18	66.2	34.8	18	69.3	33.8	18	56.7	45.8
RSCM Rrot																		
Away peak	19	18.1	14.6	19	18.9	16.3	14	18.6	14.2	18	18.5	18.9	18	21.7	22.4	18	18.3	10.0
Away mean	19	9.4	5.6	19	11.0	11.1	14	10.4	8.9	18	11.0	11.7	18	10.9	8.7	18	8.7	4.2
Away time	19	74.5	32.5	19	63.2	38.9	14	82.3	31.1	18	82.0	27.4	18	83.6	32.9	18	64.5	38.3
Return peak	19	15.9	11.7	19	15.6	14.3	14	16.4	12.3	18	13.3	10.2	18	18.5	15.1	18	11.9	4.2

	Return mean	19	8.8	6.2	19	9.5	10.2	14	8.4	5.7	18	8.4	6.5	18	12.6	11.1	18	7.8	3.1
	Return time	19	64.7	42.0	19	54.4	39.9	14	67.0	35.1	18	68.9	37.5	18	71.5	38.0	18	68.3	32.0
	Lrot																		
	Away peak	19	46.3	27.7	19	49.8	32.8	14	49.4	23.3	18	46.6	24.4	18	50.5	34.6	18	49.8	17.8
	Away mean	19	22.7	15.8	19	21.9	14.3	14	24.9	16.3	18	24.3	15.9	18	25.2	19.9	18	23.0	10.3
	Away time	19	77.3	25.8	19	66.4	34.0	14	81.2	24.2	18	85.9	25.3	18	82.3	24.1	18	79.5	22.8
	Return peak	19	44.5	28.0	19	46.4	30.2	14	41.6	21.7	18	41.2	26.3	18	44.0	38.1	18	48.6	20.6
	Return mean	19	25.1	18.1	19	23.3	16.2	14	22.8	14.3	18	26.9	17.7	18	30.3	30.9	18	31.1	17.4
	Return time	19	82.4	27.1	19	75.4	35.0	14	87.7	26.9	18	87.8	28.8	18	91.0	18.2	18	91.1	25.5
LUT	Rrot																		
	Away peak	20	6.9	6.3	20	8.7	11.4	15	7.5	9.0	19	14.1	11.9	19	12.7	11.7	19	14.3	17.1
	Away mean	20	4.8	4.7	20	6.3	8.7	15	5.2	6.8	19	9.9	8.6	19	8.7	8.1	19	10.6	13.5
	Away time	20	60.0	44.5	20	41.1	47.7	15	62.0	40.2	19	53.5	44.6	19	58.9	41.8	19	39.1	38.9
	Return peak	20	5.7	5.4	20	7.0	8.7	15	6.4	6.9	19	10.0	8.8	19	11.2	12.5	19	9.2	10.8
	Return mean	20	4.2	4.1	20	5.2	6.9	15	4.8	5.8	19	7.6	7.0	19	8.7	10.2	19	7.0	8.3
	Return time	20	52.1	45.5	20	39.0	46.5	15	55.2	42.3	19	42.5	43.8	19	52.0	38.3	19	32.4	43.1
	Lrot																		
	Away peak	20	5.6	4.2	20	5.9	6.7	15	6.5	6.0	19	8.5	6.6	19	9.6	9.6	19	8.9	8.3
	Away mean	20	3.4	2.7	20	3.4	3.1	15	4.1	3.9	19	5.5	4.2	19	6.6	7.0	19	5.7	5.5
	Away time	20	50.5	43.6	20	29.8	41.0	15	62.9	37.6	19	41.8	42.2	19	47.0	40.6	19	35.4	39.5
	Return peak	20	6.0	5.6	20	6.6	6.7	15	5.2	4.6	19	8.4	8.1	19	8.4	7.7	19	10.1	11.4
	Return mean	20	4.1	4.3	20	4.6	5.3	15	3.4	2.8	19	5.4	5.0	19	6.0	6.1	19	5.9	6.5
	Return time	20	52.3	45.9	20	34.6	40.0	15	56.4	39.7	19	38.9	41.3	19	42.4	44.6	19	33.6	39.3
RUT	Rrot																		
	Away peak	19	5.0	4.1	19	6.4	6.0	14	6.2	6.0	19	5.6	5.0	19	5.6	4.5	19	5.0	2.9
	Away mean	19	2.8	2.4	19	4.1	4.6	14	3.6	3.7	19	3.7	3.4	19	3.8	3.5	19	3.1	2.0
	Away time	19	56.6	41.2	19	51.1	45.2	14	70.8	34.3	19	35.3	42.6	19	50.1	45.6	19	45.8	45.3
	Return peak	19	5.3	4.2	19	7.2	8.1	14	4.5	3.8	19	5.3	7.6	19	4.6	3.8	19	4.2	2.3
	Return mean	19	3.1	2.5	19	5.0	6.5	14	2.9	2.2	19	3.6	5.3	19	3.2	3.4	19	2.9	1.8
	Return time	19	47.2	40.3	19	47.7	42.4	14	69.8	31.0	19	33.7	43.2	19	40.6	40.9	19	36.0	42.8

Lrot																		
Away peak	19	7.0	8.0	19	8.2	12.3	14	8.5	10.9	19	7.3	7.0	19	6.3	6.4	19	6.8	5.4
Away mean	19	4.7	5.1	19	5.7	8.6	14	5.8	7.6	19	5.1	5.7	19	4.6	5.1	19	4.6	3.9
Away time	19	59.5	38.8	19	49.2	45.3	14	77.1	24.5	19	40.1	38.3	19	39.4	40.2	19	44.3	42.7
Return peak	19	5.7	7.1	19	6.0	7.6	14	6.2	9.0	19	5.3	5.2	19	5.3	4.7	19	5.3	4.5
Return mean	19	3.8	3.6	19	3.7	4.9	14	4.5	6.8	19	4.1	4.5	19	4.1	3.8	19	4.1	3.4

(CG – control group; EG – experimental group; n – sample, % - percentage; LAS – left anterior scalene; RAS – right anterior scalene; LPC – left posterior cervical; RPC – right posterior cervical; LSCM – left sternocleidomastoid; RSCM – right sternocleidomastoid; LUT – left upper trapezius; RUT – right upper trapezius; LT4 – left paraspinal at T4; RT4 – right paraspinal at T4; LT9 – left paraspinal at T9; RT9 – right paraspinal at T9; Flex – flexion; Ext – extension; LLF – left lateral flexion; RLF – right lateral flexion; Lrot – left rotation; Rrot – right rotation)

**SUPPLEMENTARY FILE 7.5: COMPARISON OF BETWEEN GROUP DIFFERENCES
FOLLOWING ONE TREATMENT USING POST-ADJUSTED MEANS FOR THE MUSCLE
ACTIVATION PATTERNS**

ROM		Post values						p value	η^2	Adjusted means		MD	CI			
		CG			EG					CG	EG		Lower	Upper		
		n	M	SD	n	M	SD			M	M					
Flex/Ext																
LAS	Flex	Away	Peak	18	29.2	26.2	18	30.7	17.0	0.082	0.09	34.4	25.5	8.9	-1.2	19.0
		Mean	18	14.6	12.0	18	17.1	10.7	0.437	0.02	16.7	14.9	1.8	-2.8	6.3	
		Time %	18	66.3	34.3	18	62.2	29.6	0.816	0.00	63.1	65.3	-2.2	-21.5	17.1	
	Return	Peak	18	28.1	28.0	18	24.1	19.7	0.313	0.03	29.2	23.0	6.2	-6.1	18.5	
		Mean	18	14.4	13.2	18	14.8	11.9	0.784	0.00	15.1	14.1	1.0	-6.6	8.7	
		Time %	18	63.3	37.4	18	63.5	37.2	0.128	0.07	56.3	70.4	-14.0	-32.3	4.2	
	Ext	Away	Peak	18	20.9	18.4	18	22.0	15.0	0.594	0.01	23.1	19.9	3.2	-8.8	15.2
		Mean	18	12.9	9.8	18	14.0	10.1	0.977	0.00	13.5	13.4	0.1	-6.9	7.1	
		Time %	18	66.3	38.6	18	59.7	35.1	0.779	0.00	61.9	64.2	-2.3	-18.6	14.0	
Return	Peak	18	29.5	17.9	18	38.8	25.4	0.996	0.00	34.1	34.1	0.0	-11.2	11.1		
	Mean	18	19.1	10.5	18	26.2	17.1	0.684	0.01	23.3	22.0	1.3	-4.9	7.4		
	Time %	18	88.6	18.4	18	76.5	32.1	0.095	0.08	89.1	76.0	13.1	-2.4	28.6		
RAS	Flex	Away	Peak	18	21.8	14.0	18	34.3	26.9	0.560	0.01	26.8	29.3	-2.6	-11.4	6.3
		Mean	18	10.6	7.3	18	16.8	13.3	0.602	0.01	13.1	14.3	-1.3	-6.1	3.6	
		Time %	18	56.3	32.2	18	56.5	30.1	0.725	0.00	54.9	57.9	-3.0	-20.0	14.0	
	Return	Peak	18	20.3	13.1	18	26.1	20.1	0.756	0.00	22.5	24.0	-1.5	-10.9	8.0	
		Mean	18	10.5	6.9	18	14.8	10.7	0.466	0.02	11.6	13.7	-2.1	-7.8	3.6	
		Time %	18	63.8	39.1	18	63.8	39.0	0.352	0.03	59.5	68.0	-8.5	-26.8	9.8	
	Ext	Away	Peak	18	19.4	17.3	18	21.6	15.0	0.735	0.00	21.4	19.6	1.8	-8.9	12.5
		Mean	18	12.1	10.2	18	13.5	10.3	0.905	0.00	13.0	12.6	0.4	-6.3	7.2	
		Time %	17	64.3	38.9	18	63.9	28.9	0.761	0.00	65.4	62.8	2.7	-15.1	20.4	
	Return	Peak	18	23.0	14.9	18	34.9	23.2	0.854	0.00	28.6	29.3	-0.8	-9.1	7.6	

	Mean	18	14.4	8.9	18	22.8	14.9	0.796	0.00	19.0	18.3	0.7	-4.7	6.1
	Time %	18	75.8	31.4	18	74.8	33.2	0.190	0.05	80.1	70.5	9.6	-5.0	24.2
LPC	Flex													
Away	Peak	18	10.1	7.8	19	13.3	13.9	0.280	0.03	9.6	13.7	-4.1	-11.6	3.5
	Mean	18	6.5	4.7	19	8.1	6.9	0.289	0.03	6.3	8.3	-2.0	-5.8	1.8
	Time %	18	55.0	39.6	19	30.3	29.2	0.070	0.09	52.6	32.6	20.0	-1.7	41.8
Return	Peak	18	30.3	19.9	19	33.5	24.9	0.986	0.00	32.0	31.9	0.1	-10.5	10.7
	Mean	18	21.6	15.0	19	20.8	14.4	0.908	0.00	21.0	21.4	-0.4	-7.2	6.4
	Time %	18	93.2	16.9	19	72.7	31.4	0.047	0.11	91.4	74.4	17.0	0.3	33.8
	Ext													
Away	Peak	18	22.4	10.5	19	31.2	24.8	0.280	0.03	23.8	29.9	-6.1	-17.4	5.2
	Mean	18	10.9	5.5	19	16.5	14.4	0.140	0.06	11.2	16.2	-5.0	-11.7	1.7
	Time %	18	81.4	23.6	19	61.3	32.2	0.144	0.06	78.2	64.4	13.8	-4.9	32.5
Return	Peak	18	9.2	5.5	19	13.7	13.7	0.146	0.06	9.1	13.8	-4.7	-11.2	1.7
	Mean	18	5.1	2.7	19	9.6	9.5	0.051	0.11	5.1	9.6	-4.5	-8.9	0.0
	Time %	19	41.5	37.6	19	24.3	32.5	0.164	0.06	40.7	25.1	15.6	-6.7	37.8
RPC	Flex													
Away	Peak	18	11.1	10.5	19	10.8	12.0	0.685	0.01	10.2	11.7	-1.5	-9.0	6.0
	Mean	18	6.2	4.1	19	6.2	5.1	0.734	0.00	5.9	6.4	-0.5	-3.5	2.5
	Time	18	49.8	35.5	19	39.6	35.6	0.710	0.00	46.9	42.4	4.5	-19.9	28.9
Return	Peak	18	33.9	24.3	19	31.9	28.9	0.842	0.00	33.5	32.3	1.2	-11.3	13.8
	Mean	18	24.1	19.0	19	17.6	12.7	0.581	0.01	21.6	19.9	1.7	-4.4	7.8
	Time %	18	91.1	19.4	19	70.4	31.1	0.195	0.05	85.9	75.3	10.6	-5.7	26.8
	Ext													
Away	Peak	18	27.4	17.7	19	27.2	15.1	0.874	0.00	27.0	27.6	-0.6	-8.6	7.4
	Mean	18	12.9	8.7	19	13.4	7.2	0.775	0.00	12.8	13.5	-0.7	-5.4	4.1
	Time %	18	80.6	22.2	19	70.1	25.1	0.643	0.01	76.8	73.7	3.1	-10.4	16.5
Return	Peak	18	9.0	7.1	19	12.1	9.2	0.343	0.03	9.2	11.9	-2.6	-8.2	2.9
	Mean	18	5.1	3.7	19	7.9	7.1	0.157	0.06	5.1	7.9	-2.8	-6.7	1.1
	Time %	18	36.9	37.0	19	35.5	31.2	0.570	0.01	33.1	39.0	-5.9	-27.0	15.1
LT4	Flex													
Away	Peak	19	14.2	11.4	19	14.4	9.2	0.533	0.01	13.6	14.9	-1.3	-5.7	3.0
	Mean	19	10.6	8.6	19	11.1	7.2	0.771	0.00	10.6	11.1	-0.4	-3.3	2.5
	Time %	19	88.8	27.5	19	92.4	21.6	0.163	0.06	85.7	95.5	-9.8	-23.8	4.2
Return	Peak	19	15.1	10.9	19	16.4	11.8	0.304	0.03	14.2	17.3	-3.1	-9.0	2.9
	Mean	19	12.1	8.8	19	13.1	8.6	0.351	0.03	11.5	13.7	-2.2	-6.9	2.5
	Time %	19	94.5	21.7	19	97.5	10.8	0.404	0.02	93.6	98.4	-4.8	-16.3	6.7

Away	Ext							0.127	0.07	12.5	17.3	-4.8	-11.1	1.4
	Peak	19	13.9	11.0	19	15.9	13.2							
	Mean	19	10.5	8.7	19	12.3	10.9							
	Time %	19	91.6	23.4	19	93.0	15.5							
	Peak	19	12.0	9.5	19	15.4	21.3							
	Mean	19	9.2	7.1	19	10.9	11.6							
Return	Time %	19	87.2	31.0	19	83.2	28.7	0.476	0.02	82.2	88.2	-6.0	-22.8	10.9
	Flex							0.058	0.10	7.5	9.4	-1.8	-3.7	0.1
	Peak	18	9.0	10.1	19	8.0	4.2							
Away	Mean	18	7.0	8.0	19	6.1	3.3							
	Time %	18	93.0	16.9	19	90.3	15.6	0.335	0.03	94.1	89.2	4.8	-5.2	14.9
	Peak	18	8.9	9.4	19	8.5	3.5	0.017	0.16	7.3	10.0	-2.7	-4.8	-0.5
Return	Mean	18	6.8	6.4	19	7.1	3.2	0.016	0.16	5.8	8.1	-2.3	-4.2	-0.5
	Time %	18	92.1	13.2	19	94.7	17.1	0.581	0.01	92.0	94.7	-2.7	-12.7	7.2
Away	Ext							0.078	0.09	6.4	8.3	-2.0	-4.2	0.2
	Peak	18	7.1	4.4	19	7.6	4.1							
	Mean	18	5.4	3.2	19	6.0	3.4	0.046	0.11	4.7	6.6	-1.9	-3.7	0.0
Return	Time %	18	86.9	27.8	19	83.6	24.7	0.647	0.01	87.1	83.4	3.7	-12.6	20.0
	Peak	18	6.8	5.9	19	7.2	5.3	0.205	0.05	6.0	8.0	-2.0	-5.1	1.1
	Mean	18	5.1	4.1	19	5.2	3.5	0.089	0.08	4.4	5.9	-1.6	-3.4	0.3
Time %	Time %	18	83.7	27.1	19	79.0	30.4	0.305	0.03	84.5	78.2	6.2	-5.9	18.4
	Flex							0.397	0.02	25.5	21.9	3.6	-5.0	12.2
	Peak	18	21.7	24.1	18	25.7	17.1							
Away	Mean	18	10.3	10.2	18	12.8	10.8	0.588	0.01	12.1	11.0	1.0	-2.8	4.9
	Time %	18	69.2	28.4	18	72.4	25.7	0.791	0.00	69.8	71.9	-2.1	-18.4	14.1
	Peak	18	23.6	26.4	18	15.0	12.9	0.083	0.09	23.8	14.9	8.9	-1.2	19.1
Return	Mean	18	12.1	12.9	18	8.3	4.8	0.146	0.06	12.4	8.0	4.4	-1.6	10.3
	Time %	18	80.3	34.5	18	75.0	33.4	0.705	0.00	79.6	75.6	4.0	-17.3	25.3
Away	Ext							0.393	0.02	18.7	14.1	4.6	-6.1	15.3
	Peak	18	17.3	18.1	18	15.6	14.2							
	Mean	18	9.9	9.6	18	9.5	9.8	0.774	0.00	10.2	9.2	0.9	-5.6	7.4
Return	Time %	18	78.6	28.8	18	74.5	31.9	0.423	0.02	80.3	72.8	7.5	-11.3	26.4
	Peak	18	25.5	18.9	18	31.4	22.8	0.488	0.02	29.8	27.1	2.7	-5.1	10.4
	Mean	18	15.2	11.1	18	21.1	17.5	0.608	0.01	18.8	17.5	1.3	-3.7	6.3
Time %	Time %	18	91.1	16.2	18	85.2	27.6	0.034	0.13	95.7	80.7	15.0	1.2	28.8
	Flex							0.638	0.01	23.9	26.6	-2.7	-14.3	8.9
	Peak	18	16.6	7.2	18	34.0	28.7							
	Time %	18	83.7	27.1	19	79.0	30.4							

Return	Mean	18	7.5	3.2	18	16.6	14.8	0.423	0.02	11.0	13.1	-2.1	-7.5	3.2
	Time %	18	58.0	32.2	18	73.8	31.7	0.491	0.02	63.0	68.8	-5.8	-22.9	11.2
	Peak	18	16.5	9.9	18	24.8	17.9	0.288	0.03	18.2	23.1	-5.0	-14.3	4.4
	Mean	18	9.3	6.1	18	14.5	10.3	0.199	0.05	10.1	13.8	-3.7	-9.5	2.1
	Time %	18	73.9	34.2	18	81.0	32.3	0.782	0.00	78.4	76.5	1.9	-11.7	15.5
	Ext													
Away	Peak	18	15.6	14.8	18	20.9	15.1	0.837	0.00	17.8	18.7	-1.0	-10.4	8.5
	Mean	18	10.0	8.4	18	13.2	10.2	0.655	0.01	11.0	12.3	-1.3	-7.3	4.7
	Time %	18	67.8	33.9	18	79.5	31.5	0.644	0.01	75.5	71.8	3.6	-12.2	19.4
Return	Peak	18	25.1	20.7	18	36.0	25.4	0.842	0.00	30.1	31.0	-0.9	-10.2	8.4
	Mean	18	14.8	11.6	18	23.9	18.4	0.915	0.00	19.2	19.5	-0.3	-6.0	5.4
	Time %	18	82.2	25.8	18	80.6	27.7	0.207	0.05	85.7	77.1	8.7	-5.0	22.3
LUT														
Away	Flex													
	Peak	19	5.4	8.3	19	9.6	8.3	0.343	0.03	6.7	8.3	-1.6	-5.0	1.8
	Mean	19	3.9	6.5	19	6.8	6.4	0.281	0.03	4.7	6.1	-1.4	-3.9	1.2
Return	Time %	19	28.7	41.8	19	44.1	39.4	0.060	0.10	25.1	47.7	-22.6	-46.1	1.0
	Peak	19	6.3	9.0	19	9.1	9.1	0.271	0.03	6.9	8.5	-1.6	-4.5	1.3
	Mean	19	5.0	7.6	19	7.2	7.6	0.219	0.04	5.3	7.0	-1.7	-4.4	1.0
Away	Time %	19	38.1	47.2	19	52.2	41.8	0.145	0.06	34.3	56.0	-21.7	-51.2	7.8
	Ext													
	Peak	19	5.3	8.8	19	9.8	11.4	0.459	0.02	7.0	8.2	-1.1	-4.1	1.9
Return	Mean	19	4.0	6.9	19	7.1	8.6	0.376	0.02	5.0	6.1	-1.1	-3.6	1.4
	Time %	19	31.2	43.6	19	43.5	41.6	0.141	0.06	27.4	47.3	-19.9	-46.6	6.9
	Peak	19	5.0	6.8	19	8.8	9.8	0.258	0.04	6.2	7.6	-1.4	-3.9	1.1
Return	Mean	19	3.7	5.5	19	6.8	7.6	0.229	0.04	4.6	5.9	-1.3	-3.4	0.8
	Time %	19	27.4	40.4	19	44.0	45.0	0.125	0.07	25.8	45.6	-19.7	-45.2	5.7
RUT														
Away	Flex													
	Peak	18	4.7	6.4	19	5.1	5.2	0.115	0.07	5.9	4.0	1.9	-0.5	4.4
	Mean	18	3.1	4.1	19	3.8	4.3	0.235	0.04	3.9	3.0	0.9	-0.6	2.4
Return	Time %	18	35.2	38.5	19	32.6	39.0	0.917	0.00	33.3	34.3	-1.0	-20.0	18.1
	Peak	18	5.9	8.2	19	5.2	4.6	0.564	0.01	6.0	5.1	0.9	-2.1	3.8
	Mean	18	4.2	5.5	19	4.1	3.9	0.799	0.00	4.3	4.0	0.3	-2.0	2.6
Away	Time %	18	51.4	47.3	19	48.2	41.0	0.812	0.00	48.4	51.0	-2.6	-24.7	19.5
	Ext													
	Peak	18	5.2	7.4	19	5.9	6.0	0.992	0.00	5.6	5.6	0.0	-2.6	2.6
Return	Mean	18	3.7	5.5	19	4.3	4.8	0.987	0.00	4.0	4.0	0.0	-2.2	2.2
	Time %	18	49.5	45.5	19	39.4	42.3	0.854	0.00	45.3	43.4	1.9	-18.9	22.7

Return	Peak	18	5.3	7.0	19	5.0	5.3	0.688	0.01	5.4	4.9	0.5	-2.0	3.0
	Mean	18	3.3	4.5	19	3.8	4.1	0.811	0.00	3.7	3.4	0.3	-1.9	2.4
	Time %	18	42.9	44.9	18	35.6	40.2	0.736	0.00	40.9	37.6	3.2	-16.1	22.6
LT9 Flex														
Away	Peak	19	29.9	17.6	18	31.8	17.6	0.744	0.00	30.3	31.4	-1.0	-7.4	5.4
	Mean	19	23.0	13.3	18	24.9	15.7	0.971	0.00	23.9	24.0	-0.1	-5.5	5.3
	Time %	19	86.9	28.5	18	92.8	18.7	0.358	0.03	86.2	93.6	-7.4	-23.5	8.7
Return	Peak	19	27.0	13.4	18	30.3	12.6	0.627	0.01	28.1	29.2	-1.1	-5.9	3.6
	Mean	19	21.0	10.6	18	24.2	9.6	0.509	0.01	21.8	23.3	-1.5	-6.0	3.0
	Time %	19	89.6	25.2	18	97.3	11.5	0.234	0.04	89.7	97.2	-7.5	-20.2	5.1
Ext														
Away	Peak	19	20.6	11.3	18	26.8	15.0	0.183	0.05	21.5	25.8	-4.3	-10.8	2.1
	Mean	19	15.8	8.9	18	20.8	12.0	0.232	0.04	16.7	19.9	-3.2	-8.5	2.1
	Time %	19	79.7	34.9	18	92.4	21.4	0.155	0.06	79.9	92.1	-12.2	-29.3	4.8
Return	Peak	19	21.8	11.1	18	27.0	22.8	0.484	0.02	22.7	26.1	-3.4	-13.0	6.3
	Mean	19	16.7	8.6	18	19.8	12.8	0.377	0.02	17.1	19.4	-2.3	-7.5	2.9
	Time %	19	80.1	38.5	18	85.1	26.5	0.489	0.01	79.6	85.6	-5.9	-23.1	11.3
RT9 Flex														
Away	Peak	18	30.8	17.0	19	36.3	20.5	0.429	0.02	32.0	35.1	-3.1	-11.0	4.8
	Mean	18	24.2	13.3	19	28.7	17.6	0.525	0.01	25.5	27.5	-2.0	-8.5	4.4
	Time %	18	87.1	26.4	19	89.8	25.5	0.782	0.00	87.3	89.7	-2.4	-19.8	15.0
Return	Peak	18	27.8	14.6	19	34.5	15.9	0.137	0.06	28.4	34.0	-5.6	-13.1	1.9
	Mean	18	21.9	11.8	19	27.3	11.5	0.143	0.06	22.3	26.9	-4.6	-10.8	1.6
	Time %	18	80.5	34.1	19	92.5	20.0	0.186	0.05	80.3	92.6	-12.3	-30.8	6.2
Ext														
Away	Peak	18	23.7	14.4	19	29.0	13.1	0.083	0.09	23.2	29.5	-6.3	-13.5	0.9
	Mean	18	18.1	11.7	19	21.9	9.8	0.085	0.09	17.6	22.4	-4.8	-10.4	0.7
	Time %	18	75.7	38.2	19	82.5	30.6	0.562	0.01	75.9	82.4	-6.5	-28.9	15.9
Return	Peak	18	23.0	13.7	19	29.7	16.9	0.187	0.05	23.7	29.0	-5.3	-13.3	2.7
	Mean	18	17.8	11.1	19	22.7	13.3	0.147	0.06	17.8	22.6	-4.8	-11.4	1.8
	Time %	18	71.1	40.6	19	85.7	27.0	0.327	0.03	73.2	83.7	-10.5	-31.9	10.9
Lateral Flex														
LAS RLF														
Away	Peak	19	12.7	11.8	17	15.5	14.9	0.472	0.02	12.4	15.8	3.4	-6.1	12.9
	Mean	19	6.6	3.4	17	9.1	7.5	0.160	0.06	6.4	9.3	-2.8	-6.9	1.2
	Time %	19	37.2	41.4	17	33.1	38.5	0.059	0.10	24.0	47.9	-23.9	-48.7	1.0
Return	Peak	19	35.2	18.4	17	32.2	22.7	0.608	0.01	35.2	32.3	2.9	-8.6	14.4

Away	Mean	19	20.9	10.7	17	17.5	10.6	0.506	0.01	20.3	18.1	2.2	-4.4	8.7
	Time %	19	76.9	33.3	17	62.8	29.2	0.820	0.00	71.2	69.2	1.9	-15.3	19.2
	LLF													
	Peak	19	36.1	18.4	17	37.2	19.9	0.700	0.01	35.6	37.8	-2.1	-13.4	9.1
	Mean	19	21.1	12.0	17	20.2	11.6	0.915	0.00	20.9	20.5	0.4	-6.4	7.1
	Time %	19	84.2	23.2	17	73.1	29.2	0.517	0.01	81.4	76.3	5.1	-10.8	21.0
	Peak	19	30.6	20.6	17	26.8	22.1	0.772	0.00	29.8	27.7	2.1	-12.5	16.7
	Mean	19	15.7	12.1	17	16.4	16.1	0.652	0.01	15.0	17.1	-2.1	-11.5	7.3
	Time %	19	62.6	35.5	17	57.4	36.3	0.614	0.01	57.7	62.8	-5.1	-25.6	15.3
RAS														
Away	RLF													
	Peak	19	43.4	31.2	17	40.9	25.8	0.768	0.00	43.3	41.1	2.2	-12.9	17.3
	Mean	19	23.8	17.0	17	23.8	16.2	0.797	0.00	23.3	24.3	-1.0	-9.0	7.0
Return	Time %	19	85.1	31.2	17	76.5	32.0	0.974	0.00	80.9	81.2	-0.3	-16.3	15.8
	Peak	19	38.0	31.6	17	30.4	20.9	0.791	0.00	35.5	33.2	2.2	-14.7	19.2
	Mean	19	18.3	18.6	17	16.8	14.9	0.857	0.00	17.1	18.1	-1.0	-11.6	9.7
Away	Time %	19	58.9	36.2	17	53.7	34.9	0.823	0.00	57.6	55.1	2.5	-20.4	25.4
	LLF													
	Peak	19	8.0	5.1	17	14.0	13.4	0.079	0.09	8.0	14.1	-6.1	-13.0	0.8
Return	Mean	19	4.6	2.2	17	8.1	8.2	0.062	0.10	4.5	8.3	-3.8	-7.9	0.2
	Time %	19	32.8	37.0	17	26.8	30.2	0.768	0.00	31.4	28.4	3.0	-17.3	23.3
	Peak	19	25.1	16.5	17	29.4	21.8	0.445	0.02	25.6	28.8	-3.2	-11.7	5.2
Return	Mean	19	15.8	10.8	17	15.3	9.7	0.881	0.00	15.4	15.7	-0.3	-5.0	4.3
	Time %	19	75.5	36.8	17	69.1	30.8	0.865	0.00	71.8	73.3	-1.6	-20.4	17.2
LPC														
Away	RLF													
	Peak	19	12.3	7.3	18	13.9	7.7	0.270	0.04	11.8	14.4	-2.6	-7.2	2.1
	Mean	19	7.9	4.8	18	8.9	4.2	0.248	0.04	7.7	9.1	-1.5	-4.0	1.1
Return	Time %	19	67.3	39.7	18	60.8	37.1	0.656	0.01	66.6	61.6	5.0	-17.6	27.6
	Peak	19	14.9	9.8	18	15.0	10.9	0.657	0.01	15.5	14.4	1.1	-4.0	6.2
	Mean	19	10.6	6.8	18	10.4	7.2	0.539	0.01	11.0	10.0	1.0	-2.3	4.3
Away	Time %	19	78.2	35.1	18	66.0	37.6	0.357	0.03	76.7	67.5	9.1	-10.8	29.0
	LLF													
	Peak	19	20.1	13.3	18	20.5	11.1	0.810	0.00	19.9	20.7	-0.8	-7.9	6.2
Return	Mean	19	12.0	8.5	18	12.5	7.1	0.989	0.00	12.3	12.2	0.0	-3.6	3.7
	Time %	19	78.0	32.1	18	72.7	27.4	0.994	0.00	75.4	75.4	-0.1	-18.8	18.7
	Peak	19	20.3	15.0	18	20.0	21.5	0.505	0.01	18.6	21.8	-3.3	-13.1	6.6
Return	Mean	19	11.3	8.0	18	14.0	16.1	0.194	0.05	10.5	14.8	-4.3	-11.0	2.3
	Time %	19	73.3	37.1	18	67.3	35.5	0.874	0.00	71.2	69.5	1.7	-20.4	23.9

