



The immediate effect of long-axis talocrural manipulation and sham laser on sagittal motion of the ankle joint and bowling speed of club cricket pace bowlers in the eThekweni Municipality

By

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This dissertation is submitted in partial compliance with the requirements for the Master's Degree in Health Sciences: Chiropractic

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DECLARATION

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“As the candidate’s supervisors, we agree to the submission of this thesis.”

Dr Shereen Currie (PhD Sport Science)

~

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Title, name of supervisor and qualifications of the co-supervisor

Co-supervisor

DEDICATION

I want to dedicate this dissertation to my family, Peter, Susan, and Caitlan Vermaak, for their unwavering love, support and encouragement throughout this journey. Your hard work has set an example for me, and your belief in me has helped me cross the finish line.

ACKNOWLEDGEMENTS

It is with sincere gratitude and appreciation that I would like to thank the following individuals and organisations:

1. First and foremost, I would like to express my deepest gratitude to my supervisors, Drs Shereen Currie of the Department of Sport Studies, Faculty of Applied Sciences, Durban University of Technology (DUT) and Dr Junaid Shaik, of the Department of Chiropractic, Faculty of Health Science (DUT) for their guidance and invaluable support throughout this research. Your feedback has been instrumental in the quality of this dissertation.
2. Drs Junaid Shaik and Dr Prasanthi Nayager (in private practice), for their time and off-campus supervision for this study.
3. Mr Deepak Singh, Department of Physics, DUT, for his assistance with statistical analyses used in this study.
4. Every cricket club, cricket coach and club management staff for their assistance in recruiting players and providing venues for data collection.
5. All the participants of this study.
6. My family for their unwavering support throughout this study.

I would like to acknowledge further the financial support of the National Research Foundation of South Africa (NRF). This study was supported by an NRF Postgraduate Scholarship: First-time Master's Scholarship awarded to Jason Vermaak (Grant Number: PMDS23041593168).

ABSTRACT

Purpose:

The purpose of this study was to determine the immediate effect of talocrural long-axis manipulation and sham laser on sagittal ankle motion and bowling speed in club cricket pace bowlers in the eThekweni Municipality.

Method:

Fifty-four club-level pace bowlers were randomly assigned into two equal groups, Groups A and B ($n = 27$ each). Participants in Group A received a talocrural long-axis manipulation (TLAM) intervention, while participants in Group B received a sham laser intervention (placebo). All participants bowled six maximum-effort deliveries both before and after the intervention. Bowling speed ($\text{km} \cdot \text{h}^{-1}$) was measured using a SpeedTrac X Radar Gun (EMG Companies Inc., Prescott, USA). Both front and back foot ankle sagittal range of motion (ROM) ($^{\circ}$), namely, dorsiflexion and plantarflexion, were assessed using an analogue goniometer (Hitech Therapy, Durban, South Africa). For each participant, the mean of the three fastest deliveries was recorded for the pre- and post-intervention. Data were analysed using SPSS version 31. Paired sample *t*-tests were used to compare pre- and post-intervention means for ankle sagittal motion and bowling speed to determine statistical significance. To evaluate the collective influence of the intervention type (Group A: talocrural manipulation; Group B: sham laser) on changes in ankle joint ROM and bowling speed, with age as a covariate, a GLM multivariate analysis was conducted. A follow-up univariate ANOVA test was performed to determine which individual variables contributed to the overall intervention effect. The correlation between the ankle sagittal ROM and bowling speed was assessed using Spearman's correlation. An alpha level of 0.05 was set to determine statistical significance; therefore, a *p*-value of <0.05 was considered statistically significant.

Results:

The mean $\pm$ standard deviation (SD) of the age of participants was 31.7 ± 8.0 years in Group A (intervention) and 32.8 ± 7.4 years in Group B (control). In the intervention group, front foot dorsiflexion improved significantly from $110.9^{\circ} \pm 5.7$ to $101.9^{\circ} \pm 7.7$ (-9.0° , 95% CI: -11.6 to -6.4 , $p < 0.001$), and plantarflexion improved significantly from $152.9^{\circ} \pm 9.1$ to $160.0^{\circ} \pm 7.3$

(+7.1°, 95% CI: 4.5 to 9.9, $p = 0.001$). A smaller but significant improvement was also observed in back foot plantarflexion from $154.1^\circ \pm 8.2$ to $155.8^\circ \pm 7$ (+1.7°, 95% CI: 0.2 to 3.1, $p = 0.025$), with an insignificant improvement in back foot dorsiflexion (-1.3°, 95% CI: -3.3 to 0.6, $p = 0.173$). In contrast, no significant changes in front foot or back foot ROM were observed in the control group. Bowling speed in Group A increased significantly from $112.8 \pm 12.5 \text{ km} \cdot \text{h}^{-1}$ to $118 \pm 11.3 \text{ km} \cdot \text{h}^{-1}$ (+5.4 $\text{km} \cdot \text{h}^{-1}$, 95% CI: 2.6 to 8.3, $p < 0.001$). In contrast, no significant change in bowling speed was observed in Group B. A multivariate analysis confirmed that the intervention had a significant collective effect on ankle sagittal ROM and bowling speed (Pillai's Trace = 0.488, $F(5,47) = 9.0$, $p < 0.001$, partial $\eta^2 = 0.50$), independent of age. A statistically significant, moderate negative correlation ($r = -0.484$, $p = 0.049$) was observed between increases in ankle dorsiflexion ROM and bowling speed in the intervention group.

Conclusion:

TLAM of the front foot resulted in a significant increase in ankle sagittal ROM and bowling speed in club-level cricket pace bowlers, with no adverse effects reported. This provides the first evidence that front foot ankle manipulation can improve a key performance metric in pace bowling, reinforcing the ankle's crucial biomechanical role in generating bowling speed. These findings suggest that TLAM could support the performance enhancement of pace bowlers, offering a safe and non-invasive intervention that manual therapists can use within a cricket team. While improvements in ankle sagittal motion and bowling speed were observed, the effect of TLAM on other pace bowling performance metrics, such as accuracy and bounce, remains unexplored. Future research should explore these performance metrics, assess the combined impact of TLAM with upper body manipulation, and investigate the effect of TLAM in different population groups, such as female pace bowlers.

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LIST OF ABBREVIATIONS, ACRONYMS AND NOTATIONS

ANOVA:	Analysis of variance
BFC:	Back foot contact
BS:	Bowling speed
CI:	Confidence interval
cm:	Centimetres
CSA:	Cricket South Africa
DF:	Dorsiflexion
FFC:	Front foot contact
FF:	Front foot
GLM:	General linear model
GRF:	Ground reaction force
H _a	Alternative hypothesis
HVLA:	High-velocity, low-amplitude
Hz:	Hertz
ICC:	International Cricket Council
ICC:	Intraclass Correlation Coefficient
IREC:	Institutional Research Ethics Committee
KS:	Kolmogorov-Smirnov
km·h ⁻¹ :	Kilometres per hour
n.d:	No date
ODIs:	One day internationals
m:	Metre
mm:	Millimetre
N:	Newton
NRF:	National Research Foundation
TCJ:	Talocrural joint
T/20:	Twenty/twenty
<i>r</i> :	Pearson's product-moment correlation coefficient

r^2 :	R-Squared
ROM:	Range of motion
SD:	Standard deviation
SMT:	Spinal manipulation therapy
SPSS:	Statistical Package for the Social Sciences
TLAM:	Talocrural long-axis manipulation
vs:	Versus
°:	Degrees
Δ :	Difference of
²	Squared
™:	Trademark
%:	Percentage

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CHAPTER ONE: INTRODUCTION AND LITERATURE REVIEW

1.1 INTRODUCTION

Cricket is a bat-and-ball sport that originated in England during the 16th century and has since evolved into one of the most popular sports globally, particularly in countries such as India, Australia, South Africa, and England (Underdown 2006; Naha and Malcolm 2021). The game is played between two teams of 11 players on an oval field, with a rectangular 22-yard pitch at the centre and is structured around two key disciplines: batting and bowling. Bowling is broadly categorised into two types: pace bowling, which relies predominantly on speed and bounce, and spin bowling, which uses variations in ball rotation and bounce to deceive the batter. This study focused on pace bowling, a physically demanding skill that requires a highly complex biomechanical process to execute successfully (Feros, Young and O'Brien 2020).

A substantial body of evidence has investigated the relationship between upper body mechanics, especially that of the shoulder, and bowling speed (Ramachandran *et al.* 2021). Portus *et al.* (2010) reported that factors such as abdominal muscle strength, trunk stability, and shoulder alignment significantly influence bowling speed. This was supported by Ferdinands (2015), who observed a relationship between upper body mechanics and bowling speed. Ferdinands (2015) emphasised that pace bowling requires highly coordinated movements of the body, and that understanding of the contribution of upper-body kinematics is essential for maximising bowling velocity. Kinematic data from nine pace bowlers were collected using a 10-camera, 240Hz Eva motion analysis system (Motion Analysis Corp), with 45 retroreflective markers positioned on their limbs. The analysis showed that shoulder kinematics produced more torque than the thorax, emphasising the key role of shoulder biomechanics in generating bowling speed.

However, pace bowling is not solely reliant on biomechanical contributions from the upper body, but is a multifaceted, full-body technique that requires the efficient integration of several kinetic chain components (Kiely *et al.* 2021). Changes in any segment of the kinetic chain, particularly in joint ROM, can influence bowling performance. Kiely *et al.* (2021) opined that previous research, investigating the influence of kinematic data on bowling speed, tended to be unifocal and did not

adequately address the multifaceted nature of pace bowling. The authors further elaborated that multi-joint assessments are crucial in evaluating a dynamic sporting action, such as pace bowling. Specifically, the contribution of the lower limb, and more precisely the ankle joint, has been overlooked in contrast to the frequent investigation of upper body mechanics (Kiely *et al.* 2021).

The ankle joint, particularly the talocrural joint (TCJ), plays a vital role in facilitating the transfer of energy during the front foot contact (FFC) phase of pace bowling (Felton, Yeadon and King 2020). During the FFC phase, the bowler's body pivots over the front foot. If dorsiflexion at the TCJ is limited, it may impede optimal positioning and reduce kinetic energy transfer through the kinetic chain, ultimately affecting bowling speed. Manipulation of the ankle joint, specifically TLAM, has been shown to improve ankle dorsiflexion and enhance ankle function (Cosby and Grindstaff 2012). Therefore, TLAM was selected as the intervention of choice for this study.

While previous research has investigated the effects of spinal manipulation on bowling speed in cricket (Sood 2008; Levine 2016), no studies to date have examined the impact of lower-limb or ankle-specific manipulation on bowling speed. Given the ankle's critical role in transmitting ground reaction forces during the front foot contact phase, this represents a notable gap in the literature. Investigating the effects of TLAM on ankle ROM and bowling speed may therefore provide novel insights into the contribution of lower-limb manipulation and its impact on pace bowling performance.

This study focused on club-level bowlers from the eThekweni Municipality in Durban, KwaZulu-Natal, South Africa. It employed a quantitative, pre-post experimental design with an intervention and a control group. Participants were randomly assigned to either Group A, the intervention group, or Group B, the control group. The study set out to determine the effects of talocrural manipulation and sham laser on sagittal ankle motion, viz., front foot dorsiflexion and plantarflexion, and pace bowling speed. This is the first study in South Africa to investigate the effect of talocrural joint manipulation on bowling speed, providing a good basis for further research into the role the ankle plays in cricket pace bowling.

1.2 LITERATURE REVIEW

1.2.1 Introduction

To provide context for this study, the literature review provides an overview of the sport of cricket and a comprehensive examination of the biomechanical phases of pace bowling, as well as the factors that contribute to bowling speed. These factors highlight the importance of horizontal impulse and the transfer of kinetic energy through the ankle during the FFC phase of pace bowling. To support these factors, this literature review investigates the anatomical and functional characteristics of the ankle, particularly the TCJ and its relation to energy transfer during FFC.

1.2.2 Overview of Cricket

Cricket is a contest between two teams, each comprising 11 players who fulfil specialised roles, such as batters, bowlers, and wicketkeepers. There are two primary types of bowlers in a cricket team, namely pace bowlers and spin bowlers. A variety of factors influence the performance of pace bowlers (Kiely *et al.* 2021). However, bowling speed and accuracy are generally considered the most critical elements of successful pace bowling performance. Of these two, bowling speed was selected as the variable of interest in this study, as it is quantifiable and assessable under controlled experimental conditions (Pardiwala, Rao and Varshney 2017).

1.2.3 Typical Roles in a Cricket Team

Each player in a cricket team has a different role, contributing to the overall team dynamics. These roles can be categorised into specific disciplines: batting, bowling, fielding, and wicket-keeping. While some players specialise in one discipline, all players are generally required to participate in multiple roles. For example, every batter must also field, and every bowler is expected to bat. Players who excel in multiple disciplines are known as all-rounders (Realbuzz 2019).

1.2.3.1 Batting

Every player in the team has a batting responsibility, but typically, six to seven players are specialised batters. The two players who bat first are referred to as the opening pair. The batters are responsible for scoring runs for the team during the batting innings.

1.2.3.2 Bowling

Bowling is a specialised and crucial role in a cricket team. Bowlers are responsible for dismissing the opposition's batters and restricting the number of runs scored by the opposing team. Bowling can be broadly classified into pace bowling and spin bowling. Pace bowlers use speed and bounce to dismiss the batters, while spin bowlers rely primarily on variations in ball rotation and bounce. Pace bowling is further subdivided based on the bowler's average speed: slow (below $100\text{km}\cdot\text{h}^{-1}$), medium ($100\text{-}119\text{km}\cdot\text{h}^{-1}$), medium-fast ($120\text{-}129\text{km}\cdot\text{h}^{-1}$), fast-medium ($130\text{-}141\text{km}\cdot\text{h}^{-1}$), and fast (over $142\text{km}\cdot\text{h}^{-1}$) (CricClubs 2022). Spin bowlers are divided into leg-spin and off-spin bowlers, based on the direction of spin imparted to the ball.

1.2.3.3 Fielding

Every player on the team is required to field. During a fielding innings, all 11 players are on the field at the same time. The fielders' objectives are to stop the ball to prevent runs or catch it to dismiss the batters.

1.2.4 Levels of Cricket in South Africa

Cricket in South Africa is structured in a tiered format that can be visualised as a pyramid, as shown in **Figure 1.1**. At the base is school-level cricket, followed by club cricket in the middle, and professional cricket at the apex (Africa n.d.).

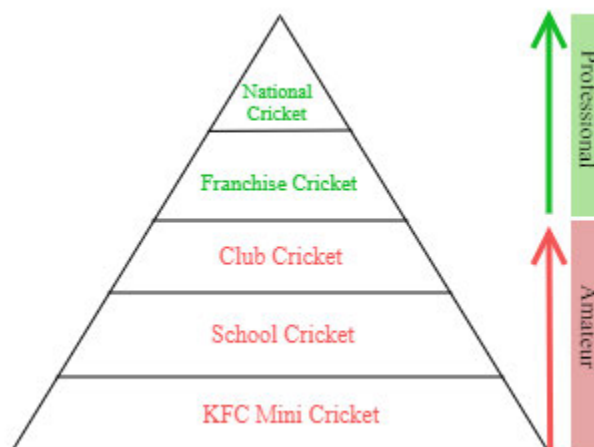


Figure 1.1. Cricket Levels in South Africa.

(Image designed by the researcher)

1.2.4.1 Club Cricket

Club cricket forms the middle tier of the pyramid, providing a platform for players who have progressed beyond the school level. Talented players can use this level as a stepping stone to progress to professional cricket. However, many of the players at this level play the sport at a social, yet competitive level. Club cricket is classified as an amateur but highly competitive level of cricket (Oliphant 2025). Given its position in the middle tier, between school and professional levels, club cricket provides a sample population that best represents all cricket players in South Africa. It creates a platform for future research at various levels of cricket, including the developmental level of school cricket and the elite level of professional cricketers. For this reason, club-level pace bowlers were the choice of participants in this research study.

1.2.4.2 Professional Cricket

Professional cricket forms the pinnacle of the South African cricketing structure, characterised by players being contracted and paid to represent their respective teams (Board 2024). At this level, players either compete in franchise cricket or for the national team, the Proteas.

1.2.5 Factors Affecting Bowling Speed

Pace bowling is a complex skill, with bowling speed being a key determinant of performance, as it directly influences the batter's reaction time and the bowler's ability to take wickets (Feros *et al.* 2020). The generation of bowling speed is multifactorial, influenced by a combination of technical, physical and biomechanical factors (Kiely *et al.* 2021). These contributing factors will be explored in greater detail to provide context for evaluating the motivation for this research study.

1.2.6.1 Technical Factors

Pace bowling is a physically demanding sport that requires skill to perform well. The pace bowling technique is a multifaceted process that involves a sequence of biomechanical phases, each contributing to the bowling speed (**Figure 1.2**). These phases are described below to provide context for the technical process of pace bowling and the required transfer of momentum needed for pace bowling (Purohit and Vijayvargia 2012).

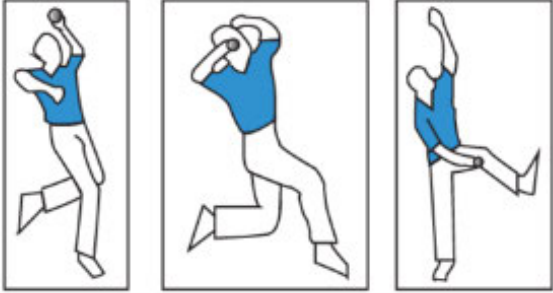
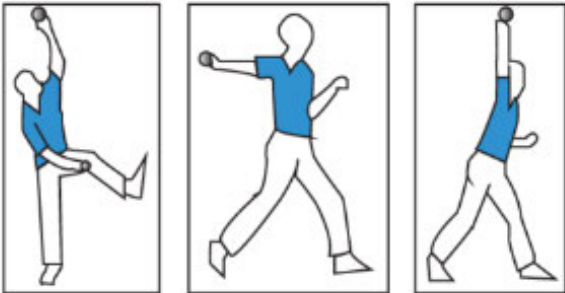
	Run-up The bowler walks or jogs, gradually increasing his speed, as he approaches the wicket. The run-up ends as he leaps into the air at the start of the pre-delivery stride. The run-up length varies between 15 m and 30 m.
	Pre-delivery stride The bowler jumps off his left foot and lands on the right or back foot. The shoulders are pointing down the wicket.
	Delivery stride The bowler lands on his back foot with the body leaning away from the batsman. The delivery stride includes back-foot strike, front-foot strike and ball release.
	Follow-through The bowling arm follows through down the outside of the left thigh.

Figure 1.2. Pace bowling phases.
(Olivier, Steward and Mckinon 2013)

The run-up

The bowling action begins with the run-up, during which the bowler accelerates from a stationary position and sprints towards the crease. This phase is critical for building momentum, as the bowler progressively increases both running speed and stride length. An optimal run-up is characterised by smooth, controlled acceleration that allows for maximum force production at the point of delivery. Momentum generated during the run-up plays a vital role in bowling speed, as pace bowlers rely on explosive lower-body power to deliver the ball at high velocity. This begins with the generation of power from the lower body during the run-up and is transferred into the ball release (Purohit and Vijayvargia 2012).

A study by Ferdinands, Marshall and Kersting (2010), which analysed kinematic data from 32 bowlers ranging from amateur to professional level, also found a significant positive correlation between run-up velocity and bowling speed ($r = 0.50$, $p < 0.001$). Multiple linear stepwise regression analysis revealed that the run-up speed contributed 11.7% to the variance in ball release speed. However, the authors noted that the largest variance in bowling speed was due to the negative deceleration of the bowler during the delivery stride, with an effect size of $r^2 = 0.66$, indicating that deceleration was strongly predictive of bowling speed. This finding does not indicate that the run-up velocity has no functional role; instead, it suggests that the rapid transfer of energy during the delivery stride is more critical.

Worthington, King and Ranson (2013) collected kinematic data from 20 elite male pace bowlers during six deliveries bowled at maximum speed to examine the different elements of pace bowling technique and their impact on bowling speed. The kinematic data was collected from 47 retro-reflective markers placed over bony landmarks (**Figure 1.3**), using a full-body marker set and an 18-camera (M² MCam) Vicon Motion Analysis System (OMG Plc., Oxford, UK) operating at 300Hz. The authors reported that the generation of speed during the run-up phase showed a strong, significant correlation with ball release speed ($r = 0.728$, $p < 0.05$). This suggests that the increased linear momentum generated during the run-up results in higher bowling speed, provided that an optimal technique is maintained during the subsequent phases (Worthington *et al.* 2013). A meta-analysis of biomechanical and physical determinants of bowling speed by Ramachandran *et al.* (2021) found that run speed was significantly correlated with bowling speed ($r = 0.50$, $p < 0.001$) based on the data gathered from seven studies.

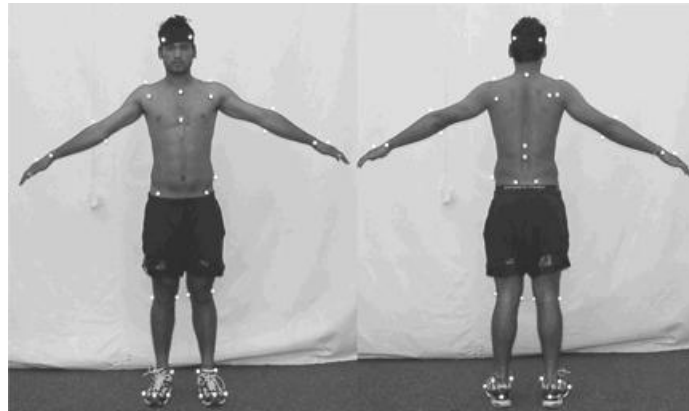


Figure 1.3. Retro-reflective tape placement.
(Worthington *et al.* 2013)

A study by Kiely *et al.* (2021) built on this work by examining the relationships between physical capacity, bowling technique, and bowling speed in 20 male pace bowlers. All participants were injury-free and part of the Australian state team ($n = 4$, 26.0 ± 4.4 years), a state under-17 or under-19 team ($n = 9$, 18.3 ± 1.1 years) or a state premier cricket team ($n = 7$, 24.9 ± 3.3). A stepwise regression analysis found that bowlers' sprint speed was significantly associated with increased bowling speed, with an effect size of $r^2 = 0.543$. Furthermore, a two-tailed Pearson analysis showed a significant correlation ($r = 0.616$, $p = 0.004$) between run-up velocity and bowling speed. Interestingly, Kiely *et al.* (2021) also reported that the run-up speed, accompanied by a decrease in time during the Back Foot Contact (BFC) phase, showed a significant, moderate inverse correlation ($r = -0.608$, $p = 0.004$) with bowling speed. The authors stated that decreased ground contact time and accompanying braking forces could allow for a more rapid transfer of energy from BFC to FFC. However, due to the small sample sizes and the absence of ground reaction force (GRF) data collected during this study, the analysis of kinetic energy transfer could not be performed, indicating that further investigation into the BFC phase is warranted.

Back Foot Contact

The BFC refers to the initial point at which the back foot contacts the ground following the run-up. For right-handed pace bowlers, the back foot refers to the right (landing) foot, while the front

foot refers to the left foot, which lands next to deliver the ball. The opposite applies to left-handed bowlers (Olivier *et al.* 2023).

According to Ranson *et al.* (2008), pace bowling actions can be categorised as front-on, side-on, mid-way, or mixed, based on the alignment of the shoulders and pelvis at BFC. A mixed action, for instance, is defined by a pelvic-to-shoulder separation angle exceeding 30°. Although the direct impact of these alignment types on bowling speed remains unclear, Ranson *et al.* (2008) hypothesised that mixed actions may increase the risk of lumbar spine injuries. This is due to the high ground reaction forces experienced during BFC, which, if not adequately dissipated through proper alignment, particularly into a side-on position, may contribute to increased lumbar spinal loading.

The optimal, side-on position is essential for aligning the body and establishing a stable base for the next phase of pace bowling technique (Purohit and Vijayvargia 2012). Kiely *et al.* (2021) further emphasise that the importance of the BFC lies in the efficient transfer of energy and the subsequent impulse generated at FFC. If the linear momentum generated through the run-up is not optimally transferred during this transitional phase, it results in less momentum being transferred to the FFC phase and subsequently onto ball release.

Ferdinands *et al.* (2015) analysed the kinematics and kinetics of the rear leg drive in fast bowling and its effect on ball release speed by using a 14-camera Cortex Motion Analysis system (version 1.0, Motion Analysis Corporation Limited, United States of America). The study was conducted on 18 pace bowlers (17.2 ± 1.7 years) from the Cricket New South Wales development squad. The results revealed that the rear leg had a negligible effect on bowling speed. The authors concluded that the front leg of a pace bowler impacts bowling speed, highlighting the essential role of the front leg and the FFC phase in pace bowling.

Front Foot Contact

The FFC refers to the phase that begins when the bowler's front foot contacts the ground, at which point the front leg acts as a strut over which the upper body pivots. Simultaneously, the upper body flexes and laterally deviates to position the arm vertically for ball release. This phase is considered a critical component of the pace bowling action, as it marks the point at which kinetic energy

generated during the run-up is transferred through the lower limbs and trunk to the bowling arm (Purohit and Vijayvargia 2012).

To understand the kinetic forces that occur at FFC, Newton's third law of motion states that for every action, there is an equal and opposite reaction. In the context of FFC, the force exerted by the bowler's front foot on the ground is met with an equal and opposite force from the ground; this is the GRF (McGinnis 2013). Another vital kinetic force is the horizontal impulse, defined as the product of the force in the horizontal plane and the duration over which it is applied (Kawamori, Nosaka and Newton 2013). According to the Impulse-Momentum Principle, impulse equals the change in momentum of an object (Bccampus 2016). Therefore, when a force is applied over a more extended period (the longer the front foot is in contact with the ground), a greater impulse is generated, resulting in a greater change in momentum.

Worthington *et al.* (2013) stressed the importance of momentum built during the run-up but further identified two additional kinematic parameters that substantially influence GRF during FFC: heel-strike technique and the front foot plant angle. The heel-strike technique, where the heel of the front foot contacts the ground first, was quantified using the global y-axis and a line drawn from the metatarsophalangeal joint; a positive angle indicated a heel strike (**Figure 1.4(a)**), while a negative angle indicated a forefoot strike. The plant angle (**Figure 1.4(b)**) was defined as the angle between a vertical line drawn down the midline of the body and a line from the hip to the ankle. A greater angle indicates a larger stride at FFC.

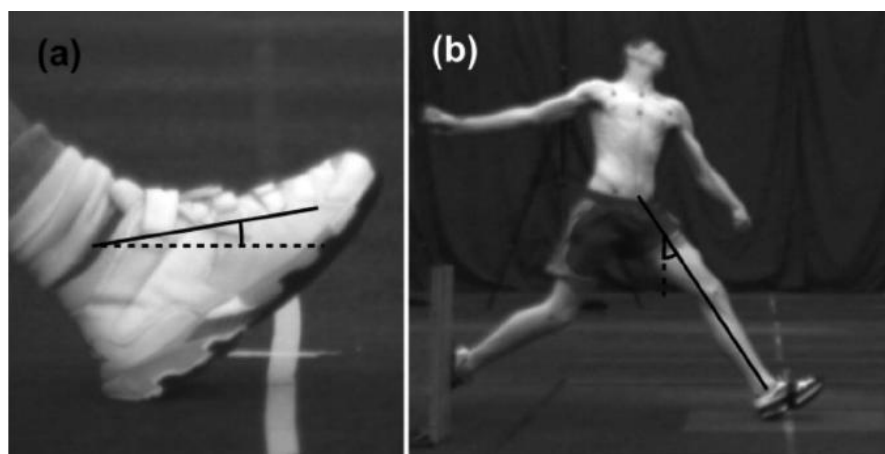


Figure 1.4. The front leg during the front foot contact phase of pace bowling.
(King, Worthington and Ranson 2015)

While the study by Worthington *et al.* (2013) established the importance of technique in generating GRF, a follow-up publication from the same dataset provided further insights into the kinetics of pace bowling. In their 2015 study, King *et al.* (2015) focused on the kinetic data and examined how ground reaction forces during FFC relate to bowling speed. Using a Kistler force plate (1008Hz, 900 x 600mm, Type 9287B; Winterthur, Switzerland), they measured six kinetic parameters during FFC: peak horizontal (braking) and vertical ground reaction forces, average loading rates in both planes, and horizontal and vertical impulses. These variables were then correlated with ball release speed and further with the kinematic variables identified in the previous publication by Worthington *et al.* (2013). The data analysis from King *et al.* (2015) revealed that a greater horizontal impulse (measured as the time from front foot contact to ball release) was significantly correlated with faster bowling speeds ($r = 0.574, p = 0.008$). Importantly, this variable was most correlated with bowling speed, explaining 33% of the variance in bowling speed. Moreover, a significant positive correlation was found between horizontal impulse and front foot plant angle, as shown in **Figure 1.5**. Notably, 50% of the variance in horizontal impulse was accounted for by the plant angle of the front foot during FFC. A lower average horizontal loading rate was significantly inversely correlated with higher bowling speeds ($r = -0.484, p = 0.031$), indicating that a gradual application of horizontal force (rather than an abrupt force) may be more effective in generating ball velocity. This finding was further supported by a moderate inverse correlation between average horizontal loading and foot angle at FFC ($r = -0.689, p = 0.001$), suggesting that bowlers landing with a dorsiflexed ankle at heel strike experience a lower horizontal loading rate. Collectively, these findings indicate that a heel-strike landing with an extended stride length facilitates a more effective conversion of linear momentum into angular momentum during FFC, ultimately contributing to increased bowling speed. King *et al.* (2015) summarised that the faster bowler's run-up, the more linear momentum is generated, which corresponds to greater angular momentum about the front foot. At FFC, the body decelerates and pivots over the front leg, converting linear momentum into angular momentum, which then drives the rotation of the trunk and arm. This kinetic sequence ultimately determines the linear velocity of the hand at the time of ball release. King *et al.* (2015) recommended that future research should employ simulation modelling to further explore the mechanical relationships within the FFC phase and their implications for increasing bowling speed.

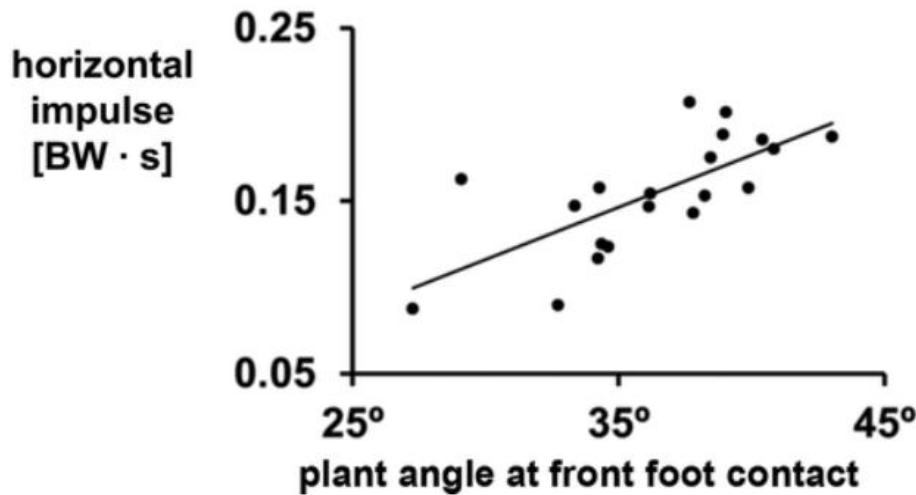


Figure 1.5. The relationship between horizontal impulse and front foot plant angle.
(King *et al.* 2015)

Felton *et al.* (2020) acknowledged that the key technical parameters within the FFC phase, previously identified by Worthington *et al.* (2013) and King *et al.* (2015), may play a fundamental role in maximising bowling speed. Felton *et al.* (2020) developed a three-dimensional torque-driven simulation model designed to optimise the mechanics of the FFC phase in pace bowling. The model can be summarised as 14 rigid segments representing the upper body and head, two arms, two upper legs, two lower legs, two two-segment feet, and two forearms and hands, that are driven by torque generators with a series of contractile and elastic components that move the rigid segments. This theoretical approach enabled a detailed analysis of the cause-and-effect relationship between specific kinematic and kinetic parameters and their impact on bowling speed. The model was informed by data collected from a professional male pace bowler who delivered 12 maximum-effort deliveries. Fifty 14mm retroreflective markers were placed in positions on the bowler's body for the calculation of the joint centres (Felton *et al.* 2020). A further 15 x 15mm retroreflective markers were placed on the ball to measure ball release speed. The data was collected using Eighteen MX13 Vicon cameras (Oxford Metrics Group Public Limited Company, Oxford, UK), sampling at 300Hz, which were used for motion capture (Felton *et al.* 2020). Furthermore, kinetic data at front foot contact were gathered from a Kistler force platform (Type 9287B, Kistler Group, Switzerland), sampling at 1800Hz (Felton *et al.* 2020). The variables

assessed included the centre of mass position, trunk orientation angle, angular velocity, as well as the angle and velocity of each joint at FFC. The results showed that the model could reliably simulate FFC kinematics, with a kinematic difference score of just 0.9% and a minimal deviation of 0.03% in bowling speed between the simulated and observed techniques. When optimised, the model predicted an increase in bowling speed of 9.8% (equivalent to $12.6\text{km}\cdot\text{h}^{-1}$). The primary difference between the optimised stimulation and the original technique was the adoption of more extended ankle and knee joint angles, which agrees with the earlier findings of Worthington *et al.* (2013). These findings validated the model's reliability and laid the groundwork for subsequent simulation-based investigations.