RPC														
Away	RLF													
	Peak	19	19.8	10.8	18	19.5	11.5	0.235	0.04	21.1	18.2	2.9	-2.0	7.8
	Mean	19	12.5	6.7	18	12.5	7.6	0.198	0.05	13.6	11.3	2.3	-1.2	5.8
Return	Time %	19	77.6	34.7	18	82.1	22.9	0.582	0.01	77.2	82.6	-5.4	-24.9	14.2
	Peak	19	15.4	9.6	18	17.4	13.9	0.789	0.00	15.9	16.9	-1.0	-8.3	6.3
	Mean	19	9.0	6.9	18	11.3	9.1	0.751	0.00	9.8	10.5	-0.8	-5.7	4.2
Away	Time %	19	61.3	40.6	18	66.3	37.2	0.553	0.01	60.1	67.5	-7.4	-32.5	17.7
	LLF													
	Peak	19	10.8	8.2	18	11.7	6.4	0.910	0.00	11.4	11.1	0.3	-4.7	5.2
Return	Mean	19	7.3	5.4	18	7.6	4.2	0.843	0.00	7.6	7.3	0.3	-3.0	3.6
	Time %	19	58.0	39.7	18	52.2	33.3	0.599	0.01	58.2	52.0	6.2	-17.7	30.1
	Peak	19	16.8	12.7	18	14.8	8.0	0.189	0.05	17.4	14.2	3.2	-1.6	8.0
Away	Mean	19	12.2	9.2	18	10.0	4.9	0.157	0.06	12.2	9.9	2.3	-0.9	5.6
	Time %	19	75.6	38.4	18	72.3	28.2	0.872	0.00	73.2	74.8	-1.6	-21.9	18.6
LT4														
Away	RLF													
	Peak	20	10.6	10.9	18	11.7	8.4	0.669	0.01	10.8	11.5	-0.6	-3.6	2.4
	Mean	20	8.6	8.8	18	9.4	7.0	0.825	0.00	9.1	8.9	0.2	-1.9	2.3
Return	Time %	20	77.0	40.0	18	88.5	28.7	0.090	0.08	74.5	91.3	-16.9	-36.5	2.8
	Peak	20	9.9	9.7	18	12.7	9.5	0.740	0.00	11.0	11.5	-0.6	-4.0	2.9
	Mean	20	8.1	7.9	18	10.5	8.0	0.604	0.01	8.9	9.6	-0.6	-3.1	1.8
Away	Time %	20	77.9	40.1	18	89.7	27.8	0.231	0.04	77.4	90.3	-12.9	-34.3	8.6
	LLF													
	Peak	20	11.0	9.9	18	11.9	7.8	0.312	0.03	10.8	12.2	-1.5	-4.4	1.4
Return	Mean	20	8.5	8.1	18	9.4	6.7	0.421	0.02	8.5	9.4	-0.9	-3.1	1.3
	Time %	20	73.1	41.5	18	88.0	28.1	0.116	0.07	72.1	89.0	-16.9	-38.2	4.4
	Peak	20	9.6	8.2	18	11.0	7.1	0.217	0.04	9.4	11.2	-1.9	-4.9	1.2
Away	Mean	20	7.9	6.9	18	9.3	6.4	0.266	0.04	7.9	9.3	-1.4	-3.8	1.1
	Time %	20	74.7	41.6	18	90.7	24.9	0.119	0.07	74.0	91.4	-17.4	-39.5	4.7
RT4														
Away	RLF													
	Peak	19	5.8	4.2	18	6.7	3.7	0.174	0.05	5.7	6.8	-1.1	-2.7	0.5
	Mean	14	6.4	4.3	19	5.8	2.9	0.739	0.00	6.3	5.9	0.4	-2.2	3.0
Return	Time %	19	75.3	36.5	18	82.3	26.1	0.936	0.00	78.4	79.1	-0.7	-19.0	17.6
	Peak	19	7.2	6.7	19	6.9	3.9	0.836	0.00	7.0	7.1	-0.1	-1.2	1.0
	Mean	19	5.8	4.2	18	6.7	3.7	0.224	0.04	5.7	6.9	-1.2	-3.1	0.7
Away	Time %	19	73.9	38.4	18	79.1	34.8	0.960	0.00	76.6	76.1	0.5	-20.7	21.7
	LLF													
	Peak	19	6.7	8.1	18	5.9	2.8	0.711	0.00	6.1	6.5	-0.4	-2.3	1.6

Return	Mean	19	5.3	5.9	18	4.7	2.3	0.773	0.00	4.9	5.1	-0.2	-1.8	1.4
	Time %	19	75.7	38.9	18	82.2	28.5	0.426	0.02	75.2	82.7	-7.5	-26.4	11.4
	Peak	19	6.7	8.5	18	6.2	2.8	0.365	0.02	6.1	6.9	-0.8	-2.6	1.0
	Mean	19	5.3	6.1	18	4.9	2.3	0.389	0.02	4.8	5.4	-0.6	-2.0	0.8
	Time %	19	77.9	37.6	18	84.9	29.3	0.630	0.01	78.8	83.9	-5.0	-25.9	15.9
LSCM RLF														
Away	Peak	19	9.0	14.3	17	14.3	15.7	0.279	0.04	8.8	14.5	-5.7	-16.2	4.8
	Mean	19	4.1	3.4	17	7.2	8.5	0.175	0.06	4.2	7.2	-3.0	-7.4	1.4
	Time %	19	35.9	31.9	17	49.4	40.4	0.175	0.06	34.5	50.9	-16.4	-40.4	7.7
Return	Peak	19	32.0	18.1	17	25.8	17.2	0.260	0.04	31.9	26.0	5.9	-4.6	16.4
	Mean	19	18.8	12.6	17	13.2	9.1	0.158	0.06	18.4	13.7	4.7	-1.9	11.3
	Time %	19	83.4	27.4	17	79.0	23.1	0.927	0.00	81.7	80.9	0.7	-15.7	17.2
LLF														
Away	Peak	19	41.7	24.4	17	40.0	26.7	0.987	0.00	40.8	41.0	-0.1	-16.7	16.4
	Mean	19	24.2	15.0	17	22.7	19.8	0.900	0.00	23.9	23.2	0.7	-10.1	11.5
	Time %	19	87.9	23.3	17	80.7	22.4	0.346	0.03	88.1	80.6	7.5	-8.5	23.5
Return	Peak	19	31.3	19.3	17	35.5	32.8	0.347	0.03	29.7	37.3	-7.5	-23.6	8.5
	Mean	19	14.9	17.0	17	20.0	20.4	0.253	0.04	14.4	20.5	-6.1	-16.7	4.5
	Time %	19	72.1	30.9	17	59.5	38.4	0.299	0.03	72.0	59.6	12.4	-11.5	36.3
RSCM RLF														
Away	Peak	19	46.0	25.2	17	51.1	30.5	0.589	0.01	46.0	51.1	-5.1	-24.3	14.0
	Mean	19	24.2	11.8	17	30.3	22.0	0.323	0.03	24.3	30.2	-5.9	-17.9	6.1
	Time %	19	85.3	31.5	17	87.0	24.7	0.595	0.01	84.1	88.3	-4.2	-20.0	11.6
Return	Peak	19	34.7	22.0	17	42.4	37.9	0.290	0.03	33.5	43.7	-10.2	-29.6	9.1
	Mean	19	15.8	17.2	17	24.2	24.6	0.176	0.06	15.9	24.2	-8.3	-20.6	3.9
	Time %	19	59.5	36.3	17	66.6	38.9	0.409	0.02	59.4	66.7	-7.3	-25.0	10.5
LLF														
Away	Peak	19	9.4	10.6	17	16.4	15.3	0.117	0.07	9.2	16.5	-7.3	-16.4	1.9
	Mean	19	4.8	3.6	17	8.6	9.3	0.102	0.08	4.7	8.7	-4.0	-8.8	0.8
	Time %	19	33.6	38.4	17	54.3	35.9	0.104	0.08	35.1	52.6	-17.5	-38.7	3.8
Return	Peak	19	25.0	20.1	17	33.6	23.8	0.494	0.01	27.1	31.2	-4.0	-15.9	7.8
	Mean	19	16.3	13.1	17	17.7	12.9	0.940	0.00	16.9	17.1	-0.3	-7.1	6.6
	Time %	19	73.0	35.5	17	83.7	25.9	0.248	0.04	72.9	83.8	-11.0	-30.0	8.0
LUT RLF														
Away	Peak	20	8.1	8.5	18	10.9	11.8	0.870	0.00	9.6	9.2	0.3	-3.7	4.3
	Mean	20	5.1	5.0	18	7.7	9.6	0.998	0.00	6.3	6.3	0.0	-3.5	3.5
	Time %	20	34.4	38.7	18	58.2	42.1	0.005	0.20	29.3	63.8	-34.5	-57.9	-11.0

Return	Peak	20	6.9	7.8	18	9.4	11.0	0.910	0.00	8.0	8.2	-0.3	-4.8	4.3
	Mean	20	4.9	5.5	18	6.4	8.2	0.968	0.00	5.6	5.6	0.1	-3.6	3.7
	Time %	20	35.7	44.2	18	49.3	40.0	0.128	0.07	32.3	53.0	-20.7	-47.5	6.2
LLF														
Away	Peak	20	12.5	13.0	18	13.6	14.1	0.453	0.02	14.0	11.9	2.1	-3.4	7.6
	Mean	20	8.9	9.6	18	9.5	11.0	0.376	0.02	10.0	8.2	1.9	-2.3	6.1
	Time %	20	54.5	38.6	18	61.2	42.5	0.231	0.04	50.7	65.4	-14.7	-39.2	9.8
Return	Peak	20	10.5	9.3	18	10.8	9.7	0.567	0.01	11.1	10.1	1.0	-2.4	4.3
	Mean	20	7.9	7.0	18	8.1	8.0	0.609	0.01	8.3	7.6	0.7	-2.0	3.3
	Time %	20	50.7	39.7	18	58.8	44.9	0.131	0.06	45.2	64.9	-19.7	-45.7	6.2
RUT														
RLF														
Away	Peak	19	9.4	10.5	18	9.4	12.4	0.276	0.04	10.5	8.3	2.2	-1.8	6.1
	Mean	19	6.4	8.0	18	6.5	8.7	0.174	0.05	7.3	5.5	1.8	-0.9	4.5
	Time %	19	58.7	43.1	18	58.0	39.0	0.624	0.01	55.7	61.1	-5.5	-27.9	17.0
Return	Peak	19	8.3	7.0	18	8.0	9.0	0.444	0.02	8.7	7.6	1.1	-1.8	4.0
	Mean	19	6.0	5.5	18	6.0	7.8	0.309	0.03	6.6	5.4	1.2	-1.1	3.5
	Time %	19	49.4	44.4	18	53.9	41.3	0.325	0.03	45.9	57.6	-11.7	-35.6	12.1
LLF														
Away	Peak	19	5.8	6.0	18	7.1	8.7	0.479	0.02	7.0	5.9	1.1	-2.1	4.3
	Mean	19	4.0	4.2	18	4.7	6.7	0.318	0.03	4.9	3.8	1.1	-1.1	3.4
	Time %	19	25.4	38.7	18	35.3	39.5	0.352	0.03	25.3	35.4	-10.1	-31.8	11.6
Return	Peak	19	5.4	6.5	18	5.2	6.2	0.177	0.05	6.2	4.3	1.9	-0.9	4.6
	Mean	19	4.1	5.2	18	3.9	4.8	0.155	0.06	4.8	3.2	1.6	-0.6	3.9
	Time %	19	37.2	43.6	18	46.2	43.9	0.321	0.03	36.6	46.8	-10.2	-30.8	10.4
LT9														
RLF														
Away	Peak	20	24.2	13.0	17	27.0	9.6	0.413	0.02	26.4	24.4	2.0	-2.9	6.9
	Mean	20	18.4	9.4	17	20.8	8.0	0.510	0.01	20.1	18.8	1.3	-2.7	5.3
	Time %	20	80.6	34.4	17	94.5	12.6	0.125	0.07	80.8	94.3	-13.4	-30.8	3.9
Return	Peak	20	25.7	12.3	17	29.4	11.3	0.530	0.01	28.3	26.4	1.8	-4.0	7.7
	Mean	20	20.2	9.9	17	23.8	9.1	0.408	0.02	22.7	20.9	1.8	-2.6	6.1
	Time %	20	82.5	34.0	17	93.7	24.0	0.561	0.01	85.0	90.7	-5.7	-25.2	13.9
LLF														
Away	Peak	20	18.6	9.3	17	24.8	9.5	0.403	0.02	20.7	22.4	-1.7	-5.8	2.4
	Mean	20	14.2	7.8	17	18.8	7.6	0.319	0.03	15.5	17.2	-1.7	-5.2	1.8
	Time %	20	70.8	40.2	17	92.8	14.2	0.019	0.15	72.1	91.2	-19.2	-35.1	-3.3
Return	Peak	20	17.2	8.3	17	21.9	11.0	0.599	0.01	18.7	20.2	-1.5	-7.2	4.2
	Mean	20	13.1	5.8	17	17.5	8.4	0.288	0.03	14.3	16.1	-1.8	-5.3	1.6

	Time %	20	68.0	42.7	17	84.6	28.4	0.051	0.11	68.0	84.6	-16.5	-33.2	0.1
RT9	RLF													
Away	Peak	19	20.8	12.5	18	29.7	13.5	0.389	0.02	23.8	26.5	-2.8	-9.3	3.7
	Mean	19	16.0	9.9	18	22.5	11.6	0.436	0.02	18.2	20.1	-2.0	-7.0	3.1
	Time %	19	63.7	41.3	18	82.2	32.4	0.905	0.00	72.0	73.4	-1.4	-24.4	21.6
Return	Peak	19	18.9	10.7	18	29.1	12.0	0.313	0.03	22.5	25.4	-2.9	-8.7	2.9
	Mean	19	14.7	8.6	18	22.6	10.3	0.164	0.06	17.0	20.1	-3.1	-7.5	1.3
	Time %	19	60.1	47.2	18	86.6	29.0	0.931	0.00	73.5	72.5	1.0	-22.8	24.8
	LLF													
Away	Peak	19	26.7	14.5	18	34.6	14.7	0.872	0.00	30.3	30.8	-0.5	-7.4	6.3
	Mean	19	20.6	12.0	18	27.4	11.5	0.947	0.00	23.8	24.0	-0.2	-5.7	5.3
	Time %	19	72.8	39.4	18	91.1	23.2	0.330	0.03	76.3	87.4	-11.1	-34.1	11.8
Return	Peak	19	25.8	13.0	18	33.8	14.4	0.280	0.03	27.9	31.6	-3.7	-10.6	3.2
	Mean	19	20.8	11.0	18	28.0	11.7	0.313	0.03	22.9	25.9	-3.1	-9.2	3.0
	Time %	19	77.0	38.4	18	89.1	27.3	0.418	0.02	78.3	87.7	-9.4	-32.8	13.9
Rotation														
LAS	Rrot													
Away	Peak	19	21.1	14.2	18	26.6	20.6	0.333	0.03	22.3	25.3	-3.1	-9.4	3.3
	Mean	19	11.9	8.0	18	16.3	12.9	0.721	0.00	13.6	14.5	-0.9	-5.9	4.1
	Time %	19	64.2	36.7	18	60.6	37.1	0.598	0.01	60.5	64.4	-3.9	-18.7	11.0
Return	Peak	19	25.2	16.0	18	26.2	19.8	0.515	0.01	24.6	26.8	-2.3	-9.2	4.7
	Mean	19	16.1	10.7	18	17.4	14.2	0.835	0.00	16.5	16.9	-0.4	-4.5	3.7
	Time %	19	68.2	38.2	18	70.6	30.5	0.633	0.01	67.2	71.6	-4.4	-23.2	14.3
	Lrot													
Away	Peak	19	26.7	26.9	18	18.7	13.4	0.662	0.01	24.0	21.6	2.3	-8.4	13.0
	Mean	19	13.3	11.7	18	11.6	9.5	0.862	0.00	12.3	12.7	-0.4	-4.8	4.1
	Time %	19	60.8	34.8	18	57.4	35.0	0.601	0.01	56.8	61.6	-4.7	-23.0	13.6
Return	Peak	19	25.0	27.9	18	17.6	17.6	0.934	0.00	21.2	21.6	-0.4	-9.7	9.0
	Mean	19	13.7	13.2	18	12.7	14.0	0.359	0.03	12.1	14.4	-2.3	-7.4	2.7
	Time %	19	55.9	42.1	18	49.8	40.5	0.869	0.00	52.0	53.8	-1.8	-23.3	19.8
RAS	Rrot													
Away	Peak	19	21.2	18.5	18	17.8	13.4	0.587	0.01	20.7	18.4	2.2	-6.0	10.5
	Mean	19	11.0	6.2	18	11.3	10.6	0.805	0.00	11.3	10.9	0.4	-3.0	3.8
	Time %	19	70.0	37.9	18	69.3	35.8	0.728	0.00	67.9	71.5	-3.6	-24.5	17.3
Return	Peak	19	22.6	28.5	18	14.8	9.7	0.784	0.00	18.2	19.5	-1.3	-11.0	8.4
	Mean	19	12.7	12.6	18	10.0	8.0	0.443	0.02	10.6	12.1	-1.5	-5.4	2.4
	Time %	19	60.1	37.4	18	56.5	38.7	0.444	0.02	54.7	62.3	-7.6	-27.5	12.3

Away	Lrot													
	Peak	19	21.9	18.1	18	16.1	9.3	0.836	0.00	19.4	18.8	0.6	-5.5	6.7
	Mean	19	11.7	9.8	18	9.4	5.6	0.989	0.00	10.6	10.6	0.0	-3.3	3.3
	Time %	19	56.7	36.8	18	60.7	36.1	0.530	0.01	55.5	62.0	-6.5	-27.3	14.3
	Peak	19	23.0	13.9	18	18.4	13.6	0.835	0.00	21.1	20.4	0.7	-6.1	7.5
	Mean	19	12.8	7.4	18	13.0	10.0	0.476	0.02	12.2	13.6	-1.4	-5.3	2.5
Return	Time %	19	66.8	38.1	18	70.2	34.6	0.559	0.01	65.3	71.8	-6.4	-28.6	15.7
LPC														
Away	Rrot													
	Peak	19	23.9	19.0	19	30.5	27.8	0.254	0.04	23.3	31.1	-7.8	-21.5	5.9
	Mean	19	16.1	15.0	19	19.0	19.9	0.998	0.00	17.6	17.6	0.0	-9.5	9.6
	Time %	19	81.7	34.4	19	81.5	25.0	0.722	0.00	83.1	80.1	3.1	-14.3	20.4
	Peak	19	22.9	12.5	19	25.0	12.8	0.796	0.00	23.5	24.5	-1.0	-8.5	6.6
	Mean	19	15.5	8.6	19	17.4	9.1	0.789	0.00	16.1	16.8	-0.7	-6.2	4.7
Return	Time %	19	83.4	32.9	19	87.7	18.8	0.367	0.02	82.2	88.9	-6.7	-21.5	8.1
Away	Lrot													
	Peak	19	55.3	32.5	19	48.9	26.2	0.684	0.01	53.8	50.4	3.4	-13.6	20.5
	Mean	19	28.6	16.1	19	29.1	18.4	0.727	0.00	28.0	29.7	-1.6	-11.1	7.9
	Time %	19	86.2	23.5	19	87.3	15.2	0.651	0.01	85.6	87.9	-2.3	-12.5	7.9
	Peak	19	46.7	30.4	19	48.8	37.2	0.933	0.00	48.2	47.4	0.9	-19.6	21.3
	Mean	19	23.0	19.3	19	31.6	27.5	0.398	0.02	24.4	30.3	-5.9	-19.8	8.1
Return	Time %	19	83.3	31.7	19	80.5	27.0	0.905	0.00	82.4	81.3	1.1	-17.2	19.3
RPC														
Away	Rrot													
	Peak	19	54.0	27.5	19	51.3	25.4	0.661	0.01	54.4	50.9	3.5	-12.4	19.3
	Mean	19	30.7	12.0	19	31.3	14.2	0.564	0.01	32.2	29.8	2.3	-5.8	10.4
	Time %	19	93.9	22.9	19	94.0	11.8	0.914	0.00	93.6	94.3	-0.7	-13.2	11.9
	Peak	19	45.4	28.7	19	54.4	37.8	0.658	0.01	47.7	52.1	-4.4	-24.4	15.6
	Mean	19	22.9	17.1	19	33.8	27.1	0.491	0.01	25.9	30.7	-4.8	-18.8	9.2
Return	Time %	19	80.3	29.3	19	90.7	16.4	0.114	0.07	79.4	91.5	-12.1	-27.3	3.1
Away	Lrot													
	Peak	19	26.2	14.3	19	29.3	28.0	0.622	0.01	26.1	29.4	-3.3	-16.8	10.2
	Mean	19	15.0	11.0	19	17.6	22.2	0.604	0.01	15.0	17.6	-2.6	-12.9	7.6
	Time %	19	74.1	31.6	19	74.2	24.9	0.641	0.01	72.0	76.3	-4.3	-22.7	14.2
	Peak	19	24.0	13.5	19	25.4	13.7	0.730	0.00	25.3	24.0	1.4	-6.5	9.2
	Mean	19	14.6	7.9	19	17.1	8.7	0.661	0.01	15.3	16.4	-1.1	-6.3	4.0
Return	Time %	19	82.6	31.3	19	84.4	27.3	0.685	0.01	81.7	85.4	-3.6	-21.7	14.4
LT4														
Away	Peak	20	12.9	12.1	19	12.9	8.6	0.648	0.01	12.5	13.3	-0.9	-4.6	2.9

Return	Mean	20	10.5	10.1	19	10.2	7.1	0.824	0.00	10.5	10.2	0.3	-2.6	3.3
	Time %	20	81.2	37.9	19	92.7	22.6	0.261	0.04	81.4	92.5	-11.1	-30.9	8.6
	Peak	20	12.5	11.5	19	11.5	7.5	0.680	0.01	11.7	12.4	-0.6	-3.7	2.4
	Mean	20	10.0	9.2	19	9.9	6.6	0.547	0.01	9.6	10.3	-0.8	-3.3	1.8
	Time %	20	78.8	39.9	19	95.8	12.5	0.066	0.09	78.5	96.1	-17.6	-36.4	1.2
Away	Lrot													
	Peak	20	10.8	9.6	19	11.0	7.2	0.869	0.00	10.8	11.0	-0.2	-3.2	2.7
	Mean	20	8.7	7.9	19	9.2	6.4	0.408	0.02	8.5	9.4	-0.9	-3.2	1.3
Return	Time %	20	76.4	38.3	19	88.5	25.9	0.229	0.04	76.3	88.6	-12.4	-32.9	8.1
	Peak	20	11.9	11.1	19	12.3	8.3	0.837	0.00	11.9	12.3	-0.4	-4.5	3.6
	Mean	20	9.9	9.1	19	10.4	7.0	0.817	0.00	10.0	10.4	-0.4	-3.5	2.8
	Time %	20	75.8	42.7	19	86.0	33.6	0.393	0.02	76.0	85.8	-9.8	-32.7	13.1
RT4														
Away	Rrot													
	Peak	19	6.5	5.8	19	6.2	3.4	0.985	0.00	6.3	6.3	0.0	-1.9	1.9
	Mean	19	5.0	4.5	19	4.9	2.7	0.948	0.00	5.0	4.9	0.1	-1.7	1.8
Return	Time %	19	80.0	29.5	19	79.4	35.4	0.774	0.00	81.0	78.4	2.5	-15.2	20.2
	Peak	19	6.9	7.1	19	7.2	5.2	0.738	0.00	6.8	7.2	-0.4	-2.9	2.0
	Mean	19	5.7	5.9	19	5.6	3.7	0.960	0.00	5.7	5.6	0.0	-1.9	2.0
Away	Time %	19	86.5	31.7	19	83.4	28.6	0.747	0.00	86.3	83.6	2.7	-14.2	19.7
	Lrot													
	Peak	19	6.9	7.4	19	6.6	4.1	0.584	0.01	6.4	7.1	-0.7	-3.0	1.7
Return	Mean	19	5.5	5.6	19	5.2	3.1	0.641	0.01	5.1	5.5	-0.4	-2.3	1.4
	Time %	19	83.7	28.3	19	84.9	24.8	0.972	0.00	84.4	84.2	0.3	-15.3	15.9
	Peak	19	7.1	7.3	19	5.6	3.0	0.548	0.01	6.7	6.0	0.7	-1.6	3.0
	Mean	19	5.7	5.7	19	4.8	2.6	0.870	0.00	5.3	5.2	0.1	-1.6	1.9
LSCM	Time %	19	81.6	31.9	19	81.7	31.5	0.875	0.00	82.4	81.0	1.5	-17.2	20.1
	Rrot													
	Peak	19	51.2	28.9	18	45.1	26.6	0.921	0.00	47.9	48.6	-0.7	-14.9	13.5
Return	Mean	19	26.1	18.2	18	24.1	16.8	0.679	0.01	24.3	26.0	-1.7	-10.1	6.7
	Time %	19	80.8	29.6	18	83.5	24.8	0.660	0.01	80.3	84.1	-3.8	-21.3	13.7
	Peak	19	47.7	26.5	18	49.5	37.9	0.747	0.00	47.3	49.9	-2.6	-18.6	13.5
Away	Mean	19	24.3	16.7	18	31.3	27.3	0.620	0.01	26.3	29.2	-2.9	-14.8	9.0
	Time %	19	84.9	23.5	18	82.0	30.6	0.686	0.01	85.2	81.7	3.5	-13.8	20.7
	Lrot													
Return	Peak	19	18.0	13.7	18	20.4	18.2	0.430	0.02	17.3	21.1	-3.9	-13.7	6.0
	Mean	19	9.6	9.5	18	9.9	10.0	0.645	0.01	9.1	10.4	-1.3	-7.0	4.4
	Time %	19	71.9	29.4	18	69.9	31.9	0.964	0.00	70.7	71.1	-0.4	-20.0	19.1

Return	Peak	19	16.7	15.3	18	15.8	15.2	0.695	0.01	15.5	17.0	-1.5	-9.3	6.3
	Mean	19	9.2	8.4	18	10.5	11.1	0.411	0.02	8.8	10.8	-2.0	-7.0	2.9
	Time %	19	68.5	32.6	18	69.3	33.8	0.918	0.00	69.4	68.3	1.1	-19.9	22.1
RSCM														
Away	Rrot													
	Peak	19	18.9	16.3	18	21.7	22.4	0.635	0.01	19.0	21.6	-2.6	-13.6	8.4
	Mean	19	11.0	11.1	18	10.9	8.7	0.663	0.01	11.5	10.3	1.2	-4.3	6.7
Return	Time %	19	63.2	38.9	18	83.6	32.9	0.127	0.07	66.0	80.6	-14.6	-33.7	4.4
	Peak	19	15.6	14.3	18	18.5	15.1	0.254	0.04	14.7	19.5	-4.8	-13.2	3.6
	Mean	19	9.5	10.2	18	12.6	11.1	0.264	0.04	9.3	12.8	-3.5	-9.7	2.8
Away	Time %	19	54.4	39.9	18	71.5	38.0	0.160	0.06	55.6	70.2	-14.6	-35.2	6.0
	Lrot													
	Peak	19	49.8	32.8	18	50.5	34.6	0.959	0.00	50.0	50.3	-0.4	-14.3	13.6
Return	Mean	19	21.9	14.3	18	25.2	19.9	0.597	0.01	22.5	24.6	-2.1	-10.0	5.9
	Time %	19	66.4	34.0	18	82.3	24.1	0.222	0.04	69.8	78.7	-8.9	-23.4	5.6
	Peak	19	46.4	30.2	18	44.0	38.1	0.985	0.00	45.1	45.3	-0.2	-18.6	18.2
Return	Mean	19	23.3	16.2	18	30.3	30.9	0.400	0.02	24.0	29.5	-5.4	-18.4	7.5
	Time %	19	75.4	35.0	18	91.0	18.2	0.091	0.08	77.2	89.1	-11.8	-25.6	2.0
LUT														
Away	Rrot													
	Peak	20	8.7	11.4	19	12.7	11.7	0.109	0.07	12.4	8.9	3.5	-0.8	7.8
	Mean	20	6.3	8.7	19	8.7	8.1	0.210	0.04	8.6	6.3	2.4	-1.4	6.1
Return	Time %	20	41.1	47.7	19	58.9	41.8	0.104	0.07	39.5	60.6	-21.1	-46.7	4.5
	Peak	20	7.0	8.7	19	11.2	12.5	0.499	0.01	9.7	8.4	1.3	-2.5	5.0
	Mean	20	5.2	6.9	19	8.7	10.2	0.615	0.01	7.3	6.5	0.8	-2.4	4.1
Away	Time %	20	39.0	46.5	19	52.0	38.3	0.226	0.04	37.5	53.6	-16.1	-42.7	10.4
	Lrot													
	Peak	20	5.9	6.7	19	9.6	9.6	0.821	0.00	7.5	7.9	-0.4	-4.2	3.4
Return	Mean	20	3.4	3.1	19	6.6	7.0	0.467	0.02	4.5	5.4	-0.9	-3.3	1.6
	Time %	20	29.8	41.0	19	47.0	40.6	0.068	0.09	27.7	49.2	-21.5	-44.7	1.7
	Peak	20	6.6	6.7	19	8.4	7.7	0.973	0.00	7.4	7.5	-0.1	-3.6	3.4
Return	Mean	20	4.6	5.3	19	6.0	6.1	0.818	0.00	5.1	5.4	-0.3	-3.1	2.4
	Time %	20	34.6	40.0	19	42.4	44.6	0.320	0.03	32.2	45.0	-12.9	-38.8	13.0
RUT														
Away	Rrot													
	Peak	19	6.4	6.0	19	5.6	4.5	0.325	0.03	6.7	5.4	1.3	-1.3	3.9
	Mean	19	4.1	4.6	19	3.8	3.5	0.369	0.02	4.4	3.5	1.0	-1.2	3.1
Return	Time %	19	51.1	45.2	19	50.1	45.6	0.217	0.04	43.4	57.8	-14.5	-37.8	8.9
	Peak	19	7.2	8.1	19	4.6	3.8	0.151	0.06	7.2	4.6	2.6	-1.0	6.3
	Mean	19	5.0	6.5	19	3.2	3.4	0.202	0.05	5.1	3.1	2.1	-1.2	5.3

	Time %	19	47.7	42.4	19	40.6	40.9	0.985	0.00	44.3	44.0	0.2	-24.0	24.5
	Lrot													
Away	Peak	19	8.2	12.3	19	6.3	6.4	0.251	0.04	8.4	6.1	2.3	-1.7	6.2
	Mean	19	5.7	8.6	19	4.6	5.1	0.266	0.04	5.9	4.4	1.5	-1.2	4.3
	Time %	19	49.2	45.3	19	39.4	40.2	0.761	0.00	42.5	46.0	-3.5	-26.7	19.7
Return	Peak	19	6.0	7.6	19	5.3	4.7	0.801	0.00	5.8	5.4	0.4	-2.5	3.2
	Mean	19	3.7	4.9	19	4.1	3.8	0.878	0.00	3.8	4.0	-0.2	-2.5	2.2
	Time %	19	43.4	43.8	19	44.1	42.8	0.531	0.01	39.9	47.6	-7.7	-32.5	17.1
LT9	Rrot													
Away	Peak	20	23.2	12.6	18	24.6	11.3	0.182	0.05	25.7	21.9	3.8	-1.8	9.4
	Mean	20	18.6	9.9	18	19.5	8.8	0.193	0.05	20.5	17.4	3.1	-1.7	7.9
	Time %	20	79.7	35.1	18	94.9	15.1	0.081	0.08	80.1	94.6	-14.5	-30.9	1.9
Return	Peak	20	22.8	11.8	18	24.8	11.8	0.538	0.01	24.6	22.7	1.9	-4.2	7.9
	Mean	20	18.6	9.6	18	20.3	9.0	0.541	0.01	20.1	18.7	1.3	-3.1	5.7
	Time %	20	78.9	37.3	18	94.7	17.3	0.226	0.04	81.4	91.9	-10.6	-27.9	6.8
	Lrot													
Away	Peak	20	19.0	9.2	18	21.4	9.2	0.514	0.01	20.8	19.5	1.3	-2.6	5.2
	Mean	20	14.8	7.8	18	16.7	7.7	0.546	0.01	16.2	15.2	1.0	-2.4	4.4
	Time %	20	74.5	40.2	18	88.2	24.9	0.348	0.03	77.0	85.5	-8.6	-26.9	9.7
Return	Peak	20	21.0	11.5	18	19.9	8.9	0.284	0.03	21.7	19.1	2.6	-2.3	7.5
	Mean	20	16.7	9.1	18	16.8	7.8	0.561	0.01	17.2	16.2	1.0	-2.5	4.6
	Time %	20	75.6	38.8	18	92.3	20.4	0.084	0.08	76.3	91.5	-15.2	-32.5	2.2
RT9	Rrot													
Away	Peak	19	21.8	13.5	19	26.5	12.4	0.983	0.00	24.1	24.2	0.0	-3.8	3.7
	Mean	19	16.9	10.9	19	21.4	10.4	0.741	0.00	18.9	19.4	-0.5	-3.8	2.7
	Time %	19	68.0	45.5	19	83.4	32.3	0.835	0.00	74.5	76.9	-2.3	-24.9	20.3
Return	Peak	19	20.7	12.4	19	26.7	13.2	0.337	0.03	22.6	24.8	-2.1	-6.6	2.3
	Mean	19	16.8	10.1	19	22.3	11.9	0.296	0.03	18.6	20.5	-1.9	-5.6	1.8
	Time %	19	64.8	44.7	19	87.0	28.0	0.349	0.03	70.4	81.4	-11.0	-34.7	12.6
	Lrot													
Away	Peak	19	26.2	14.1	19	31.4	14.0	0.865	0.00	29.0	28.6	0.4	-4.1	4.9
	Mean	19	19.9	11.0	19	25.3	11.6	0.779	0.00	22.3	22.9	-0.6	-4.5	3.4
	Time %	19	69.2	44.6	19	90.7	22.6	0.134	0.06	71.5	88.4	-16.9	-39.3	5.5
Return	Peak	19	24.0	13.6	19	28.5	12.6	0.994	0.00	26.2	26.2	0.0	-4.5	4.5
	Mean	19	19.8	11.6	19	24.0	10.6	0.927	0.00	21.8	22.0	-0.2	-4.5	4.1
	Time %	19	68.9	44.0	19	90.1	25.8	0.136	0.06	70.5	88.6	-18.1	-42.1	6.0