While Felton *et al.* (2020) focused on creating and validating a model using data from a single professional pace bowler, the authors expanded on this work by utilising the same three-dimensional torque-driven simulation model with the aim of identifying consistent biomechanical patterns associated with optimal FFC technique across multiple pace bowlers (Felton *et al.* 2023). This study employed a group-based sample approach; specifically, ten male professional pace bowlers were assessed using the model and followed the same protocol, delivering 12 balls at maximum effort. The results demonstrated that the model successfully simulated the technique of all 10 participants, with a mean kinematic difference of just 1.9%. Optimisation of each bowler's technique resulted in a significantly increased mean bowling speed of $17.28\text{km}\cdot\text{h}^{-1}$ ($p < 0.001$). Among the kinetic parameters, the most consistent change across participants was a significant reduction in the mean horizontal braking rate during front foot contact ($p = 0.008$). Although the study did not report exact values for all kinematic parameters, it noted that four joints, one of which was the ankle, showed significant differences between the original and optimised joint angles as seen in **Figure 1.6**. These findings provide further evidence that optimising the FFC phase can significantly enhance bowling speed, which agrees with the results of previous studies (Worthington *et al.* 2013; King *et al.* 2015; Felton *et al.* 2020). Specifically, the results reinforce that an extended front leg, combined with a heel-strike technique, effectively decelerates the lower body and efficiently converts linear momentum (from the run-up) into angular momentum. This underscores the critical biomechanical role of the FFC phase in maximising pace bowling performance.

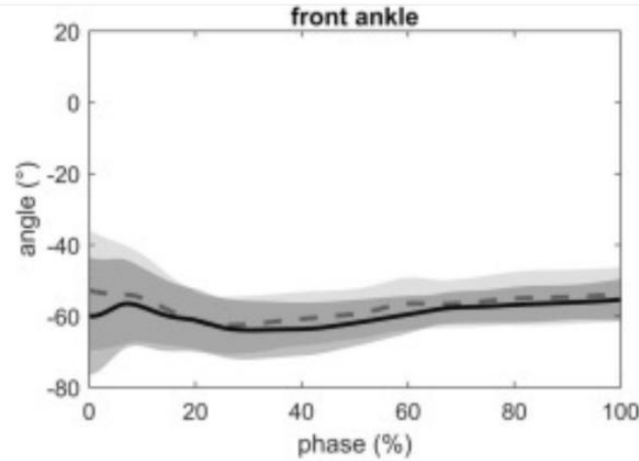


Figure 1.6. The mean and standard deviation of the kinematic variables for the current technique (grey dashed line) and optimised technique (black solid line). (Felton *et al.* 2023)

Callaghan *et al.* (2021) reached a similar conclusion that greater deceleration at FFC allows for a larger amount of kinetic energy to be transferred through the body, resulting in a higher bowling speed. Their study aimed to investigate the relationship between ground reaction forces (braking peaks and impulses), lower-limb strength and power, and bowling speed in pace bowlers. However, these variables were examined independently of pace bowling technique and kinematics. The study involved 13 male pace bowlers, playing either first or second grade cricket in an Australian state premier competition, each delivering 12 maximum-effort balls with a four-minute rest between overs. GRF data was collected using a three-dimensional force plate (9287CA, Kistler Group, Winterthur, Switzerland). Bowling speed was assessed using the Stalker Pro II speed radar gun (Stalker Radar, Oregon, United States of America) that was positioned behind the batter's stumps, facing the bowler. Strength and power were assessed using countermovement jump and isometric mid-thigh pull tests. The countermovement jump was measured by the participants standing on the previously mentioned force plate and instructed to jump as high as possible (Callaghan *et al.* 2021). While the isometric mid-thigh pull test was performed by the participants standing on the same force plate with a customised power rack, which allowed the bar to be attached to the participant (Callaghan *et al.* 2021). Each participant was instructed to grip the bar in a similar position to a power clean and lift the bar as hard as possible. Callaghan *et al.* (2021)

investigated the relationship between GRFs, lower limb strength and bowling speed. A Bayesian linear regression analysis revealed a correlation between greater peak GRF during FFC and bowling speed, with no association with lower limb strength. However, the strength of the evidence was weak compared to the Null model (Bayes Factor = 1.713), indicating that for each one-unit change in peak braking force, there was a $-2.52\text{km}\cdot\text{h}^{-1}$ change in BRS (Callaghan *et al.* 2021). The limited evidence supporting associations between bowling speed and lower-limb strength and power measurements may be due to the use of inappropriate testing protocols. The authors stated that countermovement jump and isometric mid-thigh pull may not accurately reflect the dynamic movements required during pace bowling. This could be due to inter-participant variation in pace bowling technique among the participants, which limits the ability to find global characteristics associated with bowling speed, and therefore, a larger sample size is recommended to ascertain the factors associated with increased bowling speed (Callaghan *et al.* 2021). Additionally, a key limitation of the study was the absence of kinematic data, which restricted the ability to account for factors such as body positioning and joint angles. These findings suggest that a single factor does not determine bowling speed, but rather the result of a complex interaction between anthropometric characteristics, physical capacity, and technique.

Bowling Arm and Ball Release

The final phase of the bowling technique involves the biomechanics of the upper limb, particularly the bowling arm. This phase requires shoulder joint circumduction, maintaining full elbow extension, and achieving an optimal wrist position for releasing the ball. A well-timed release is essential to ensure both accuracy and maximal ball speed (Purohit and Vijayvargia 2012).

In conclusion, while the upper limb executes the final release of the ball, research exists that highlights that the generation of bowling speed is heavily dependent on the earlier phases, particularly the run-up and FFC. These phases highlighted the crucial role of the lower limb and ankle kinematics in generating and transferring kinetic energy to the bowling arm, ultimately enhancing the ball's release speed.

1.2.6.2 Physical and Anatomical Factors

Anthropometric characteristics of pace bowlers can affect the bowling speeds they are able to produce. A study by Glazier, Paradis and Cooper (2000) conducted on nine cricket pace bowlers from the University of Wales Institute, Cardiff found that shoulder-to-wrist length ($r = 0.626, p < 0.05$) and total arm length ($r = 0.583, p < 0.05$) were significantly and positively correlated with bowling speed. The authors stated that the statistical power for these r -values was 62.1% and 49% respectively, which was reported as a relatively large effect. The participants' bowling speed was measured with a Speedchek™ Personal Sports Radar Gun (Tribar Industries, Canada) and was placed in line with the stumps facing the bowler. These findings suggest that bowlers with longer torsos and arm lengths are likely to bowl faster; however, this was disputed by Johnstone *et al.* (2014).

Johnstone *et al.* (2014) conducted a systematic review aimed at exploring the physiological factors associated with bowling speed and providing a foundation for future research into strength and conditioning. While acknowledging the results by Glazier *et al.* (2000), the authors argued that while a longer arm will produce a greater velocity of the wrist during ball release, they also stated that a longer arm will create a greater moment of inertia, which will slow the circumduction of the arm. Consequently, other anatomical variables may play a more critical role in generating bowling speed. Johnstone *et al.* (2014) reported that bowlers with greater anterior-posterior chest depth and larger arm girth produced higher bowling speeds, stating that increased muscularity of the upper body could account for between 36% to 45% of the variance in bowling speed. This finding is anatomically plausible, as the circumduction of the arm during ball release is powered by the musculature in these regions.

Building on the finding that muscular strength may positively influence bowling speed, Feros, Young and O'Brien (2019) and Feros *et al.* (2020) investigated the effects of resistance training on club-level pace bowlers and reported a significant moderate positive correlation ($r^2 = 0.56, p = 0.005$) between pull-up strength and bowling speed. The researchers suggested that the same muscles involved in pull-ups are also engaged in bowling arm circumduction and that increased strength in these muscle groups may enhance torque production at the glenohumeral joint. This agrees with the early study by Glazier *et al.* (2000), who found a non-significant but positive relationship between bowling arm angular velocity and ball speed ($r = 0.358, p = 0.172$). Feros *et*

al. (2020) concluded that strength and conditioning programmes with a focus on upper-body pulling strength may positively influence bowling speed.

A meta-analysis by Ramachandran *et al.* (2021) found that upper-body strength training can improve bowling speed. The tests to determine upper body strength included pull-ups, bench press and deltoid throws, shoulder adduction, abduction, internal and external rotation (Ramachandran *et al.* 2021). Three studies in the meta-analysis revealed a moderate but statistically significant effect of shoulder strength on bowling speed ($r = 0.58, p < 0.001$). The significant finding supports the hypothesis that upper-body strength training can influence bowling speed.

Felton *et al.* (2025) explored the effect of muscular strength on bowling speed using a 16-segment planar torque-driven computer simulation model. This same model had previously been employed to evaluate the FFC phase of pace bowling (Felton *et al.* 2020; Felton *et al.* 2023). In this study, data from ten elite male pace bowlers, part of the England and Wales Cricket Board, were used in the simulated model to assess the impact of optimising strength parameters on bowling speed. The findings revealed that a 5.0% increase in lower-body strength resulted in a 1.5% increase in bowling speed. In contrast, a combined 5.0% increase in both lower body and shoulder strength produced only a 2.0% increase. Felton *et al.* (2025) noted that this increase was relatively modest compared to the 13.5% gain achieved when the same model optimised the bowler's biomechanical technique. These results suggest that although physical strength is a contributing factor, biomechanical efficiency may play an even more critical role in enhancing bowling speed. Given the pivotal role the lower limb, specifically the ankle, plays in the biomechanical process of pace bowling, it is essential to understand the anatomical structure, functional mechanics and range of motion of the ankle joint.

1.2.6 Overview of the Anatomy, Function, and Range of Motion of the Ankle

1.2.7.1 Anatomy

The ankle, also known as the TCJ, is a hinged synovial joint at the junction of the lower leg and foot (Brockett and Chapman 2016). It is formed by the articulation of the ankle's osseous components: tibia, fibula, and talus (Manganaro and Alsayouri 2023). The lateral malleolus (the terminal prominence of the fibula) forms the lateral border of the joint. The superior articular

surface and medial malleolus (the terminal prominence of the tibia) form the superior and medial borders, respectively. The talus forms the inferior border of the joint. Collectively, these borders form the talocrural joint, also known as the ankle mortise (**Figure 1.7**).

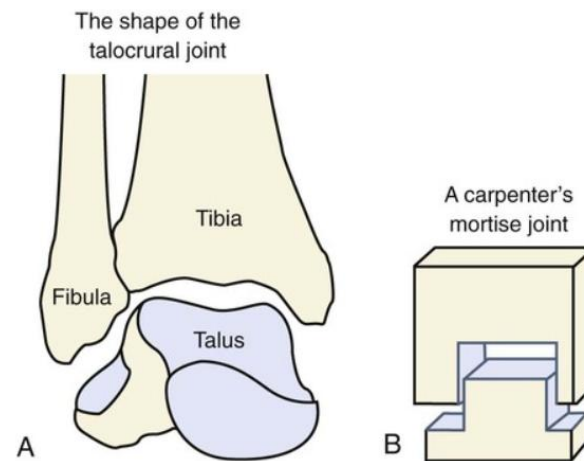


Figure 1.7. The talocrural joint.
(MusculoskeletalKey n.d.)

Immediately beneath the TCJ lies the subtalar joint, forming the second joint in the hindfoot. The subtalar joint is formed by the articulation between the talus (superior border) and the calcaneus (inferior border) (Fernández *et al.* 2020). The ankle is stabilised by strong ligaments that prevent excessive inversion and eversion. The deltoid ligament stabilises the medial ankle, while the lateral ankle is stabilised by three different ligaments: the anterior talofibular ligament, posterior talofibular ligament, and calcaneofibular ligament (Manganaro and Alsayouri 2023).

The movement of the ankle is controlled by the muscles of the lower leg, which are divided into three distinct compartments (Jones 2019). The posterior compartment contains the powerful soleus, gastrocnemius, posterior tibialis, and plantaris muscles, facilitating plantarflexion and ankle inversion. The anterior compartment contains the anterior tibialis, extensor hallucis longus, and extensor digitorum longus muscles, which are responsible for dorsiflexion. Eversion of the ankle is controlled by the peroneus longus and peroneus brevis, which are found in the lateral compartment (Jones 2019).

1.2.7.2 Function

The ankle is vital to the body's kinematic chain and biomechanical function, including:

- Transmitting ground reaction forces.
- Supporting the body's weight.
- Absorption of ground reaction forces.
- Proprioception and balance.

It exhibits antithetical properties, being both rigid and flexible. The rigid structure of the ankle allows for weight-bearing and protection, while its flexible structure enables it to adapt to various terrains during movement (Brockett and Chapman 2016).

1.2.7.3 Range of Motion

Ankle motion can be divided into four categories: plantarflexion, dorsiflexion, inversion and eversion (Brockett and Chapman 2016). This study focuses on sagittal plane motion, specifically plantarflexion and dorsiflexion, as these are the primary movements occurring at the TCJ, with 91.8% of dorsiflexion occurring at the TCJ (Smith *et al.* 2019). According to Brockett and Chapman (2016), the normal sagittal range of motion in the ankle is between 65° and 75°, consisting of approximately 10° to 20° of dorsiflexion and 40° to 55° of plantarflexion.

Dorsiflexion can be described as the motion where the ankle brings the foot up, in a cephalic direction, whereas plantarflexion brings the foot down, in a cephalad direction (Norkin and White 2016). As shown in **Figure 1.8**, the direction of dorsiflexion motion will result in a decrease in the angle between the foot and the lower limb. In contrast, when the foot moves in the plantarflexion direction, the angle between the lower leg and the foot will increase (Norkin and White 2016).

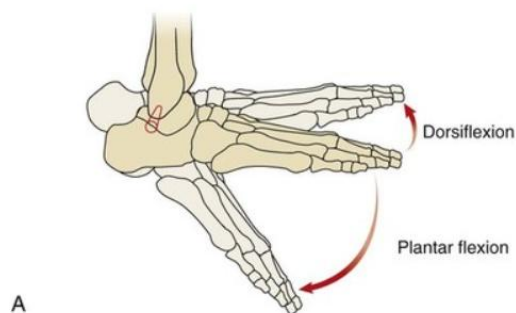


Figure 1.8. The different ankle motions.
(MusculoskeletalKey n.d.)

These values were supported by Ugbolue *et al.* (2021), who examined potential differences in dorsiflexion and plantarflexion between left and right ankles in healthy male and female participants. The study included 22 individuals (12 males and 10 females) with mean ages of 23.64 and 22.18 years, respectively. Using a Vicon Bonita Motion Analysis System (Vicon United Kingdom, Oxford, UK) with reflective markers placed on the lateral malleolus, calcaneus, and second metatarsal, the authors reported mean dorsiflexion and plantarflexion in the right ankle of 21.99° and -42.57°, respectively, for males. The left ankle showed similar values, namely, 20.07° dorsiflexion and -46.24° plantarflexion. The authors hypothesised that females would have greater standing ankle ROM than males, and their findings supported this hypothesis. Female participants demonstrated greater sagittal ankle ROM in both dorsiflexion and plantarflexion compared to males (Ugbolue *et al.* 2021). Specifically, the mean dorsiflexion and plantarflexion in the right ankle for females were 23.03° and -57.47°, respectively, while the left ankle showed 20.61° dorsiflexion and -57.42° plantarflexion. These differences could be attributed to physiological factors such as increased ankle joint ligament laxity, which tends to vary between sexes and has been shown to influence joint ROM (Wilkerson and Mason 2000).

Given these sex-based differences in ankle mobility, the current study employed a homogenous male sample to control for potential confounding variables and ensure consistency in ankle ROM. This approach enabled a more accurate assessment of the effects of TLAM on ankle motion and bowling speed, eliminating the variability introduced by sex-based differences in ankle joint biomechanics. Although Ugbolue *et al.* (2021) used computer-based gait analysis to capture ankle

movement, an earlier study by Wang, Hussaini and Scott (2019) compared the reliability of smartphone goniometers with that of traditional universal goniometers. In their study, 24 patients (mean age: 52 years) who presented to the senior authors' foot and ankle clinics with ankle pathology participated. Three smartphone applications, DrG (image-based), Gonio, and Clino (both accelerometer-based), were tested using a single iPhone SE (Apple, Cupertino, California), and their measurements were compared against a plastic Bluejay universal goniometer (Los Angeles, California). The results revealed that Lin's concordance correlation coefficient test showed moderate correlation, with DrG showing the strongest correlation ($r_{LC} = 0.935$, 95% CI = 0.915-0.950 for UG-DrG) with the universal goniometer. Moreover, a two-way mixed model demonstrated excellent interrater reliability for all smartphone applications compared to the universal goniometer, with intraclass correlation coefficients ranging from 0.777 to 0.912 (all $p < 0.001$). Despite these positive results, the authors concluded that the universal manual goniometer, which is the instrument utilised in this study, remains the clinical standard and the most used tool for measuring ankle dorsiflexion and plantarflexion (Wang, Hussaini and Scott 2019).

While TCJ governs sagittal ankle motion, ankle inversion and eversion are thought to mainly occur at the subtalar joint (Brockett and Chapman 2016). However, the ankle joint's primary functions are dorsiflexion and plantarflexion, allowing the foot to move up and down. These motions are crucial in activities like running and jumping (Panoutsakopoulos *et al.* 2021), and with 91% of dorsiflexion occurring at the TCJ (Smith *et al.* 2019), it becomes a key joint in pace bowling.

Several factors can influence ankle ROM, namely restrictions in non-contractile structures such as the joint capsule or ligaments, arthrokinematic restriction, osteokinematic restrictions of the joint, previous injuries, scar tissue, and overall physical activity levels (Dill *et al.* 2014). These restrictions have been associated with altered lower limb mechanics during dynamic activities, which may affect performance. To control for these factors, the current study, therefore, included only asymptomatic participants with no history of recent ankle injuries or known ankle joint pathology. Each participant underwent a detailed medical history and screening process. This inclusion criterion ensured that all observed changes in ankle ROM and bowling speed could be attributed to the intervention itself rather than pre-existing ankle dysfunction, thereby strengthening the validity of the study's findings.

Understanding the biomechanics and functioning of the ankle during in pace bowling will shed light on its role in generating bowling speed and potentially help identify ways to enhance pace bowling performance.

1.2.7 The Importance of the Ankle Joint in Cricket Pace Bowling

To unlock the full potential of a pace bowler, the research by Callaghan *et al.* (2021) emphasised that no single isolated kinetic variable is solely responsible for determining bowling speed. Instead, maximising pace requires coordinated movement of multiple kinematic segments across all phases of the bowling action. Two phases were identified as particularly influential in generating bowling speed: the run-up and FFC phases. Within these phases, the ankle, specifically the TCJ, plays a pivotal role in optimising biomechanical efficiency and facilitating effective energy transfer through the kinetic chain.

To evaluate the ankle's role in the run phase of pace bowling, Petersen *et al.* (2014) investigated the effects of running speed on joint kinetics, specifically examining ankle and knee joint moments. Using a three-dimensional motion capture system (Qualisys, Gothenburg, Sweden) with eight Pro-Reflex MCU infrared high-speed cameras and 36 retro-reflective markers, they collected kinematic data from 33 participants who ran at speeds of $8\text{km}\cdot\text{h}^{-1}$, $12\text{km}\cdot\text{h}^{-1}$, and $16\text{km}\cdot\text{h}^{-1}$. The results demonstrated that as running speed increased from $7.96\text{km}\cdot\text{h}^{-1}$ to $15.91\text{km}\cdot\text{h}^{-1}$, the mean peak plantarflexion moment at the ankle increased by $0.74\text{N}\cdot\text{m}\cdot\text{kg}^{-1}$. In percentage terms, peak plantarflexion moment increased by 33.18%, while peak knee extension moment increased by 24.19%. These findings suggest that the ankle contributes a substantial proportion of the force generation required for higher-speed running. By extension, this highlights the ankle's critical role in pace bowling, particularly during the run-up phase, where increased running speed has been shown to correlate positively with bowling speed ($r = 0.616$, $p = 0.004$) as reported by Kiely *et al.* (2021).

The ankle's most significant influence on bowling speed, however, occurs during the FFC phase. Worthington *et al.* (2013) and Felton *et al.* (2020) found that FFC biomechanics play a crucial role in enhancing bowling speed. These authors found that the most optimal FFC position is an extended front leg (large stride forward), with a heel-strike technique, resulting in a 9.8% increase

in bowling speed. Achieving a biomechanically optimal position requires the ankle to dorsiflex at initial contact, which facilitates a larger stride forward, as illustrated in **Figure 1.9**. During King *et al.* (2015) investigation, it was revealed that the kinetic variable with the greatest impact on bowling speed was horizontal impulse. This variable single-handedly accounted for 33% of the variance in bowling speed. Furthermore, horizontal impulse was strongly correlated with the plant angle at FFC, with 50% of the variation in impulse being explained by the position of the plant angle, specifically when the foot was in a dorsiflexed heel-strike position (King *et al.* 2015). Importantly, the ankle serves as a crucial link in the pace bowling action. During FFC, this dorsiflexed landing position enables the ankle to act as the primary pivot point for converting linear momentum from the run-up into angular momentum through the lower body to the upper body (King *et al.* 2015). However, to achieve this vital conversion of angular momentum, the ankle must transition from full dorsiflexion to full plantarflexion as the upper body rotates over the ankle (King *et al.* 2015). This rotation effectively acts as a lever to push the body over the front leg, creating more angular momentum and transmitting energy upwards through spinal rotation and trunk flexion, ultimately contributing to the rapid circumduction of the bowling arm (King *et al.* 2015). This produces a faster linear velocity of the hand at ball release. Together, these findings suggest that efficient sagittal plane movement of the ankle is biomechanically essential for generating high bowling speeds. King *et al.* (2015) further explained the correlation between the plant angle of the front foot and ball release speed by explaining the mechanics of the FFC phase of pace bowling. When the pace bowler adopts a larger plant angle, the dorsiflexed position of the ankle allows for a larger stride forward at front foot contact. This finding suggests that this position enables a pace bowler to convert more momentum generated during the run-up into ball speed. This mechanism is further supported by the observed link between the plant angle and horizontal impulse; bowlers with a larger plant angle were able to generate a larger horizontal impulse (King *et al.* 2015). The authors found a significant inverse correlation between horizontal ($r = -0.484$, $p = 0.031$) and vertical loading rates ($r = -0.452$, $p = 0.046$) and ball release speed, which indicates that a rapid transfer of energy is not essential for bowling faster. This implies that a larger horizontal impulse is beneficial for increasing bowling speed. A larger horizontal impulse is produced through a longer contact time over which the ground reaction forces act to produce the impulse. Furthermore, both horizontal and vertical loading rates were significantly correlated with initial foot angle, suggesting that a heel strike technique reduces peak loading rates.

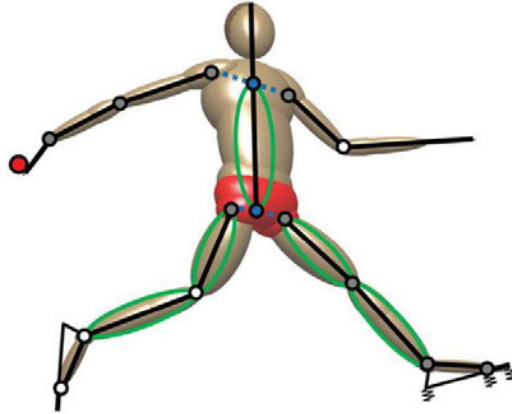


Figure 1.9. Biomechanical model showing ankle and knee extension during optimal front foot contact phase.

(Felton *et al.* 2020)

In summary, a restricted motion at the TCJ can interrupt this kinetic sequence. Limited dorsiflexion may prevent proper heel-strike landing and full stride length, forcing compensations at the knee or hip and reducing the effectiveness of ground reaction force transmission (Worthington *et al.* 2013). Similarly, impaired plantarflexion may restrict the pace bowler's ability to pivot over the front leg, limiting trunk rotation and reducing the velocity transferred to the bowling arm and wrist. Therefore, efficient dorsiflexion and plantarflexion are biomechanically essential to maximise force transmission through the kinetic chain, culminating in higher ball release speeds and overall bowling performance. The following section investigates the impact of ankle biomechanics on sports outside of cricket, highlighting the crucial role of the ankle joint within the kinetic chain.

1.2.8 The Importance of Ankle Mobility Beyond Cricket

A systematic review by Almansoof, Nuhmani and Muaidi (2023) on the role of ankle dorsiflexion in sports performance reported that ankle dorsiflexion ROM plays a pivotal role across a broad spectrum of athletic activities, influencing performance outcomes. Beyond cricket, dorsiflexion governs the ability to absorb ground reaction forces during landing and facilitates efficient force transmission through the lower-limb kinetic chain. The authors reported that greater ankle

dorsiflexion is associated with improved quadriceps and core musculature activation and enhanced power generation in asymptomatic participants. These findings illustrate the influence of ankle mobility on muscle activation and kinetic transfer higher up the chain. Moreover, the review identified ankle dorsiflexion as a key performance metric in sports such as running, soccer, judo, surfing, ice-skating, basketball, powerlifting, and volleyball. Notably, increased ankle dorsiflexion ROM improved the effectiveness of arm swing during vertical jumping in volleyball athletes, a movement pattern biomechanically similar to the arm swing phase in pace bowling. This demonstrates that ankle dorsiflexion can act as a mechanical link between lower-limb kinetics and upper-limb power generation, reinforcing the concept that the entire kinetic chain is vital in dynamic sports performance. The review emphasises that adequate ankle dorsiflexion is essential for optimal energy transfer and overall performance in many sports. Interestingly, cricket was not mentioned in this systematic review, providing a research gap that the current study aims to address. By applying these biomechanical insights to cricket, it becomes plausible that enhancing ankle mobility may positively influence the kinetic transfer during FFC, thereby contributing to greater bowling velocity. Given the ankle's critical role in facilitating sagittal plane motion across multiple sporting disciplines, interventions that enhance dorsiflexion ROM may also hold potential for improving cricket pace bowling performance. One such intervention is TLAM, a manual therapy technique proposed to improve ankle joint mobility (Beazell *et al.* 2012). The following section examines the mechanism, application, and existing evidence for TLAM, as well as its potential impact on the biomechanics of pace bowling.

1.2.9 Introduction to Joint Manipulation

Joint manipulation is a manual therapy technique commonly used by chiropractors, physiotherapists, osteopaths, and other healthcare professionals to restore motion to a restricted or hypomobile joint (LaPelusa and Bordoni 2023). It is typically defined as a high-velocity, low-amplitude (HVLA) thrust applied to a synovial joint, often producing an audible “pop” or cavitation sound, which is believed to be related to gas bubble formation within the joint capsule (LaPelusa and Bordoni 2023). The manipulation is performed along the joint plane to increase

joint ROM, reduce pain, enhance functional performance, and modulate the neuromuscular system (LaPelusa and Bordonni 2023).

Joint restriction refers to a limitation in the normal physiological movement of a joint (Dill *et al.* 2014). It can be due to factors such as joint capsule tightness, muscular guarding, scar tissue, or intra-articular adhesions (Dill *et al.* 2014). Clinicians determine the presence of joint restrictions through a combination of physical examination, including passive joint play assessment, end-feel testing, range of motion comparisons, and palpation for tenderness or stiffness (Nyberg and Smith 2013; Manske and Rohrberg 2015). During passive joint play assessment, clinicians use their hands to assess the end-feel within the joint, relying on tactile feedback from mechanoreceptors in the fingertips (Nyberg and Smith 2013). These include Meissner corpuscles, Pacinian corpuscles, Merkel discs, and Ruffini endings, which help identify abnormal joint motion (Nyberg and Smith 2013). A normal end-feel is characterised by a firm, abrupt, non-yielding stop at the end of ROM, while an abnormal end-feel may feel rubbery or mushy, and prematurely stop, suggesting a joint restriction (Manske and Rohrberg 2015).

Joint manipulation can be applied to both the spine and the extremities. In spinal manipulation, commonly known as spinal manipulative therapy (SMT), clinicians target specific vertebral segments, such as the lumbar spine, to relieve pain and improve mobility. Although physiotherapists or osteopathic clinicians can legally perform SMT, chiropractors perform 94% of SMT in the United States of America (Yuandong 2024). Lumbar spine SMT is often used for patients presenting with mechanical low back pain and has shown immediate and long-term benefits in terms of pain relief and improved movement (Montoro *et al.* 2024). In a randomised placebo-controlled double-blind mixed experimental trial by Montoro *et al.* (2024), 48 participants received lumbar SMT three times per week over four weeks. Participants who received SMT reported greater pain relief when compared to a control intervention, with a reported 65% reduction in perceived pain. This medium effect ($\eta^2_p = 0.07$) lasted for 12 weeks after SMT.

In the extremities, manipulation may be used on joints such as the shoulder, wrist, hip, knee, or ankle, and is a standard treatment method for chiropractors (Wong 2013). A systematic review of manipulative therapy by Brantingham *et al.* (2009) reported that extremity manipulation is the second most frequently applied therapy within the chiropractic profession, with 76.1% of

chiropractors using both spinal and extremity procedures. Pellow and Brantingham (2001) examined the effectiveness of ankle manipulation for managing subacute and chronic grade one and two inversion sprains, highlighting the importance of incorporating extremity manipulation therapy in chiropractic care. The study involved 30 participants, who were randomly assigned to either an intervention group or a control group. Fifteen participants in the intervention group received TLAM, while the control group received a five-minute sham laser placebo treatment. The TLAM technique is the same intervention used in the current study. Each participant lay supine on the table while the clinician positioned their hands to stabilise the foot: the thumbs were placed on the plantar surface (sole) of the foot, and the fingers wrapped around the dorsal surface. The clinician then dorsiflexed and applied long-axis traction to the foot. A single HVLA thrust was then applied in a caudal direction, parallel to the floor, to complete the manipulation. Participants were treated over a period of four weeks, with a maximum of eight sessions. Ankle dorsiflexion ROM and pain levels (measured using the Short Form McGill Pain Questionnaire) were assessed at the first and final treatment sessions, as well as one month after the final session. The results showed a significant reduction in pain in the TLAM group at both the final treatment session ($p = 0.004$) and the one-month follow-up ($p < 0.001$). Additionally, ankle dorsiflexion significantly ($p < 0.001$) improved in the TLAM group ($+7.46^\circ$) compared to the control group ($+0.67^\circ$) at the one-month follow-up. The authors explained that ankle sprains often lead to reduced dorsiflexion due to impaired talar motion within the mortise, which compromises bony stability during locomotion (Pellow and Brantingham 2001). Furthermore, TLAM may restore this motion by inducing joint distraction, breaking intra-articular adhesions, and promoting normal healing processes, thereby improving dorsiflexion, reducing pain, and lowering the risk of recurrent injury (Pellow and Brantingham 2001).