(CG – control group; EG – experimental group; n – sample; M – mean; SE – standard deviation; CI – confidence interval; η^2 – partial eta squared; ave – average; % - percentage; LAS – left anterior scalene; RAS – right anterior scalene; LPC – left posterior cervical; RPC – right posterior cervical; LSCM – left

sternocleidomastoid; RSCM – right sternocleidomastoid; LUT – left upper trapezius; RUT – right upper trapezius; LT4 – left paraspinal at T4; RT4 – right paraspinal at T4; LT9 – left paraspinal at T9; RT9 – right paraspinal at T9; Flex – flexion; Ext – extension; LLF – left lateral flexion; RLF – right lateral flexion; Lrot – left rotation; Rrot – right rotation)

**SUPPLEMENTARY FILE 7.6: COMPARISON OF BETWEEN GROUP DIFFERENCES AT THE
FOURTH VISIT USING POST-ADJUSTED MEANS FOR THE MUSCLE ACTIVATION PATTERNS**

		4th visit post measures						p value	η2	CG	EG	MD	CI	
		CG			EG								Low	High
		n	M	SD	n	M	SD							
FLEX/EXT														
LAS Away	Flex													
	Peak	13	28.0	20.7	18	30.4	11.6	0.077	0.1	33.9	26.1	7.8	-0.9	16.4
	Mean	13	16.0	11.7	18	14.0	5.7	0.116	0.1	17.5	12.8	4.7	-1.2	10.7
Return	Time %	13	71.0	33.8	18	51.1	29.1	0.099	0.1	70.9	51.2	19.6	-4.0	43.2
	Peak	13	21.5	11.9	18	25.5	13.7	0.632	0.0	22.5	24.8	-2.3	-11.8	7.3
	Mean	13	11.8	5.9	18	14.2	7.8	0.295	0.0	11.5	14.4	-2.9	-8.4	2.6
Away	Time %	13	76.0	34.3	18	58.3	34.3	0.198	0.1	75.4	58.7	16.7	-9.2	42.6
	Ext													
	Peak	13	14.1	9.2	18	17.9	10.8	0.948	0.0	16.4	16.2	0.2	-7.4	7.9
Return	Mean	13	8.8	4.0	18	10.9	6.2	0.725	0.0	9.6	10.3	-0.7	-4.7	3.3
	Time %	13	67.1	38.4	18	51.1	38.1	0.260	0.0	66.9	51.2	15.7	-12.3	43.8
	Peak	13	32.1	18.3	18	37.7	21.8	0.534	0.0	37.5	33.8	3.7	-8.4	15.8
Away	Mean	13	18.7	10.0	18	26.8	16.4	0.994	0.0	23.4	23.4	0.0	-8.3	8.3
	Time %	13	84.2	19.0	18	71.0	39.5	0.211	0.1	85.5	70.1	15.4	-9.2	40.1
	RAS													
Away	Flex													
	Peak	14	26.6	16.7	18	32.7	18.9	0.849	0.0	30.7	29.5	1.2	-11.4	13.8
	Mean	14	13.7	9.0	18	15.1	7.0	0.681	0.0	15.1	13.9	1.2	-4.7	7.1
Return	Time %	14	68.3	29.6	18	67.8	28.8	0.967	0.0	68.2	67.8	0.4	-21.2	22.1
	Peak	14	19.1	9.6	18	27.5	18.3	0.364	0.0	21.1	25.9	-4.8	-15.5	5.9
	Mean	14	9.7	4.0	18	15.3	8.8	0.141	0.1	10.5	14.6	-4.1	-9.6	1.4
Away	Time %	14	66.7	34.2	18	73.0	37.9	0.593	0.0	66.3	73.3	-7.1	-33.9	19.7
	Ext													
	Peak	14	12.7	6.0	18	15.7	8.9	0.931	0.0	14.5	14.3	0.2	-4.9	5.4
Return	Mean	14	8.4	3.8	18	9.4	4.7	0.343	0.0	9.5	8.4	1.1	-1.2	3.4
	Time %	13	65.4	38.5	18	70.7	28.5	0.676	0.0	65.5	70.6	-5.2	-30.2	19.9
	Peak	14	25.1	12.3	18	36.5	24.5	0.949	0.0	31.3	31.7	-0.4	-11.6	10.9
Away	Mean	14	15.0	7.4	18	25.2	17.0	0.863	0.0	20.4	21.0	-0.7	-8.8	7.4
	Time %	14	75.6	29.0	18	86.7	24.7	0.351	0.0	76.7	85.9	-9.2	-29.1	10.7

LPC														
Away	Flex													
	Peak	15	12.5	12.8	19	8.8	9.3	0.418	0.0	12.2	9.1	3.1	-4.6	10.7
	Mean	15	8.0	7.3	19	6.0	6.0	0.378	0.0	8.0	6.0	2.0	-2.5	6.5
Return	Time %	15	44.2	31.9	19	45.7	38.3	0.631	0.0	42.2	47.4	-5.2	-27.0	16.6
	Peak	15	38.6	26.0	19	29.3	18.6	0.253	0.0	38.2	29.7	8.5	-6.4	23.4
	Mean	15	23.9	15.6	19	18.4	13.8	0.433	0.0	23.1	19.1	4.0	-6.3	14.2
Away	Time %	15	85.8	26.5	19	80.3	29.5	0.776	0.0	84.4	81.4	3.0	-18.5	24.6
	Ext													
	Peak	15	35.9	24.9	19	29.7	14.8	0.363	0.0	36.0	29.6	6.4	-7.7	20.4
Return	Mean	15	17.0	12.8	19	14.9	8.9	0.592	0.0	17.0	15.0	2.0	-5.6	9.6
	Time %	15	74.0	29.5	19	81.8	21.4	0.187	0.1	71.4	83.8	-12.4	-31.2	6.3
	Peak	15	10.0	5.5	19	7.7	6.4	0.217	0.0	10.1	7.7	2.4	-1.5	6.2
Away	Mean	15	6.0	3.5	19	5.0	4.0	0.283	0.0	6.2	4.9	1.3	-1.1	3.8
	Time %	15	38.5	35.1	19	40.7	39.8	0.785	0.0	37.8	41.2	-3.5	-29.1	22.2
RPC														
Away	Flex													
	Peak	14	10.2	8.2	19	8.3	6.1	0.933	0.0	9.2	9.1	0.2	-4.2	4.6
	Mean	14	6.8	4.9	19	5.3	3.3	0.452	0.0	6.5	5.6	0.9	-1.5	3.3
Return	Time %	14	44.0	30.8	19	49.0	35.4	0.37	0.0	40.8	51.3	-10.5	-34.1	13.1
	Peak	14	40.0	24.9	19	33.3	18.1	0.374	0.0	39.7	33.5	6.2	-7.8	20.1
	Mean	14	24.1	13.9	19	20.4	13.8	0.72	0.0	23.0	21.2	1.7	-8.1	11.6
Away	Time %	14	87.8	18.2	19	79.5	29.0	0.519	0.0	86.6	80.3	6.3	-13.4	26.0
	Ext													
	Peak	14	37.9	25.9	19	31.7	14.9	0.441	0.0	37.1	32.2	4.8	-7.8	17.5
Return	Mean	14	19.3	13.3	19	16.0	8.8	0.427	0.0	19.0	16.2	2.8	-4.3	10.0
	Time %	14	77.3	25.6	19	82.1	22.6	0.295	0.0	75.2	83.7	-8.5	-24.7	7.8
	Peak	14	10.9	5.8	19	7.1	3.5	0.025	0.2	11.0	7.0	3.9	0.5	7.3
Away	Mean	14	6.2	3.0	19	4.2	1.8	0.022	0.2	6.2	4.2	2.1	0.3	3.8
	Time %	13	43.0	38.5	19	42.7	39.3	0.739	0.0	40.3	44.6	-4.3	-30.4	21.9
LT4														
Away	Flex													
	Peak	14	18.1	17.1	19	17.5	14.0	0.714	0.0	16.9	18.4	-1.5	-9.7	6.7
	Mean	14	13.9	13.1	19	13.6	10.2	0.971	0.0	13.6	13.8	-0.1	-6.5	6.3
Return	Time %	14	71.5	42.2	19	89.9	28.9	0.071	0.1	69.6	91.3	-21.7	-45.4	2.0
	Peak	14	20.6	16.9	19	17.4	10.6	0.709	0.0	19.6	18.1	1.5	-6.5	9.5
	Mean	14	16.9	14.0	19	14.8	9.3	0.855	0.0	16.0	15.4	0.6	-6.5	7.8
Away	Time %	14	79.8	36.2	19	93.0	21.4	0.027	0.2	75.9	96.0	-20.1	-37.7	-2.5
	Ext													
	Peak	14	20.9	22.1	19	15.5	11.4	0.858	0.0	18.3	17.5	0.8	-8.1	9.7

Return	Mean	14	16.1	17.0	19	12.0	9.8	0.804	0.0	14.2	13.3	0.9	-6.5	8.3
	Time %	14	70.9	37.5	19	82.5	33.9	0.138	0.1	68.9	84.0	-15.1	-35.4	5.1
	Peak	14	18.7	20.6	19	14.9	15.1	0.651	0.0	17.7	15.7	2.0	-6.9	10.8
	Mean	14	14.0	14.8	19	10.8	9.9	0.691	0.0	13.0	11.6	1.4	-5.7	8.5
	Time %	14	59.2	42.1	19	78.7	34.5	0.081	0.1	57.2	80.1	-22.9	-48.8	3.0
RT4		Flex												
Away	Peak	14	7.8	5.2	19	7.8	3.9	0.937	0.0	7.7	7.9	-0.1	-3.5	3.2
	Mean	14	6.0	3.7	19	5.9	2.7	0.966	0.0	6.0	6.0	0.0	-2.3	2.4
	Time %	14	94.3	9.0	19	86.7	30.9	0.393	0.0	94.4	86.6	7.8	-10.6	26.2
Return	Peak	14	8.3	4.7	19	9.0	4.0	0.557	0.0	8.2	9.1	-0.9	-4.2	2.3
	Mean	14	6.8	3.8	19	7.3	3.0	0.641	0.0	6.8	7.4	-0.6	-3.1	2.0
	Time %	14	97.7	6.9	19	89.8	24.9	0.257	0.0	97.7	89.8	8.0	-6.1	22.1
		Ext												
Away	Peak	14	8.3	4.8	19	7.9	4.7	0.916	0.0	8.0	8.2	-0.2	-3.7	3.3
	Mean	14	6.3	3.7	19	5.7	3.6	0.882	0.0	5.8	6.0	-0.2	-2.8	2.4
	Time %	14	93.6	13.1	19	81.8	35.4	0.066	0.1	96.4	79.8	16.6	-1.1	34.3
Return	Peak	14	7.0	4.1	19	6.4	3.9	0.990	0.0	6.7	6.6	0.0	-2.7	2.7
	Mean	14	5.3	3.2	19	4.7	2.9	0.943	0.0	5.0	4.9	0.1	-2.1	2.2
	Time %	14	85.2	25.7	19	80.7	37.1	0.323	0.0	88.5	78.2	10.2	-10.6	31.1
LSCM		Flex												
Away	Peak	13	20.6	12.5	18	24.5	17.5	0.837	0.0	23.4	22.5	0.9	-8.4	10.3
	Mean	13	11.3	7.0	18	10.9	7.7	0.445	0.0	12.2	10.3	1.8	-3.0	6.7
	Time %	13	63.8	38.6	18	61.3	35.1	0.831	0.0	64.0	61.2	2.8	-24.0	29.7
Return	Peak	13	16.4	7.7	18	18.0	13.3	0.809	0.0	16.8	17.7	-1.0	-9.2	7.3
	Mean	13	8.4	3.5	18	10.2	6.9	0.458	0.0	8.5	10.1	-1.6	-6.0	2.8
	Time %	13	61.8	41.2	18	67.4	38.3	0.655	0.0	61.2	67.8	-6.6	-36.3	23.2
		Ext												
Away	Peak	13	12.5	10.9	18	11.8	8.3	0.564	0.0	13.2	11.3	1.8	-4.6	8.3
	Mean	13	6.9	4.1	18	7.1	5.1	0.917	0.0	6.9	7.1	-0.2	-3.3	3.0
	Time %	13	62.7	39.6	18	55.5	42.1	0.64	0.0	62.7	55.5	7.2	-24.0	38.3
Return	Peak	13	33.7	23.8	18	34.2	24.5	0.572	0.0	36.1	32.6	3.5	-9.0	16.0
	Mean	13	19.9	16.1	18	23.7	18.7	0.879	0.0	22.5	21.9	0.6	-7.3	8.5
	Time %	13	79.4	29.4	18	82.2	24.3	0.820	0.0	82.4	80.1	2.3	-18.1	22.7
RSCM		Flex												
Away	Peak	14	22.4	16.0	18	29.7	15.9	0.878	0.0	26.0	26.9	-0.9	-12.6	10.8
	Mean	14	11.7	8.4	18	12.9	6.5	0.564	0.0	13.2	11.7	1.5	-3.8	6.8
	Time %	14	75.7	26.2	18	65.2	30.0	0.262	0.0	76.5	64.6	11.9	-9.4	33.3

Return	Peak	14	18.9	13.1	18	25.8	21.2	0.647	0.0	21.1	24.0	-2.9	-15.7	9.9
	Mean	14	10.1	5.6	18	14.1	9.0	0.385	0.0	11.0	13.4	-2.4	-8.1	3.2
	Time %	14	76.6	38.4	18	80.1	25.9	0.974	0.0	78.4	78.7	-0.4	-22.8	22.1
Ext														
Away	Peak	14	13.5	10.0	18	15.7	14.4	0.854	0.0	15.2	14.4	0.7	-7.4	8.9
	Mean	14	8.4	5.5	18	9.8	8.9	0.925	0.0	9.1	9.3	-0.2	-5.3	4.8
	Time %	14	81.5	34.9	18	72.4	36.8	0.271	0.0	84.5	70.1	14.4	-11.9	40.8
Return	Peak	14	37.5	29.6	18	39.3	26.7	0.715	0.0	40.1	37.3	2.8	-12.7	18.3
	Mean	14	21.7	18.6	18	26.4	19.0	0.926	0.0	24.6	24.1	0.4	-9.3	10.2
	Time %	14	76.8	33.0	18	84.3	31.6	0.753	0.0	79.0	82.6	-3.6	-26.5	19.4
LUT														
Away	Peak	15	5.5	7.6	19	9.4	12.3	0.415	0.0	6.9	8.4	-1.5	-5.4	2.3
	Mean	15	4.2	6.0	19	7.3	9.9	0.237	0.0	4.9	6.8	-1.9	-5.1	1.3
	Time %	15	56.3	37.5	19	31.6	38.4	0.102	0.1	54.9	32.6	22.3	-4.6	49.2
Return	Peak	15	6.3	8.2	19	9.5	13.7	0.195	0.1	6.3	9.5	-3.1	-7.9	1.7
	Mean	15	5.0	6.9	19	7.3	9.5	0.112	0.1	4.8	7.5	-2.7	-6.1	0.7
	Time %	15	70.3	40.1	19	40.3	39.4	0.099	0.1	66.5	43.3	23.3	-4.6	51.1
Ext														
Away	Peak	15	6.2	7.2	19	10.8	14.9	0.342	0.0	7.6	9.6	-2.0	-6.3	2.3
	Mean	15	4.7	5.8	19	8.1	11.1	0.227	0.0	5.5	7.5	-2.0	-5.4	1.3
	Time %	15	60.5	43.4	19	35.5	40.9	0.197	0.1	57.3	38.0	19.2	-10.5	49.0
Return	Peak	15	7.0	7.6	19	8.6	12.1	0.946	0.0	8.0	7.8	0.1	-4.1	4.4
	Mean	15	4.7	5.5	19	6.4	9.3	0.748	0.0	5.4	5.9	-0.5	-3.8	2.8
	Time %	15	66.0	38.8	19	28.9	39.8	0.012	0.2	64.3	30.3	34.0	8.1	59.9
RUT														
Away	Peak	14	4.1	6.3	19	3.5	2.8	0.276	0.0	4.6	3.1	1.5	-1.3	4.2
	Mean	14	3.0	4.7	19	2.7	2.4	0.343	0.0	3.4	2.4	1.0	-1.1	3.1
	Time %	14	56.5	34.7	19	35.8	40.8	0.141	0.1	56.5	35.7	20.8	-7.3	48.9
Return	Peak	14	5.3	6.2	19	4.1	2.9	0.595	0.0	5.0	4.3	0.8	-2.2	3.8
	Mean	14	3.9	5.3	19	3.1	2.4	0.663	0.0	3.8	3.2	0.6	-2.0	3.2
	Time %	14	74.6	35.0	19	51.1	40.4	0.126	0.1	73.4	52.0	21.4	-6.4	49.2
Ext														
Away	Peak	14	5.7	6.3	19	4.6	3.7	0.558	0.0	5.6	4.7	0.9	-2.3	4.1
	Mean	14	4.2	5.3	19	3.3	2.7	0.49	0.0	4.2	3.3	0.9	-1.8	3.6
	Time %	14	67.9	36.5	19	44.7	43.7	0.175	0.1	66.1	46.0	20.1	-9.5	49.7
Return	Peak	14	6.7	8.6	19	3.5	3.3	0.149	0.1	6.4	3.7	2.8	-1.0	6.6
	Mean	14	4.4	5.8	19	2.7	2.5	0.164	0.1	4.5	2.6	1.9	-0.8	4.6

	Time %	14	64.0	37.2	18	43.4	43.5	0.205	0.1	63.2	44.1	19.0	-11.0	49.1
LT9	Flex													
Away	Peak	15	34.2	22.4	18	32.6	11.5	0.622	0.0	34.6	32.2	2.4	-7.4	12.2
	Mean	15	28.0	18.7	18	25.6	8.4	0.412	0.0	28.5	25.2	3.4	-4.9	11.6
	Time %	15	92.7	15.8	18	94.3	23.5	0.810	0.0	92.6	94.4	-1.8	-16.7	13.2
Return	Peak	15	32.1	19.0	18	32.3	12.2	0.575	0.0	33.5	31.2	2.3	-6.0	10.6
	Mean	15	25.5	14.6	18	26.9	10.8	0.861	0.0	26.6	26.0	0.7	-6.9	8.3
	Time %	15	80.3	32.6	18	91.5	25.6	0.223	0.0	80.8	91.1	-10.3	-27.2	6.6
	Ext													
Away	Peak	15	24.3	15.8	18	26.3	12.9	0.967	0.0	25.5	25.3	0.2	-8.4	8.7
	Mean	15	19.3	13.6	18	20.1	9.8	0.766	0.0	20.4	19.3	1.1	-6.4	8.6
	Time %	15	67.2	41.8	18	86.1	31.6	0.086	0.1	68.1	85.3	-17.2	-37.1	2.6
Return	Peak	15	27.4	19.7	18	27.3	12.8	0.639	0.0	28.6	26.3	2.3	-7.5	12.0
	Mean	15	21.9	17.3	18	20.2	10.5	0.502	0.0	22.5	19.7	2.8	-5.6	11.2
	Time %	15	72.5	36.4	18	87.6	28.7	0.166	0.1	72.4	87.7	-15.3	-37.3	6.7
RT9	Flex													
Away	Peak	14	37.7	16.2	19	34.0	10.3	0.130	0.1	39.0	33.1	6.0	-1.9	13.8
	Mean	14	30.4	12.8	19	27.4	8.6	0.142	0.1	31.4	26.7	4.7	-1.7	11.2
	Time %	14	97.9	6.4	19	92.1	24.3	0.418	0.0	97.8	92.2	5.6	-8.3	19.5
Return	Peak	14	36.6	15.3	19	33.6	12.4	0.135	0.1	38.0	32.6	5.4	-1.8	12.6
	Mean	14	29.9	13.6	19	27.0	10.3	0.175	0.1	30.9	26.3	4.7	-2.2	11.5
	Time %	14	92.0	19.0	19	95.5	12.6	0.529	0.0	92.0	95.5	-3.6	-14.9	7.8
	Ext													
Away	Peak	14	31.2	15.0	19	26.2	13.4	0.260	0.0	31.2	26.2	5.0	-3.9	13.8
	Mean	14	23.9	11.8	19	19.9	10.4	0.259	0.0	23.8	20.1	3.7	-2.9	10.2
	Time %	14	85.3	30.5	19	84.5	31.2	0.765	0.0	86.6	83.5	3.1	-17.7	23.9
Return	Peak	14	29.6	15.0	19	28.4	12.6	0.555	0.0	30.3	27.9	2.4	-5.9	10.8
	Mean	14	21.8	12.6	19	21.6	11.2	0.860	0.0	22.1	21.4	0.7	-7.1	8.4
	Time %	14	79.1	32.3	19	85.1	32.2	0.624	0.0	79.2	85.0	-5.8	-29.9	18.3
LF														
LAS	RLF													
Away	Peak	13	8.4	4.9	18	8.8	4.8	0.803	0.0	8.4	8.8	-0.4	-3.8	3.0
	Mean	13	5.4	3.3	18	5.6	3.1	0.883	0.0	5.4	5.6	-0.2	-2.4	2.1
	Time %	13	32.3	31.7	18	20.8	33.2	0.756	0.0	27.7	24.1	3.6	-19.6	26.8
Return	Peak	13	39.8	24.1	18	30.9	18.3	0.254	0.0	38.7	31.6	7.1	-5.4	19.5
	Mean	13	22.9	14.7	18	16.3	8.7	0.240	0.0	21.9	17.0	4.9	-3.4	13.2
	Time %	13	81.0	22.7	18	51.8	35.1	0.044	0.1	78.6	53.5	25.2	0.8	49.6

Away	LLF													
	Peak	13	43.0	17.3	18	36.8	18.5	0.78	0.0	40.2	38.8	1.5	-9.1	12.1
	Mean	13	24.0	8.8	18	20.5	9.6	0.515	0.0	23.2	21.1	2.0	-4.3	8.4
Return	Time %	13	88.7	12.9	18	64.0	35.1	0.035	0.1	88.3	64.3	24.1	1.8	46.3
	Peak	13	30.5	16.6	18	31.2	22.0	0.755	0.0	29.7	31.8	-2.1	-15.7	11.6
	Mean	13	15.2	9.2	18	17.7	12.0	0.574	0.0	15.5	17.5	-2.1	-9.6	5.4
	Time %	13	79.6	24.3	18	52.6	42.7	0.064	0.1	78.6	53.3	25.4	-1.6	52.3
RAS														
Away	RLF													
	Peak	14	41.8	16.9	18	40.7	22.0	0.782	0.0	40.2	41.9	-1.7	-13.9	10.6
	Mean	14	25.9	11.2	18	23.7	12.9	0.874	0.0	25.0	24.4	0.6	-7.4	8.7
Return	Time %	14	97.3	8.9	18	82.2	33.1	0.123	0.1	97.5	82.0	15.5	-4.4	35.4
	Peak	14	28.0	15.8	18	32.3	24.3	0.353	0.0	26.5	33.4	-6.9	-21.9	8.1
	Mean	14	12.7	7.9	18	16.9	14.4	0.322	0.0	12.6	17.0	-4.4	-13.2	4.5
	Time %	14	69.8	31.5	18	60.1	40.3	0.471	0.0	69.8	60.1	9.7	-17.5	37.0
Away	LLF													
	Peak	14	7.0	3.8	18	8.4	5.7	0.452	0.0	7.0	8.4	-1.4	-5.2	2.4
	Mean	14	4.3	2.4	18	5.3	3.3	0.469	0.0	4.4	5.2	-0.8	-2.9	1.4
Return	Time %	14	29.0	31.3	18	30.8	33.0	0.809	0.0	28.6	31.2	-2.5	-23.6	18.5
	Peak	14	28.2	14.7	18	33.4	20.9	0.339	0.0	28.1	33.5	-5.4	-16.8	6.0
	Mean	14	16.1	8.3	18	18.1	12.7	0.449	0.0	15.6	18.4	-2.8	-10.4	4.7
	Time %	14	77.1	25.0	18	77.4	26.6	0.826	0.0	76.1	78.3	-2.2	-22.5	18.1
LPC														
Away	RLF													
	Peak	14	14.7	11.7	19	11.6	11.6	0.449	0.0	14.8	11.6	3.2	-5.3	11.7
	Mean	14	10.8	9.9	19	7.5	6.7	0.256	0.0	10.9	7.5	3.4	-2.6	9.4
Return	Time %	14	71.8	27.9	19	65.2	35.6	0.558	0.0	71.5	65.5	6.0	-14.8	26.9
	Peak	14	20.8	14.3	19	16.3	10.9	0.239	0.0	21.1	16.1	5.0	-3.5	13.5
	Mean	14	15.8	11.4	19	11.8	9.8	0.253	0.0	15.9	11.7	4.2	-3.2	11.6
	Time %	14	87.7	26.2	19	85.5	22.9	0.828	0.0	85.4	87.2	-1.8	-18.2	14.7
Away	LLF													
	Peak	14	23.3	11.6	19	18.2	8.7	0.117	0.1	23.5	18.1	5.5	-1.5	12.4
	Mean	14	14.7	9.1	19	11.5	6.1	0.11	0.1	15.1	11.2	3.9	-0.9	8.8
Return	Time %	14	85.7	15.4	19	83.7	23.4	0.967	0.0	84.4	84.7	-0.3	-15.2	14.6
	Peak	14	17.3	11.5	19	14.8	8.2	0.346	0.0	17.7	14.5	3.2	-3.6	10.0
	Mean	14	12.1	9.9	19	10.2	5.7	0.207	0.1	12.9	9.6	3.3	-1.9	8.4
	Time %	14	78.8	24.5	19	77.3	34.0	0.732	0.0	76.6	79.0	-2.4	-16.5	11.7
RPC														
Away	RLF													
	Peak	14	20.9	9.2	19	19.0	8.5	0.37	0.0	21.1	18.8	2.3	-2.9	7.5

Return	Mean	14	14.5	6.9	19	12.8	5.3	0.179	0.1	14.9	12.5	2.5	-1.2	6.1
	Time %	14	89.2	26.1	19	90.8	25.7	0.338	0.0	86.2	93.1	-6.9	-21.4	7.6
	Peak	14	15.9	8.9	19	14.5	7.6	0.551	0.0	16.1	14.4	1.7	-4.1	7.4
	Mean	14	9.9	6.0	19	9.4	4.7	0.513	0.0	10.3	9.1	1.2	-2.5	5.0
	Time %	14	75.1	31.1	19	74.0	38.2	0.815	0.0	73.0	75.5	-2.5	-23.7	18.8
Away	LLF													
	Peak	14	10.4	6.7	19	9.7	5.7	0.357	0.0	11.1	9.2	2.0	-2.3	6.3
	Mean	14	7.0	4.4	19	6.0	2.7	0.234	0.0	7.3	5.8	1.5	-1.0	4.1
Return	Time %	14	55.7	32.2	19	56.9	39.1	0.939	0.0	55.9	56.8	-0.9	-24.9	23.1
	Peak	14	19.9	10.9	19	17.4	8.3	0.441	0.0	19.5	17.6	1.9	-3.0	6.8
	Mean	14	14.1	7.9	19	11.8	5.1	0.413	0.0	13.6	12.2	1.5	-2.1	5.0
	Time %	14	80.8	33.7	19	88.0	21.9	0.122	0.1	77.5	90.4	-12.9	-29.5	3.7
LT4														
Away	RLF													
	Peak	14	13.8	13.7	19	10.9	7.9	0.349	0.0	13.3	11.3	2.0	-2.3	6.2
	Mean	14	11.3	11.5	19	9.2	6.8	0.248	0.0	11.3	9.1	2.2	-1.6	5.9
Return	Time %	14	76.2	36.3	19	80.9	33.9	0.315	0.0	73.1	83.2	-10.1	-30.2	10.0
	Peak	14	12.5	11.5	19	11.2	7.9	0.288	0.0	13.2	10.8	2.4	-2.1	6.9
	Mean	14	10.3	9.3	19	9.4	6.6	0.462	0.0	10.6	9.2	1.4	-2.4	5.2
	Time %	14	68.7	37.9	19	81.3	34.6	0.218	0.1	69.5	80.7	-11.2	-29.5	7.0
Away	LLF													
	Peak	14	15.2	14.1	19	11.5	7.7	0.391	0.0	14.3	12.1	2.2	-3.0	7.4
	Mean	14	11.4	11.2	19	9.1	6.7	0.487	0.0	10.9	9.5	1.4	-2.7	5.6
Return	Time %	14	66.4	38.9	19	81.0	33.0	0.097	0.1	65.9	81.4	-15.5	-34.1	3.0
	Peak	14	13.4	11.8	19	10.8	8.5	0.432	0.0	12.9	11.1	1.8	-2.8	6.5
	Mean	14	10.7	9.4	19	8.8	7.4	0.40	0.0	10.6	8.9	1.7	-2.3	5.6
	Time %	14	65.3	42.0	19	77.5	37.3	0.269	0.0	65.3	77.4	-12.1	-34.1	9.9
RT4														
Away	RLF													
	Peak	14	6.4	4.3	19	5.8	2.9	0.73	0.0	6.3	5.8	0.4	-2.1	3.0
	Mean	14	4.8	3.2	19	4.5	2.2	0.845	0.0	4.7	4.6	0.2	-1.8	2.1
Return	Time %	14	81.8	34.3	19	82.1	37.0	0.648	0.0	85.0	79.8	5.3	-18.1	28.6
	Peak	14	6.2	3.8	19	6.4	3.8	0.811	0.0	6.1	6.4	-0.3	-3.1	2.4
	Mean	14	5.0	3.3	19	4.9	2.5	0.926	0.0	5.0	4.9	0.1	-2.0	2.2
	Time %	14	76.7	40.1	19	83.4	35.5	0.886	0.0	79.6	81.2	-1.6	-24.0	20.9
Away	LLF													
	Peak	14	6.5	4.1	19	5.9	2.6	0.626	0.0	6.5	5.9	0.6	-1.9	3.1
	Mean	14	5.2	3.4	19	4.6	1.9	0.511	0.0	5.2	4.6	0.6	-1.3	2.6
	Time %	14	84.6	29.3	19	83.7	36.3	0.975	0.0	83.9	84.2	-0.4	-23.2	22.5