These findings underscore the value of chiropractic management for extremity conditions and provide support for TLAM's clinical effectiveness.

1.2.9.1 Talocrural Long-axis Manipulation

Manipulation of the ankle joint, particularly the talocrural joint, is a commonly used intervention to improve sagittal plane motion, especially dorsiflexion (Beazell *et al.* 2012). The TCJ primarily allows dorsiflexion and plantarflexion movements, due to its anatomical structure (Smith *et al.*

2019). TLAM is a specific HVLA thrust technique that targets the talocrural joint and aims at restoring sagittal motion in the ankle joint (Beazell *et al.* 2012; Ritter 2019).

The manipulation is performed with the clinician's hands positioned around the ankle, with both fifth digits in contact with the dorsal aspect of the talus and the thumbs resting on the plantar surface of the foot. Axial traction is applied along the long axis of the leg. At the same time, the ankle is slightly dorsiflexed, and a single HVLA thrust in the caudal direction is performed to complete the manipulation (Sillevis, Regalado and Shamus 2022).

Cosby and Grindstaff (2012) explained that restricted posterior talar movement may negatively affect dorsiflexion. Specifically, this is based on the arthrokinematic principle that during dorsiflexion, the talus must glide posteriorly within the ankle TCJ (Vinenzino *et al.* 2006). Cosby and Grindstaff (2012) further suggested that manipulation may improve dorsiflexion ROM by restoring the posterior glide of the talus. In addition to restoring joint ROM through mechanical means, joint manipulation has also been shown to produce neurophysiological effects that may contribute to short-term improvements in ROM. Pickar (2002) explains that HVLA manipulation stimulates mechanoreceptors in periarticular tissues, reducing muscle spindle sensitivity and reflex muscle inhibition, which can decrease protective guarding around the joint. This process may allow for a short-term improvement in ROM. Similarly, Bialosky *et al.* (2009) propose a model in which the effects of manipulation arise from interactions among mechanical changes (such as improved posterior glide of the talus), peripheral neurophysiological responses (mechanoreceptor stimulation), and central nervous system effects (altered pain perception). Together, these mechanisms may improve joint mobility, enhance arthrokinematic motion, and increase muscular stretch tolerance, thereby contributing to the immediate increases in ROM observed following TLAM in asymptomatic individuals. However, the duration of these neurophysiological and mechanical effects remains unclear, and the literature does not yet establish how long TLAM-induced improvements in ROM persist. Consequently, this study recommends that future research employ a crossover design to determine the time-dependent effect of TLAM. A limited number of studies have examined the immediate effects of TLAM. Of these, three investigated the immediate changes in dorsiflexion in asymptomatic participants, producing conflicting results, while one explored the impact of TLAM on the functional performance of injured participants.

Talocrural manipulation as an ergogenic aid

Previous research has highlighted the therapeutic use of TLAM to restore ankle motion and reduce pain in individuals with an injury (Pellow and Brantingham 2001) and functional performance with an existing pathology (Kamali, Sinaei and Bahadorian 2017). However, in the context of this study, TLAM is regarded as an ergogenic aid, a manual intervention designed to enhance normal joint mobility and improve biomechanical efficiency in healthy cricket pace bowlers. In this sense, TLAM may optimise the functional movement of the talocrural joint and facilitate improved kinetic chain performance without addressing pathology (Fryer *et al.* 2002; Davenport *et al.* 2013; Ritter 2019). The current study, therefore, investigates TLAM as an ergogenic tool designed to enhance ankle mobility and bowling speed in club-level pace bowlers, rather than as a therapeutic treatment for injury.

The effect of talocrural manipulation on asymptomatic participants

The study by Fryer, Mudge and McLaughlin (2002) involved 41 asymptomatic individuals (15 males and 26 females), who were randomly assigned to either an intervention or control group. Only healthy volunteers were permitted to participate in this study. Any participants with a history of significant lower limb injuries or surgeries, or recent ankle sprains (less than six months) were excluded. Therefore, the current study also employed similar inclusion and exclusion criteria. Dorsiflexion was measured before and immediately after a single HVLA manipulation. Instead of using a traditional goniometer, dorsiflexion was assessed by marking anatomical landmarks (head of the fibula, lateral malleolus, and head of the fifth metatarsal) with black ink and analysing digital images captured with a Canon camera (Canon Incorporated, Tokyo, Japan) using Swinger (Webbsoft Technologies, Melbourne, Australia) motion analysis software (version 1.26). All participants were placed in a supine position on a Biodex table (Biodex Medical Systems Incorporated, New York, United States of America), with their hips and knees flexed at 90°. The thigh and lower leg were secured with Velcro straps to ensure they remained at a 90° angle. A two-tailed paired sample *t*-test found a significant difference ($p = 0.036$) between pre- and post-intervention dorsiflexion with a small mean change of +1.4° in the experimental group. However, the control group also showed a significant increase of 1.7° ($p < 0.001$). Independent samples *t*-tests found no significant differences between the groups ($p > 0.87$), suggesting no clear impact of

TLAM on ankle dorsiflexion in this cohort. The method used to measure the degree of dorsiflexion in Fryer, Mudge and McLaughlin's (2002) study differed slightly from that employed in the current research, as angles were captured photographically rather than measured with a goniometer. As illustrated in **Figure 1.10**, the anatomical reference lines used were drawn between the head of the fifth metatarsal and the lateral malleolus, and from the lateral malleolus to the heel. Consequently, the angle facing the plantar surface of the foot was measured, as indicated by the arrow in **Figure 1.10**. This approach results in an improved dorsiflexion ROM corresponding to a positive mean change. In contrast, the current study measured dorsiflexion ROM using a goniometer aligned along the fibula and fifth metatarsal, capturing the opposite angle on the x-axis. Therefore, the increase in dorsiflexion ROM in the current study was reflected as a negative mean change, accounting for the apparent discrepancy in directional values between the two studies.

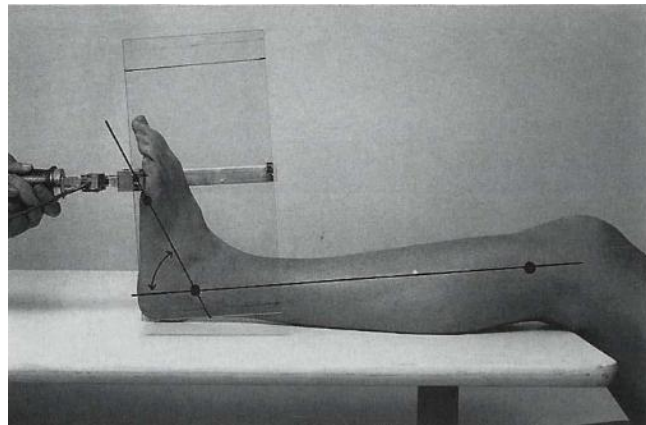


Figure 1.10. Anatomical lines used for ankle ROM measurement.

(Nield *et al.* 1993)

Davenport *et al.* (2013) examined the immediate effects of TLAM on ankle dorsiflexion and corticospinal excitability in six healthy individuals aged 30 to 51 years. The study excluded participants with a lower extremity pathology or a lower extremity injury within the past year, ensuring a cohort of healthy, asymptomatic individuals. All participants received a single TLAM intervention. Each participant was seated on a treatment table with the lower body stabilised using a belt. A licensed physical therapist performed the TLAM intervention by grasping the participant's foot, placing the thenar eminence on the plantar surface. The therapist delivered an

HVLA thrust parallel to the long axis of the lower leg. Dorsiflexion was assessed pre- and post-intervention by a blinded examiner with a 15.24cm goniometer. All participants lay prone on a table, and dorsiflexion was measured with the knee fully extended and flexed. With the knee in a fully extended position, dorsiflexion improved significantly following TLAM ($p < 0.001$), increasing from -6.5° to $+2^{\circ}$, indicating a clinically relevant improvement. And a significant increase ($p < 0.001$) from $+5.0^{\circ}$ to $+14.0^{\circ}$ was reported with the knee in a flexed position. The study did not specify the anatomical reference lines used for measuring ankle ROM, nor did it explain the basis for the recorded dorsiflexion values. A plausible explanation is that dorsiflexion was measured relative to the neutral position of the foot, which corresponds to a 90° angle between the tibia and the foot (Norkin and White 2016). In this method, angles measured below 90° are expressed as negative values, while those above 90° are expressed as positive values, depending on the direction of motion relative to the neutral position. This interpretation may provide context for the reported pre- and post-intervention values.

The use of a non-standardised method of assessing dorsiflexion, relying on photographic analysis using computer software in Fryer *et al.* (2002) study, rather than the traditional method of measuring joint ROM with a goniometer used by Davenport *et al.* (2013), could account for the divergent results. However, when compared to a study conducted at the University of Johannesburg, Ritter (2019) found similar results to those of Davenport *et al.* (2013). This study involved 100 asymptomatic participants allocated to four groups ($n = 25$ each): TLAM, tibiofibular manipulation, combined TLAM and tibiofibular manipulation, and a control group that received no intervention. Any participant who had undergone lower extremity surgery, experienced an injury within the last six months, or was unable to perform a weight-bearing lunge was excluded from the study. Dorsiflexion was measured immediately post-intervention using a standard universal goniometer. The participant was placed in a weight-bearing lunge position, keeping the foot flat on the ground while lunging forward as far as possible. The fulcrum of the goniometer was positioned over the lateral malleolus, with the stationary arm aligned along the fibular head and the moving arm aligned with the fifth metatarsal (Ritter 2019). The mean ankle dorsiflexion in Group A (TLAM group) increased from 33.54° pre-intervention to 35.73° post-intervention. In contrast, the control group showed minimal change, with a pre-intervention mean dorsiflexion of 32.22° and a post-intervention mean of 32.83° . The TLAM group demonstrated a significant

improvement, with a mean change of 2.19° ($p = 0.005$), whereas the control group did not ($p = 0.528$), further reinforcing the efficacy of TLAM in enhancing ankle mobility. Within Ritter's (2019) study, the same anatomical landmarks and angular reference lines were used to obtain the goniometric measurements as in the current study. However, several methodological differences exist. Firstly, dorsiflexion was measured in a weight-bearing lunge position, whereas participants in the current study were positioned supine on a treatment table. Secondly, a standard goniometer provides two potential readings: the absolute angle between the arms of the goniometer and the angular displacement measured "from the start," as illustrated in **Figure 1.11**. Ritter (2019) recorded the latter, representing displacement from the starting position. These readings correspond to those of Fryer, Mudge and McLaughlin (2002), where a positive mean change indicated an increase in dorsiflexion ROM. In contrast, the current study recorded the actual angle between the goniometer arms, resulting in a negative mean change when dorsiflexion ROM increased.

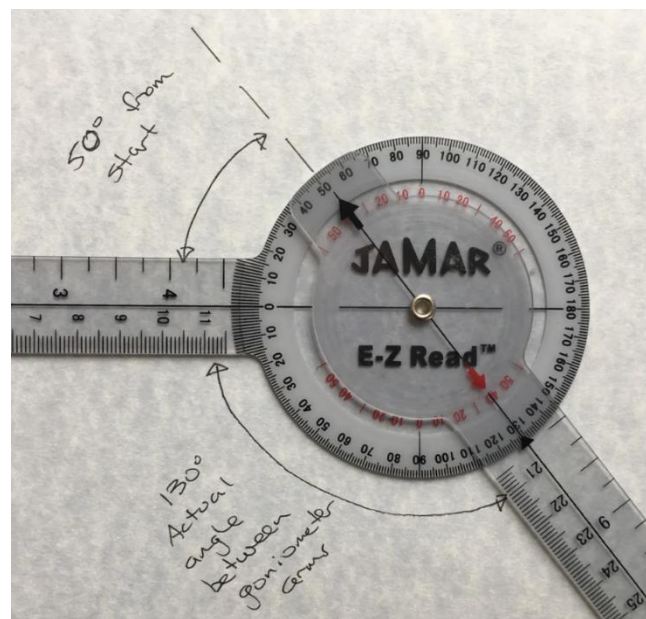


Figure 1.11. The two different readings on a standard goniometer.

(<https://www.instructables.com/Goniometer-for-Joint-Range-of-Motion-Measurement/>)

An early article by Bohannon, Tiberio and Zito (1997) highlighted several critical considerations regarding the measurement of ankle dorsiflexion, which are relevant to the methodologies used by

Fryer *et al.* (2002), Davenport *et al.* (2013), Ritter (2019) and the current study. One of these issues is the choice of landmarks and anatomical lines used to measure ankle ROM. One of the primary issues identified was the selection of anatomical landmarks and reference lines used to assess ankle ROM. The authors noted that while the landmarks between the fibula, lateral malleolus and the fifth metatarsal, as employed in the current study, accurately represent dorsiflexion motion, careful interpretation of the resulting values is required. Furthermore, Bohannon *et al.* (1997) stated that when dorsiflexion ROM is measured photographically, a different angular relationship is obtained due to the use of alternative landmarks, specifically between the lateral malleolus and the heel. Secondly, the authors reported that dorsiflexion end ROM tends to be greater when assessed in a weight-bearing position compared with a non-weight-bearing (supine) position. Therefore, it is essential to clarify the method and interpretation of the results obtained when measuring dorsiflexion ROM (Bohannon, Tiberio and Zito 1997).

The effect of talocrural manipulation as a therapeutic modality

Although the above studies focused on the immediate effects of TLAM on dorsiflexion ROM on asymptomatic participants, a key outcome of the current study, this research also aims to investigate the impact of TLAM on a functional performance outcome: bowling speed. A double-blind, randomised clinical trial by Kamali, Sinaei and Bahadorian (2017) explored the effects of TLAM on the functional performance of athletes with chronic ankle instability. Although Kamali, Sinaei and Bahadorian (2017) investigated functional outcomes in this study, it is important to note that the participants had an underlying pathology, and TLAM was therefore used as a treatment modality to enhance functional performance. The trial included 40 athletes (18 males and 22 females), aged between 15 and 40 years, all of whom had experienced at least one prior ankle sprain. Participants were randomly assigned to either a TLAM intervention group ($n = 20$) or a sham treatment control group ($n = 20$). In the intervention group, participants sat with their hips and knees flexed and a wedge under the foot for support. A blinded physical therapist applied a HVLA thrust to the talus in a posterior direction using hand-over-hand contact (Kamali *et al.* 2017). In the control group, the same positioning and hand placement were used, but no thrust was applied, simulating the intervention for one minute as a sham manipulation. Importantly, all participants were able to complete a 24m running test without experiencing pain. Functional performance was assessed using a single-leg hop test, a 24m sprint test, and the Y-balance test.

There were significant improvements ($p < 0.001$) in all functional tests for the TLAM group. In contrast, the control group showed no significant improvements in any tests ($p > 0.05$), except for a marginal improvement in the Y-balance test ($p = 0.03$). Between-group comparisons using ANOVA confirmed statistically significant differences across all functional performance outcomes ($p < 0.05$), with the sprint test being particularly relevant, as run-up speed has previously been identified as a critical factor influencing bowling performance in pace bowlers.

1.2.9.2 The Hypothesised Effect of TLAM on Bowling Speed

Based on the reviewed literature, TLAM may positively influence bowling speed in cricket pace bowlers through its effect on ankle sagittal ROM, specifically dorsiflexion. The biomechanics of pace bowling, particularly the FFC phase, requires the ankle to transition from dorsiflexion at initial heel strike to plantarflexion during the delivery stride (Worthington *et al.* 2013; King *et al.* 2015; Felton *et al.* 2020; Felton *et al.* 2023). A restricted range of motion at the TCJ may impair this dorsiflexion-to-plantarflexion transition, limiting the bowler's ability to transfer force efficiently through the kinetic chain. This impairment may prevent the ankle from adequately redirecting the GRFs during FFC. A sequential transfer of kinetic energy occurs during FFC, from the lower limb (which is built up during the run-up) through the trunk and into the bowling arm (Worthington *et al.* 2013). This could ultimately limit the transfer of energy along the kinetic chain and potentially reduce bowling speed (Worthington *et al.* 2013).