Return	Peak	14	6.0	4.0	19	5.7	2.9	0.829	0.0	6.0	5.7	0.3	-2.3	2.8
	Mean	14	4.9	3.2	19	4.6	2.3	0.83	0.0	4.8	4.6	0.2	-1.8	2.2
	Time %	14	83.2	30.7	19	81.5	34.3	0.704	0.0	84.6	80.5	4.0	-17.5	25.6
LSCM		RLF												
Away	Peak	13	4.7	2.0	18	6.6	5.6	0.297	0.0	5.0	6.4	-1.4	-4.1	1.3
	Mean	13	3.4	1.7	18	4.0	3.0	0.628	0.0	3.5	3.9	-0.4	-2.3	1.4
	Time %	13	32.4	38.4	18	32.5	41.1	0.742	0.0	29.8	34.3	-4.5	-32.0	23.1
Return	Peak	13	37.7	24.1	18	36.8	24.4	0.803	0.0	36.1	37.9	-1.8	-16.7	13.0
	Mean	13	21.3	14.0	18	19.7	16.4	0.89	0.0	19.9	20.6	-0.7	-11.5	10.0
	Time %	13	79.9	24.8	18	69.7	28.2	0.650	0.0	76.8	72.0	4.8	-16.6	26.2
		LLF												
Away	Peak	13	41.2	24.4	18	49.1	19.2	0.046	0.1	38.1	51.3	-13.2	-26.1	-0.3
	Mean	13	22.4	14.6	18	26.8	11.1	0.094	0.1	21.2	27.6	-6.4	-14.0	1.2
	Time %	13	76.1	27.4	18	85.3	16.3	0.148	0.1	74.5	86.5	-12.1	-28.7	4.6
Return	Peak	13	30.8	22.2	18	38.2	23.1	0.285	0.0	30.2	38.6	-8.4	-24.2	7.4
	Mean	13	13.2	10.3	18	19.3	12.3	0.233	0.1	14.2	18.6	-4.4	-11.7	3.0
	Time %	13	60.4	35.3	18	66.3	36.4	0.713	0.0	61.2	65.7	-4.5	-29.2	20.2
RSCM		RLF												
Away	Peak	14	50.0	18.5	18	51.0	20.7	0.879	0.0	50.0	51.1	-1.1	-15.8	13.6
	Mean	14	30.9	13.8	18	31.6	12.3	0.891	0.0	30.9	31.6	-0.6	-10.3	9.0
	Time %	14	97.3	8.9	18	93.2	17.7	0.407	0.0	97.5	93.0	4.5	-6.4	15.5
Return	Peak	14	27.3	16.3	18	43.1	28.6	0.046	0.1	26.6	43.7	-17.0	-33.8	-0.3
	Mean	14	12.3	9.6	18	20.3	14.7	0.121	0.1	12.9	19.8	-7.0	-15.9	2.0
	Time %	14	68.9	34.3	18	61.6	32.1	0.575	0.0	68.4	62.0	6.5	-16.8	29.7
		LLF												
Away	Peak	14	5.6	3.0	18	5.8	2.9	0.621	0.0	5.4	5.9	-0.5	-2.4	1.5
	Mean	14	3.7	2.2	18	3.5	1.6	0.737	0.0	3.7	3.5	0.2	-1.1	1.6
	Time %	14	45.1	32.9	18	21.4	27.1	0.026	0.2	45.4	21.1	24.3	3.1	45.5
Return	Peak	14	33.2	17.3	18	36.7	18.2	0.648	0.0	33.6	36.4	-2.8	-15.2	9.6
	Mean	14	17.5	9.2	18	19.3	13.0	0.636	0.0	17.4	19.4	-2.0	-10.4	6.4
	Time %	14	82.0	29.3	18	73.8	30.9	0.495	0.0	81.7	74.1	7.6	-14.9	30.1
LUT		RLF												
Away	Peak	15	8.1	10.4	19	10.3	10.6	0.827	0.0	9.6	9.1	0.5	-4.2	5.2
	Mean	15	5.6	7.7	19	7.3	7.2	0.575	0.0	7.0	6.1	0.9	-2.3	4.0
	Time %	15	52.8	45.4	19	32.9	38.4	0.285	0.0	50.3	34.8	15.6	-13.6	44.8
Return	Peak	15	5.8	6.4	19	8.2	9.3	0.766	0.0	6.9	7.4	-0.5	-4.0	3.0
	Mean	15	4.2	4.6	19	5.2	5.0	0.866	0.0	4.8	4.7	0.2	-1.7	2.0

Away	Time %	15	54.0	42.5	19	36.0	44.4	0.384	0.0	51.2	38.3	13.0	-17.0	43.0
	LLF													
	Peak	15	11.3	12.1	19	14.4	14.8	0.52	0.0	12.2	13.8	-1.6	-6.5	3.4
	Mean	15	7.3	8.4	19	9.7	10.0	0.473	0.0	8.0	9.1	-1.2	-4.4	2.1
	Time %	15	78.4	27.1	19	45.5	43.0	0.029	0.1	73.1	49.7	23.4	2.6	44.1
	Return													
Return	Peak	15	9.9	10.4	19	12.0	11.1	0.67	0.0	10.6	11.5	-0.9	-5.1	3.3
	Mean	15	7.3	8.0	19	9.0	8.6	0.566	0.0	7.8	8.7	-0.9	-4.0	2.2
	Time %	15	70.9	36.6	19	43.9	42.5	0.224	0.0	64.0	49.3	14.7	-9.5	38.9
RUT														
Away	RLF													
	Peak	14	8.4	9.4	19	7.2	6.6	0.407	0.0	8.6	7.0	1.6	-2.3	5.5
	Mean	14	5.7	7.2	19	5.2	4.9	0.494	0.0	6.0	4.9	1.0	-2.0	4.0
Return	Time %	14	86.7	22.0	19	55.3	45.3	0.055	0.1	83.0	58.0	25.1	-0.6	50.7
	Peak	14	7.8	10.1	19	7.5	6.4	0.916	0.0	7.8	7.6	0.2	-4.2	4.6
	Mean	14	5.6	7.8	19	5.5	4.7	0.844	0.0	5.7	5.4	0.3	-3.0	3.7
Away	Time %	14	83.8	23.6	19	56.2	41.8	0.076	0.1	80.8	58.4	22.4	-2.5	47.3
	LLF													
	Peak	14	4.8	6.9	19	6.2	5.8	0.758	0.0	5.2	5.8	-0.6	-4.6	3.4
Return	Mean	14	3.1	4.8	19	4.0	3.9	0.805	0.0	3.4	3.8	-0.3	-3.0	2.4
	Time %	14	39.3	37.5	19	38.8	39.5	0.975	0.0	39.3	38.8	0.4	-27.7	28.6
	Peak	14	4.5	5.8	19	4.4	3.3	0.435	0.0	5.0	4.0	1.0	-1.5	3.4
Return	Mean	14	2.9	3.3	19	2.8	1.9	0.395	0.0	3.2	2.6	0.6	-0.9	2.1
	Time %	14	62.4	37.1	19	39.6	42.0	0.132	0.1	61.6	40.1	21.5	-6.8	49.8
LT9														
Away	RLF													
	Peak	15	30.5	20.5	18	25.9	8.7	0.087	0.1	32.6	24.2	8.4	-1.3	18.1
	Mean	15	24.1	17.4	18	20.5	7.2	0.122	0.1	25.7	19.2	6.6	-1.9	15.0
Return	Time %	15	77.9	39.6	18	90.4	24.0	0.231	0.0	77.3	90.9	-13.6	-36.3	9.1
	Peak	15	30.5	18.3	18	28.7	9.0	0.178	0.1	32.8	26.8	6.0	-2.9	14.9
	Mean	15	24.4	14.5	18	23.7	7.2	0.233	0.0	26.4	22.0	4.4	-3.0	11.7
Away	Time %	15	76.3	35.8	18	91.7	23.9	0.314	0.0	79.2	89.3	-10.1	-30.4	10.1
	LLF													
	Peak	15	22.4	13.1	18	22.8	7.9	0.406	0.0	24.2	21.3	2.9	-4.1	9.8
Return	Mean	15	17.4	11.7	18	17.1	6.5	0.455	0.0	18.5	16.2	2.3	-3.9	8.5
	Time %	15	66.9	41.8	18	78.3	32.0	0.444	0.0	68.2	77.2	-8.9	-32.4	14.6
	Peak	15	21.9	14.8	18	19.1	8.9	0.154	0.1	23.6	17.6	6.0	-2.4	14.3
Return	Mean	15	17.2	12.2	18	15.0	7.5	0.186	0.1	18.5	13.9	4.6	-2.3	11.5
	Time %	15	64.1	44.2	18	71.1	39.1	0.591	0.0	63.9	71.3	-7.4	-35.1	20.4
RT9														
RLF														

Away	Peak	14	24.2	12.7	19	26.6	10.7	0.322	0.0	27.7	24.0	3.7	-3.9	11.3
	Mean	14	16.9	9.5	19	19.7	8.5	0.517	0.0	19.6	17.7	1.8	-3.8	7.4
	Time %	14	68.3	40.3	19	85.3	31.9	0.832	0.0	76.4	79.3	-2.9	-30.3	24.5
Return	Peak	14	20.7	10.2	19	24.0	11.5	0.380	0.0	24.5	21.2	3.4	-4.4	11.1
	Mean	14	15.0	8.1	19	17.7	9.0	0.668	0.0	17.3	16.0	1.3	-4.7	7.2
	Time %	14	63.5	43.6	19	81.6	34.1	0.713	0.0	70.6	76.4	-5.8	-37.7	26.1
LLF														
Away	Peak	14	31.9	16.3	19	30.0	11.1	0.091	0.1	35.0	27.8	7.2	-1.2	15.7
	Mean	14	23.9	11.4	19	23.3	9.0	0.12	0.1	26.4	21.4	5.0	-1.4	11.4
	Time %	14	82.5	34.0	19	89.0	26.5	0.803	0.0	84.6	87.5	-2.9	-26.2	20.4
Return	Peak	14	31.1	17.5	19	32.7	10.7	0.558	0.0	33.5	30.9	2.6	-6.4	11.7
	Mean	14	24.6	14.1	19	27.0	9.2	0.760	0.0	26.7	25.5	1.2	-6.8	9.2
	Time %	14	75.9	35.3	19	91.4	23.6	0.235	0.0	77.3	90.4	-13.1	-35.1	9.0
Rot														
LAS Positive														
Away	Peak	13	14.3	5.2	18	15.7	9.0	0.718	0.0	14.6	15.5	-0.9	-6.0	4.2
	Mean	13	8.2	3.5	18	9.6	5.0	0.784	0.0	8.7	9.1	-0.4	-3.4	2.6
	Time %	13	62.0	30.3	18	46.6	38.9	0.22	0.1	60.8	47.4	13.4	-8.5	35.2
Return	Peak	13	17.9	5.4	18	22.3	16.1	0.248	0.0	17.6	22.4	-4.8	-13.1	3.5
	Mean	13	11.5	4.7	18	17.0	11.6	0.110	0.1	11.9	16.7	-4.8	-10.9	1.2
	Time %	13	72.3	28.8	18	64.1	44.8	0.530	0.0	72.7	63.9	8.8	-19.5	37.1
Lrot														
Away	Peak	13	22.0	10.9	18	19.0	8.8	0.645	0.0	21.1	19.7	1.4	-4.9	7.7
	Mean	13	11.7	5.9	18	11.3	6.3	0.959	0.0	11.5	11.4	0.1	-4.1	4.3
	Time %	13	75.7	28.0	18	48.9	38.4	0.041	0.1	74.6	49.7	24.9	1.1	48.7
Return	Peak	13	16.9	8.2	18	16.8	9.1	0.661	0.0	16.1	17.4	-1.3	-7.0	4.5
	Mean	13	9.2	4.3	18	11.8	7.3	0.176	0.1	9.1	11.9	-2.8	-6.8	1.3
	Time %	13	63.8	33.0	18	52.2	46.6	0.460	0.0	63.0	52.8	10.2	-17.7	38.1
RAS Rrot														
Away	Peak	14	21.5	16.5	18	16.5	5.6	0.145	0.1	21.7	16.3	5.4	-2.0	12.7
	Mean	14	11.2	6.1	18	9.5	3.2	0.145	0.1	11.5	9.2	2.3	-0.8	5.5
	Time %	14	76.3	30.9	18	69.8	36.9	0.664	0.0	75.7	70.3	5.4	-19.8	30.5
Return	Peak	14	18.9	17.7	18	15.0	7.6	0.631	0.0	17.9	15.8	2.1	-6.7	10.9
	Mean	14	9.2	4.9	18	9.9	5.8	0.529	0.0	9.0	10.1	-1.2	-4.9	2.6
	Time %	14	67.7	36.9	18	61.5	40.5	0.774	0.0	66.5	62.4	4.1	-24.9	33.1
Lrot														
Away	Peak	14	14.3	7.0	18	17.8	9.7	0.119	0.1	13.5	18.4	-4.9	-11.2	1.3

Return	Mean	14	8.2	4.4	18	9.5	4.8	0.288	0.0	7.9	9.7	-1.8	-5.2	1.6
	Time %	14	65.3	26.9	18	57.2	32.5	0.438	0.0	65.6	57.0	8.6	-13.8	31.0
	Peak	14	14.0	5.6	18	21.8	13.5	0.040	0.1	13.7	22.0	-8.3	-16.1	-0.4
	Mean	14	9.1	4.1	18	16.0	10.1	0.031	0.2	9.5	15.7	-6.2	-11.7	-0.6
	Time %	14	63.7	34.5	18	77.9	34.1	0.211	0.1	62.9	78.5	-15.6	-40.5	9.3
LPC														
Away	Rrot													
	Peak	15	20.2	12.2	19	23.2	14.5	0.525	0.0	20.2	23.3	-3.1	-12.8	6.7
	Mean	15	13.5	9.3	19	12.6	8.8	0.779	0.0	13.5	12.6	0.9	-5.6	7.5
Return	Time %	15	84.3	28.4	19	92.1	18.9	0.384	0.0	84.6	91.9	-7.3	-24.2	9.6
	Peak	15	25.6	12.7	19	21.6	12.5	0.242	0.0	26.0	21.2	4.8	-3.4	13.1
	Mean	15	16.3	10.7	19	15.4	10.7	0.608	0.0	16.8	15.0	1.9	-5.5	9.3
	Time %	15	89.1	25.7	19	94.2	18.3	0.473	0.0	88.9	94.4	-5.5	-20.9	9.9
Away	Lrot													
	Peak	15	51.3	21.1	19	54.1	20.9	0.573	0.0	50.6	54.7	-4.1	-18.7	10.6
	Mean	15	30.7	11.0	19	29.0	14.2	0.779	0.0	30.5	29.2	1.2	-7.7	10.2
Return	Time %	15	91.4	13.3	19	90.2	13.2	0.825	0.0	91.3	90.3	1.0	-8.4	10.4
	Peak	15	45.4	24.6	19	57.7	22.3	0.238	0.0	46.8	56.6	-9.7	-26.2	6.8
	Mean	15	24.7	14.7	19	35.8	18.4	0.232	0.0	26.7	34.2	-7.6	-20.3	5.1
	Time %	15	85.0	21.2	19	94.6	16.0	0.131	0.1	85.0	94.6	-9.6	-22.2	3.0
RPC														
Away	Rrot													
	Peak	14	59.4	18.1	19	59.7	23.9	1.000	0.0	59.6	59.6	0.0	-14.6	14.6
	Mean	14	37.9	15.0	19	36.5	14.8	0.512	0.0	39.0	35.6	3.4	-7.0	13.8
Return	Time %	14	98.9	3.9	19	97.0	7.9	0.796	0.0	98.1	97.5	0.6	-3.9	5.1
	Peak	14	47.6	21.7	19	61.0	25.9	0.343	0.0	51.0	58.4	-7.4	-23.2	8.3
	Mean	14	24.2	11.8	19	36.7	20.7	0.306	0.0	27.5	34.3	-6.9	-20.4	6.6
	Time %	14	86.3	14.9	19	85.8	30.6	0.854	0.0	85.1	86.7	-1.5	-18.4	15.3
Away	Lrot													
	Peak	14	23.5	12.4	19	22.6	11.7	0.654	0.0	24.0	22.2	1.8	-6.2	9.8
	Mean	14	13.3	5.5	19	10.3	3.6	0.059	0.1	13.4	10.3	3.1	-0.1	6.3
Return	Time %	14	74.6	24.3	19	71.3	29.8	0.904	0.0	72.1	73.2	-1.1	-18.9	16.7
	Peak	14	29.3	16.2	19	29.4	17.3	0.646	0.0	30.9	28.2	2.7	-9.2	14.7
	Mean	14	16.5	7.4	19	19.0	11.0	0.749	0.0	17.2	18.4	-1.1	-8.4	6.1
	Time %	14	88.8	23.0	19	87.3	29.2	0.897	0.0	88.6	87.4	1.2	-17.0	19.3
LT4														
Away	Rrot													
	Peak	14	15.0	12.4	19	12.9	12.3	0.808	0.0	14.2	13.5	0.8	-5.7	7.3
	Mean	14	12.5	10.1	19	10.7	10.9	0.777	0.0	11.9	11.1	0.8	-5.0	6.6
	Time %	14	73.3	39.9	19	88.4	28.3	0.161	0.1	72.4	89.1	-16.7	-40.3	7.0

Return	Peak	14	14.9	12.1	19	13.5	13.7	0.826	0.0	13.7	14.5	-0.8	-8.0	6.4
	Mean	14	12.3	9.7	19	11.2	10.1	0.904	0.0	11.5	11.8	-0.3	-5.5	4.9
	Time %	14	75.0	40.1	19	89.2	26.1	0.215	0.1	74.9	89.3	-14.5	-37.8	8.9
Lrot														
Away	Peak	14	13.5	10.6	19	13.8	13.7	0.725	0.0	12.9	14.3	-1.3	-8.9	6.3
	Mean	14	10.6	8.6	19	10.8	10.7	0.642	0.0	10.0	11.3	-1.3	-7.1	4.4
	Time %	14	69.3	39.3	19	86.5	26.3	0.135	0.1	69.7	86.1	-16.4	-38.2	5.4
Return	Peak	14	13.0	10.3	19	13.8	14.5	0.871	0.0	13.1	13.7	-0.6	-8.4	7.1
	Mean	14	10.9	8.8	19	11.2	11.4	0.92	0.0	10.9	11.2	-0.3	-6.5	5.9
	Time %	14	64.3	41.7	19	86.8	26.6	0.075	0.1	64.8	86.4	-21.6	-45.6	2.3
RT4														
Away	Peak	14	6.1	4.3	19	6.2	3.0	0.783	0.0	6.0	6.3	-0.3	-2.9	2.2
	Mean	14	5.0	3.5	19	5.0	2.5	0.900	0.0	4.9	5.0	-0.1	-2.2	2.0
	Time %	14	86.2	28.0	19	83.6	36.7	0.758	0.0	86.7	83.2	3.5	-19.2	26.2
Return	Peak	14	5.8	4.2	19	7.1	5.5	0.376	0.0	5.7	7.2	-1.5	-4.9	1.9
	Mean	14	4.8	3.4	19	5.6	3.6	0.412	0.0	4.7	5.7	-1.0	-3.3	1.4
	Time %	14	82.1	33.6	19	83.8	35.1	0.904	0.0	82.3	83.7	-1.4	-24.4	21.7
Lrot														
Away	Peak	14	6.5	3.6	19	6.8	3.9	0.685	0.0	6.3	6.9	-0.6	-3.3	2.2
	Mean	14	5.1	3.0	19	5.1	2.3	0.881	0.0	5.0	5.1	-0.1	-2.1	1.8
	Time %	14	87.9	24.3	19	87.6	29.6	0.845	0.0	88.8	86.9	1.9	-17.7	21.5
Return	Peak	14	5.9	3.2	19	6.0	3.0	0.755	0.0	5.8	6.1	-0.3	-2.5	1.9
	Mean	14	5.0	2.8	19	5.0	2.3	0.788	0.0	4.8	5.1	-0.2	-2.1	1.6
	Time %	14	86.6	31.8	19	85.2	34.8	0.843	0.0	87.2	84.8	2.3	-21.5	26.1
LSCM														
Away	Peak	13	51.8	19.5	18	54.0	15.8	0.507	0.0	50.6	54.9	-4.3	-17.5	8.9
	Mean	13	23.8	12.5	18	25.3	8.8	0.417	0.0	22.9	26.0	-3.1	-10.8	4.6
	Time %	13	76.6	24.8	18	80.5	27.0	0.247	0.0	73.3	82.8	-9.5	-25.9	6.9
Return	Peak	13	51.5	22.3	18	59.5	17.8	0.243	0.0	51.5	59.5	-8.0	-21.8	5.8
	Mean	13	27.8	18.7	18	36.1	16.8	0.401	0.0	29.5	34.8	-5.3	-18.1	7.5
	Time %	13	81.1	21.5	18	88.2	23.7	0.430	0.0	81.4	88.0	-6.6	-23.4	10.2
Lrot														
Away	Peak	13	15.6	9.5	18	18.0	14.3	0.601	0.0	15.7	18.0	-2.3	-11.0	6.5
	Mean	13	7.6	4.1	18	8.2	7.8	0.830	0.0	7.7	8.2	-0.5	-5.2	4.2
	Time %	13	52.5	36.6	18	48.7	37.9	0.833	0.0	52.0	49.1	2.9	-25.3	31.2
Return	Peak	13	10.4	5.9	18	9.9	5.6	0.895	0.0	10.3	10.0	0.3	-4.0	4.6
	Mean	13	5.8	3.1	18	6.7	4.0	0.534	0.0	5.8	6.7	-0.8	-3.6	1.9

	Time %	13	47.5	41.4	18	56.7	45.8	0.635	0.0	48.8	55.8	-7.0	-36.8	22.8
RSCM	Rrot													
Away	Peak	14	18.6	14.2	18	18.3	10.0	0.610	0.0	19.4	17.7	1.7	-5.0	8.4
	Mean	14	10.4	8.9	18	8.7	4.2	0.303	0.0	10.7	8.4	2.3	-2.2	6.7
	Time %	14	82.3	31.1	18	64.5	38.3	0.132	0.1	83.2	63.8	19.4	-6.2	45.1
Return	Peak	14	16.4	12.3	18	11.9	4.2	0.187	0.1	16.1	12.1	4.0	-2.1	10.1
	Mean	14	8.4	5.7	18	7.8	3.1	0.704	0.0	8.4	7.8	0.6	-2.5	3.6
	Time %	14	67.0	35.1	18	68.3	32.0	0.936	0.0	67.2	68.1	-1.0	-25.1	23.2
	Lrot													
Away	Peak	14	49.4	23.3	18	49.8	17.8	0.885	0.0	49.0	50.1	-1.0	-15.7	13.6
	Mean	14	24.9	16.3	18	23.0	10.3	0.724	0.0	24.7	23.1	1.7	-8.0	11.3
	Time %	14	81.2	24.2	18	79.5	22.8	0.742	0.0	81.8	79.0	2.8	-14.5	20.2
Return	Peak	14	41.6	21.7	18	48.6	20.6	0.371	0.0	41.7	48.6	-6.9	-22.4	8.6
	Mean	14	22.8	14.3	18	31.1	17.4	0.279	0.0	24.0	30.2	-6.2	-17.6	5.3
	Time %	14	87.7	26.9	18	91.1	25.5	0.799	0.0	88.3	90.7	-2.4	-21.6	16.8
LUT	Rrot													
Away	Peak	15	7.5	9.0	19	14.3	17.1	0.471	0.0	12.4	10.4	2.0	-3.5	7.5
	Mean	15	5.2	6.8	19	10.6	13.5	0.932	0.0	8.4	8.1	0.2	-4.9	5.3
	Time %	15	62.0	40.2	19	39.1	38.9	0.097	0.1	61.7	39.4	22.3	-4.3	48.9
Return	Peak	15	6.4	6.9	19	9.2	10.8	0.480	0.0	8.8	7.3	1.4	-2.7	5.5
	Mean	15	4.8	5.8	19	7.0	8.3	0.430	0.0	6.7	5.5	1.2	-1.8	4.2
	Time %	15	55.2	42.3	19	32.4	43.1	0.133	0.1	55.1	32.5	22.5	-7.3	52.3
	Lrot													
Away	Peak	15	6.5	6.0	19	8.9	8.3	0.773	0.0	8.1	7.6	0.4	-2.6	3.5
	Mean	15	4.1	3.9	19	5.7	5.5	0.742	0.0	5.2	4.9	0.3	-1.7	2.3
	Time %	15	62.9	37.6	19	35.4	39.5	0.030	0.1	62.9	35.5	27.4	2.9	51.9
Return	Peak	15	5.2	4.6	19	10.1	11.4	0.441	0.0	7.2	8.5	-1.4	-5.0	2.2
	Mean	15	3.4	2.8	19	5.9	6.5	0.573	0.0	4.5	5.1	-0.6	-2.6	1.5
	Time %	15	56.4	39.7	19	33.6	39.3	0.108	0.1	55.3	34.4	20.9	-4.9	46.6
RUT	Rrot													
Away	Peak	14	6.2	6.0	19	5.0	2.9	0.347	0.0	6.3	4.9	1.4	-1.6	4.3
	Mean	14	3.6	3.7	19	3.1	2.0	0.410	0.0	3.8	3.0	0.8	-1.1	2.6
	Time %	14	70.8	34.3	19	45.8	45.3	0.193	0.1	67.4	48.3	19.1	-10.2	48.4
Return	Peak	14	4.5	3.8	19	4.2	2.3	0.717	0.0	4.5	4.2	0.3	-1.5	2.2
	Mean	14	2.9	2.2	19	2.9	1.8	0.846	0.0	3.0	2.9	0.1	-1.1	1.4
	Time %	14	69.8	31.0	19	36.0	42.8	0.024	0.2	69.1	36.6	32.5	4.7	60.4
	Lrot													

Away	Peak	14	8.5	10.9	19	6.8	5.4	0.593	0.0	8.2	7.0	1.1	-3.1	5.4
	Mean	14	5.8	7.6	19	4.6	3.9	0.576	0.0	5.6	4.8	0.8	-2.2	3.8
	Time %	14	77.1	24.5	19	44.3	42.7	0.019	0.2	77.1	44.3	32.8	5.8	59.9
Return	Peak	14	6.2	9.0	19	5.3	4.5	0.819	0.0	6.0	5.5	0.5	-4.2	5.2
	Mean	14	4.5	6.8	19	4.1	3.4	0.782	0.0	4.5	4.0	0.5	-2.9	3.9
	Time %	14	59.9	36.0	19	53.2	48.1	0.699	0.0	59.6	53.5	6.1	-25.8	38.0
LT9		Rrot												
Away	Peak	15	25.8	16.4	18	23.8	7.8	0.269	0.0	27.3	22.5	4.8	-3.9	13.6
	Mean	15	21.7	14.3	18	19.2	7.2	0.218	0.1	23.0	18.2	4.8	-3.0	12.6
	Time %	15	71.4	40.2	18	91.5	23.8	0.076	0.1	71.2	91.6	-20.3	-43.0	2.3
Return	Peak	15	25.4	14.9	18	26.0	9.3	0.379	0.0	27.5	24.3	3.2	-4.1	10.5
	Mean	15	21.6	13.3	18	22.0	7.5	0.383	0.0	23.3	20.6	2.7	-3.5	8.9
	Time %	15	74.1	40.6	18	93.2	23.7	0.210	0.1	77.8	90.1	-12.3	-31.9	7.3
		Lrot												
Away	Peak	15	23.8	16.8	18	23.8	6.7	0.340	0.0	25.8	22.2	3.6	-4.0	11.3
	Mean	15	18.9	13.7	18	17.8	5.3	0.349	0.0	20.0	16.9	3.1	-3.6	9.8
	Time %	15	74.0	39.8	18	85.6	28.6	0.542	0.0	76.8	83.3	-6.5	-27.9	15.0
Return	Peak	15	23.4	15.8	18	20.7	6.5	0.233	0.0	24.6	19.7	4.9	-3.3	13.1
	Mean	15	19.5	13.5	18	17.4	6.4	0.294	0.0	20.4	16.6	3.7	-3.4	10.9
	Time %	15	66.8	44.7	18	83.6	31.9	0.204	0.1	67.6	82.9	-15.4	-39.5	8.8
RT9		Rrot												
Away	Peak	14	23.7	10.8	19	26.4	10.4	0.702	0.0	26.0	24.7	1.3	-5.5	8.1
	Mean	19	13.8	11.4	19	20.1	8.3	0.123	0.1	14.4	19.5	-5.0	-11.5	1.4
	Time %	14	75.3	37.4	19	83.3	32.0	0.926	0.0	79.2	80.4	-1.2	-27.2	24.8
Return	Peak	19	16.9	14.1	19	26.2	13.7	0.059	0.1	17.0	26.1	-9.1	-18.6	0.4
	Mean	19	14.0	11.6	19	21.6	11.1	0.072	0.1	14.3	21.3	-7.0	-14.7	0.7
	Time %	14	77.8	41.3	19	85.9	31.2	0.565	0.0	77.8	85.9	-8.1	-36.6	20.3
		Lrot												
Away	Peak	19	20.8	17.0	19	27.7	9.7	0.262	0.0	21.7	26.8	-5.1	-14.2	4.0
	Mean	19	16.7	13.3	19	22.3	7.9	0.243	0.0	17.4	21.6	-4.3	-11.6	3.0
	Time %	14	84.6	24.9	19	89.2	26.7	0.552	0.0	84.0	89.7	-5.7	-25.2	13.7
Return	Peak	19	20.2	16.8	19	30.0	14.5	0.136	0.1	21.4	28.8	-7.4	-17.2	2.4
	Mean	19	16.8	14.1	19	25.5	11.4	0.110	0.1	17.9	24.4	-6.5	-14.6	1.6
	Time %	14	79.3	33.8	19	90.8	25.7	0.345	0.0	80.0	90.3	-10.3	-32.1	11.6

(CG – control group; EG – experimental group; M – mean; SE – standard error; MD – mean difference; CI – confidence interval; η^2 – partial eta squared; ave – average; LAS – left anterior scalene; RAS – right anterior scalene; LPC – left posterior cervical; RPC – right posterior cervical; LSCM – left sternocleidomastoid; RSCM – right sternocleidomastoid; LUT – left upper trapezius; RUT – right upper trapezius; LT4 – left paraspinal at T4; RT4 – right paraspinal at T4; LT9 – left

paraspinal at T9; RT9 - right paraspinal at T9; Flex – flexion; Ext – extension; LLF – left lateral flexion; RLF – right lateral flexion; Lrot – left rotation; Rrot – right rotation)

SUPPLEMENTARY FILE 8.1: SPINAL KINEMATIC MEASURES TAKEN PRE-, POST- AND AT THE FOURTH VISIT DURING THE UNILATERAL TASK

Motion Outcome	CG						EG					
	Pre (n=19)		Post (n=19)		4th (n=15)		Pre (n=19)		Post (n=19)		4th (n=19)	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Cervical												
Flex-ext												
Peak value	14.6	10.5	12.8	11.1	12.4	11.5	8.9	10.6	8.2	9.2	7.9	8.6
Lift Range	30.1	12.4	30.4	12.7	29.7	12.7	28.6	10.1	28.1	8.6	28.2	6.8
Velocity ave	18.9	8.4	22.5	12.2	27.1	14.1	20.6	10.5	23.0	11.3	23.6	9.2
Jerk ave	1091.6	427.6	1237.7	532.2	1410.2	711.4	1158.5	552.9	1521.3	740.0	1527.7	657.1
Lower Range	22.4	11.1	22.6	9.6	21.1	8.5	21.7	8.0	20.4	6.2	18.9	7.7
Velocity ave	12.3	6.1	14.1	6.6	14.2	6.1	16.0	8.8	15.4	3.9	16.2	7.0
Jerk avg	1003.6	502.7	1198.1	505.0	1303.5	653.4	1362.7	769.7	1482.2	501.0	1495.7	624.2
LF												
Peak value	4.1	5.2	4.2	6.9	4.9	5.1	0.7	6.4	2	7.1	3.6	5.2
Lift Range	12.1	4.4	12.8	7	13.4	5.9	12.9	4.4	13.7	4.8	14.7	4.4
Velocity ave	8.1	3.4	10.3	8.3	12.9	8.1	10.1	5.5	12.2	6.4	12.5	5.9
Jerk ave	684.7	279.9	828.5	538.2	992.3	442.4	802.1	373.6	1013	439.2	995.3	426.4
Lower Range	9.7	3.8	10.5	4.4	11.7	5.6	12.4	7.6	13.2	5.7	13	5.4
Velocity ave	5.7	2.4	7.1	3	7.9	3.9	9.4	9.3	10	4.2	10.5	4.7
Jerk avg	663.2	287.9	769.1	340.2	847.7	462.1	911.7	644.7	1015.2	402.1	1009.8	346.3
Rot												
Peak value	15.2	6	17.5	6.7	17	7.5	16.5	7.2	17.6	6.9	17.4	5.8
Lift Range	7.4	4	6.3	3.3	8	3.3	8	4.3	8.2	4.5	8	3.9
Velocity ave	5.9	2.9	6.3	2.7	9	3.8	6.6	2.6	7.9	3.3	8.1	3.6
Jerk ave	700.2	291.5	782.5	316.7	1033.1	401.7	835.3	296.9	919.7	342.2	977.7	370

Lower	Range	9	5.4	7.9	3.4	8.9	2.8	10.5	4.1	10.6	4.5	10.7	4.2
	Velocity ave	5.8	2.3	6.3	2.6	7.3	2.6	8.4	4.3	8.5	3.2	9.5	3.4
	Jerk avg	643.1	222.8	724.1	310.4	819	304.8	928.3	562	969.3	312.1	1046.6	381
Upper thoracic													
Flex-ext													
Peak value		-2.3	2.1	-2.2	2.0	-1.8	1.9	-1.8	2.0	-2.2	2.3	-1.6	1.7
Lift	Range	2.1	0.9	2.3	1.3	2.1	1.1	2.3	1.1	2.5	1.2	2.2	1.1
	Velocity ave	2.3	1.9	2.7	1.9	2.9	2.1	2.4	1.2	2.7	1.3	2.7	1.3
	Jerk ave	569.9	711.3	622.5	726.9	696.7	829.9	551.0	462.7	556.5	484.6	681.7	715.8
Lower	Range	3.1	1.6	3.4	1.5	2.9	1.0	3.7	1.7	3.8	1.5	3.2	1.1
	Velocity ave	2.1	1.5	2.6	1.7	2.6	2.4	2.8	1.3	2.9	1.2	3.1	1.2
	Jerk avg	445.6	486.7	587.9	661.0	547.5	633.7	463.1	322.4	535.7	448.7	643.6	469.0
LF													
Peak value		-9.1	3.2	-9.2	3.2	-8.4	4.1	-8.6	3.4	-8.3	3.6	-7.7	3.6
Lift	Range	9.8	3.4	9.6	2.4	9.2	3.5	9.2	3.5	9.1	3.5	9.0	3.8
	Velocity ave	5.9	2.7	6.3	1.7	7.8	3.3	6.2	3.3	6.6	2.8	7.0	3.3
	Jerk ave	420.7	243.0	412.2	205.0	535.2	316.0	468.9	227.0	488.4	218.5	544.1	329.8
Lower	Range	9.7	3.3	9.7	2.7	10.0	3.4	9.4	3.4	9.6	3.9	9.8	3.8
	Velocity ave	4.6	2.4	4.7	1.6	5.3	2.5	5.1	1.8	5.3	1.4	6.3	2.4
	Jerk avg	391.5	251.8	375.5	172.7	462.6	285.1	488.6	259.6	484.5	196.8	604.7	330.3
Rot													
Peak value		8.4	4.1	8.0	4.1	8.8	3.9	6.8	5.2	7.0	4.1	8.8	5.2
Lift	Range	10.2	2.8	9.7	2.1	8.9	2.0	10.1	2.9	10.6	2.9	10.6	2.6
	Velocity ave	8.5	3.8	9.3	4.1	10.4	3.8	9.6	3.9	10.9	4.4	10.9	3.8
	Jerk ave	711.5	506.4	751.5	496.2	897.5	510.8	958.6	587.2	988.0	477.7	971.2	486.4
Lower	Range	10.3	2.4	9.8	2.0	8.8	1.9	10.4	3.1	10.4	3.0	9.8	2.3
	Velocity ave	6.8	2.6	7.2	2.3	7.5	3.3	8.4	3.5	8.6	2.3	8.9	2.2
	Jerk avg	626.6	394.4	650.8	345.7	812.9	496.1	892.4	476.4	965.7	544.1	1126.0	644.4
Lower thoracic													
Flex-ext													
Peak value		-9.7	2.8	-9.5	3.2	-9.2	4.7	-8.3	3.7	-9.3	3.1	-8.2	3.7
Lift	Range	3.8	1.2	4.0	1.5	3.3	1.4	3.2	1.1	3.4	1.2	3.5	1.6
	Velocity ave	2.7	1.2	3.2	1.3	3.6	2.0	2.6	0.9	3.0	1.2	3.2	1.1
	Jerk ave	407.8	331.7	459.1	410.2	450.2	250.2	462.2	261.4	444.1	230.0	506.7	311.5
Lower	Range	4.3	1.3	4.6	1.6	3.8	1.2	4.1	1.9	4.3	1.7	4.5	1.7
	Velocity ave	2.3	0.9	2.6	1.1	2.6	1.1	2.6	1.2	2.9	1.0	3.3	1.8
	Jerk avg	368.4	284.2	427.9	329.9	427.3	274.9	463.6	381.0	475.0	281.3	519.5	281.4

LF													
Peak value		-6.5	3.6	-9.2	3.2	-6.2	3.4	-7.1	3.3	-8.3	3.6	-7.3	4.0
Lift	Range	7.3	3.0	9.6	2.4	7.2	3.0	7.5	2.9	9.1	3.5	7.6	2.9
	Velocity ave	4.5	2.1	6.3	1.7	6.0	2.9	5.0	2.5	6.6	2.8	5.7	2.2
	Jerk ave	523.3	365.7	412.2	205.0	695.1	458.7	637.8	318.2	488.4	218.5	760.4	429.6
Lower	Range	7.0	2.3	9.7	2.7	6.9	2.3	7.0	3.5	9.6	3.9	7.6	3.2
	Velocity ave	3.5	1.3	4.7	1.6	4.2	2.0	3.9	1.7	5.3	1.4	5.3	2.3
	Jerk avg	529.7	423.8	375.5	172.7	597.0	364.1	576.2	267.6	484.5	196.8	769.9	449.2
Rot													
Peak value		-0.2	3.2	0.0	2.6	0.7	3.9	2.0	3.8	2.6	4.5	1.7	3.2
Lift	Range	3.8	1.9	3.4	1.3	3.2	1.0	4.2	1.6	4.2	1.5	3.9	1.4
	Velocity ave	4.0	2.3	4.3	2.4	4.7	2.0	4.3	1.6	4.6	1.4	4.9	2.1
	Jerk ave	970.8	969.1	1004.7	1017.5	1218.8	796.9	1180.8	740.3	1178.9	730.2	1333.1	815.3
Lower	Range	4.6	2.3	4.0	1.6	3.6	1.7	4.8	1.8	4.9	2.3	3.9	1.4
	Velocity ave	3.7	2.0	3.9	1.8	4.0	1.7	4.4	1.7	5.1	2.2	4.9	2.0
	Jerk avg	900.1	797.9	964.6	869.9	1024.5	832.7	1116.6	579.2	1295.8	773.4	1436.3	865.3

(range – degrees, velocity – m/s, jerk – m/s³; AVE – average; M – mean; SD – standard deviation; CG – control group; EG – experimental group; Flex-ext – flexion – extension; LF- lateral flexion; Rot – rotation)

**SUPPLEMENTARY FILE 8.2: POST-ADJUSTED MEANS FOR THE SPINAL KINEMATIC
OUTCOMES DURING THE UNILATERAL ARM TASK AT THE POST-MEASURE**

Motion Outcome		CG				EG				MD	SE	p-value	CI		η^2
		M	SE	CI		M	SE	CI					Low	High	
				Low	High			Low	High						
CROM															
Flex-ext															
Peak value		10.2	1.1	7.9	12.6	10.9	1.2	8.4	13.3	-0.6	1.7	0.717	-4.2	2.9	0.00
Lift	Range	29.8	1.4	26.9	32.6	28.8	1.5	25.8	31.8	1.0	2.1	0.632	-3.2	5.2	0.01
	Velocity avg	23.3	2.0	19.3	27.3	22.1	2.1	17.9	26.4	1.2	2.9	0.695	-4.8	7.1	0.01
	Jerk avg	1283.5	97.7	1084.6	1482.3	1438	103	1228.5	1647.5	-154.5	144.8	0.294	-449.2	140.1	0.03
Lower	Range	22.4	1.0	20.3	24.4	20.6	1.1	18.4	22.7	1.8	1.5	0.238	-1.2	4.8	0.04
	Velocity avg	15.2	0.9	13.3	17.1	13.9	1	11.9	15.9	1.3	1.4	0.360	-1.5	4.1	0.03
	Jerk avg	1308.8	80.5	1145.1	1472.6	1359.6	84	1188.6	1530.6	-50.8	119.7	0.674	-294.2	192.7	0.01
LF															
Peak value		2.7	1.1	0.5	4.9	3.4	1.1	1.1	5.7	-0.7	1.6	0.674	-4.0	2.6	0.01
Lift	Range	13.3	0.9	11.4	15.2	13.1	1	11.1	15.1	0.2	1.4	0.912	-2.7	3.0	0.00
	Velocity avg	11.4	1.3	8.7	14.2	10.8	1.4	8	13.6	0.7	2.0	0.744	-3.4	4.7	0.00
	Jerk avg	901.7	70.6	758	1045.4	925.3	74.1	774.5	1076	-23.5	104.6	0.823	-236.3	189.2	0.00
Lower	Range	11.5	0.8	9.9	13	11.9	0.8	10.3	13.5	-0.5	1.1	0.684	-2.7	1.8	0.01
	Velocity avg	7.9	0.6	6.7	9.1	8.8	0.6	7.6	10.1	-1.0	0.9	0.290	-2.8	0.9	0.03
	Jerk avg	843.3	62	717.1	969.4	916	64.9	784	1048	-72.8	92.2	0.435	-260.3	114.7	0.02
Rot															
Peak value		18	1	16	20.1	17.1	1.1	14.9	19.3	0.9	1.5	0.554	-2.2	4.0	0.01
Lift	Range	6.7	0.6	5.4	8	7.9	0.7	6.5	9.3	-1.3	0.9	0.196	-3.2	0.7	0.05
	Velocity avg	6.5	0.6	5.4	7.7	7.6	0.6	6.4	8.7	-1.0	0.8	0.219	-2.7	0.6	0.05
	Jerk avg	839	57.9	721.2	956.8	853.7	60.8	730	977.5	-14.7	86.4	0.866	-190.5	161.0	0.00
Lower	Range	8.3	0.8	6.8	9.9	9.8	0.8	8.1	11.5	-1.5	1.2	0.209	-3.8	0.9	0.05
	Velocity avg	7	0.6	5.8	8.1	7.8	0.6	6.6	9	-0.8	0.9	0.344	-2.6	0.9	0.03
	Jerk avg	793.3	59.8	671.7	914.9	881.2	62.5	754.1	1008.4	-87.9	89.8	0.335	-270.6	94.7	0.03
Upper thoracic															
Flex-ext															

Peak value		-2	0.4	-2.8	-1.1	-2.4	0.4	-3.3	-1.5	0.5	0.6	0.456	-0.8	1.7	0.02
Lift	Range	2.4	0.2	2	2.7	2.4	0.2	2	2.7	0.0	0.3	0.949	-0.5	0.5	0.00
	Velocity avg	2.8	0.2	2.4	3.2	2.6	0.2	2.2	3.1	0.2	0.3	0.539	-0.4	0.8	0.01
	Jerk avg	618	54.8	506.5	729.5	554.1	57.9	436.2	672	63.9	81.5	0.439	-101.9	229.7	0.02
Lower	Range	3.6	0.2	3.3	4	3.6	0.2	3.2	3.9	0.1	0.3	0.798	-0.5	0.6	0.00
	Velocity avg	3	0.2	2.7	3.4	2.6	0.2	2.2	2.9	0.4	0.3	0.102	-0.1	1.0	0.08
	Jerk avg	595.2	59.1	475	715.5	533.5	62.4	406.5	660.4	61.8	87.7	0.486	-116.7	240.3	0.02
LF															
Peak value		-9.1	0.6	-10.2	-7.9	-8.5	0.6	-9.7	-7.3	-0.5	0.8	0.52	-2.2	1.1	0.01
Lift	Range	9.4	0.4	8.5	10.3	9.4	0.5	8.4	10.4	0.0	0.7	0.991	-1.4	1.4	0.00
	Velocity avg	6.4	0.4	5.6	7.2	6.7	0.4	5.9	7.5	-0.3	0.6	0.55	-1.5	0.8	0.01
	Jerk avg	429	32.1	363.7	494.3	473.2	33.8	404.4	541.9	-44.2	47.6	0.36	-141.0	52.7	0.03
Lower	Range	9.6	0.5	8.5	10.7	9.9	0.6	8.8	11.1	-0.3	0.8	0.693	-1.9	1.3	0.01
	Velocity avg	4.9	0.3	4.4	5.5	5.1	0.3	4.5	5.7	-0.2	0.4	0.704	-1.0	0.7	0.00
	Jerk avg	406.8	28.4	349	464.6	443.5	29.8	382.8	504.2	-36.6	42.2	0.391	-122.5	49.2	0.02
Rot															
Peak value		7.5	0.6	6.2	8.7	7.6	0.7	6.3	8.9	-0.1	0.9	0.878	-2.0	1.7	0.00
Lift	Range	9.6	0.4	8.9	10.4	10.7	0.4	9.9	11.4	-1.1	0.5	0.055	-2.1	0.0	0.11
	Velocity avg	9.9	0.6	8.6	11.2	10.3	0.7	9	11.7	-0.5	1.0	0.624	-2.4	1.5	0.01
	Jerk avg	836.8	74.5	685.2	988.4	897.6	78.1	738.7	1056.4	-60.7	110.7	0.587	-286.1	164.6	0.01
Lower	Range	9.9	0.4	9.1	10.7	10.5	0.4	9.7	11.4	-0.6	0.6	0.286	-1.9	0.6	0.03
	Velocity avg	7.8	0.3	7.2	8.4	7.9	0.3	7.3	8.6	-0.2	0.4	0.741	-1.1	0.8	0.00
	Jerk avg	763	72	616.4	909.5	825.3	75.2	672.2	978.4	-62.3	107.6	0.566	-281.2	156.6	0.01
Lower thoracic															
Flex-ext															
Peak value		-9.2	0.6	-10.4	-8.1	-9.5	0.6	-10.7	-8.3	0.3	0.9	0.750	-1.5	2.0	0.00
Lift	Range	3.9	0.3	3.3	4.5	3.6	0.3	2.9	4.2	0.3	0.5	0.530	-0.6	1.2	0.01
	Velocity avg	3.3	0.2	2.8	3.7	2.9	0.2	2.4	3.4	0.3	0.3	0.290	-0.3	1.0	0.03
	Jerk avg	481.4	46	387.8	574.9	424	48.4	325.5	522.5	57.4	68.1	0.406	-81.2	195.9	0.02
Lower	Range	4.7	0.2	4.2	5.2	4.4	0.3	3.9	4.9	0.3	0.4	0.495	-0.5	1.0	0.01
	Velocity avg	2.9	0.1	2.6	3.1	2.8	0.1	2.5	3.1	0.1	0.2	0.672	-0.3	0.5	0.01
	Jerk avg	466.3	41.4	382.1	550.6	436.2	43.5	347.6	524.8	30.1	61.3	0.626	-94.6	154.9	0.01
LF															
Peak value		-6.8	0.5	-7.7	-5.8	-7.6	0.5	-8.6	-6.6	0.9	0.7	0.224	-0.6	2.3	0.04
Lift	Range	7.1	0.4	6.3	7.9	7.5	0.4	6.6	8.3	-0.3	0.6	0.580	-1.5	0.9	0.01
	Velocity avg	5.7	0.5	4.7	6.6	5.5	0.5	4.5	6.5	0.2	0.7	0.825	-1.3	1.6	0.00
	Jerk avg	683.6	45.2	591.5	775.7	624.9	47.6	528.1	721.7	58.7	67.3	0.389	-78.2	195.6	0.02

Lower	Range	6.9	0.5	5.9	7.8	7.3	0.5	6.3	8.3	-0.4	0.7	0.528	-1.8	1.0	0.01
	Velocity avg	4	0.2	3.6	4.5	4.2	0.2	3.7	4.7	-0.2	0.3	0.556	-0.9	0.5	0.01
	Jerk avg	606.2	41.4	522.1	690.4	636.4	43.6	547.8	725.1	-30.2	61.3	0.625	-154.9	94.5	0.01
Rot															
Peak value		1.4	0.5	0.4	2.4	1.7	0.5	0.7	2.7	-0.3	0.7	0.681	-1.8	1.2	0.01
Lift	Range	3.5	0.3	3	4.1	4.2	0.3	3.6	4.8	-0.7	0.4	0.114	-1.5	0.2	0.07
	Velocity avg	4.4	0.3	3.8	5.1	4.6	0.3	3.9	5.2	-0.1	0.5	0.809	-1.1	0.8	0.00
	Jerk avg	1097.4	97.6	898.7	1296	1091.3	102.7	882.4	1300.2	6.1	144.7	0.967	-288.4	300.5	0.00
Lower	Range	4.1	0.4	3.2	5	4.9	0.4	4	5.8	-0.8	0.6	0.205	-2.1	0.5	0.05
	Velocity avg	4.2	0.3	3.6	4.9	4.8	0.3	4.1	5.5	-0.6	0.5	0.225	-1.6	0.4	0.04
	Jerk avg	1073.3	111.5	846.4	1300.2	1182.4	117.2	944	1420.8	-109.1	165.3	0.514	-445.5	227.3	0.01

(range – degrees, velocity – m/s, jerk – m/s³; AVE – average; M – mean; SE - standard error; CI – confidence interval; MD – mean difference; CG – control group; EG – experimental group; Flex-ext – flexion – extension; LF- lateral flexion; Rot – rotation; η^2 – partial eta squared)

**SUPPLEMENTARY FILE 8.3: POST-ADJUSTED MEANS FOR THE SPINAL KINEMATIC
OUTCOMES DURING THE UNILATERAL ARM TASK AT THE FOURTH VISIT**

Motion Outcome		CG				EG				MD	SE	p-value	CI		η^2
		M	SE	CI		M	SE	CI							
				Low	High			Low	High						
CROM															
Flexion-extension															
Peak value		10.7	1.7	7.1	14.2	8.5	1.6	5.2	11.8	2.2	2.4	0.383	-2.8	7.1	0.03
Lift	Range	29.7	1.8	26.1	33.4	27.5	1.7	24.0	30.9	2.3	2.5	0.362	-2.8	7.3	0.03
	Velocity avg	27.8	2.0	23.6	31.9	22.2	1.9	18.3	26.1	5.6	2.8	0.056	-0.2	11.4	0.12
	Jerk avg	1431.3	122.8	1180.0	1682.5	1512.4	116.7	1273.7	1751.1	-81.1	170.7	0.638	-430.1	268.0	0.01
	Lower	Range	21.0	1.5	17.8	24.2	18.5	1.5	15.5	21.5	2.5	2.2	0.261	-1.9	6.9
	Velocity avg	15.0	1.4	12.2	17.9	14.4	1.3	11.7	17.1	0.6	2.0	0.751	-3.4	4.6	0.00
	Jerk avg	1416.2	128.7	1153.1	1679.4	1355.5	120.4	1109.3	1601.7	60.7	178.6	0.736	-304.5	425.9	0.00
Lateral flexion															
Peak value		3.7	1.1	1.6	5.9	4.1	1.0	2.0	6.1	-0.3	1.5	0.825	-3.4	2.7	0.00
Lift	Range	13.7	1.1	11.5	15.9	14.1	1.0	12.0	16.2	-0.4	1.5	0.790	-3.5	2.7	0.00
	Velocity avg	13.7	1.3	11.1	16.4	11.6	1.2	9.1	14.1	2.2	1.8	0.240	-1.5	5.9	0.05
	Jerk avg	1040.4	77.4	882.1	1198.6	976.6	73.1	827.1	1126.1	63.7	107.1	0.557	-155.4	282.8	0.01
	Lower	Range	12.4	1.0	10.4	14.4	11.8	0.9	9.9	13.7	0.6	1.4	0.653	-2.2	3.4
	Velocity avg	8.5	0.8	6.8	10.3	9.1	0.8	7.5	10.7	-0.6	1.2	0.641	-2.9	1.8	0.01
	Jerk avg	909.6	83.4	739.0	1080.1	904.4	78.1	744.6	1064.2	5.2	115.8	0.965	-231.6	242.0	0.00
Rotation															
Peak value		17.0	1.3	14.3	19.6	17.7	1.2	15.2	20.2	-0.7	1.8	0.695	-4.4	3.0	0.01
Lift	Range	8.0	0.9	6.2	9.9	7.9	0.9	6.2	9.7	0.1	1.3	0.937	-2.5	2.7	0.00
	Velocity avg	9.0	0.8	7.5	10.6	8.0	0.7	6.6	9.5	1.0	1.0	0.349	-1.1	3.1	0.03
	Jerk avg	1083.7	85.5	908.9	1258.6	921.0	80.6	756.2	1085.8	162.8	119.0	0.182	-80.7	406.2	0.06
	Lower	Range	9.7	0.8	8.1	11.2	9.9	0.7	8.4	11.3	-0.2	1.1	0.835	-2.4	2.0
	Velocity avg	8.0	0.7	6.6	9.4	8.6	0.6	7.3	9.9	-0.6	1.0	0.532	-2.6	1.4	0.01
	Jerk avg	874.2	83.5	703.5	1045.0	955.4	77.7	796.5	1114.3	-81.2	116.9	0.493	-320.3	157.9	0.02
Upper thoracic															
Flexion-extension															
Peak value		-1.6	0.4	-2.4	-0.8	-1.7	0.4	-2.5	-1.0	0.2	0.6	0.773	-1.0	1.3	0.00

Lift	Range	2.1	0.3	1.5	2.7	2.1	0.3	1.6	2.7	0.0	0.4	0.937	-0.8	0.8	0.00
	Velocity avg	2.9	0.3	2.3	3.5	2.5	0.3	1.9	3.1	0.4	0.4	0.383	-0.5	1.3	0.03
	Jerk avg	675.3	156.6	355.1	995.5	633.5	149.5	327.7	939.3	41.8	219.0	0.850	-406.1	489.6	0.00
Lower	Range	3.0	0.2	2.5	3.4	3.2	0.2	2.8	3.6	-0.2	0.3	0.504	-0.8	0.4	0.02
	Velocity avg	2.8	0.4	2.0	3.6	2.7	0.4	1.9	3.5	0.1	0.6	0.903	-1.1	1.2	0.00
	Jerk avg	539.2	104.3	325.8	752.5	588.5	99.6	384.9	792.1	-49.4	145.7	0.737	-347.3	248.6	0.00
Lateral flexion															
Peak value		-8.4	0.6	-9.7	-7.1	-7.3	0.6	-8.5	-6.0	-1.1	0.9	0.224	-3.0	0.7	0.05
Lift	Range	9.1	0.7	7.7	10.5	8.9	0.7	7.5	10.2	0.2	1.0	0.813	-1.7	2.2	0.00
	Velocity avg	7.9	0.5	6.8	9.0	6.6	0.5	5.6	7.6	1.3	0.7	0.084	-0.2	2.8	0.10
	Jerk avg	542.3	78.1	382.6	701.9	508.7	74.1	357.2	660.3	33.5	108.5	0.759	-188.3	255.3	0.00
Lower	Range	10.0	0.8	8.5	11.5	9.9	0.7	8.4	11.4	0.1	1.1	0.916	-2.0	2.3	0.00
	Velocity avg	5.6	0.5	4.6	6.5	5.7	0.4	4.8	6.6	-0.2	0.6	0.808	-1.5	1.2	0.00
	Jerk avg	486.8	70.5	342.6	631.1	553.2	66.7	416.7	689.6	-66.3	97.9	0.503	-266.6	133.9	0.02
Rotation															
Peak value		8.4	1.0	6.4	10.3	9.7	0.9	7.8	11.5	-1.3	1.3	0.338	-4.1	1.4	0.01
Lift	Range	8.9	0.5	7.8	10.0	10.7	0.5	9.7	11.8	-1.8	0.8	0.021	-3.4	-0.3	0.17
	Velocity avg	10.6	0.7	9.1	12.0	10.7	0.7	9.3	12.1	-0.1	1.0	0.884	-2.2	1.9	0.03
	Jerk avg	929.1	120.1	683.5	1174.7	872.6	113.4	640.8	1104.5	56.5	166.7	0.737	-284.5	397.4	0.06
Lower	Range	8.8	0.6	7.7	10.0	9.7	0.5	8.6	10.8	-0.9	0.8	0.281	-2.5	0.7	0.00
	Velocity avg	8.0	0.5	6.9	9.1	8.0	0.5	7.0	9.0	0.0	0.7	0.974	-1.5	1.5	0.01
	Jerk avg	848.8	137.2	568.2	1129.4	1015.0	128.8	751.3	1278.3	-166.0	190.8	0.391	-556.3	224.2	0.02
Lower thoracic															
Flexion-extension															
Peak value		-8.6	0.8	-10.2	-7.0	-8.4	0.8	-9.9	-6.8	-0.2	1.1	0.843	-2.5	2.1	0.00
Lift	Range	3.0	0.4	2.3	3.8	3.6	0.4	2.8	4.3	-0.5	0.6	0.336	-1.7	0.6	0.03
	Velocity avg	3.5	0.3	2.8	4.1	3.1	0.3	2.5	3.8	0.3	0.5	0.479	-0.6	1.3	0.02
	Jerk avg	453.8	69.2	312.2	595.4	476.7	66.0	341.9	611.6	-22.9	96.4	0.814	-220.0	174.1	0.00
Lower	Range	3.6	0.3	3.0	4.3	4.6	0.3	4.0	5.2	-0.9	0.4	0.037	-1.8	-0.1	0.14
	Velocity avg	2.7	0.3	2.1	3.4	3.1	0.3	2.5	3.6	-0.3	0.4	0.461	-1.2	0.6	0.02
	Jerk avg	437.3	64.1	306.2	568.3	469.9	60.8	345.6	594.2	-32.6	88.9	0.716	-214.4	149.2	0.01
Lateral flexion															
Peak value		-6.5	0.8	-8.1	-4.9	-7.3	0.7	-8.8	-5.8	0.7	1.1	0.503	-1.5	2.9	0.02
Lift	Range	7.3	0.7	5.9	8.6	7.3	0.6	6.1	8.6	0.0	0.9	0.963	-1.9	1.8	0.00
	Velocity avg	6.2	0.4	5.3	7.1	5.4	0.4	4.6	6.3	0.7	0.6	0.236	-0.5	2.0	0.05
	Jerk avg	718.7	101.4	511.4	926.0	682.5	95.9	486.3	878.7	36.2	140.8	0.799	-251.8	324.3	0.00
Lower	Range	6.9	0.6	5.7	8.1	7.2	0.6	6.1	8.4	-0.3	0.8	0.708	-2.0	1.4	0.01

	Velocity avg	4.5	0.4	3.6	5.3	4.8	0.4	4.0	5.6	-0.3	0.6	0.555	-1.5	0.8	0.01
	Jerk avg	599.2	94.6	405.6	792.7	709.3	89.8	525.6	893.1	-110.2	131.5	0.409	-379.2	158.8	0.02
Rotation															
Peak value		1.5	0.7	-0.1	3.0	1.2	0.7	-0.2	2.6	0.3	1.0	0.805	-1.8	2.4	0.00
Lift	Range	3.2	0.3	2.6	3.8	4.0	0.3	3.4	4.6	-0.8	0.4	0.089	-1.7	0.1	0.10
	Velocity avg	4.7	0.5	3.7	5.6	5.0	0.4	4.1	5.9	-0.4	0.7	0.582	-1.7	1.0	0.01
	Jerk avg	1229.0	193.8	832.2	1624.9	1241.0	183.9	864.5	1616.9	-12.1	269.2	0.964	-562.6	538.3	0.00
Lower	Range	3.6	0.4	2.8	4.4	4.1	0.4	3.3	4.8	-0.5	0.5	0.359	-1.6	0.6	0.03
	Velocity avg	4.0	0.4	3.2	4.8	4.8	0.4	4.0	5.6	-0.8	0.5	0.166	-1.9	0.3	0.07
	Jerk avg	1047.5	184.4	670.5	1424.6	1344.3	174.8	986.8	1701.7	-296.7	255.9	0.256	-820.1	226.7	0.04

(range – degrees, velocity – m/s, jerk – m/s³; AVE – average; M – mean; SE - standard error; CI – confidence interval; MD – mean difference; CG – control group; EG – experimental group; Flex-ext – flexion – extension; LF- lateral flexion; Rot – rotation; η^2 – partial eta squared)

**SUPPLEMENTARY FILE 8.4: PRE, POST AND FOURTH VISIT MEASURES OF MUSCLE
ACTIVATION DURING THE UNILATERAL TASK (%)**

Motion	Phase	Activation	CG						EG					
			Pre (n=17)		Post (n=17)		4th (n=14)		Pre (n=18)		Post (n=18)		4th (n=18)	
			M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
LAS	Lift	Peak	37.7	23.6	38.4	22.1	38.7	26.0	45.3	23.5	41.9	22.1	40.1	25.3
		Mean	25.4	16.3	25.9	15.8	25.7	17.5	28.8	14.4	26.3	12.9	24.9	14.5
		Time %	90.6	23.2	88.7	28.0	87.4	26.8	81.7	31.4	84.4	28.3	72.3	37.4
	Lower	Peak	36.5	22.7	36.8	21.3	36.5	22.8	41.6	19.3	40.8	19.8	34.9	20.6
		Mean	22.0	13.8	21.8	13.6	19.1	11.6	24.9	10.5	24.6	11.3	19.8	11.6
		Time %	90.7	24.7	89.2	26.6	85.5	28.6	80.5	30.7	83.9	32.8	67.6	40.2
RAS	Lift	Peak	59.2	28.4	63.0	32.3	58.4	27.1	60.7	21.7	61.8	25.5	67.8	24.7
		Mean	39.3	19.2	40.8	21.5	38.4	17.1	38.4	14.8	39.1	17.5	43.8	16.1
		Time %	99.8	0.8	92.4	23.5	96.3	10.0	95.3	15.5	96.3	7.7	93.6	23.5
	Lower	Peak	52.5	28.4	53.4	27.8	48.7	24.4	57.9	24.0	63.2	26.6	61.9	22.7
		Mean	30.7	16.5	31.3	16.3	27.4	13.4	34.9	15.6	36.2	18.4	34.6	14.4
		Time %	98.3	5.1	91.4	24.8	86.9	26.1	96.1	16.7	93.2	18.4	91.5	26.0
LPC	Lift	Peak	32.7	20.7	29.1	14.7	33.4	18.7	35.5	18.4	32.7	20.3	28.0	22.3
		Mean	23.4	15.6	20.4	10.5	23.8	13.4	25.5	12.8	22.5	12.4	19.6	15.5
		Time %	93.7	13.7	93.0	23.4	94.1	11.8	97.3	8.1	94.8	13.2	95.2	18.8
	Lower	Peak	30.2	17.4	26.4	13.5	30.5	16.6	34.7	19.4	31.7	19.0	25.6	19.3
		Mean	20.0	12.0	17.4	8.9	20.1	11.2	22.4	12.2	19.7	12.0	17.5	16.2
		Time %	91.0	22.4	91.9	25.2	95.8	15.2	95.6	13.1	94.6	15.6	93.4	21.6
RPC	Lift	Peak	48.8	20.7	50.0	21.2	45.6	18.7	53.2	18.1	49.7	18.3	54.2	23.9
		Mean	32.6	14.1	33.1	14.2	32.8	14.2	35.1	11.2	33.8	11.2	35.6	13.9
		Time %	98.9	4.2	91.7	23.6	95.7	9.7	91.1	21.8	98.5	4.8	99.9	0.6
	Lower	Peak	41.7	19.7	40.8	18.9	38.6	18.4	47.1	18.8	45.6	18.0	45.6	23.4
		Mean	24.1	11.6	24.0	11.1	23.9	11.4	28.6	12.2	26.0	9.8	26.6	13.9
		Time %	94.5	19.0	88.6	29.5	91.7	26.0	89.8	27.6	97.7	9.4	99.2	2.4
LT4	Lift	Peak	23.1	11.2	24.4	13.4	27.1	17.3	21.3	8.2	22.3	9.9	23.9	13.7
		Mean	16.7	9.0	17.3	10.3	20.3	13.6	15.2	6.7	15.4	6.9	16.3	8.5
		Time %	100.0	0.0	92.4	24.6	87.4	29.1	98.6	4.3	99.5	1.3	98.1	6.3
	Lower	Peak	22.8	12.5	24.0	14.8	28.7	19.9	22.2	8.1	23.4	10.2	22.2	10.3
		Mean	13.6	7.9	14.3	9.0	16.6	11.7	13.7	6.3	14.3	6.8	13.6	6.7