TLAM has been shown to increase dorsiflexion ROM (Davenport *et al.* 2013; Ritter 2019). By improving TCJ mobility, TLAM may enable a more dorsiflexed ankle position at FFC, thereby facilitating a greater stride length and enhancing the conversion of linear to angular momentum, all of which are critical determinants of bowling speed (King *et al.* 2015). This aligns with findings from Felton *et al.* (2020), who reported that optimal kinematic positioning during FFC was associated with increased bowling speed.

Moreover, TLAM resulted in an improved performance in functional exercises requiring explosive lower limb force, such as sprinting and jumping (Kamali *et al.* 2017). Given the strong relationship between run-up speed and bowling speed (Kiely *et al.* 2021), TLAM may enhance propulsion and the generation of linear energy during the run-up, as well as the effectiveness of the FFC phase, contributing to higher bowling speeds.

Therefore, this study hypothesises that TLAM, by increasing ankle dorsiflexion range of motion and improving kinetic chain efficiency, will result in a significant increase in bowling speed immediately post-intervention.

1.2.10 Sham Laser Interventions in Manual Therapy Research

In clinical research, randomised controlled trials with a control group (placebo intervention) are one of the highest levels of evidence, with the success of the studied intervention based on the observed efficacy compared to a placebo (Bialosky *et al.* 2011). Sham interventions are essential controls used to distinguish the specific physiological effects of a treatment from placebo effects. A sham intervention is designed to mimic the appearance and context of the therapeutic procedure without delivering its active therapeutic component (Bialosky *et al.* 2011). This approach enables researchers to maintain participant blinding and rigorously assess the efficacy of manual interventions.

In manual medicine, sham techniques are widely used in spinal and extremity manipulation studies. For example, a sham spinal manipulation may involve placing the patient in a standard manipulative position without delivering the HVLA thrust (Rodríguez *et al.* 2007). Similarly, sham laser therapy may involve application of the device without activation or touching the participant (e.g., a deactivated laser), minimising the visual and tactile perception to the participant (MacIntyre *et al.* 2014).

In the context of the current study, a sham laser intervention was selected as the control. This involved applying a deactivated laser above the skin of the TCJ for 30 seconds with the participants' eyes covered, mimicking the same duration as TLAM. Compared to the method used by Kamali, Sinaei and Bahadorian (2017), the advantage of this approach is that the laser was positioned above the skin, thereby providing no tactile stimulation to the area and offering a more rigorous placebo for isolating the mechanical effects of TLAM. By blinding participants to group allocation and using a credible placebo, the study aimed to isolate the true physiological effect of TLAM on ankle sagittal motion and bowling speed, thereby enhancing the internal validity of the study design (Bialosky *et al.* 2011). Without a sham control, it would be difficult to determine

whether observed changes were due to the mechanical effects of the manipulation or other psychological factors such as the Hawthorne effect (McCarney *et al.* 2007).

1.3 PROBLEM STATEMENT

Despite the growing body of literature examining the biomechanics of pace bowling, the research focus has predominantly been on the upper body, particularly shoulder, trunk, and arm mechanics (Rana and Mittal 2022). Research investigating the contribution of lower limb biomechanics, especially the role of the ankle joint, remains limited. This is surprising, given that the literature has identified the front leg and its associated kinematics as critical to generating bowling speed (Rana and Mittal 2022). Yet, there is a noticeable lack of empirical data examining how specific lower limb structures, such as the talocrural joint, contribute to performance outcomes, such as bowling speed.

A similar trend is observed in chiropractic-based literature, where most research has examined the effect of upper body manipulation on bowling speed (Sood 2008; Levine 2016). To date, no studies have directly assessed the impact of ankle joint manipulation, specifically TLAM, on bowling speed in cricket pace bowlers.

This highlights a gap in both biomechanical and chiropractic research. The lack of evidence regarding the influence of ankle manipulation on performance outcomes such as bowling speed warrants further investigation. Therefore, the research problem focuses on the lack of research data on the effect of the ankle on the bowling speed in cricket pace bowlers.

1.4 AIM AND OBJECTIVES

1.4.1 Aim

This study aimed to determine the immediate effect of TLAM and sham laser on the bowling speed and sagittal ankle motion in club-level cricket pace bowlers from the eThekweni Municipality. Due

to the lack of research that quantifies the term “immediate effect”, a time frame of one to five minutes post-intervention was considered as immediate, for the purpose of this study.

1.4.2 Objectives

The objectives of this study were to:

1. Compare the pre-intervention ankle dorsiflexion to the immediate post-intervention ankle dorsiflexion.
2. Compare the pre-intervention ankle plantarflexion to the immediate post-intervention ankle plantarflexion.
3. Compare the pre-intervention bowling speed to the immediate post-test bowling speed.
4. Determine the correlation between the bowling speed and sagittal ankle motion post-intervention.

1.4.3 Research Questions

1. What is the immediate effect of TLAM on ankle dorsiflexion and plantarflexion ROM in club cricket pace bowlers?
2. What is the immediate effect of talocrural joint manipulation on bowling speed in club-level cricket pace bowlers?
3. Does a change in ankle sagittal motion correlate to a significant change in bowling speed in club cricket pace bowlers?

1.5 HYPOTHESES

1.5.1 Alternative Hypothesis

For objectives 1, 2, and 3, with respect to TLAM, the Alternative Hypotheses (H_a) were set based on previously conducted studies by Davenport *et al.* (2013), Kamali *et al.* (2017) and Ritter (2019).

These state that:

1. There will be a significant difference in the front ankle dorsiflexion compared to sham laser immediately after TLAM.
2. There will be a significant difference in the front ankle plantarflexion compared to sham laser immediately after TLAM.
3. There will be a significant difference in bowling speed compared to sham laser immediately after TLAM.
4. There will be a significant correlation between sagittal ROM of the front ankle joint and bowling speed post-TLAM.

1.6 DELIMITATIONS

The study was not focused on the neurophysiological effects of TLAM nor the impact of myofascial trigger points of the calf muscles on bowling speed. Further delimitations include that the study did not include female pace bowlers and that the findings are not applicable to spin bowlers, pace bowlers with ankle injuries or pace bowlers younger than 18 or older than 50 years of age.

1.7 OVERVIEW OF THE DISSERTATION

This dissertation adopts a dissertation-by-publication format and is organised into six main chapters, each fulfilling a distinct purpose in examining the immediate effect of TLAM on ankle sagittal range of motion and bowling speed in club-level pace bowlers.

1.7.1 Chapter One: Introduction and Literature Review

This chapter introduces the study and presents an in-depth literature review. It outlines the background of cricket, key factors influencing bowling speed, and the biomechanical role of the ankle. It concludes by identifying the research problem, aims, objectives, and hypotheses.

1.7.2 Chapter Two: Methodology

The research design, participant recruitment, intervention procedures, measurement tools, statistical analysis methods employed in the study, as well as the ethical considerations are presented in this chapter.

1.7.3 Chapter Three: Results

Chapter Three presents the study's results, including the effects of TLAM and sham laser on ankle dorsiflexion, plantarflexion, and bowling speed. It also provides the correlation between changes in ankle ROM and bowling speed.

1.7.4 Chapter Four: Discussion, conclusions, and recommendations

Chapter Four provides a robust discussion of the results in the context of existing literature. It discusses the biomechanical implications of the findings, evaluates the significance of TLAM on pace bowling performance, addresses potential limitations of the study, provides a conclusion, and offers recommendations for future research.

1.7.5 Chapter Five: Manuscript

The manuscript based on the current study, submitted to the Journal of Sports Sciences, an accredited peer-reviewed journal, is presented in this chapter.

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CHAPTER TWO: METHODOLOGY

2.1 STUDY DESIGN

The research paradigm was a quantitative, experimental, controlled trial with a pre-test-post-test design. The design consisted of two groups: viz., an experimental and a control group.

2.2 APPROVAL TO CONDUCT THE STUDY

Approval to conduct the study was obtained from the Institutional Research Ethics Committee (IREC) of the Durban University of Technology, with Ethics Clearance number: IREC 243/24 (**Appendix 1**).

2.3 STUDY POPULATION

The target population for this study was club-level pace bowlers competing in amateur cricket within the eThekwin Municipality. The estimated population size for the study was 60, based on an estimate of 10 pace bowlers in each of the six amateur cricket clubs in the eThekwin Municipality.

2.4 SAMPLING METHOD

Sixty prospective participants were eligible for enrolment in the study (after consulting with the cricket clubs). A purposive homogeneous sampling method was employed to recruit participants who met the inclusion criteria, specifically males, asymptomatic, and club-level pace bowlers. This non-probability sampling technique involves deliberately selecting individuals who share specific, predefined characteristics relating to the research aims, thereby creating a uniform cohort for focused investigation (Etikan, Musa and Alkassim 2015). In this study, the homogeneous characteristics required for inclusion were male participants who were asymptomatic and free of ankle injury or pathology, and active club-level pace bowlers within the eThekwin Municipality.

These characteristics were carefully selected using the study's inclusion criteria, ensuring that all participants accurately represented the chosen cohort of cricket pace bowlers. This sampling method reduces variability related to skill level, sex, and injury history. Once eligible participants were selected and provided informed consent, they were randomly assigned to two groups (TLAM intervention and sham laser control) using a simple randomisation procedure to ensure equal group distribution and minimise selection bias after the purposive sampling process.

2.5 SAMPLE SIZE

The study sample consisted of 52 participants, with a 95% confidence level. The sample size was calculated using an online sample size calculator (<https://www.qualtrics.com/blog/calculating-sample-size/>). A total of 57 participants were recruited for the study, five more than the required 52. Three of the participants were excluded from the study as they did not meet the inclusion criteria (ankle surgery within one year, ankle inversion sprain within one year, and not within the age range of 18 to 50 years). Twenty-seven participants were randomly assigned to the intervention group (Group A) and twenty-seven were randomly assigned to the control group (Group B). Therefore, of the 60 available participants, 54 participated in the current study (90%).

2.6 RECRUITMENT OF THE PARTICIPANTS

The participants were recruited from amateur cricket clubs in the eThekweni Municipality. Each club committee board provided consent to recruit participants for this study, and approval was obtained from the IREC. Each team's coach identified the prospective cricket pace bowlers within the club and invited them to join the study.

2.7 INCLUSION CRITERIA

The prospective participant must have been:

- I. A member of a cricket club who has at least played one cricket game for the club during the 2025 season.
- II. Between the ages of 18 and 50 years, as this age group is commonly found in professional cricket and is less likely to have conditions such as osteoarthritis (Paget, Tol and Reurink 2021).
- III. Of the male sex, as it provided a homogeneous sample. Males pace bowlers also bowl at greater speeds than females and have a different kinematic process during backfoot contact (Felton *et al.* 2019).
- IV. Able to bowl at a speed greater than $100\text{km}\cdot\text{h}^{-1}$ (Jowitt *et al.* 2020) that is measured during the player's warmup deliveries.

2.8 EXCLUSION CRITERIA

The exclusion criteria were determined through a thorough case history conducted under the guidance of an on-site clinician. Prospective participants were excluded from the study if they had any contraindications to ankle manipulation, such as trauma, fracture, ankle sprain, or surgery to the lower limb or ankle within the past 12 months, or a history of deep vein thrombosis of the calf (Raymond 2021).

2.9 CONSULTATION

At the consultation, the research study and data collection procedure were explained in detail to all participants. Every prospective participant was then provided with an information letter and informed consent sheet (**Appendices 2 and 3**). During the explanation of the research study, the participants were informed that they would receive either ankle joint manipulation or laser interventions. Once written informed consent was obtained, each prospective participant underwent a medical case history assessment to identify contraindications and an orthopaedic test of the ankle (**Appendix 4**). These tests were conducted in a separate closed-off area to ensure the

participants' privacy (**Figure 2.1**). These medical assessments were supervised by an onsite qualified chiropractor.



Figure 2.1. Private consultation area.
(Image taken by researcher)

2.9.1 Group Allocation

Laminated papers labelled “A” or “B”, of equal size, were placed in a black bag, with the number of papers equal to the number of participants. Twenty-seven participants were randomly assigned to the intervention group (Group A) and twenty-seven to the control group (Group B), by choosing a paper labelled “A” or “B” from the bag.

2.10 ANKLE DORSIFLEXION AND PLANTARFLEXION INSTRUMENT

2.10.1 Analogue Goniometer

Goniometry is the science of measuring the joint ranges in each plane of the joint (Gandbhir and Cunha 2024). A goniometer is an instrument used to measure the angle or ROM of a joint. For the current study, the participants' front foot and back foot ankle dorsiflexion and plantarflexion were recorded. Active joint motion is defined as joint movement achieved solely through the individual's

own muscular contraction, without the application of any external force by the researcher (Gandbhir and Cunha 2024).

A short-arm analogue goniometer (HiTech, Durban, South Africa) was used as the measuring instrument of choice in this study. This instrument was used to measure the degree of dorsiflexion and plantarflexion of the ankle or talocrural joint (Gandbhir and Cunha 2024). Ankle sagittal motion can be divided into two categories: plantarflexion and dorsiflexion (Brockett and Chapman 2016). Dorsiflexion is the movement of the foot in the cephalic direction towards the tibia, while plantarflexion is the movement of the foot in the caudal direction away from the tibia (Norkus and Floyd 2001). Prior to data collection, the researcher underwent training with the supervisor on the use of the goniometer.

The analogue goniometer has demonstrated strong validity and reliability for measuring ankle range of motion. According to Kolber and Hanney (2012), the study demonstrates excellent intra-rater reliability, with values greater than 0.94. Supporting this, Konor *et al.* (2017) reported reliability coefficients ranging from 0.85 to 0.96 for ankle ROM measurements using an analogue goniometer. Notably, standard goniometers have demonstrated excellent inter-rater reliability for ankle sagittal ROM (ICC > 0.90) (Konor *et al.* 2017). However, this study employed a single-rater design whereby the researcher was solely responsible for all goniometric measurements throughout data collection. However, a qualified chiropractor observed all goniometric measurements to ensure they were performed correctly and consistently.

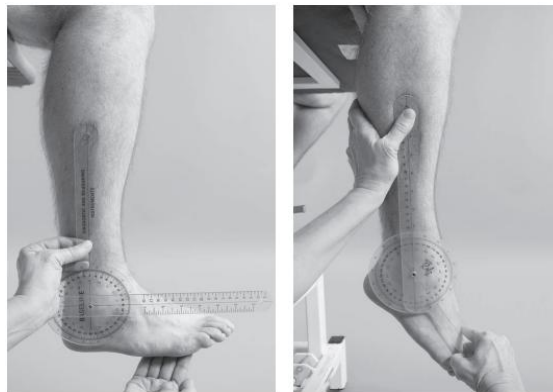
2.10.1.1 Assessment of ankle dorsiflexion and plantarflexion

The participant was laid supine on the portable chiropractic table. The ankle dorsiflexion and plantarflexion were measured with the knee in full extension with a goniometer in the standard manner (Davenport *et al.* 2013). To improve pre-post-test reliability, the measuring technique used by Fong *et al.* (2011) and Cosby and Grindstaff (2012), whereby the axis was set over a mark on the lateral malleolus with the stationary arm parallel to the fibula, and the movement arm was positioned parallel to the fifth metatarsal, was used in the current study, as shown in **Figure 2.2**. In this set-up, illustrated in **Figure 2.2**, when the foot moves into dorsiflexion (i.e., the foot moves closer to the shin), the angle between the stationary arm and the movable arm decreases. A smaller angle between the foot and the shin therefore reflects a greater degree of dorsiflexion. Conversely, during plantarflexion (when the foot moves away from the lower limb), this angle increases,

indicating a greater degree of plantarflexion. This interpretation aligns with standard biomechanical measurements, where dorsiflexion is defined as the movement that reduces the angle between the dorsum of the foot and the leg (Brockett and Chapman 2016; Norkin and White 2016). If the stationary arm of the goniometer is established as the zero axis, any movement of the movable arm of the goniometer towards this axis will result in a decrease in the measured angle, whereas movement away from the axis will produce a greater angle, as illustrated in **Figure 2.3**. On this basis, a negative change in dorsiflexion angle from pre- to post-intervention indicates an increase in dorsiflexion ROM. In contrast, a positive change reflects an increase in plantarflexion ROM.