		Time %	100.0	0.1	90.1	28.5	82.2	34.4	97.9	6.3	98.7	4.4	94.4	18.2
RT4	Lift	Peak	82.6	12.4	82.8	15.0	83.4	6.8	86.8	6.4	87.6	8.1	85.4	9.0
		Mean	56.3	11.8	54.3	13.4	58.6	10.9	56.4	11.8	57.2	12.6	57.5	11.6
		Time %	99.9	0.6	93.6	23.4	99.7	1.1	98.9	4.4	100.0	0.0	98.2	7.6
	Lower	Peak	81.1	15.9	79.2	17.5	83.8	7.9	84.6	11.1	88.9	10.4	87.3	6.3
		Mean	43.2	11.1	40.8	12.1	41.8	8.7	48.2	10.2	50.8	11.5	48.8	11.6
		Time %	99.5	1.7	93.4	23.6	99.1	2.7	99.8	0.8	100.0	0.0	99.8	0.7
LSCM	Lift	Peak	40.9	23.9	43.5	26.2	43.0	21.4	45.7	21.5	44.2	21.8	45.1	23.7
		Mean	28.4	17.0	30.2	17.8	29.7	14.3	30.2	15.0	29.3	14.7	29.6	15.2
		Time %	98.6	5.9	91.7	24.7	96.5	7.9	98.0	7.8	98.4	3.7	93.4	15.2
	Lower	Peak	43.6	26.1	46.0	27.7	45.0	20.7	46.4	19.6	48.1	22.8	47.0	20.3
		Mean	26.5	16.3	27.1	16.4	25.3	11.9	27.6	12.9	28.5	14.2	27.7	13.5
		Time %	96.5	8.8	90.8	24.2	92.5	14.5	97.9	7.8	98.7	4.6	92.2	17.1
RSCM	Lift	Peak	25.5	17.6	26.5	17.6	28.5	24.2	35.8	24.6	34.7	17.6	39.2	26.6
		Mean	17.0	12.4	17.6	12.0	18.5	16.5	21.5	14.9	19.5	10.3	24.6	15.8
		Time %	84.6	29.1	82.4	33.1	88.3	23.2	90.0	22.1	94.0	11.9	89.5	22.6
	Lower	Peak	22.7	16.4	22.8	14.8	22.5	19.2	32.7	21.3	35.6	26.1	34.6	21.1
		Mean	13.8	9.6	13.7	9.0	12.2	8.5	20.2	14.3	20.3	16.2	19.8	12.7
		Time %	77.9	36.8	73.8	39.8	83.0	32.9	92.7	19.2	92.9	19.0	87.9	28.0
LUT	Lift	Peak	54.5	26.0	51.3	23.9	53.1	21.9	52.3	21.5	50.6	23.2	52.7	23.4
		Mean	36.8	17.4	35.7	17.5	37.5	16.8	36.8	15.9	36.0	17.1	37.2	16.1
		Time %	98.9	1.8	93.8	22.8	99.7	1.0	96.3	7.8	92.8	16.2	96.4	5.8
	Lower	Peak	49.9	24.1	48.2	22.7	48.9	21.9	51.0	20.8	49.7	21.8	49.7	22.3
		Mean	32.6	17.2	32.0	15.9	32.7	16.2	34.5	14.5	33.4	15.0	33.1	15.0
		Time %	98.7	5.5	90.0	25.9	99.2	1.9	96.9	8.4	92.0	23.0	94.6	11.9
RUT	Lift	Peak	92.0	5.0	89.2	7.9	87.3	5.6	86.7	5.6	85.8	8.7	90.9	6.2
		Mean	69.7	7.5	66.8	9.7	64.1	10.0	63.3	9.7	64.3	11.4	68.3	9.7
		Time %	100.0	0.0	92.7	23.7	99.4	2.2	98.6	6.2	99.4	2.1	99.5	1.8
	Lower	Peak	81.5	14.5	82.7	14.4	78.9	19.8	78.9	16.0	79.9	12.8	81.7	14.3
		Mean	56.5	12.9	57.5	13.7	54.8	19.5	55.3	16.2	54.5	14.5	56.2	13.1
		Time %	99.9	0.4	93.8	23.6	100.0	0.0	99.7	0.9	100.0	0.0	100.0	0.0
LT9	Lift	Peak	66.3	20.4	71.9	24.5	65.7	17.0	65.2	20.7	66.3	22.0	66.3	21.8
		Mean	43.9	11.7	47.4	15.7	45.3	13.0	44.4	13.9	45.1	14.9	45.4	14.2
		Time %	99.8	0.9	94.5	22.9	93.9	16.2	99.6	1.2	99.8	0.8	97.6	8.6
	Lower	Peak	66.8	21.1	68.1	22.3	66.0	17.6	64.2	18.6	67.4	21.9	64.0	20.3
		Mean	38.6	11.4	40.5	12.7	38.9	11.7	37.7	12.5	39.5	12.8	38.3	14.7
		Time %	100.0	0.0	93.3	22.9	90.5	23.5	97.8	6.9	98.5	3.5	95.1	11.0

RT9	Lift	Peak	47.2	21.6	46.7	20.1	45.6	17.2	46.8	17.6	50.9	21.3	53.2	22.6
		Mean	31.7	15.5	31.7	15.5	30.4	12.6	30.4	12.8	33.3	17.0	33.8	14.6
		Time %	93.6	15.9	86.9	29.6	91.8	22.5	96.9	9.6	91.9	24.3	92.6	23.7
	Lower	Peak	44.6	19.2	47.7	20.2	47.8	19.0	53.6	21.0	53.4	18.2	55.8	22.5
		Mean	25.8	11.7	26.6	11.9	25.3	9.4	30.9	11.5	31.7	12.2	32.0	13.4
		Time %	90.4	24.4	81.8	30.5	85.2	26.7	98.3	6.2	92.1	22.5	90.8	24.1

(CG – control group; EG – expimental group; M – mean; SD – standard deviation; % - percentage; LAS – left anterior scalene; RAS – right anterior scalene; LPC – left posterior cervical; RPC – right posterior cervical; LSCM – left sternocleidomastoid; RSCM – right sternocleidomastoid; LUT – left upper trapezius; RUT – right upper trapezius; LT4 – left paraspinal at T4; RT4 – right paraspinal at T4; LT9 – left paraspinal at T9; RT9 - right paraspinal at T9)

**SUPPLEMENTARY FILE 8.5: POST-ADJUSTED MEANS FOR MUSCLE ACTIVATION
PATTERNS AFTER THE ONE TREATMENT FOR THE UNILATERAL ARM TASK (%)**

Motion	Phase	Activation	CG				EG				MD	SE	p-value	CI		η²
			M	SE	CI		M	SE	CI							
					Low	High			Low	High						
LAS	Lift	Peak	41.6	2.4	36.7	46.5	38.6	2.5	33.6	43.7	3.0	3.5	0.407	-4.2	10.2	0.02
		Mean	27.4	1.4	24.4	30.3	24.9	1.5	21.9	28	2.4	2.1	0.268	-1.9	6.8	0.04
		Time %	84.3	4	76.3	92.4	89.4	4.1	80.9	97.8	-5.0	5.9	0.405	-17.1	7.1	0.02
	Lower	Peak	39.3	1.5	36.3	42.3	38.3	1.5	35.2	41.4	1.0	2.2	0.647	-3.4	5.4	0.01
		Mean	23.1	1.1	21	25.3	23.3	1.1	21.1	25.5	-0.1	1.6	0.928	-3.3	3.0	0.00
		Time %	84.9	5	74.7	95.2	88.6	5.2	78	99.3	-3.7	7.5	0.626	-19.0	11.6	0.01
RAS	Lift	Peak	63.4	3.3	56.7	70.1	61.8	3.4	54.8	68.8	1.6	4.9	0.746	-8.4	11.6	0.00
		Mean	40	2.3	35.3	44.7	40.2	2.4	35.3	45.2	-0.3	3.5	0.944	-7.4	6.9	0.00
		Time %	90.2	4.2	81.7	98.7	99.6	4.4	90.6	108.5	-9.3	6.3	0.149	-22.2	3.5	0.07
	Lower	Peak	55.7	2.7	50.3	61.1	61.1	2.8	55.5	66.8	-5.4	4.0	0.181	-13.5	2.7	0.06
		Mean	33.3	1.4	30.4	36.1	34.4	1.4	31.4	37.3	-1.1	2.1	0.597	-5.3	3.1	0.01
		Time %	89	4.4	80	98	96.6	4.6	87.2	105.9	-7.6	6.6	0.260	-21.0	5.9	0.04
LPC	Lift	Peak	30.8	3	24.7	36.9	29.7	3.1	23.5	36	1.1	4.4	0.808	-7.9	10.0	0.00
		Mean	21.7	2.2	17.3	26.2	20.1	2.2	15.5	24.6	1.6	3.2	0.612	-4.9	8.2	0.01
		Time %	92.7	3.8	85	100.4	96.3	3.9	88.4	104.2	-3.6	5.6	0.522	-14.9	7.7	0.01
	Lower	Peak	28.6	2.9	22.7	34.6	27.7	3	21.6	33.8	0.9	4.3	0.828	-7.8	9.7	0.00
		Mean	18.6	2	14.7	22.6	17.1	2	13.1	21.2	1.5	2.9	0.608	-4.4	7.3	0.01
		Time %	91.4	4.6	82.1	100.8	95.8	4.7	86.3	105.4	-4.4	6.8	0.52	-18.2	9.4	0.01
RPC	Lift	Peak	52.9	2.4	48	57.8	46	2.5	40.9	51.1	6.9	3.6	0.063	-0.4	14.2	0.11
		Mean	34.6	1.9	30.8	38.4	31.9	2	27.9	36	2.7	2.8	0.351	-3.1	8.4	0.03
		Time %	90.9	4.2	82.3	99.4	100.2	4.3	91.3	109	-9.3	6.2	0.144	-22.0	3.4	0.07
	Lower	Peak	43.2	2.8	37.4	49	42.7	3	36.6	48.7	0.5	4.2	0.897	-8.1	9.1	0.00
		Mean	25.8	1.8	22.1	29.6	23.6	1.9	19.7	27.4	2.3	2.7	0.410	-3.3	7.8	0.02
		Time %	87.9	5	77.8	98	99.1	5.1	88.6	109.6	-11.2	7.3	0.137	-26.2	3.8	0.07
LSCM	Lift	Peak	45.9	3	39.8	51.9	41.9	3.1	35.6	48.2	4.0	4.4	0.373	-5.0	13.0	0.03
		Mean	31.1	2.3	26.4	35.8	28.3	2.4	23.3	33.2	2.8	3.4	0.413	-4.1	9.8	0.02
		Time %	90.7	4.3	82	99.5	100.1	4.5	90.9	109.3	-9.3	6.4	0.156	-22.4	3.8	0.06
	Lower	Peak	47.2	2.7	41.7	52.7	47.3	2.8	41.6	53.1	-0.1	4.0	0.971	-8.3	8.0	0.00

		Mean	27.6	1.7	24.1	31.2	28	1.8	24.3	31.8	-0.4	2.6	0.870	-5.7	4.9	0.00
		Time %	90.1	4.3	81.3	98.8	100.1	4.5	91.1	109.2	-10.1	6.4	0.123	-23.0	2.9	0.08
RSCM	Lift	Peak	30.4	2.3	25.7	35	30.1	2.3	25.3	34.8	0.3	3.3	0.931	-6.5	7.1	0.00
		Mean	19.4	1.7	16	22.8	17.1	1.7	13.6	20.7	2.3	2.5	0.367	-2.8	7.3	0.03
		Time %	82.2	5.1	71.7	92.6	95.6	5.3	84.8	106.5	-13.5	7.6	0.086	-29.0	2.0	0.09
	Lower	Peak	27.8	2.5	22.7	33	30.4	2.6	25.1	35.7	-2.6	3.7	0.493	-10.2	5.0	0.02
		Mean	16.7	1.7	13.1	20.2	17.2	1.8	13.5	20.8	-0.5	2.5	0.845	-5.7	4.7	0.00
		Time %	77	6.7	63.3	90.8	90.6	7	76.3	104.8	-13.6	10.1	0.189	-34.1	7.0	0.06
LUT	Lift	Peak	50.7	2.3	46	55.3	50.7	2.4	45.7	55.6	0.0	3.4	0.996	-7.0	6.9	0.00
		Mean	35.9	1.5	32.8	39	35.3	1.6	32	38.6	0.6	2.3	0.805	-4.1	5.2	0.00
		Time %	91.7	4.6	82.4	101.1	95.1	4.8	85.3	105	-3.4	7.0	0.625	-17.6	10.7	0.01
	Lower	Peak	48.9	2	44.9	52.9	48.4	2.1	44.2	52.7	0.5	2.9	0.866	-5.5	6.5	0.00
		Mean	33.1	1.2	30.7	35.5	31.7	1.2	29.2	34.3	1.4	1.7	0.441	-2.2	4.9	0.02
		Time %	88.9	5.4	78	99.9	92.3	5.7	80.7	103.8	-3.4	8.0	0.676	-19.7	12.9	0.01
RUT	Lift	Peak	86.7	1.8	83	90.4	88.1	1.8	84.3	91.8	-1.4	2.8	0.627	-7.0	4.3	0.01
		Mean	63.5	1.8	59.8	67.3	67.3	1.9	63.5	71.1	-3.8	2.8	0.179	-9.5	1.8	0.06
		Time %	91.4	4.1	83.1	99.6	101.7	4.1	93.3	110.1	-10.4	6.0	0.095	-22.6	1.9	0.09
	Lower	Peak	81.5	1.6	78.2	84.9	81.2	1.7	77.8	84.6	0.3	2.4	0.891	-4.6	5.3	0.00
		Mean	57.1	1.3	54.4	59.7	54.8	1.4	52	57.5	2.3	2.0	0.254	-1.7	6.3	0.04
		Time %	92.7	4	84.4	100.9	102	4.1	93.6	110.4	-9.3	6.0	0.13	-21.5	2.9	0.07
LT4	Lift	Peak	23.3	0.9	21.6	25.1	23.5	0.9	21.6	25.3	-0.1	1.3	0.921	-2.7	2.4	0.00
		Mean	16.5	0.4	15.7	17.3	16.4	0.4	15.5	17.2	0.1	0.6	0.863	-1.1	1.3	0.00
		Time %	91.6	4.1	83.3	99.9	101.9	4.3	93.2	110.6	-10.3	6.1	0.098	-22.7	2.0	0.08
	Lower	Peak	23.7	1.2	21.4	26.1	23.7	1.2	21.2	26.1	0.1	1.7	0.973	-3.4	3.5	0.00
		Mean	14.5	0.5	13.4	15.6	14	0.6	12.9	15.2	0.4	0.8	0.59	-1.2	2.0	0.01
		Time %	88.6	4.7	79.1	98.2	102	4.9	92	112.1	-13.4	7.0	0.064	-27.6	0.8	0.10
RT4	Lift	Peak	83.9	2.6	78.6	89.1	86.7	2.6	81.4	92.1	-2.9	3.8	0.457	-10.7	4.9	0.01
		Mean	53.9	1.9	50	57.8	57.8	2	53.8	61.8	-3.9	2.8	0.173	-9.7	1.8	0.06
		Time %	92.7	4	84.5	100.9	101.9	4.1	93.5	110.2	-9.2	6.0	0.132	-21.3	2.9	0.07
	Lower	Peak	80.1	2.5	75	85.3	88.3	2.6	83	93.5	-8.1	3.7	0.038	-15.7	-0.5	0.13
		Mean	43	1.6	39.7	46.3	48.6	1.7	45.2	52	-5.6	2.5	0.031	-10.6	-0.6	0.14

		Time %	92	4	83.9	100.1	102.6	4.1	94.3	110.9	-10.6	5.9	0.082	-22.6	1.4	0.09
LT9	Lift	Peak	71.7	2.3	67.1	76.3	66.1	2.4	61.3	71	5.5	3.4	0.110	-1.3	12.4	0.08
		Mean	48	1.5	44.9	51.2	44	1.6	40.7	47.3	4.0	2.3	0.085	-0.6	8.7	0.09
		Time %	93.9	3.8	86.1	101.7	101.6	4.1	93.3	109.9	-7.7	5.8	0.192	-19.4	4.0	0.05
	Lower	Peak	66.8	2.2	62.4	71.2	68.7	2.3	64	73.4	-1.9	3.2	0.562	-8.5	4.7	0.01
		Mean	40.3	1.1	38.1	42.5	39.2	1.1	36.9	41.5	1.1	1.6	0.493	-2.1	4.3	0.01
		Time %	92.6	3.9	84.6	100.6	99.9	4.1	91.5	108.3	-7.3	5.9	0.225	-19.2	4.7	0.04
RT9	Lift	Peak	46.7	1.8	43	50.3	50.6	1.8	46.9	54.4	-4.0	2.6	0.143	-9.3	1.4	0.07
		Mean	31	1.1	28.7	33.3	33.8	1.2	31.5	36.2	-2.8	1.7	0.103	-6.2	0.6	0.08
		Time %	88.5	6.5	75.3	101.6	89.7	6.6	76.3	103.1	-1.2	9.5	0.900	-20.5	18.1	0.00
	Lower	Peak	51.7	2.1	47.4	56	49.5	2.2	45	53.9	2.2	3.2	0.487	-4.2	8.7	0.02
		Mean	29.3	1.2	26.8	31.7	29	1.2	26.4	31.5	0.3	1.8	0.856	-3.3	4.0	0.00
		Time %	84.4	6.3	71.6	97.3	88.9	6.4	75.9	101.9	-4.5	9.3	0.633	-23.4	14.4	0.01

(CG – control group; EG – expimental group; M – mean; SE – standard error; MD – mean difference; % - percentage; η^2 – partial eta squared; LAS – left anterior scalene; RAS – right anterior scalene; LPC – left posterior cervical; RPC – right posterior cervical; LSCM – left sternocleidomastoid; RSCM – right sternocleidomastoid; LUT – left upper trapezius; RUT – right upper trapezius; LT4 – left paraspinal at T4; RT4 – right paraspinal at T4; LT9 – left paraspinal at T9; RT9 - right paraspinal at T9)

**SUPPLEMENTARY FILE 8.6: POST-ADJUSTED MEANS FOR MUSCLE ACTIVATION PATTERNS
AT THE FOURTH VISIT FOR THE UNILATERAL ARM TASK (%)**

Motion	Phase	Activation	CG				EG				MD	SE	p value	CI		η^2
			M	SE	CI		M	SE	CI					Low	High	
					Low	High			Low	High						
LAS	Lift	Peak	40.1	3.7	32.6	47.7	38.4	3.3	31.6	45.2	1.7	5	0.73	-8.5	12.0	0.01
		Mean	25.4	2.4	20.5	30.3	25	2.2	20.6	29.5	0.4	3.2	0.913	-6.3	7.0	0.00
		Time %	89	8.8	70.9	107	67.8	7.9	51.6	84	21.2	12	0.089	-3.4	45.8	0.11
	Lower	Peak	36.1	3.5	28.9	43.3	34.7	3.2	28.2	41.3	1.4	4.8	0.773	-8.4	11.2	0.00
		Mean	18.9	2.1	14.5	23.3	19.7	1.9	15.7	23.6	-0.8	2.9	0.798	-6.8	5.3	0.00
		Time %	87.4	9.5	68	106.8	63.1	8.5	45.6	80.5	24.3	12.9	0.07	-2.1	50.8	0.12
RAS	Lift	Peak	60.5	4.1	52	69	66.3	3.9	58.2	74.3	-5.8	5.8	0.329	-17.6	6.1	0.04
		Mean	38.6	3	32.5	44.7	43.4	2.8	37.6	49.2	-4.8	4.2	0.264	-13.4	3.8	0.05
		Time %	96.5	5.4	85.4	107.5	93.5	5	83.1	103.8	3	7.6	0.696	-12.6	18.7	0.01
	Lower	Peak	51.3	3.7	43.8	58.8	60.3	3.4	53.2	67.3	-9	5.1	0.09	-19.4	1.5	0.1
		Mean	29.5	2.2	24.9	34.1	32.6	2.1	28.4	36.9	-3.1	3.1	0.321	-9.4	3.2	0.04
		Time %	87.3	7.2	72.5	102	89.8	6.8	75.9	103.6	-2.5	10.1	0.806	-23.2	18.2	0.00
LPC	Lift	Peak	34.3	3.6	26.9	41.8	25.2	3.4	18.4	32.1	9.1	5	0.082	-1.2	19.4	0.1
		Mean	24.7	2.9	18.7	30.6	17.5	2.7	12	22.9	7.2	4	0.084	-1	15.4	0.1
		Time %	94.9	3	88.8	101.1	93.2	2.7	87.6	98.8	1.8	4.1	0.67	-6.7	10.2	0.01
	Lower	Peak	32.3	3.7	24.6	40	21.9	3.4	14.8	28.9	10.4	5.2	0.053	-0.2	21.0	0.13
		Mean	21.2	3.5	14.1	28.2	14.9	3.2	8.4	21.4	6.2	4.8	0.201	-3.5	16.0	0.06
		Time %	96.3	4.6	86.9	105.7	91.6	4.2	83	100.2	4.7	6.3	0.465	-8.3	17.7	0.02
RPC	Lift	Peak	47.4	3.5	40.2	54.6	50.8	3.2	44.2	57.4	-3.4	4.9	0.491	-13.4	6.6	0.02
		Mean	33.5	2.3	28.8	38.2	34.5	2.1	30.1	38.8	-1	3.2	0.763	-7.5	5.6	0.00
		Time %	95.6	1.7	92	99.2	99.8	1.6	96.6	103	-4.2	2.4	0.094	-9.1	0.8	0.1
	Lower	Peak	40.6	3.6	33.3	47.9	42.6	3.3	35.8	49.4	-2	5	0.693	-12.1	8.2	0.01
		Mean	25.7	2.3	21.1	30.4	23.8	2.1	19.6	28	1.9	3.1	0.537	-4.4	8.3	0.01
		Time %	91.8	3.8	84	99.6	98.3	3.5	91.2	105.4	-6.5	5.2	0.226	-17.2	4.3	0.05
LSCM	Lift	Peak	42.5	4.4	33.5	51.6	43.5	4.0	35.3	51.8	-1	6.1	0.87	-13.4	11.4	0.00
		Mean	28.8	2.6	23.5	34.2	29.1	2.4	24.2	34.0	-0.3	3.6	0.94	-7.7	7.1	0.00
		Time %	96.2	3.6	88.9	103.5	92.7	3.2	86.0	99.3	3.6	4.8	0.466	-6.4	13.5	0.02
	Lower	Peak	43.6	4.2	35.1	52.2	46.1	3.8	38.3	53.9	-2.5	5.8	0.673	-14.3	9.4	0.01

RSCM	Lift	Mean	24.4	2.5	19.2	29.6	27.2	2.3	22.5	31.9	-2.8	3.5	0.425	-10	4.3	0.03
		Time %	92.0	4.6	82.5	101.5	93.2	4.2	84.5	101.8	-1.1	6.3	0.86	-14.1	11.9	0.00
		Peak	31.0	6.3	18.0	44.0	34.1	5.9	22.1	46.2	-3.1	8.7	0.726	-21	14.8	0.01
	Lower	Mean	19.7	4.0	11.5	27.9	22.0	3.8	14.2	29.7	-2.3	5.6	0.687	-13.7	9.2	0.01
		Time %	89.9	5.9	77.8	102.0	86.8	5.5	75.6	98.1	3.1	8.2	0.712	-13.8	19.9	0.01
		Peak	25.9	4.2	17.4	34.5	31.6	3.9	23.7	39.5	-5.7	5.8	0.332	-17.5	6.1	0.04
	LUT	Mean	14.0	2.4	9.2	18.8	18.2	2.2	13.7	22.6	-4.2	3.2	0.207	-10.8	2.5	0.06
		Time %	87.7	7.5	72.3	103.0	82.2	6.9	68.1	96.4	5.4	10.5	0.609	-16	26.9	0.01
		Peak	51	4	42.8	59.1	53	3.9	45.1	60.9	-2	5.7	0.726	-13.6	9.6	0.00
RUT	Lift	Mean	36.6	2.9	30.7	42.4	37	2.7	31.4	42.6	-0.4	4	0.913	-8.6	7.7	0.00
		Time %	99.1	1	97	101.3	96.9	1	94.9	98.9	2.2	1.4	0.134	-0.7	5.2	0.08
		Peak	48.3	4	40.1	56.5	48.5	3.9	40.6	56.4	-0.2	5.6	0.973	-11.7	11.3	0.00
	Lower	Mean	32.9	3	26.7	39.1	31.6	2.9	25.7	37.5	1.3	4.2	0.758	-7.3	9.9	0.00
		Time %	99.4	2.2	94.8	103.9	93.7	2.1	89.4	98	5.7	3.1	0.078	-0.7	12.0	0.1
		Peak	86.7	1.7	83.2	90.2	91.5	1.5	88.4	94.7	-4.9	2.4	0.053	-9.8	0.1	0.13
	LUT	Mean	62.1	2.6	56.7	67.4	70.7	2.3	65.9	75.5	-8.6	3.7	0.026	-16.1	-1.1	0.17
		Time %	99.3	0.6	98.2	100.5	99.4	0.5	98.3	100.4	0	0.8	0.981	-1.6	1.5	0.00
		Peak	77.7	4.6	68.3	87.2	83.8	4.3	75	92.6	-6	6.5	0.361	-19.4	7.3	0.03
LT4	Lift	Mean	53.6	4	45.4	61.8	58.1	3.7	50.5	65.6	-4.5	5.6	0.43	-15.9	7	0.02
		Time %	100	0	100	100	100	0	100	100	0	0	.	0	0,0	.
		Peak	24.3	3	18.1	30.6	25.4	2.8	19.7	31.1	-1.1	4.2	0.802	-9.6	7.5	0
	Lower	Mean	18.3	2	14.2	22.3	17.4	1.8	13.6	21.1	0.9	2.7	0.75	-4.7	6.5	0
		Time %	86.5	4.8	76.6	96.4	97.2	4.4	88.2	106.2	-	6.6	0.117	-24.1	2.8	0.09
		Peak	26.4	2.4	21.4	31.4	23.4	2.2	18.9	28	3	3.3	0.381	-3.8	9.8	0.03
	RT4	Mean	15.7	1.6	12.5	19	13.7	1.5	10.6	16.7	2.1	2.2	0.348	-2.4	6.6	0.03
		Time %	79.8	6.6	66.3	93.3	95.2	6	83	107.5	-	9	0.096	-33.8	2.9	0.1
		Peak	83.3	2.3	78.5	88.1	85.4	2.1	81	89.7	-2.1	3.3	0.525	-8.8	4.6	0.02
LT9	Lift	Mean	58.3	2.9	52.3	64.2	58.4	2.6	53	63.9	-0.2	4	0.967	-8.3	8,0	0
		Time %	99.8	1.6	96.5	103.1	97.5	1.5	94.5	100.5	2.3	2.2	0.313	-2.3	6.8	0.04
		Peak	83.8	1.9	79.8	87.7	88	1.8	84.4	91.7	-4.3	2.7	0.123	-9.7	1.2	0.08
	Lower	Mean	43.3	2.6	37.9	48.7	48.4	2.4	43.5	53.3	-5.1	3.7	0.184	-12.7	2.6	0.06
		Time %	99.1	0.5	98.1	100.1	99.7	0.5	98.8	100.7	-0.6	0.7	0.405	-2	0.8	0.03
		Peak	64.1	3.9	56.1	72	64.3	3.9	56.3	72.3	-0.2	5.6	0.97	-11.7	11.3	0
	LUT	Mean	44.6	3	38.5	50.8	43.1	3	36.9	49.2	1.5	4.3	0.724	-7.3	10.4	0.01
		Time %	94.6	3.1	88.3	100.9	96	3.1	89.7	102.3	-1.4	4.4	0.751	-10.5	7.7	0
		Peak	15.4													

RT9	Lower	Peak	64.2	4.3	55.4	73	63.4	4.4	54.5	72.3	0.8	6.3	0.897	-12.1	13.7	0
		Mean	38	3.1	31.7	44.3	36.7	3.1	30.4	43	1.3	4.4	0.772	-7.8	10.4	0
		Time %	91.4	4.4	82.4	100.3	92.4	4.3	83.5	101.2	-1	6.3	0.877	-13.8	11.8	0
	Lift	Peak	45.3	5.2	34.7	55.9	51.8	4.7	42.1	61.5	-6.5	7.1	0.371	-21.1	8.1	0.03
		Mean	29.7	3.3	23	36.4	33.2	3	27.1	39.4	-3.5	4.5	0.446	-12.8	5.8	0.02
		Time %	93.6	6	81.3	105.8	87.6	5.4	76.5	98.8	5.9	8.3	0.479	-11	22.8	0.02
	Lower	Peak	49.4	5.2	38.7	60.1	53.6	4.8	43.9	63.4	-4.3	7.3	0.561	-19.1	10.6	0.01
		Mean	26.3	2.8	20.5	32.1	30.1	2.6	24.8	35.3	-3.8	3.9	0.34	-11.8	4.2	0.03
		Time %	87.1	6.6	73.5	100.7	85.6	6	73.4	97.9	1.5	9.2	0.875	-17.3	20.3	0

(CG – control group; EG – expimental group; M – mean; SE – standard error; MD – mean difference; % - percentage; η^2 – partial eta squared; LAS – left anterior scalene; RAS – right anterior scalene; LPC – left posterior cervical; RPC – right posterior cervical; LSCM – left sternocleidomastoid; RSCM – right sternocleidomastoid; LUT – left upper trapezius; RUT – right upper trapezius; LT4 – left paraspinal at T4; RT4 – right paraspinal at T4; LT9 – left paraspinal at T9; RT9 - right paraspinal at T9)

**SUPPLEMENTARY FILE 8.7: SPINAL KINEMATIC MEASURES AT THE THREE TIME POINTS
FOR THE BILATERAL ARM TASK**

Motion Outcome		CG						EG					
		Pre (n=18)		Post (n=18)		4th (n=15)		Pre (n=19)		Post (n=19)		4th (n=19)	
		M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Cervical													
Flexion-extension													
	Peak value	31.0	20.7	27.3	19.0	28.1	15.2	18.7	22.0	24.8	25.3	20.0	28.0
Lift	Range	52.7	25.1	50.5	21.9	47.3	15.8	40.7	21.5	46.0	27.7	48.5	23.7
	Velocity avg	35.1	16.4	35.3	18.8	44.1	27.9	33.2	18.0	39.1	23.4	48.9	31.3
	Jerk avg	1895.1	937.0	2198.0	1373.0	2517.3	2025.5	2140.2	1174.2	2267.5	1681.7	3534.5	3986.5
Lower	Range	40.0	27.5	38.9	24.6	35.4	15.2	29.5	20.5	33.9	29.2	37.6	25.2
	Velocity avg	30.3	15.6	31.7	18.4	31.4	20.6	25.6	17.4	31.1	29.3	36.9	22.8
	Jerk avg	1955.3	780.6	2234.8	1222.1	2616.2	2016.9	2228.2	1725.1	2806.1	2507.1	3544.3	2498.6
Lateral flexion													
	Peak value	0.8	2.4	-0.5	2.5	0.9	2.7	-0.2	2.6	0.3	3.0	0.3	2.5
Lift	Range	5.3	7.1	4.5	2.5	4.4	1.8	4.6	2.9	4.4	2.3	3.8	1.6
	Velocity avg	5.9	9.5	4.6	2.3	5.1	2.7	5.7	5.2	5.2	2.3	5.4	3.1
	Jerk avg	746.6	389.0	983.5	514.3	994.2	597.0	1153.5	1297.5	886.5	495.7	1073.7	665.8
Lower	Range	4.4	4.6	4.5	2.6	4.2	2.0	4.1	2.2	4.7	2.3	4.2	1.9
	Velocity avg	5.2	4.4	5.3	2.9	5.1	2.3	4.8	2.4	5.9	3.5	6.1	3.4
	Jerk avg	1325.2	1767.0	1037.4	545.7	1003.2	485.8	899.7	486.7	979.8	386.4	1173.6	554.2
Rotation													
	Peak value	2.4	4.4	0.3	5.4	1.0	5.2	0.8	3.9	0.8	4.0	0.2	4.2
Lift	Range	7.7	11.1	5.2	2.3	4.6	2.0	6.6	5.7	4.7	2.6	5.1	2.3
	Velocity avg	9.3	18.7	5.3	2.7	5.7	3.1	7.9	7.4	5.7	2.5	6.7	3.4
	Jerk avg	2821.1	8187.4	1019.5	509.1	1001.8	589.9	1270.6	1617.5	994.8	425.3	1413.3	1172.8
Lower	Range	7.9	13.4	5.9	2.3	5.0	2.5	4.9	2.1	4.6	1.7	4.9	1.4
	Velocity avg	8.3	13.8	6.1	2.7	5.4	1.8	5.6	2.9	6.1	2.7	6.5	2.5

	Jerk avg	2313.8	5708.7	1024.9	477.3	956.8	410.4	1183.3	1145.7	1088.7	454.6	1159.5	465.1
Upper thoracic													
Flexion-extension													
	Peak value	-3.3	2.9	-1.9	3.6	-2.4	3.0	-2.6	2.8	-2.9	2.8	-1.3	4.0
Lift	Range	5.0	2.6	4.8	2.0	4.6	1.9	4.8	2.5	4.2	2.2	4.5	2.0
	Velocity avg	4.2	4.2	3.6	1.4	4.0	1.8	4.2	2.0	4.0	2.2	4.8	2.6
	Jerk avg	373.5	160.2	404.6	193.7	526.9	364.1	395.8	203.4	391.1	203.5	552.2	358.0
Lower	Range	6.6	2.7	5.6	2.3	5.7	2.5	5.7	2.7	5.4	2.8	5.4	2.0
	Velocity avg	4.8	2.4	4.2	1.5	4.1	1.6	5.0	2.6	4.8	2.4	5.1	2.2
	Jerk avg	461.9	189.3	445.2	248.8	386.8	139.4	399.2	228.2	470.0	330.5	502.3	250.3
Lateral flexion													
	Peak value	0.8	2.2	0.5	2.0	1.0	3.4	-0.2	2.4	0.0	3.2	1.4	7.8
Lift	Range	3.9	2.7	2.9	1.5	3.8	2.2	4.5	7.2	2.9	1.4	6.8	17.1
	Velocity avg	3.2	1.9	2.9	1.6	3.8	2.3	3.4	2.7	3.2	1.8	8.0	20.0
	Jerk avg	638.0	709.7	489.0	280.7	695.2	547.7	599.2	677.3	576.0	461.2	947.9	1249.0
Lower	Range	3.7	2.3	3.4	2.1	4.2	2.6	5.8	10.8	4.0	2.7	7.2	17.1
	Velocity avg	3.6	1.5	3.6	1.9	3.8	1.6	4.6	4.6	4.9	4.3	8.9	20.6
	Jerk avg	547.8	260.0	617.5	307.8	659.3	461.3	714.9	773.5	920.1	1027.0	1196.0	1822.6
Rotation													
	Peak value	0.3	3.8	0.8	3.6	-0.2	4.0	-0.9	4.0	-1.0	3.7	15.1	48.7
Lift	Range	5.5	6.0	4.1	2.5	4.5	2.9	5.6	6.2	4.2	2.0	6.8	11.4
	Velocity avg	5.0	6.1	3.8	1.7	4.4	2.3	5.1	3.6	4.6	2.3	10.2	21.8
	Jerk avg	741.7	516.1	647.4	366.7	812.1	465.9	848.3	847.4	784.8	562.9	3808.6	12665.9
Lower	Range	6.3	6.5	4.7	3.2	5.0	2.1	4.6	2.3	5.5	4.4	9.7	22.9
	Velocity avg	6.1	7.1	4.6	2.1	5.1	2.1	5.0	2.5	6.4	5.1	11.1	23.2
	Jerk avg	880.7	539.9	1527.4	3079.4	937.2	441.7	1044.9	912.1	1162.2	890.4	4351.2	14052.7
Lower thoracic													
Flexion-extension													
	Peak value	-7.8	3.9	-8.9	7.0	-5.7	4.2	-9.5	14.1	-9.8	11.4	-10.9	18.3
Lift	Range	11.9	17.6	8.1	2.9	6.9	2.1	10.8	11.5	7.9	4.7	8.1	4.4
	Velocity avg	8.1	13.7	5.3	2.9	5.4	2.3	8.8	13.6	6.3	3.4	6.8	3.3
	Jerk avg	435.3	245.6	412.2	215.7	415.2	197.8	1515.1	4877.7	463.0	205.0	551.3	362.9

Lower	Range	10.7	12.6	7.8	3.0	6.6	2.0	8.7	6.1	8.4	5.1	7.8	4.7
	Velocity avg	7.5	9.7	5.4	2.8	4.8	1.9	6.2	3.6	6.4	3.4	6.4	3.1
	Jerk avg	491.4	268.6	429.7	255.6	454.9	261.1	469.6	298.0	553.4	298.9	668.4	474.9
Lateral flexion													
Peak value		1.5	6.6	1.2	3.4	0.2	2.2	-2.0	10.2	1.2	5.1	-0.5	5.8
Lift	Range	7.3	20.0	2.7	1.4	2.3	1.1	5.8	12.3	2.2	1.4	2.8	1.7
	Velocity avg	6.0	13.6	2.7	1.3	2.9	1.8	5.8	13.2	2.8	1.3	3.4	2.1
	Jerk avg	580.5	373.7	589.2	280.0	717.9	575.3	1711.4	5052.6	632.4	284.3	734.9	349.5
Lower	Range	8.6	22.1	2.6	1.2	2.3	0.8	4.7	8.4	3.4	3.5	3.1	2.0
	Velocity avg	7.8	17.0	2.9	1.2	2.7	1.1	3.7	3.7	4.3	5.2	4.0	2.8
	Jerk avg	732.5	412.6	655.1	369.9	671.6	378.8	651.3	297.9	891.4	948.0	932.3	629.6
Rotation													
Peak value		-1.1	3.1	0.1	1.8	0.9	2.1	6.0	22.5	1.1	2.4	-4.7	27.5
Lift	Range	3.1	2.9	2.6	1.1	2.1	0.9	7.1	13.7	3.3	1.9	3.5	2.6
	Velocity avg	4.2	4.7	2.9	1.1	3.0	1.4	6.7	11.6	4.2	2.2	4.0	1.2
	Jerk avg	1002.7	877.8	798.5	432.9	860.3	475.7	1385.9	2409.0	988.5	697.4	929.3	289.3
Lower	Range	3.8	3.9	2.6	1.1	2.2	0.9	5.9	9.6	4.5	3.8	3.2	1.9
	Velocity avg	4.6	4.6	3.4	1.7	3.4	1.7	5.5	4.7	5.9	4.1	4.5	2.8
	Jerk avg	1087.9	745.2	982.2	725.6	1043.3	534.7	1010.4	548.5	1250.8	858.3	1189.9	648.0

(range – degrees, velocity – m/s, jerk – m/s³; AVE – average; M – mean; SD – standard deviation; CG – control group; EG – experimental group; Flex-ext – flexion – extension; LF- lateral flexion; Rot – rotation)

**SUPPLEMENTARY FILE 8.8: POST-ADJUSTED MEANS FOR THE POST-INITIAL TREATMENT
FOR THE BILATERAL ARM TASK**

Motion	Outcome	Control				Intervention				MD	SE	p value	CI		η ²
		M	SE	CI		M	SE	CI					Low	High	
CROM															
Flexion-extension															
	Peak value	21.8	3.2	15.4	28.3	29.8	3.2	23.3	36.3	-8.0	4.6	0.094	-17.4	1.4	0.09
Lift	Range	45.2	3.7	37.6	52.7	51.0	3.8	43.4	58.7	-5.9	5.4	0.285	-16.9	5.1	0.04
	Velocity avg	34.2	3.1	27.9	40.6	40.2	3.3	33.5	46.8	-5.9	4.6	0.206	-15.2	3.4	0.05
	Jerk avg	2343.4	234.4	1864.7	2822.2	2149.5	240.1	1659.3	2639.8	193.9	339.2	0.572	-498.8	886.6	0.01
Lower	Range	33.7	3.9	25.8	41.6	38.2	3.9	30.2	46.2	-4.5	5.6	0.435	-16.0	7.0	0.02
	Velocity avg	28.9	3.9	21.0	36.9	33.4	4.1	25.1	41.7	-4.5	5.7	0.437	-16.2	7.2	0.02
	Jerk avg	2411.8	248.8	1903.7	2919.9	2627.9	255.7	2105.7	3150.1	-216.1	361.0	0.554	-953.3	521.1	0.01
Lateral flexion															
	Peak value	-0.8	0.6	-2.0	0.3	0.7	0.6	-0.5	1.9	-1.6	0.8	0.069	-3.3	0.1	0.10
Lift	Range	4.5	0.6	3.3	5.6	4.3	0.6	3.1	5.5	0.1	0.8	0.866	-1.6	1.9	0.00
	Velocity avg	4.6	0.5	3.5	5.7	5.1	0.6	3.9	6.2	-0.4	0.8	0.589	-2.1	1.2	0.01
	Jerk avg	1061.9	95.0	868.1	1255.7	814.3	94.6	621.3	1007.3	247.6	135.6	0.078	-29.0	524.1	0.10
Lower	Range	4.5	0.5	3.5	5.5	4.5	0.5	3.5	5.5	-0.1	0.7	0.942	-1.5	1.4	0.00
	Velocity avg	5.2	0.6	4.0	6.5	5.6	0.6	4.3	6.8	-0.3	0.9	0.718	-2.2	1.5	0.00
	Jerk avg	1016.8	100.6	812.0	1221.6	953.2	103.4	742.5	1163.9	63.6	147.2	0.669	-236.3	363.5	0.01
Rotation															
	Peak value	-0.1	1.1	-2.4	2.2	1.2	1.2	-1.1	3.6	-1.3	1.7	0.439	-4.7	2.1	0.02
Lift	Range	5.2	0.5	4.1	6.4	4.5	0.6	3.4	5.7	0.7	0.8	0.366	-0.9	2.4	0.03
	Velocity avg	5.3	0.6	4.1	6.6	5.4	0.6	4.1	6.6	0.0	0.9	0.967	-1.8	1.8	0.00
	Jerk avg	1030.0	110.9	803.8	1256.1	944.8	116.1	708.1	1181.5	85.2	163.0	0.605	-247.3	417.7	0.01
Lower	Range	5.8	0.5	4.8	6.7	4.8	0.5	3.8	5.8	1.0	0.7	0.173	-0.4	2.4	0.06
	Velocity avg	6.0	0.6	4.8	7.3	5.9	0.6	4.7	7.2	0.1	0.9	0.945	-1.8	1.9	0.00
	Jerk avg	1031.3	106.3	814.7	1247.8	1019.4	109.3	796.8	1241.9	11.9	155.0	0.939	-303.9	327.7	0.00
Upper thoracic															
Flexion-extension															
	Peak value	-2.0	0.4	-2.8	-1.1	-2.4	0.4	-3.3	-1.5	1.3	1.1	0.223	-0.8	3.5	0.00
Lift	Range	2.4	0.2	2.0	2.7	2.4	0.2	2.0	2.7	0.2	0.6	0.756	-1.0	1.4	0.03

Lower	Velocity avg	2.8	0.2	2.4	3.2	2.6	0.2	2.2	3.1	-0.5	0.6	0.357	-1.7	0.6	0.01
	Jerk avg	618.0	54.8	506.5	729.5	554.1	57.9	436.2	672.0	31.1	50.9	0.545	-72.6	134.8	0.04
	Range	3.6	0.2	3.3	4.0	3.6	0.2	3.2	3.9	-0.7	0.6	0.251	-1.9	0.5	0.06
	Velocity avg	3.0	0.2	2.7	3.4	2.6	0.2	2.2	2.9	-0.7	0.5	0.181	-1.7	0.3	0.04
	Jerk avg	595.2	59.1	475.0	715.5	533.5	62.4	406.5	660.4	-81.0	68.7	0.247	-221.1	59.1	0.00
Lateral flexion															
Peak value		-9.1	0.6	-10.2	-7.9	-8.5	0.6	-9.7	-7.3	-0.1	0.6	0.882	-1.2	1.1	0.00
Lift	Range	9.4	0.4	8.5	10.3	9.4	0.5	8.4	10.4	0.2	0.5	0.717	-0.8	1.2	0.01
	Velocity avg	6.4	0.4	5.6	7.2	6.7	0.4	5.9	7.5	-0.2	0.5	0.679	-1.3	0.9	0.02
	Jerk avg	429.0	32.1	363.7	494.3	473.2	33.8	404.4	541.9	-78.8	111.7	0.485	-306.2	148.6	0.01
	Range	9.6	0.5	8.5	10.7	9.9	0.6	8.8	11.1	-0.3	0.6	0.641	-1.5	1.0	0.03
Lower	Velocity avg	4.9	0.3	4.4	5.5	5.1	0.3	4.5	5.7	-0.9	1.0	0.348	-2.9	1.1	0.04
	Jerk avg	406.8	28.4	349.0	464.6	443.5	29.8	382.8	504.2	-226.7	211.7	0.292	-657.8	204.4	0.04
Rotation															
Peak value		7.5	0.6	6.2	8.7	7.6	0.7	6.3	8.9	1.3	1.2	0.282	-1.2	3.8	0.01
Lift	Range	9.6	0.4	8.9	10.4	10.7	0.4	9.9	11.4	-0.4	0.8	0.655	-1.9	1.2	0.06
	Velocity avg	9.9	0.6	8.6	11.2	10.3	0.7	9.0	11.7	-1.0	0.7	0.191	-2.5	0.5	0.04
	Jerk avg	836.8	74.5	685.2	988.4	897.6	78.1	738.7	1056.4	-162.4	149.7	0.287	-468.7	143.8	0.09
	Range	9.9	0.4	9.1	10.7	10.5	0.4	9.7	11.4	-2.1	1.3	0.105	-4.7	0.5	0.12
Lower	Velocity avg	7.8	0.3	7.2	8.4	7.9	0.3	7.3	8.6	-2.6	1.4	0.062	-5.4	0.1	0.02
	Jerk avg	763.0	72.0	616.4	909.5	825.3	75.2	672.2	978.4	669.8	801.8	0.410	-967.8	2307.3	0.00
Lower thoracic															
Flexion-extension															
Peak value		-9.2	0.6	-10.4	-8.1	-9.5	0.6	-10.7	-8.3	-0.9	3.2	0.780	-7.5	5.7	0.00
Lift	Range	3.9	0.3	3.3	4.5	3.6	0.3	2.9	4.2	0.2	1.4	0.880	-2.6	3.0	0.00
	Velocity avg	3.3	0.2	2.8	3.7	2.9	0.2	2.4	3.4	-0.6	1.1	0.580	-2.9	1.6	0.01
	Jerk avg	481.4	46.0	387.8	574.9	424.0	48.4	325.5	522.5	-16.5	76.3	0.830	-172.1	139.0	0.00
	Range	4.7	0.2	4.2	5.2	4.4	0.3	3.9	4.9	-1.1	1.3	0.401	-3.8	1.5	0.02
Lower	Velocity avg	2.9	0.1	2.6	3.1	2.8	0.1	2.5	3.1	-1.1	1.0	0.268	-3.1	0.9	0.04
	Jerk avg	466.3	41.4	382.1	550.6	436.2	43.5	347.6	524.8	-154.6	71.4	0.038	-300.3	-8.9	0.13
Lateral flexion															
Peak value		-6.8	0.5	-7.7	-5.8	-7.6	0.5	-8.6	-6.6	0.5	1.5	0.732	-2.5	3.6	0.00
Lift	Range	7.1	0.4	6.3	7.9	7.5	0.4	6.6	8.3	0.6	0.5	0.216	-0.4	1.6	0.05
	Velocity avg	5.7	0.5	4.7	6.6	5.5	0.5	4.5	6.5	0.2	0.4	0.705	-0.7	1.0	0.01
	Jerk avg	683.6	45.2	591.5	775.7	624.9	47.6	528.1	721.7	-3.6	99.4	0.971	-206.3	199.1	0.00
	Range	6.9	0.5	5.9	7.8	7.3	0.5	6.3	8.3	-1.1	0.9	0.235	-3.0	0.8	0.04
Lower	Velocity avg	4.0	0.2	3.6	4.5	4.2	0.2	3.7	4.7	-2.0	1.4	0.159	-4.8	0.8	0.06

Rotation	Jerk avg	606.2	41.4	522.1	690.4	636.4	43.6	547.8	725.1	-511.4	195.7	0.014	-910.4	-112.4	0.18
	Peak value	1.4	0.5	0.4	2.4	1.7	0.5	0.7	2.7	-0.4	0.7	0.563	-1.9	1.1	0.01
Lift	Range	3.5	0.3	3.0	4.1	4.2	0.3	3.6	4.8	-0.4	0.5	0.451	-1.3	0.6	0.02
	Velocity avg	4.4	0.3	3.8	5.1	4.6	0.3	3.9	5.2	-1.1	0.6	0.065	-2.2	0.1	0.11
Lower	Jerk avg	1097.4	97.6	898.7	1296.0	1091.3	102.7	882.4	1300.2	-185.3	203.0	0.368	-599.4	228.7	0.03
	Range	4.1	0.4	3.2	5.0	4.9	0.4	4.0	5.8	-1.7	0.8	0.041	-3.4	-0.1	0.13
	Velocity avg	4.2	0.3	3.6	4.9	4.8	0.3	4.1	5.5	-2.6	0.9	0.006	-4.4	-0.8	0.22
	Jerk avg	1073.3	111.5	846.4	1300.2	1182.4	117.2	944.0	1420.8	-410.8	165.7	0.019	-748.7	-72.8	0.17

(range – degrees, velocity – m/s, jerk – m/s³; AVE – average; M – mean; SE - standard error; CI – confidence interval; MD – mean difference; CG – control group; EG – experimental group; Flex-ext – flexion – extension; LF- lateral flexion; Rot – rotation; η^2 – partial eta squared)

SUPPLEMENTARY FILE 8.9: POST-ADJUSTED MEANS FOR THE FOURTH VISIT FOR THE BILATERAL ARM TASK

Motion Outcome		CG				EG				MD	SE	p-value	CI		η²
		M	SE	CI		M	SE	CI					Low	High	
				Low	High			Low	High						
CROM															
Flexion-extension															
Peak value		26.7	5.6	15.2	38.2	18.1	5.3	7.3	28.9	8.6	7.8	0.280	-7.4	24.7	0.04
Lift	Range	44.7	4.0	36.5	53.0	49.5	3.8	41.8	57.3	-4.8	5.6	0.397	-16.3	6.6	0.03
	Velocity avg	42.8	5.7	31.2	54.5	49.5	5.5	38.2	60.7	-6.7	8.0	0.409	-23.0	9.6	0.02
	Jerk avg	2669.0	787.6	1052.9	4285.0	3577.0	736.7	2065.2	5088.5	-907.9	1080.0	0.408	-3123.8	1308.1	0.03
Lower	Range	33.1	3.8	25.3	41.0	38.2	3.6	30.8	45.6	-5.1	5.3	0.348	-16.0	5.8	0.03
	Velocity avg	28.7	3.6	21.4	36.1	37.8	3.4	30.8	44.9	-9.1	5.0	0.080	-19.4	1.2	0.11
	Jerk avg	2752.7	460.5	1807.8	3697.5	3412.6	432.6	2525.0	4300.3	-659.9	633.6	0.307	-1959.9	640.0	0.04
Lateral flexion															
Peak value		0.6	0.5	-0.5	1.6	0.1	0.5	-0.9	1.1	0.5	0.7	0.477	-1.0	2.0	0.02
Lift	Range	4.3	0.4	3.5	5.2	3.6	0.4	2.8	4.4	0.7	0.6	0.215	-0.4	1.9	0.05
	Velocity avg	5.1	0.8	3.6	6.6	5.1	0.7	3.6	6.5	0.0	1.0	0.995	-2.1	2.1	0.00
	Jerk avg	1000.8	171.7	649.1	1352.5	973.3	156.3	653.2	1293.5	27.5	232.1	0.906	-447.9	502.9	0.00
Lower	Range	4.2	0.5	3.1	5.2	4.4	0.5	3.4	5.4	-0.2	0.7	0.819	-1.6	1.3	0.00
	Velocity avg	5.0	0.7	3.6	6.4	5.9	0.7	4.5	7.2	-0.9	1.0	0.382	-2.9	1.1	0.03
	Jerk avg	1001.1	128.6	738.1	1264.0	1073.6	121.5	825.0	1322.1	-72.5	179.6	0.689	-439.9	294.9	0.01
Rotation															
Peak value		0.6	1.1	-1.7	3.0	0.2	1.1	-2.0	2.5	0.4	1.6	0.820	-2.9	3.7	0.00
Lift	Range	4.6	0.5	3.5	5.6	4.9	0.5	4.0	5.9	-0.4	0.7	0.584	-1.8	1.0	0.01
	Velocity avg	5.7	0.8	4.1	7.3	6.2	0.7	4.6	7.7	-0.5	1.1	0.673	-2.7	1.8	0.01
	Jerk avg	1021.2	247.1	515.0	1527.3	1274.4	237.4	788.1	1760.8	-253.3	346.4	0.471	-962.8	456.2	0.02
Lower	Range	5.0	0.5	3.9	6.0	5.1	0.5	4.1	6.1	-0.2	0.7	0.825	-1.7	1.3	0.00
	Velocity avg	5.4	0.6	4.2	6.5	6.2	0.5	5.1	7.3	-0.8	0.8	0.320	-2.4	0.8	0.03
	Jerk avg	963.5	106.1	746.5	1180.5	1060.8	100.1	856.0	1265.5	-97.3	147.6	0.515	-399.1	204.5	0.02
Upper thoracic															
Flexion-extension															
Peak value		-2.2	0.9	-4.0	-0.4	-1.4	0.8	-3.2	0.3	-0.8	1.2	0.536	-3.3	1.7	0.01
Lift	Range	4.5	0.5	3.5	5.5	4.8	0.5	3.8	5.7	-0.3	0.7	0.674	-1.7	1.1	0.01

Lower	Velocity avg	3.9	0.6	2.7	5.1	4.9	0.6	3.8	6.1	-1.0	0.8	0.209	-2.7	0.6	0.05
	Jerk avg	522.6	84.4	349.8	695.4	539.7	81.7	372.4	707.1	-17.1	118.4	0.886	-259.6	225.4	0.00
	Range	5.5	0.5	4.4	6.6	5.9	0.5	4.9	6.9	-0.4	0.7	0.576	-1.9	1.1	0.01
	Velocity avg	4.1	0.5	3.1	5.1	5.3	0.5	4.4	6.2	-1.2	0.7	0.077	-2.6	0.1	0.10
	Jerk avg	368.4	47.3	271.5	465.4	507.8	45.5	414.6	601.0	-139.4	66.3	0.045	-275.3	-3.5	0.14
Lateral flexion															
Lower	Peak value	0.9	1.7	-2.6	4.4	1.5	1.7	-1.9	4.9	-0.6	2.5	0.811	-5.6	4.4	0.00
	Lift Range	3.8	3.5	-3.3	10.9	6.6	3.3	-0.1	13.4	-2.8	4.8	0.565	-12.7	7.1	0.01
	Velocity avg	4.0	4.0	-4.3	12.2	7.5	3.8	-0.4	15.3	-3.5	5.6	0.538	-14.9	8.0	0.01
	Jerk avg	717.0	266.6	171.7	1262.3	886.6	252.8	369.6	1403.7	-169.7	370.5	0.650	-927.4	588.1	0.01
	Range	4.0	3.5	-3.2	11.2	7.1	3.3	0.3	13.9	-3.1	4.9	0.533	-13.1	6.9	0.01
Lower	Velocity avg	3.5	4.2	-5.0	12.0	8.8	3.9	0.7	16.8	-5.3	5.8	0.368	-17.1	6.5	0.03
	Jerk avg	670.7	378.8	-104.1	1445.4	1174.1	358.6	440.7	1907.4	-503.4	526.7	0.347	-1580.7	573.9	0.03
Rotation															
Lower	Peak value	0.1	9.9	-20.2	20.4	13.1	9.4	-6.0	32.3	-13.0	13.8	0.354	-41.3	15.2	0.03
	Lift Range	4.5	2.4	-0.3	9.4	6.9	2.2	2.3	11.4	-2.3	3.3	0.486	-9.0	4.4	0.02
	Velocity avg	4.6	4.4	-4.4	13.7	9.2	4.2	0.6	17.9	-4.6	6.2	0.459	-17.2	8.0	0.02
	Jerk avg	860.6	2551.5	-4357.8	6079.1	3317.8	2421.2	-1634.1	8269.7	-2457.2	3543.8	0.494	-9705.1	4790.7	0.02
	Range	5.1	4.7	-4.5	14.7	9.3	4.5	0.1	18.5	-4.2	6.6	0.533	-17.8	9.4	0.01
Lower	Velocity avg	5.3	4.7	-4.4	15.0	10.3	4.6	1.0	19.6	-4.9	6.7	0.466	-18.6	8.8	0.02
	Jerk avg	942.1	2828.0	-4841.7	6725.9	3793.0	2681.4	-1691.2	9276.8	-2850.7	3925.4	0.474	-10879.1	5177.6	0.02
Lower thoracic															
Flexion-extension															
Lower	Peak value	-5.8	3.6	-13.2	1.7	-9.7	3.4	-16.7	-2.6	3.9	5.1	0.442	-6.4	14.3	0.02
	Lift Range	7.1	0.9	5.2	9.0	8.0	0.9	6.1	9.8	-0.9	1.3	0.515	-3.5	1.8	0.02
	Velocity avg	5.4	0.8	3.8	7.0	6.5	0.7	5.0	8.0	-1.0	1.1	0.347	-3.2	1.2	0.03
	Jerk avg	416.7	78.5	256.2	577.3	512.6	74.2	360.8	664.3	-95.8	109.1	0.387	-319.1	127.4	0.03
	Range	6.8	0.8	5.2	8.4	7.8	0.7	6.3	9.3	-1.0	1.1	0.373	-3.2	1.2	0.03
Lower	Velocity avg	4.9	0.7	3.5	6.3	6.3	0.6	5.0	7.6	-1.4	0.9	0.149	-3.3	0.5	0.07
	Jerk avg	467.8	104.9	253.4	682.3	618.7	100.7	412.8	824.6	-150.8	147.6	0.315	-452.7	151.1	0.04
Lateral flexion															
Lower	Peak value	0.1	1.3	-2.5	2.7	-0.4	1.2	-2.8	2.1	0.5	1.8	0.779	-3.1	4.1	0.00
	Lift Range	2.3	0.4	1.5	3.1	2.8	0.4	2.1	3.6	-0.5	0.5	0.332	-1.6	0.6	0.03
	Velocity avg	3.0	0.5	1.9	4.0	3.2	0.5	2.2	4.2	-0.3	0.7	0.728	-1.7	1.2	0.00
	Jerk avg	735.7	117.0	496.4	975.1	672.0	110.6	445.8	898.3	63.7	162.8	0.698	-269.2	396.6	0.01

Lower	Range	2.3	0.4	1.4	3.1	3.3	0.4	2.5	4.1	-1.1	0.6	0.07	-2.2	0.1	0.11
	Velocity avg	2.7	0.6	1.5	3.9	4.1	0.6	2.9	5.3	-1.4	0.8	0.102	-3.1	0.3	0.09
	Jerk avg	651.6	139.1	367.2	936.0	957.1	132.9	685.2	1228.9	-305.5	195.7	0.129	-705.8	94.8	0.08
Rotation															
Peak value		0.9	5.6	-10.5	12.3	-4.2	5.3	-15.1	6.7	5.1	7.8	0.518	-10.9	21.1	0.02
Lift	Range	2.2	0.5	1.1	3.3	3.5	0.5	2.5	4.5	-1.3	0.7	0.084	-2.8	0.2	0.10
	Velocity avg	3.0	0.3	2.3	3.7	3.9	0.3	3.3	4.6	-0.9	0.5	0.058	-1.9	0.0	0.12
	Jerk avg	872.2	100.9	665.6	1078.8	903.5	97.2	704.4	1102.5	-31.2	141.2	0.826	-320.4	258.0	0.00
Lower	Range	2.2	0.4	1.4	3.1	3.2	0.4	2.4	4.0	-1.0	0.6	0.108	-2.2	0.2	0.09
	Velocity avg	3.4	0.6	2.1	4.7	4.6	0.6	3.3	5.8	-1.2	0.9	0.188	-3.0	0.6	0.06
	Jerk avg	1032.5	152.6	719.9	1345.2	1189.2	147.5	887.1	1491.3	-156.7	214.1	0.47	-595.3	282.0	0.02

(range – degrees, velocity – m/s, jerk – m/s³; AVE – average; M – mean; SE - standard error; CI – confidence interval; MD – mean difference; CG – control group; EG – experimental group; Flex-ext – flexion – extension; LF- lateral flexion; Rot – rotation; η^2 – partial eta squared)

**SUPPLEMENTARY FILE 8.10: MUSCLE ACTIVITY MEASURES TAKEN AT THE THREE TIME
POINTS FOR THE BILATERAL ARM TASK**

Muscle	Phase	Activation	CG						EG					
			Pre (n=17)		Post (n=17)		4th (n=14)		Pre (n=18)		Post (n=18)		4th (n=18)	
			M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
LAS	Lift	Peak	60.3	23.2	60.9	24.8	64.2	29.6	61.9	28.2	59.6	30.7	58.3	22.8
		Mean	36.8	14.5	36.7	15.2	37.8	18.3	38.2	18.6	36.4	19.9	34.6	13.2
		Time %	95.6	11.4	91.7	24.1	96.8	8.4	88.3	17.2	91.2	12.6	89.6	19.4
	Lower	Peak	47.8	21.6	44.9	21.9	53.0	23.2	56.3	26.5	55.6	32.0	49.3	20.6
		Mean	29.4	14.8	28.5	15.9	32.4	14.8	36.8	20.1	35.9	23.8	33.5	15.6
		Time %	97.2	8.6	96.5	8.7	98.2	5.9	88.8	21.0	93.3	19.9	86.4	27.1
RAS	Lift	Peak	57.0	26.2	58.8	26.8	55.6	24.3	56.0	25.1	54.8	23.2	60.3	22.9
		Mean	35.7	16.9	35.3	17.3	33.6	14.8	33.9	16.8	32.2	14.3	35.8	14.3
		Time %	98.9	2.7	91.1	24.1	92.0	17.6	92.1	12.1	90.9	19.1	92.1	23.6
	Lower	Peak	44.6	22.6	42.0	20.7	44.1	22.0	51.9	23.4	51.3	26.1	49.7	20.8
		Mean	27.7	14.5	26.8	14.8	26.0	12.4	32.8	17.3	34.0	20.0	34.1	16.0
		Time %	97.9	5.9	88.7	25.0	88.4	24.5	95.2	14.5	94.9	14.5	92.8	24.2
LPC	Lift	Peak	59.8	27.2	60.8	27.4	64.7	25.4	64.8	23.0	62.2	31.2	56.7	24.8
		Mean	38.1	17.9	38.6	18.3	39.6	16.3	41.2	17.0	38.3	19.5	35.6	15.5
		Time %	93.9	22.1	93.4	24.2	93.3	20.4	96.7	6.7	97.1	4.6	98.0	6.1
	Lower	Peak	48.0	22.6	43.3	20.8	48.3	22.7	48.8	22.8	43.1	26.2	39.9	21.4
		Mean	25.0	11.4	24.9	12.9	28.7	15.3	30.6	16.9	27.4	17.5	24.0	12.5
		Time %	91.3	19.1	92.4	24.5	91.5	20.8	91.3	22.9	93.8	14.5	99.0	3.2
RPC	Lift	Peak	56.1	29.5	61.7	26.9	56.6	26.5	55.5	22.1	51.2	26.4	57.6	23.5
		Mean	36.3	19.8	38.8	19.5	35.1	16.0	35.5	16.4	31.9	17.9	35.1	15.3
		Time %	99.5	1.9	90.1	25.9	95.8	8.8	85.2	27.4	93.9	13.5	96.0	11.4
	Lower	Peak	40.4	21.3	46.0	21.2	43.3	22.4	45.3	21.9	43.1	36.0	40.5	21.6