Figure 2.2. Goniometer placement.
(Beng 2018)



**Figure 2.3. Dorsiflexion vs. plantarflexion angles.
(Norkin and White 2016)**

2.11 BOWLING SPEED INSTRUMENT

2.11.1 SpeedTrac™ X Radar Gun

A Radar gun is an instrument used to measure the velocity of an object (Robinson and Robinson 2016). In the current study, it was used to measure bowling speed through the principle of the Doppler Effect, which measures the velocity of the ball (Robinson and Robinson 2016). The echo of radio waves, known as the Doppler Shift, is measured as the ball travels through the air (Robinson and Robinson 2016). The radar gun emits a specific frequency, which is reflected off the moving ball in the air and then measured by the radar gun. The change in frequency is then converted to ball speed and displayed as $\text{km}\cdot\text{h}^{-1}$ (Robinson and Robinson 2016). The protective cricket netting used in practice facilities does not impact the data collected by the radar gun, as per the SpeedTrac X Manual Guidelines. Previous studies by Sood (2008) and Anand *et al.* (2017) have placed the radar gun in line with stumps behind protective netting. Maximum accuracy and repeatability are achieved when the radar gun is positioned behind a net, aligned with the direction of the cricket ball (Smith and Burke 2021). Additionally, manufacturer guidelines for radar devices, such as the Pocket Radar Ball Coach, another brand of radar guns, indicate that radar guns are not susceptible to interference from netting, as radio waves can easily travel through it (PocketRadar n.d.). The range of the SpeedTrac™ Radar Gun is between 10 and 199 $\text{km}\cdot\text{hr}^{-1}$, and to date, all bowling speeds assessed have been found to be within this range. The accuracy of the radar gun is within two to three km/hr^{-1} as per the manufacturer's guidelines. According to Anand *et al.* (2017), a radar gun is a reliable and valid tool for measuring ball speed, and it is a device that is used to measure bowling speed worldwide at all levels of cricket.

The radar device used for this research was a SpeedTrac X™ Radar Gun (EMG Companies Incorporated, Prescott, United States of America). The device was correctly calibrated, according to the manufacturer's instructions, before each use. It was set at a standard height of one metre, using a tripod to align the radar gun with the cricket ball and maintain a standardised position, as seen in **Figure 2.3**. According to Abdioglu, Akyildiz and Clemente (2022), the SpeedTrac™ X is

a valid and reliable radar gun for measuring ball speed. The study investigated the intra-unit reliability of the SpeedTrac™ X and compared its concurrent validity to that of the Pocket Radar™ device. A strong positive correlation was found between the two radar guns ($r = 0.932, p < 0.001$), and the intra-unit reliability of the SpeedTrac X™ was also high ($r = 0.964, p < 0.001$), confirming its consistency and accuracy in measuring ball velocity. This finding was validated by further studies conducted by Hernandez-Belmonte and Sanchez-Pay (2020) and Maddigan, Behm and Belfry (2013). The device was set up at the bottom of the pitch, behind protective netting and correctly calibrated according to the manufacturer's guidelines, as illustrated in **Figure 2.4**.



Figure 2.4. SpeedTrac™ X radar gun on a tripod.
(Image taken by researcher)

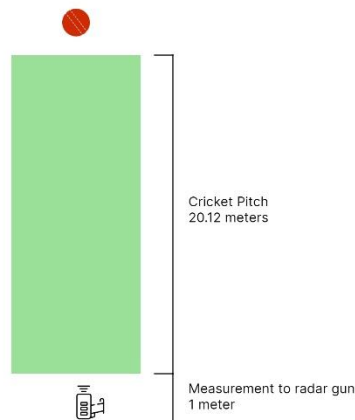


Figure 2.5 Radar gun layout.
(Image designed by the researcher)

2.12 CRICKET BALLS

According to international men's standards, a 156-gram cricket is the standard men's cricket ball (Wickington and Linthorne 2017). A 156-gram cricket ball is used at all levels of cricket in South Africa, from under-15 school cricket to professional cricket (Board 2017). This research study used 156g red cricket balls following international standards. Each participant bowled their respective six deliveries with the same cricket ball. No participant was allowed to switch to a different cricket ball once they had bowled their first delivery. This method was used to minimise any external factor that could influence the results obtained.

2.13 INTERVENTION

2.13.1 Group A: Talocrural long-axis manipulation

The participants were instructed to lie supine on the portable chiropractic table and hold onto the edge of the table to stabilise the lower extremities. The hands of the researcher were positioned around the ankle so that both fifth digits were in contact with the dorsal aspect of the talus, and the

thumbs rested on the plantar surface of the foot, as seen in **Figure 2.5**. The joint was distracted, and a single HVLA thrust was performed in the caudal direction, manipulating the TCJ (Sillevis *et al.* 2022). The FFC phase of pace bowling was the primary phase investigated in this study, and the front foot was established as a crucial foot in the biomechanics of pace bowling; therefore, the bowler's front foot was the focus of the intervention. If the cricket pace bowler was right-hand dominant, the front foot was the left foot. Therefore, intervention was performed on the left foot. Likewise, if the pace bowler was left-hand dominant, the front foot was the right foot.



Figure 2.6 Hand Placement During Talocrural Long-axis Manipulation.
(Sillevis *et al.* 2022)

2.13.2 Group B: Sham laser intervention

To increase the validity of the study, it was necessary to include a control group. The sham laser technique was the placebo of choice in this study, as it has been a method previously used in manipulation studies (Sood 2008). Furthermore, because the technique did not require any physical contact, and the participants' eyes were covered, visual perception and tactile stimulation were avoided, minimising any external factors that could influence the results. In the control group, the participant was instructed to lie supine on the portable chiropractic table and observe as the researcher switched on the laser machine (Globus, Codogné, Italy). The treatment protocol was set on the laser to authenticate the procedure; however, the laser was deactivated when the

participant fitted the protective eyewear, and therefore, produced no therapeutic benefit to the participant. The head of the laser was not placed in contact with the patient's skin. The head of the laser was directed along the TCJ for 30 seconds. For the procedure to mimic regular laser therapy, the participant and clinician wore protective eyewear. The procedure produced no change in temperature, sound, or vibration (Cotler 2016). The placebo treatment was anticipated to pose no adverse effects to the participant.

2.13.3 Research Summary

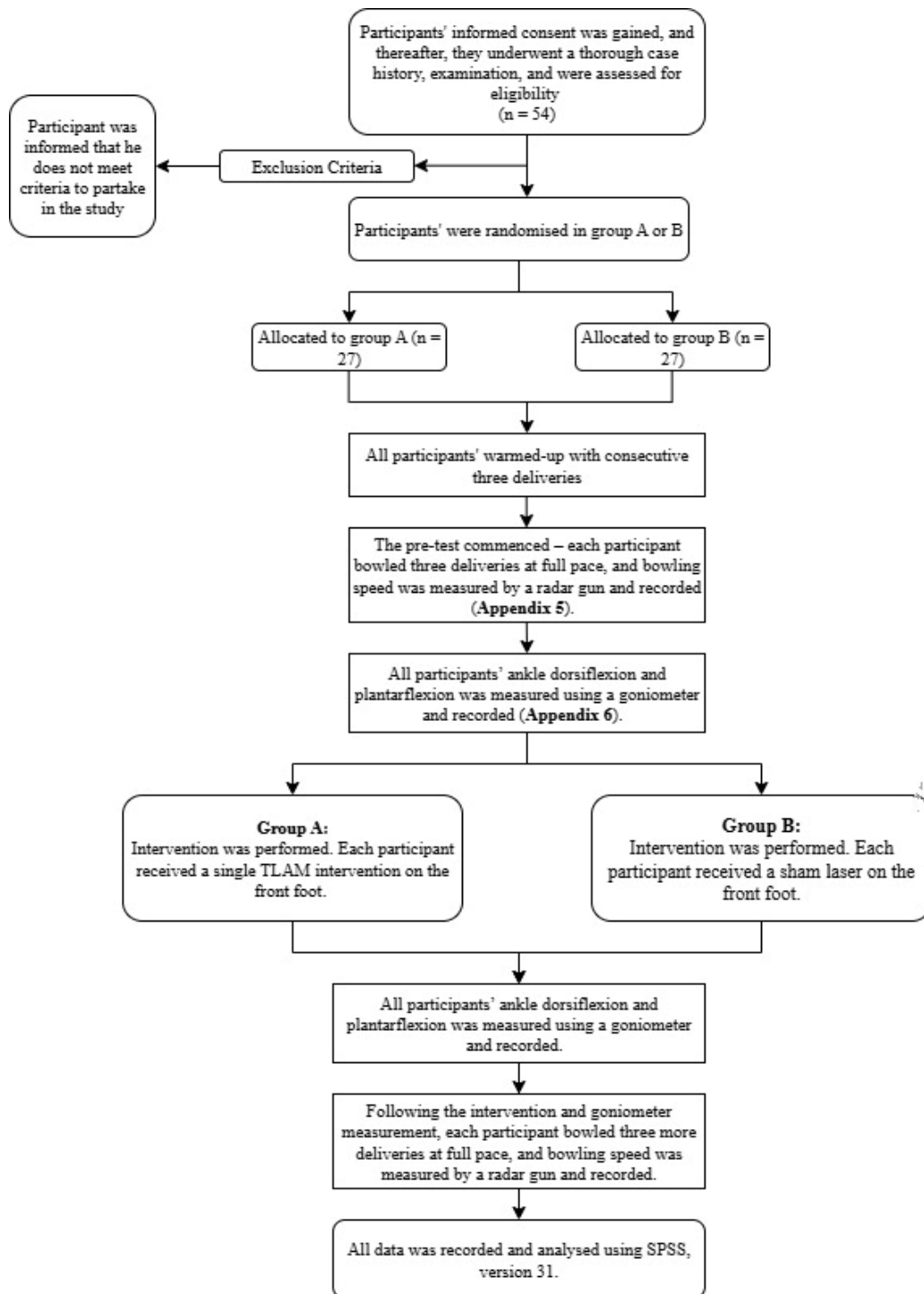


Figure 2.7 Research summary.

The entire procedure was supervised onsite by a qualified chiropractor registered with the Allied Health Professions Council of South Africa.

The post-intervention bowling speed data collected were within five minutes following the intervention. For this study, a time frame of one to five minutes was considered as immediate. This allowed for the assessment of any immediate changes in ankle ROM and bowling speed resulting from the TLAM intervention.

2.14 DATA ANALYSIS

The latest version of SPSS, version 31, was used to analyse the data. The researcher was assisted with the data analysis by the statistician from the Durban University of Technology, who guided the selection and implementation of appropriate statistical tests.

Before conducting inferential analyses, the data were tested for normality using the One-Sample Kolmogorov-Smirnov test (KS) with Lilliefors Significance Correction and Monte Carlo approximation. The results indicated that most variables did not significantly deviate from a normal distribution ($p > 0.05$), supporting the use of parametric statistical tests for subsequent analyses. The summary table (**Appendix 8**) shows that there were no significant differences in outcomes between the parametric (t -tests and ANOVA) and their non-parametric equivalents (Wilcoxon and Mann-Whitney tests), supporting the validity of the parametric analyses. A paired sample t -test was used to compare the intra-group results for both the front and back feet, analysing the changes from pre-test to post-test results within each group. To evaluate the collective influence of the intervention type (Group A: talocrural Manipulation; Group B: laser Therapy) on changes in ankle joint ROM and bowling speed, a General Linear Model (GLM) multivariate analysis was conducted. Follow-up univariate analysis of variance (ANOVA) tests were performed to determine which individual variables contributed to the overall intervention effect. Spearman's correlation was used to analyse the relationship between outcome variables, such as changes in bowling speed, ankle dorsiflexion, and ankle plantarflexion. Although the data generally met the assumptions of normality, minor deviations were observed for certain variables (e.g., change in pre-dorsiflexion front foot and bowling speed). Therefore, Spearman's correlation was applied as

a non-parametric measure of rank correlation when assessing the relationship between change scores for bowling speed, dorsiflexion, and plantarflexion. This approach was methodologically appropriate, as the relationship between change in bowling speed and change in dorsiflexion was assessed using difference scores, which may not follow strict normality. An alpha value of 0.05 was assigned to assess significant values. Therefore, a p -value of <0.05 was considered statistically significant.

2.15 ETHICAL CONSIDERATIONS

2.15.1 Autonomy

Written informed consent was obtained from all participants once they understood the study's purpose, procedures, and potential risks and benefits.

Ankle manipulation had the potential for mild side effects, such as post-manipulation stiffness and soreness (Brantingham *et al.* 2012); however, the risks of side effects are minimal, with no serious adverse effects being reported previously.

Various steps were implemented to mitigate the potential of mild side effects, such as:

- Each participant was screened for contraindication for manipulation, which lowered the risk of side effects (Raymond 2021).
- A qualified chiropractor observed the entire manipulation intervention.

Participants' privacy was protected through confidentiality and data protection throughout the study, with each participant assigned a specific number to maintain anonymity. Although the medical case history (**Appendix 4**) required participants to provide their names for clinical and medico-legal purposes, two separate data files were created to maintain anonymity during data handling and statistical analysis:

- A secure file containing participant names and their number. This file was accessible only to the researcher and supervisors.

- An anonymised dataset containing only participant numbers (no names), which was the version provided to the statistician for analysis.

This two-document system ensured that no identifiable information was accessible to individuals outside the research team and that all statistical analysis was performed using anonymised data. All documents were placed in a password-protected hard drive. The hard drive will be stored in a secure location for a period of five years and then destroyed. After a period of five years, all recorded data will be permanently erased from the hard drive, and the hard drive will be responsibly disposed of in an electronic waste bin. Participants maintained the right to withdraw at any time without penalty.

2.15.2 Beneficence

The participants were briefed on the study's potential benefits during the consultation. These included contributing to the advancement of research in pace bowling, exploring the role of chiropractic manipulation in affecting bowling speed, and benefiting the cricket community. Since the participants were cricketers, the findings may also have direct relevance to their own performance and development. Additionally, each participant received one complimentary treatment at the Durban University of Technology Chiropractic Day Clinic in recognition of their participation in the research study. The findings of this study will be presented to the management and coaches of the KwaZulu-Natal Cricket Union, and a manuscript will be submitted to an accredited journal.

2.15.3 Non-maleficence

Before inclusion, all participants underwent a screening for contraindications as stated in the exclusion criteria, which was under the supervision of an on-site clinician. Adherence to inclusion and exclusion factors minimised risks, and the presence of a qualified chiropractor throughout data collection ensured participant safety. No adverse effects were expected or reported by participants from either group.

2.15.4 Justice

Random assignment to Group A or Group B was conducted using a blind method to prevent participant bias.

While the study involved an element of deception for participants in the sham laser group, it was anticipated to pose no adverse effects. Post-data collection, participants in the control group were informed of the placebo treatment. Their permission was obtained to use their results, with the option to withdraw their data if they declined. No participant in the sham laser group declined for their data to be used in this study.

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CHAPTER THREE: RESULTS

3.1 AGE DESCRIPTIVE ANALYSIS

A total of 54 cricket pace bowlers, aged between 18 and 48 years, participated in this study. Participants were categorised and divided equally ($n = 27$) into two groups: Group A (intervention) and Group B (control). The minimum, maximum, range, and mean $\pm$ SD descriptive statistics for age in each group, as well as the overall sample, are summarised in **Table 3.1**.

Table 3.1. The mean $\pm$ SD and range of the ages of the participants.

Group	Number	Minimum	Maximum	Range	Mean $\pm$ SD
A	27.0	18.0	47.0	29.0	31.7 $\pm$ 8.0
B	27.0	18.0	48.0	30.0	32.8 $\pm$ 7.4
Overall	54.0	18.0	48.0	30.0	32.2 $\pm$ 7.6

3.2 ANKLE DORSIFLEXION AND PLANTARFLEXION RANGE OF MOTION

3.2.1 Intra-Group Analysis

The participants' change in mean and SD between pre- and post-intervention dorsiflexion and plantarflexion, for both the front foot and back foot, 95% confidence intervals, and p -values, are presented in **Table 3.2** for both groups. A standard paired samples t -test was used to assess within-group changes.