		Mean	23.4	12.7	26.0	12.9	26.3	14.5	28.3	16.0	25.3	16.6	24.9	13.1
		Time %	92.6	19.2	85.8	31.0	83.5	32.0	86.4	24.1	89.6	23.1	95.6	14.2
LT4	Lift	Peak	82.3	10.9	86.4	17.5	84.4	10.4	76.1	18.5	75.4	23.7	74.6	20.1
		Mean	50.7	11.7	52.9	11.6	56.7	10.4	47.5	16.1	47.7	19.2	49.0	15.1
		Time %	100.0	0.0	94.1	23.5	98.2	6.3	98.5	5.1	98.9	3.7	99.9	0.4
	Lower	Peak	56.8	23.5	57.2	24.6	64.1	14.1	57.8	21.5	61.2	22.0	54.6	20.3
		Mean	34.0	15.4	33.4	16.0	38.4	9.4	36.9	15.3	40.4	16.2	34.8	13.0
		Time %	99.7	1.2	94.3	23.5	93.1	18.7	100.0	0.0	100.0	0.0	97.0	10.3
RT4	Lift	Peak	50.7	22.5	51.7	21.3	41.6	15.6	47.4	15.5	47.8	16.1	49.2	22.1
		Mean	30.0	15.6	31.4	13.8	27.2	10.0	28.5	10.0	30.8	14.2	32.9	17.3
		Time %	99.8	1.0	93.9	24.2	99.9	0.2	98.0	5.0	97.0	10.0	100.0	0.1
	Lower	Peak	35.5	23.7	33.3	21.4	27.7	13.3	39.1	15.7	42.8	15.5	38.6	20.6
		Mean	20.3	13.6	19.6	13.4	16.2	8.5	24.8	10.0	26.7	9.8	24.2	13.9
		Time %	97.1	11.4	92.8	24.2	97.0	11.3	100.0	0.0	99.1	2.7	99.3	3.1
LSCM	Lift	Peak	27.0	19.3	29.9	23.4	22.3	10.6	28.8	20.0	28.2	20.0	30.6	21.6
		Mean	16.9	12.7	17.7	12.9	12.7	5.9	15.5	11.4	15.9	12.9	17.8	13.9
		Time %	90.3	20.9	86.9	26.9	72.8	35.6	79.7	25.0	85.3	26.0	81.7	18.3
	Lower	Peak	26.1	18.2	26.3	17.4	17.9	7.7	28.9	17.5	28.2	21.6	29.9	22.6
		Mean	16.6	12.8	15.8	10.9	10.3	5.0	17.5	12.3	17.3	15.6	19.9	16.7
		Time %	88.7	21.7	87.9	25.1	66.7	38.0	91.1	21.5	91.9	16.5	88.5	20.6
RSCM	Lift	Peak	29.9	23.0	29.2	19.6	24.9	14.4	39.2	27.3	36.8	24.3	44.5	26.5
		Mean	17.9	13.1	16.8	10.9	14.3	7.4	22.2	16.0	20.4	13.6	25.1	14.4
		Time %	88.4	25.2	80.2	30.9	85.4	28.3	87.3	21.6	93.6	12.6	87.9	22.2
	Lower	Peak	25.8	19.3	25.7	20.0	20.4	11.4	35.8	24.7	35.8	27.6	40.5	25.8
		Mean	16.7	12.8	15.1	11.9	12.4	7.7	22.1	17.6	22.2	20.3	27.7	19.8
		Time %	82.3	32.6	77.9	28.7	84.8	30.1	92.2	15.0	97.6	6.7	89.1	21.5
LUT	Lift	Peak	89.0	6.2	86.5	9.8	87.2	7.0	88.1	13.7	86.3	14.4	87.4	5.7
		Mean	63.6	9.5	62.2	10.1	63.9	8.2	61.1	18.5	58.6	18.9	63.6	9.4
		Time %	99.9	0.4	94.1	23.5	99.6	1.6	94.2	12.9	93.7	15.1	97.0	6.6
	Lower	Peak	78.6	16.5	77.1	18.8	81.7	10.0	78.1	16.0	76.9	21.7	81.9	14.6

		Mean	52.4	16.3	55.3	15.6	56.6	12.4	53.3	18.8	54.4	20.2	58.3	15.6
		Time %	99.9	0.4	92.5	23.8	99.9	0.5	96.8	11.9	98.1	6.4	98.5	5.4
RUT	Lift	Peak	82.7	13.8	84.2	12.0	82.4	7.2	74.8	17.2	73.2	18.2	82.2	11.3
		Mean	60.7	12.6	60.3	10.8	56.6	9.2	51.1	20.1	48.3	19.3	56.7	13.9
		Time %	99.9	0.4	93.6	24.2	99.7	1.2	95.8	10.0	95.4	12.9	97.5	5.9
	Lower	Peak	70.7	16.6	71.9	17.7	70.7	19.2	64.4	21.3	62.8	22.8	69.6	20.1
		Mean	47.9	15.7	49.3	15.7	46.1	17.9	43.5	17.9	44.3	19.6	48.6	17.1
		Time %	99.8	0.7	92.4	24.4	99.6	1.5	96.7	12.5	99.4	2.7	99.0	3.1
LT9	Lift	Peak	53.8	18.9	57.7	21.1	54.8	25.1	59.0	20.8	55.2	20.1	62.5	21.3
		Mean	36.7	15.2	38.8	15.2	38.1	17.8	38.0	13.6	36.7	13.3	41.6	16.7
		Time %	99.6	1.4	94.2	23.5	97.0	7.8	97.9	4.3	99.4	1.4	99.4	2.0
	Lower	Peak	44.0	21.0	45.3	22.2	45.2	24.1	52.8	21.0	50.7	19.1	52.3	19.5
		Mean	28.0	13.1	28.3	14.6	28.9	16.1	33.7	13.1	33.5	13.3	34.2	14.2
		Time %	99.7	0.7	91.3	25.0	90.4	19.5	97.4	7.6	97.0	8.4	96.3	7.4
RT9	Lift	Peak	65.9	18.6	71.4	21.8	71.4	21.0	63.3	17.6	62.6	17.6	64.5	17.1
		Mean	43.8	13.4	45.9	14.6	48.0	16.1	42.4	15.1	42.2	14.6	41.6	12.5
		Time %	99.4	1.3	93.8	24.2	99.8	0.8	98.4	4.9	99.0	2.6	98.7	3.3
	Lower	Peak	55.4	21.4	54.5	20.6	51.7	22.3	60.9	20.6	58.8	19.4	57.1	17.1
		Mean	33.8	13.6	32.9	14.5	32.3	14.4	39.8	14.9	38.1	13.3	35.6	11.9
		Time %	98.4	4.1	92.5	24.3	97.3	8.4	98.5	5.0	95.9	8.8	95.9	7.4

(CG – control group; EG – experimental group; M – mean; SD – standard deviation; % - percentage; LAS – left anterior scalene; RAS – right anterior scalene; LPC – left posterior cervical; RPC – right posterior cervical; LSCM – left sternocleidomastoid; RSCM – right sternocleidomastoid; LUT – left upper trapezius; RUT – right upper trapezius; LT4 – left paraspinal at T4; RT4 – right paraspinal at T4; LT9 – left paraspinal at T9; RT9 – right paraspinal at T9)

SUPPLEMENTARY FILE 8.11: POST-ADJUSTED MUSCLE ACTIVITY MEASURES FOR POST-INITIAL TREATMENT FOR THE BILATERAL ARM TASK

Muscle	Phase	Activation	Control				Intervention				MD	SE	p value	CI		η^2
			M	SE	CI		M	SE	CI					Low	High	
					Low	High			Low	High						
LAS	Lift	Peak	62.1	4.1	53.6	70.5	57.5	4.2	48.9	66.2	4.5	6.1	0.461	-7.9	16.9	0.02
		Mean	37.6	2.8	31.9	43.3	34.9	2.8	29.1	40.7	2.7	4.1	0.514	-5.6	11.0	0.01
		Time %	88.3	3.4	81.3	95.3	94.4	3.5	87.3	101.5	-6.1	5.0	0.229	-16.4	4.1	0.05
	Lower	Peak	48.9	3.9	40.9	56.9	51.9	4.0	43.8	60.0	-3.0	5.7	0.605	-14.6	8.7	0.01
		Mean	32.2	2.5	27.0	37.4	32.7	2.6	27.4	37.9	-0.5	3.7	0.895	-8.0	7.1	0.00
		Time %	95.2	4.0	87.0	103.3	94.5	3.9	86.6	102.5	0.6	5.8	0.918	-11.3	12.5	0.00
RAS	Lift	Peak	59.7	3.8	51.9	67.5	52.1	3.9	44.1	60.1	7.5	5.6	0.190	-3.9	19.0	0.06
		Mean	35.4	2.5	30.3	40.5	31.0	2.5	25.8	36.2	4.4	3.6	0.234	-3.0	11.9	0.05
		Time %	86.8	5.2	76.2	97.4	95.9	5.3	85.1	106.7	-9.1	7.8	0.257	-25.0	6.9	0.04
	Lower	Peak	45.2	3.2	38.7	51.7	48.0	3.2	41.4	54.6	-2.8	4.6	0.557	-12.2	6.7	0.01
		Mean	29.4	1.9	25.4	33.3	31.5	2.0	27.5	35.5	-2.1	2.8	0.455	-7.9	3.6	0.02
		Time %	86.3	4.5	77.2	95.5	98.6	4.6	89.2	108.0	-12.2	6.6	0.075	-25.8	1.3	0.10
LPC	Lift	Peak	63.7	5.2	53.0	74.3	57.4	5.2	46.8	68.1	6.2	7.6	0.417	-9.2	21.6	0.02
		Mean	40.7	3.4	33.6	47.7	34.7	3.4	27.7	41.7	5.9	5.0	0.241	-4.2	16.1	0.04
		Time %	92.6	4.2	84.1	101.1	99.4	4.2	90.9	107.9	-6.8	6.0	0.27	-19.1	5.5	0.04
	Lower	Peak	43.9	4.7	34.4	53.4	40.5	4.7	30.9	50.0	3.4	6.8	0.618	-10.4	17.3	0.01
		Mean	27.4	2.8	21.7	33.2	23.5	2.8	17.8	29.2	3.9	4.1	0.346	-4.4	12.2	0.03
		Time %	91.0	4.7	81.5	100.6	97.1	4.7	87.6	106.6	-6.0	6.8	0.378	-19.8	7.7	0.03
RPC	Lift	Peak	61.9	3.8	54.1	69.7	50.4	3.9	42.5	58.3	11.5	5.6	0.049	0.1	22.9	0.12
		Mean	38.7	2.7	33.3	44.2	31.3	2.7	25.8	36.8	7.4	3.9	0.065	-0.5	15.4	0.11
		Time %	88.0	5.0	77.7	98.2	97.2	4.9	87.1	107.3	-9.2	7.3	0.217	-24.2	5.7	0.05
	Lower	Peak	48.4	6.8	34.5	62.3	38.8	6.8	25.0	52.7	9.6	9.8	0.339	-10.5	29.6	0.03
		Mean	27.4	3.4	20.5	34.3	22.6	3.4	15.7	29.5	4.8	4.9	0.333	-5.2	14.8	0.03
		Time %	83.0	5.9	71.0	95.0	93.7	5.9	81.7	105.6	-10.7	8.5	0.221	-28.1	6.8	0.05
LT4	Lift	Peak	84.1	4.2	75.5	92.8	76.6	4.3	67.8	85.5	7.5	6.2	0.234	-5.1	20.0	0.04
		Mean	51.4	2.6	46.2	56.7	48.5	2.7	43.1	53.9	2.9	3.7	0.446	-4.7	10.5	0.02
		Time %	93.5	4.0	85.3	101.8	100.8	4.1	92.4	109.2	-7.3	5.9	0.228	-19.3	4.8	0.05
	Lower	Peak	57.1	3.7	49.6	64.7	62.2	3.9	54.4	70.1	-5.1	5.4	0.357	-16.2	6.0	0.03
		Mean	34.4	1.8	30.7	38.2	39.9	1.9	36.0	43.8	-5.4	2.7	0.054	-11.0	0.1	0.11

		Time %	93.8	4.0	85.7	101.9	101.7	4.1	93.4	110.1	-7.9	5.8	0.182	-19.8	3.9	0.06
RT4	Lift	Peak	50.4	2.4	45.5	55.2	49.2	2.4	44.4	54.1	1.1	3.5	0.744	-5.9	8.2	0.00
		Mean	30.5	1.8	26.8	34.2	31.7	1.8	28.0	35.4	-1.2	2.6	0.645	-6.6	4.1	0.01
		Time %	93.5	4.7	83.9	103.1	97.9	4.6	88.5	107.4	-4.5	6.8	0.519	-18.4	9.5	0.01
	Lower	Peak	34.3	2.5	29.2	39.4	42.9	2.5	37.8	48.1	-8.6	3.7	0.026	-16.1	-1.1	0.15
		Mean	21.2	1.8	17.7	24.8	25.8	1.8	22.2	29.4	-4.6	2.6	0.085	-9.9	0.7	0.09
		Time %	92.1	4.2	83.6	100.7	101.1	4.2	92.6	109.6	-8.9	6.1	0.15	-21.3	3.4	0.07
LSCM	Lift	Peak	31.7	2.9	25.8	37.7	25.1	3.0	18.9	31.2	6.7	4.3	0.133	-2.1	15.5	0.07
		Mean	17.7	1.7	14.3	21.2	15.1	1.7	11.5	18.6	2.7	2.5	0.298	-2.5	7.8	0.04
		Time %	82.6	5.4	71.6	93.7	89.2	5.5	77.9	100.6	-6.6	8.1	0.422	-23.1	10.0	0.02
	Lower	Peak	27.7	2.9	21.9	33.6	26.6	3.0	20.6	32.7	1.1	4.2	0.795	-7.5	9.7	0.00
		Mean	16.2	1.6	13.0	19.5	17.0	1.6	13.6	20.3	-0.8	2.3	0.745	-5.6	4.0	0.00
		Time %	87.8	5.0	77.6	98.0	92.3	5.1	81.9	102.8	-4.5	7.3	0.541	-19.4	10.4	0.01
RSCM	Lift	Peak	33.0	3.5	25.9	40.1	31.0	3.5	23.7	38.2	2.1	5.1	0.688	-8.3	12.4	0.01
		Mean	18.6	2.1	14.4	22.8	17.5	2.1	13.2	21.7	1.1	3.0	0.705	-5.0	7.3	0.01
		Time %	79.1	5.0	68.9	89.4	95.9	5.1	85.5	106.3	-16.8	7.3	0.029	-31.7	-1.8	0.15
	Lower	Peak	30.4	3.4	23.4	37.4	30.9	3.5	23.8	37.9	-0.5	5.0	0.919	-10.6	9.6	0.00
		Mean	17.7	2.1	13.4	22.0	19.7	2.1	15.3	24.0	-2.0	3.0	0.517	-8.2	4.2	0.01
		Time %	77.9	5.4	66.9	88.9	98.0	5.3	87.2	108.7	-20.1	7.8	0.015	-36.0	-4.1	0.19
LUT	Lift	Peak	86.4	3.0	80.2	92.5	86.6	3.1	80.2	92.9	-0.2	4.4	0.966	-9.2	8.8	0.00
		Mean	61.5	3.5	54.5	68.6	59.7	3.6	52.4	67.0	1.8	5.1	0.719	-8.5	12.1	0.00
		Time %	93.4	4.9	83.4	103.4	95.0	5.0	84.8	105.2	-1.6	7.2	0.83	-16.3	13.2	0.00
	Lower	Peak	76.5	2.4	71.7	81.4	78.2	2.5	73.1	83.2	-1.6	3.5	0.643	-8.7	5.5	0.01
		Mean	55.5	1.9	51.6	59.4	54.8	2.0	50.8	58.9	0.6	2.8	0.819	-5.1	6.4	0.00
		Time %	91.3	4.0	83.1	99.5	100.8	4.1	92.4	109.3	-9.5	5.9	0.116	-21.5	2.5	0.08
RUT	Lift	Peak	82.2	3.3	75.4	88.9	74.7	3.3	68.0	81.4	7.4	4.8	0.132	-2.4	17.2	0.07
		Mean	57.8	3.4	50.9	64.8	50.5	3.4	43.6	57.3	7.4	4.9	0.144	-2.7	17.4	0.07
		Time %	92.4	4.9	82.5	102.4	97.0	4.8	87.3	106.8	-4.6	7.1	0.521	-19.1	9.9	0.01
	Lower	Peak	68.8	2.3	64.1	73.5	65.9	2.3	61.2	70.6	2.9	3.3	0.391	-3.9	9.7	0.02
		Mean	47.1	2.0	43.0	51.1	46.4	2.0	42.4	50.5	0.6	2.9	0.828	-5.3	6.5	0.00
		Time %	91.7	4.2	83.0	100.3	101.3	4.2	92.7	109.9	-9.6	6.1	0.128	-22.1	2.9	0.07
LT9	Lift	Peak	59.9	2.7	54.5	65.4	52.6	2.8	47.0	58.3	7.3	3.9	0.073	-0.7	15.3	0.10
		Mean	39.3	1.6	36.1	42.5	36.2	1.6	32.8	39.5	3.1	2.3	0.185	-1.6	7.8	0.05
		Time %	93.9	4.1	85.6	102.1	101.0	4.1	92.6	109.4	-7.1	6.0	0.24	-19.3	5.0	0.04
	Lower	Peak	48.7	2.5	43.7	53.7	47.9	2.6	42.7	53.2	0.7	3.7	0.845	-6.8	8.2	0.00
		Mean	30.7	1.6	27.5	33.9	31.6	1.6	28.2	34.9	-0.9	2.4	0.698	-5.7	3.9	0.01
		Time %	90.5	4.6	81.2	99.8	98.3	4.7	88.7	107.9	-7.9	6.8	0.253	-21.6	5.9	0.04

RT9	Lift	Peak	70.5	3.1	64.2	76.9	63.0	3.1	56.7	69.4	7.5	4.5	0.108	-1.7	16.7	0.08
		Mean	45.3	2.1	41.0	49.6	42.9	2.1	38.6	47.3	2.4	3.1	0.449	-3.9	8.6	0.02
		Time %	93.0	4.2	84.5	101.5	101.0	4.2	92.5	109.5	-8.0	6.1	0.196	-20.4	4.3	0.05
	Lower	Peak	55.7	2.9	49.8	61.7	58.7	2.9	52.7	64.6	-2.9	4.3	0.499	-11.7	5.8	0.02
		Mean	34.9	2.0	30.7	39.0	36.9	2.0	32.7	41.0	-2.0	3.0	0.512	-8.1	4.1	0.01
		Time %	92.1	4.5	82.8	101.3	97.0	4.5	87.8	106.3	-5.0	6.6	0.456	-18.4	8.4	0.02

(CG – control group; EG – expimental group; M – mean; SE – standard error; MD – mean difference; % - percentage; η^2 – partial eta squared; LAS – left anterior scalene; RAS – right anterior scalene; LPC – left posterior cervical; RPC – right posterior cervical; LSCM – left sternocleidomastoid; RSCM – right sternocleidomastoid; LUT – left upper trapezius; RUT – right upper trapezius; LT4 – left paraspinal at T4; RT4 – right paraspinal at T4; LT9 – left paraspinal at T9; RT9 - right paraspinal at T9)

**SUPPLEMENTARY FILE 8.12: POST-ADJUSTED MUSCLE ACTIVITY MEASURES FOR THE
FOURTH VISIT FOR THE BILATERAL ARM TASK**

Muscle	Phase	Activation	Control		Intervention						MD	SE	p value	CI		η²
			M	SE	CI		M	SE	CI							
					Low	High			Low	High				Low	High	
LAS	Lift	Peak	65.4	6.0	53.0	77.7	53.8	5.4	42.6	65.0	11.6	8.2	0.169	-5.2	28.4	0.07
		Mean	38.6	3.9	30.5	46.7	31.8	3.5	24.5	39.0	6.8	5.3	0.213	-4.1	17.8	0.06
		Time %	97.6	4.6	88.2	107.0	89.4	4.0	81.1	97.7	8.2	6.2	0.196	-4.5	20.8	0.06
	Lower	Peak	55.0	4.9	44.8	65.1	45.5	4.4	36.4	54.6	9.5	6.7	0.166	-4.2	23.2	0.07
		Mean	34.0	3.2	27.5	40.6	30.0	2.9	24.2	35.9	4.0	4.3	0.364	-4.9	12.9	0.03
		Time %	99.2	6.1	86.6	111.8	84.4	5.5	73.1	95.6	14.9	8.3	0.087	-2.3	32.0	0.11
RAS	Lift	Peak	56.3	5.5	44.9	67.7	59.5	5.2	48.8	70.1	-3.2	7.7	0.683	-19.1	12.7	0.01
		Mean	33.9	3.7	26.4	41.4	35.6	3.4	28.6	42.6	-1.7	5.1	0.743	-12.1	8.8	0.00
		Time %	93.3	6.2	80.7	106.0	90.8	5.7	79.1	102.5	2.5	8.8	0.780	-15.6	20.6	0.00
	Lower	Peak	47.1	4.7	37.5	56.7	47.6	4.3	38.7	56.5	-0.6	6.5	0.932	-13.9	12.7	0.00
		Mean	28.2	2.9	22.2	34.1	32.5	2.7	27.0	38.0	-4.3	4.0	0.289	-12.6	3.9	0.04
		Time %	89.1	6.7	75.2	102.9	90.7	6.4	77.7	103.8	-1.7	9.5	0.862	-21.2	17.9	0.00
LPC	Lift	Peak	67.0	4.6	57.5	76.5	52.3	4.3	43.6	61.0	14.8	6.4	0.029	1.7	27.9	0.16
		Mean	41.2	3.4	34.2	48.1	32.9	3.1	26.5	39.2	8.3	4.7	0.086	-1.3	17.9	0.10
		Time %	93.4	3.8	85.6	101.1	97.7	3.4	90.7	104.8	-4.4	5.2	0.408	-15.0	6.3	0.03
	Lower	Peak	49.2	4.9	39.2	59.2	36.2	4.5	27.0	45.4	13.0	6.8	0.064	-0.8	26.9	0.12
		Mean	31.0	2.8	25.2	36.7	19.6	2.5	14.4	24.8	11.4	3.9	0.006	3.5	19.3	0.24
		Time %	91.5	3.5	84.4	98.7	97.9	3.2	91.4	104.4	-6.4	4.8	0.197	-16.2	3.5	0.06
RPC	Lift	Peak	56.6	4.3	47.9	65.4	56.2	3.9	48.2	64.3	0.4	5.9	0.946	-11.8	12.6	0.00
		Mean	35.0	2.8	29.2	40.7	34.5	2.6	29.2	39.8	0.4	3.9	0.915	-7.6	8.4	0.00
		Time %	94.7	2.9	88.7	100.6	97.5	2.6	92.2	102.8	-2.8	4.0	0.486	-11.0	5.4	0.02
	Lower	Peak	45.4	4.8	35.5	55.2	36.4	4.4	27.4	45.4	9.0	6.6	0.188	-4.6	22.5	0.06
		Mean	27.6	3.0	21.5	33.8	21.8	2.7	16.2	27.4	5.9	4.1	0.169	-2.6	14.3	0.07
		Time %	82.4	6.0	70.2	94.7	96.0	5.5	84.8	107.2	-13.6	8.2	0.11	-30.5	3.3	0.09
LT4	Lift	Peak	81.3	3.6	73.9	88.8	75.0	3.3	68.3	81.7	6.4	4.9	0.207	-3.7	16.4	0.05
		Mean	54.3	2.7	48.8	59.7	49.9	2.4	44.9	54.8	4.4	3.6	0.227	-2.9	11.7	0.05
		Time %	98.3	1.1	96.1	100.6	99.6	1.0	97.6	101.7	-1.3	1.5	0.393	-4.3	1.8	0.00
	Lower	Peak	62.7	3.7	55.2	70.3	56.0	3.4	49.0	62.9	6.7	5.0	0.187	-3.5	17.0	0.10
		Mean	38.2	2.2	33.7	42.7	35.7	2.0	31.5	39.8	2.5	3.0	0.402	-3.6	8.6	0.15

		Time %	94.2	3.8	86.5	101.8	95.9	3.4	88.9	102.9	-1.7	5.1	0.74	-12.2	8.7	0.11
RT4	Lift	Peak	40.3	4.3	31.6	49.1	49.7	3.9	41.7	57.6	-9.3	5.9	0.124	-21.4	2.7	0.01
		Mean	26.1	3.2	19.5	32.7	33.5	2.9	27.5	39.6	-7.5	4.4	0.103	-16.6	1.6	0.03
		Time %	99.9	0.0	99.8	100.0	100.0	0.0	99.9	100.1	-0.1	0.1	0.362	-0.2	0.1	0.03
	Lower	Peak	28.5	4.5	19.2	37.8	38.8	4.2	30.3	47.3	-10.3	6.3	0.114	-23.2	2.6	0.02
		Mean	17.6	3.0	11.6	23.7	23.6	2.7	18.0	29.2	-6.0	4.2	0.164	-14.5	2.6	0.01
		Time %	98.8	0.7	97.4	100.2	98.0	0.6	96.8	99.3	0.8	0.9	0.425	-1.2	2.7	0.00
LSCM	Lift	Peak	22.6	3.8	14.7	30.5	28.5	3.5	21.2	35.8	-5.9	5.3	0.276	-16.8	5.0	0.00
		Mean	12.3	2.6	7.0	17.7	16.7	2.4	11.8	21.7	-4.4	3.7	0.240	-11.9	3.1	0.05
		Time %	74.9	7.8	58.9	91.0	77.2	7.1	62.7	91.7	-2.3	11.0	0.838	-25.0	20.4	0.02
	Lower	Peak	18.1	4.5	8.9	27.3	28.8	4.1	20.3	37.2	-10.7	6.2	0.095	-23.4	2.0	0.01
		Mean	10.0	3.1	3.6	16.5	19.5	2.9	13.6	25.4	-9.4	4.3	0.039	-18.3	-0.5	0.05
		Time %	66.5	8.4	49.2	83.9	86.9	7.7	71.0	102.7	-20.3	11.6	0.091	-44.1	3.5	0.00
RSCM	Lift	Peak	27.4	5.2	16.8	38.0	39.9	4.8	30.0	49.7	-12.5	7.1	0.091	-27.2	2.1	0.01
		Mean	15.3	2.9	9.3	21.4	22.9	2.7	17.3	28.5	-7.5	4.1	0.074	-15.9	0.8	0.00
		Time %	86.6	6.7	72.9	100.3	85.4	6.2	72.6	98.2	1.1	9.3	0.903	-17.9	20.2	0.00
	Lower	Peak	23.3	4.9	13.3	33.3	36.3	4.5	27.0	45.5	-13.0	6.7	0.065	-26.8	0.9	0.01
		Mean	14.1	3.6	6.7	21.6	25.4	3.4	18.5	32.4	-11.3	5.0	0.034	-21.6	-0.9	0.00
		Time %	87.9	6.6	74.5	101.4	84.7	6.1	72.2	97.2	3.2	9.2	0.729	-15.7	22.1	0.04
LUT	Lift	Peak	87.2	1.5	84.0	90.4	88.4	1.5	85.4	91.4	-1.2	2.2	0.586	-5.6	3.2	0.06
		Mean	63.6	1.9	59.7	67.6	66.0	1.8	62.2	69.8	-2.4	2.7	0.381	-7.9	3.1	0.05
		Time %	99.5	1.3	96.9	102.1	97.7	1.2	95.3	100.1	1.8	1.8	0.326	-1.8	5.4	0.03
	Lower	Peak	81.0	2.7	75.6	86.5	83.7	2.6	78.6	88.9	-2.7	3.7	0.469	-10.3	4.9	0.06
		Mean	56.4	2.7	50.9	61.9	58.6	2.6	53.3	63.8	-2.2	3.7	0.559	-9.9	5.5	0.03
		Time %	99.1	0.2	98.7	99.5	99.2	0.2	98.8	99.6	-0.1	0.3	0.788	-0.7	0.5	0.00
RUT	Lift	Peak	82.1	2.7	76.5	87.	83.1	2.5	78.1	88.2	-1.0	3.7	0.785	-8.7	6.6	0.00
		Mean	54.9	2.8	49.2	60.7	59.5	2.5	54.3	64.7	-4.6	3.8	0.242	-12.4	3.3	0.05
		Time %	99.5	1.2	97.0	102.0	98.1	1.1	95.8	100.3	1.4	1.7	0.410	-2.1	4.9	0.02
	Lower	Peak	68.5	4.4	59.5	77.4	72.2	4.0	64.1	80.4	-3.8	6.0	0.534	-16.1	8.5	0.01
		Mean	44.1	3.8	36.4	51.9	50.7	3.5	43.6	57.8	-6.6	5.2	0.216	-17.3	4.1	0.05
		Time %	99.4	0.7	98.0	100.7	99.2	0.6	98.0	100.4	0.2	0.9	0.840	-1.7	2.0	0.00
LT9	Lift	Peak	56.3	5.5	44.9	67.6	60.0	5.7	48.4	71.6	-3.8	8.1	0.645	-20.5	12.9	0.01
		Mean	38.2	3.8	30.5	45.9	39.5	3.8	31.6	47.3	-1.3	5.5	0.816	-12.5	9.9	0.00
		Time %	97.6	1.4	94.7	100.4	98.1	1.3	95.4	100.8	-0.6	2.0	0.783	-4.6	3.5	0.00
	Lower	Peak	47.3	5.0	37.0	57.6	50.5	5.1	40.0	61.0	-3.3	7.5	0.665	-18.5	12.0	0.01
		Mean	30.6	3.5	23.4	37.7	32.2	3.5	24.9	39.4	-1.6	5.1	0.755	-12.1	8.9	0.00
		Time %	89.9	3.4	82.8	96.9	94.9	3.4	87.9	102.0	-5.0	5.0	0.324	-15.3	5.2	0.04

RT9	Lift	Peak	71.5	3.9	63.4	79.6	62.7	3.6	55.3	70.2	8.8	5.5	0.119	-2.4	20.0	0.09
		Mean	47.8	2.9	41.9	53.7	40.7	2.7	35.3	46.1	7.1	4.0	0.087	-1.1	15.3	0.10
		Time %	99.8	0.7	98.3	101.3	98.7	0.7	97.3	100.1	1.1	1.0	0.301	-1.0	3.1	0.04
	Lower	Peak	54.3	3.7	46.6	61.9	54.5	3.4	47.5	61.5	-0.2	5.2	0.966	-11.0	10.5	0.00
		Mean	34.7	2.6	29.5	39.9	33.5	2.3	28.8	38.3	1.2	3.6	0.749	-6.2	8.5	0.00
		Time %	97.5	2.1	93.3	101.7	95.1	1.9	91.3	99.0	2.3	2.8	0.418	-3.5	8.2	0.02

(CG – control group; EG – expimental group; M – mean; SE – standard error; MD – mean difference; % - percentage; η^2 – partial eta squared; LAS – left anterior scalene; RAS – right anterior scalene; LPC – left posterior cervical; RPC – right posterior cervical; LSCM – left sternocleidomastoid; RSCM – right sternocleidomastoid; LUT – left upper trapezius; RUT – right upper trapezius; LT4 – left paraspinal at T4; RT4 – right paraspinal at T4; LT9 – left paraspinal at T9; RT9 - right paraspinal at T9)

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