Group A showed statistically significant improvements in three out of four ROM domains, notably:

- Front foot dorsiflexion with a pre- and post-intervention means $\pm$ SD of $110.9^\circ \pm 5.7^\circ$ and $101.9^\circ \pm 7.7^\circ$, respectively, with a mean change of -9.0° ($p < 0.001$).
- Front foot plantarflexion with a pre- and post-intervention means $\pm$ SD of $152.9^\circ \pm 9.1^\circ$ and $160.0^\circ \pm 7.3^\circ$, respectively, with a mean change of $+7.1^\circ$ ($p < 0.001$).

- Back foot plantarflexion with a pre- and post-intervention means $\pm$ SD of $154.1^\circ \pm 8.2^\circ$ and $155.8^\circ \pm 7.0^\circ$, respectively, with a mean change of $+1.7^\circ$ ($p = 0.025$).

Backfoot dorsiflexion showed no significant improvement ($p = 0.173$) in ROM with pre- and post-intervention means $\pm$ SD of $108.3^\circ \pm 6.1^\circ$ and $107.0^\circ \pm 6.0^\circ$, respectively, with a mean change of -1.3° .

In contrast, participants in Group B showed small changes across all ROM domains, but none were statistically significant ($p > 0.15$ for all measures):

- Front foot dorsiflexion with a pre- and post-intervention means $\pm$ SD of $110.3^\circ \pm 7.0^\circ$ and $109.3^\circ \pm 6.4^\circ$, respectively, with a mean change of -1.0° .
- Front foot plantarflexion with a pre- and post-intervention means $\pm$ SD of $152.0^\circ \pm 7.4^\circ$ and $153.2^\circ \pm 6.9^\circ$, respectively, with a mean change of $+1.2^\circ$.
- Back foot dorsiflexion with a with a pre- and post-intervention means $\pm$ SD of $110.7^\circ \pm 6.1^\circ$ and $111.6^\circ \pm 6.6^\circ$, respectively, with a mean change of $+0.9^\circ$.
- Back foot plantarflexion with a pre- and post-intervention means $\pm$ SD of $152.8^\circ \pm 7.4^\circ$ and $153.1^\circ \pm 7.1^\circ$, respectively, with a mean change of $+0.3^\circ$.

Table 3.2. Ankle range of motion data analysis.

Group	ROM	Mean $\pm$ SD ($^\circ$)	95% Confidence intervals		<i>p</i> -value
			Lower	Upper	
A	Dorsiflexion FF	-9.0 ± 6.7	11.6	-6.4	<0.001
	Dorsiflexion BF	-1.3 ± 4.9	-3.3	0.6	0.173
	Plantarflexion FF	7.1 ± 6.8	4.5	9.9	<0.001
	Plantarflexion BF	1.7 ± 3.6	0.2	3.1	0.025
B	Dorsiflexion FF	-1.0 ± 3.7	-2.5	0.4	0.152
	Dorsiflexion BF	0.9 ± 6.0	-1.5	3.2	0.484
	Plantarflexion FF	1.2 ± 5.2	-0.9	3.2	0.266
	Plantarflexion BF	0.3 ± 4.0	-1.2	1.9	0.665

FF = Front Foot

BF = Back Foot

3.3 BOWLING SPEED

3.3.1 Intra-Group Analysis

The change in mean and SD between pre- and post-intervention bowling speed, 95% confidence intervals, and *p*-value, are tabulated in **Table 3.3**. A standard paired samples *t*-test was used to assess within-group changes.

Group A showed statistically significant improvement ($p < 0.001$) in bowling speed, with a pre- and post-intervention means $\pm$ SD of $112.8\text{km}\cdot\text{h}^{-1} \pm 12.5\text{km}\cdot\text{h}^{-1}$ and $118.0\text{km}\cdot\text{h}^{-1} \pm 11.3\text{km}\cdot\text{h}^{-1}$, respectively, with a mean change of $+5.4\text{km}\cdot\text{h}^{-1} \pm 7.2\text{km}\cdot\text{h}^{-1}$.

In contrast, participants in Group B showed no statistically significant improvement ($p = 0.775$) in bowling speed, with a pre- and post-intervention means $\pm$ SD of $111.8\text{km}\cdot\text{h}^{-1} \pm 12.2\text{km}\cdot\text{h}^{-1}$ and $112.1\text{km}\cdot\text{h}^{-1} \pm 12.3\text{km}\cdot\text{h}^{-1}$, respectively, with a mean minimal change of $+0.3\text{km}\cdot\text{h}^{-1} \pm 4.7\text{km}\cdot\text{h}^{-1}$. A 95% CI that included zero (-1.6, 2.1) suggests no meaningful effect from the laser intervention.

Table 3.3. Bowling speed data analysis.

Group	Mean $\pm$ SD ($\text{km}\cdot\text{h}^{-1}$)	95% Confidence intervals		<i>p</i> -value
		Lower	Upper	
A	5.4 ± 7.2	2.6	8.3	<0.001
B	0.3 ± 4.7	-1.6	2.1	0.775

3.4 THE CORRELATION BETWEEN BOWLING SPEED AND ANKLE RANGE OF MOTION

In Group A, the change in bowling speed was borderline significant, moderately, and inversely correlated with the change in front foot dorsiflexion, with a Spearman's correlation coefficient of -0.484 ($p = 0.049$). The correlation between the change in bowling speed and the change in front foot dorsiflexion ROM is presented as a Scatterplot in **Figure 3.1**.

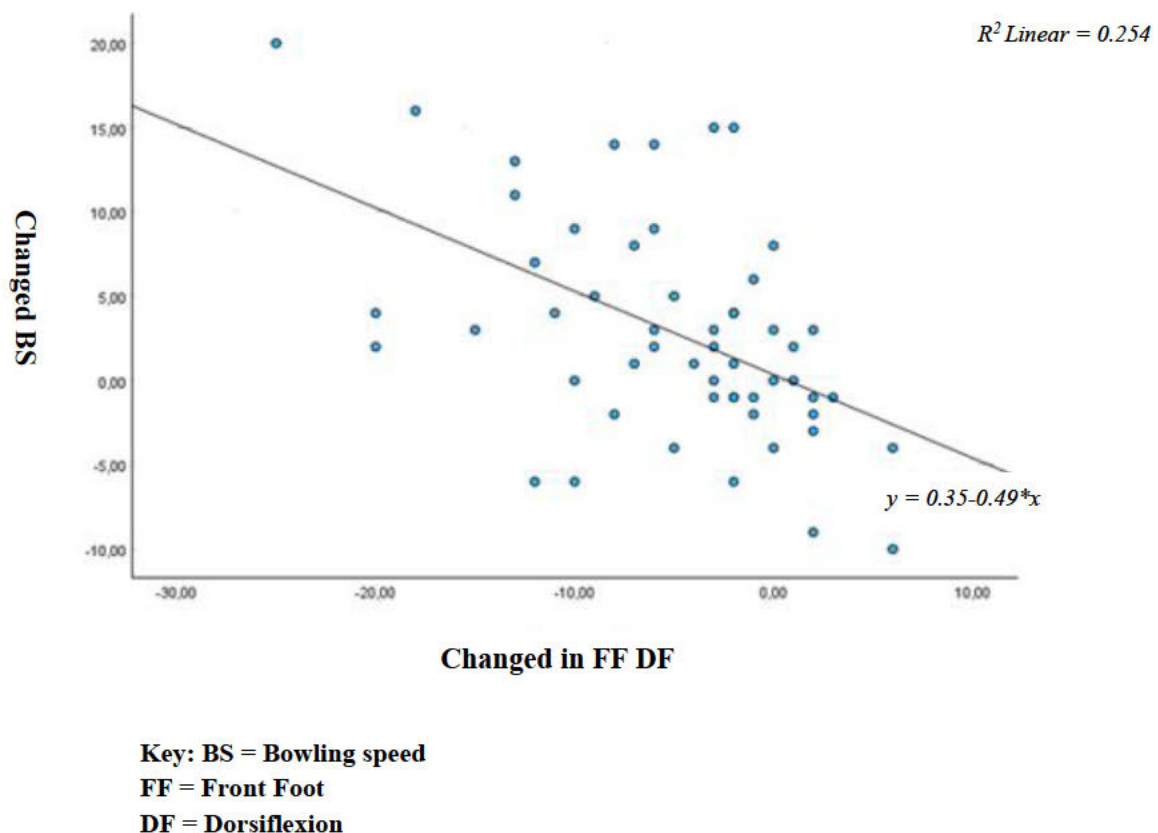


Figure 3.1. Scatterplot and trendline of the correlation between the change in bowling speed and the change in front foot dorsiflexion ROM.

3.5 COLLECTIVE INFLUENCE OF THE INTERVENTION TYPE ON CHANGES IN ANKLE ROM AND BOWLING SPEED

A GLM multivariate analysis was conducted to evaluate the combined effect of intervention type (Group A: TLAM, Group B: sham laser) on changes in the following dependent variables:

- Front foot dorsiflexion
- Front foot plantarflexion
- Back foot dorsiflexion
- Back foot plantarflexion
- Bowling speed

The intervention group was set as the fixed factor, and age was included as a covariate to assess whether it influenced the dependent variables. The multivariate test (**Table 3.4**) revealed a statistically significant effect of the intervention on the combined set of dependent variables (Pillai's Trace = 0.488, $F(5.0, 47.0) = 9.0, p < 0.001$), indicating that the intervention type had a substantial influence on ankle ROM and bowling speed outcomes. Age was not a significant covariate (Pillai's Trace = 0.032, $F(5.0, 47.0) = 0.3, p = 0.907$), suggesting that the intervention's effectiveness was consistent across the adult age spectrum and not influenced by participants' age.

Follow-up univariate ANOVA tests (**Table 3.5**) identified the specific variables contributing to the overall effect. Significant between-group differences were observed in:

- Front foot dorsiflexion: Group A showed a significantly greater improvement in ROM compared to Group B ($F(1, 51) = 29.1, p < 0.001$).
- Front foot plantarflexion: Significant improvement in ROM was also found in Group A ($F(1, 51) = 13.2, p < 0.001$).
- Bowling speed: Significantly increased post-intervention bowling speeds were found in Group A compared to Group B ($F(1, 51) = 9.5, p = 0.003$).

No significant between-group differences were observed for back foot dorsiflexion ($F = 2.3, p = 0.133$) or back foot plantarflexion ($F = 1.6, p = 0.208$), indicating that TLAM primarily affected the manipulated (front) ankle.

Table 3.4. Multivariate tests for a combined set of dependent variables.

Effect	Test	Value	F	Hypothesis df	Error df	<i>p</i> -value	Partial Eta ²
Intercept	Pillai's Trace	0.064	0.7	5.0	47.0	0.664	<0.1
Age	Pillai's Trace	0.032	0.3	5.0	47.0	0.907	<0.1
Group	Pillai's Trace	0.488	9.0	5.0	47.0	< 0.001	0.5

Computed using alpha = 0.05

Table 3.5. ANOVA test of between-groups effects for key outcomes.

Dependent variable	Mean square	F	<i>p</i> -value	Partial eta squared
Change in Front Foot Dorsiflexion	856.3	29.1	<0.001*	0.4
Change in Front Foot Plantarflexion	497.4	13.2	0.001*	0.2
Change in Back Foot Dorsiflexion	69.4	2.3	0.133	<0.1
Change in Back Foot Plantarflexion	23.9	1.6	0.208	<0.1
Change in Bowling Speed	355.5	9.5	0.003*	0.2

Computed using alpha = 0.05

*** = Significant value**

CHAPTER FOUR: DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

4.1 SYNTHESIS OF THE RESEARCH FINDINGS

The study recruited 54 male club-level pace bowlers from the eThekweni Municipality, aged between 18 and 48 years (mean $\pm$ SD: 32.2 ± 7.6 years). Participants were evenly divided ($n = 27$) into an intervention group (TLAM) and a control group (sham laser). Multivariate testing confirmed that age did not significantly influence any of the outcome measures, indicating that the effects of TLAM were consistent across the adult age range represented in this cohort. The study aimed to determine the immediate effect of TLAM and sham laser on the bowling speed and sagittal ankle motion in club-level cricket pace bowlers from the eThekweni Municipality. The results of this study effectively addressed the four specific objectives outlined in Chapter One. The intervention group showed a statistically significant improvement in both dorsiflexion (a mean change of -9.0° ; $p < 0.001$) and plantarflexion (a mean change of 7.1° ; $p < 0.001$) in the manipulated ankle (i.e., the front foot at FFC), fulfilling the first and second objectives. Secondly, a statistically significant increase in bowling speed was observed in the intervention group, with a mean increase of $5.4\text{km}\cdot\text{h}^{-1}$ ($p < 0.001$), achieving the third objective, which was to compare pre-test and post-test bowling speeds. Lastly, a borderline significant, moderate negative correlation ($r = -0.484$, $p = 0.049$) was identified between the change in front foot dorsiflexion and the change in bowling speed, meeting the criteria of the fourth objective. These findings collectively support the study's hypothesis and highlight the biomechanical importance of the ankle, specifically the talocrural joint, in contributing to pace bowling speed.

A moderate negative correlation ($r = -0.484$, $p = 0.049$) was observed between front foot dorsiflexion and bowling speed, suggesting that as the dorsiflexion angle decreased (reflecting greater dorsiflexion ROM), bowling speed increased. The biomechanical relationship between a decreased dorsiflexion angle and greater dorsiflexion is consistent with Norkin and White (2013). While the increase in bowling speed aligns with Worthington *et al.* (2013) and King *et al.* (2015), who described the importance of a dorsiflexed ankle at FFC for achieving a heel strike, which contributes to optimal braking force and kinetic energy transfer. The improved ankle ROM

observed in this study is consistent with previous work by Cosby and Grindstaff (2012), who also reported an increase in ankle dorsiflexion following joint manipulation.

Importantly, no significant changes in front foot ankle dorsiflexion, plantarflexion, or bowling speed were observed in the control group. An anomalous finding of a significant increase in back foot plantarflexion pre- and post-intervention requires confirmation in a future study with a more sensitive instrument to assess ankle ROM. This strengthens the conclusion that TLAM specifically contributed to the observed improvements in both bowling speed and ankle sagittal motion. The study therefore addresses a gap in the literature regarding the impact of lower limb manipulation, particularly the ankle, on pace bowling speed, which has previously focused largely on spinal manipulative interventions (Sood 2008; Levine 2016).

4.2 ANKLE RANGE OF MOTION: COMPARISON WITH PREVIOUS RESEARCH AND EXPLANATION OF THE RESULTS

In the current study, TLAM produced a mean improvement of 9.0° in front foot dorsiflexion ROM and 7.1° in plantarflexion ROM (**Table 1.2**). These results are consistent with previous research supporting the effect of TLAM in improving ankle mobility (Pellow and Brantingham 2001; Davenport *et al.* 2013b; Ritter 2019). Ritter (2019) and Davenport *et al.* (2013) reported a respective 2.2° ($p = 0.005$) and 8.5° ($p < 0.001$) improvement in dorsiflexion in asymptomatic participants. In comparison, Pellow and Brantingham (2001) observed a 7.5° ($p < 0.001$) improvement in dorsiflexion in participants with a history of ankle inversion sprains. In contrast to the findings of Pellow and Brantingham (2001), Davenport *et al.* (2013) and Ritter (2019), Fryer *et al.* (2002) reported only a 1.4° improvement in dorsiflexion, alongside an unexpected significant 1.7° ($p < 0.001$) in the control group. In the current study, no significant change in dorsiflexion was observed in the control group (-1.0° , $p = 0.152$). Participant characteristics and measurement techniques may explain differences in outcomes between these studies. The study by Pellow and Brantingham (2001) observed ROM improvements in participants with a history of sub-acute or chronic ankle inversion sprains, and Fryer *et al.* (2002) observed ROM improvements primarily in participants with chronic ankle instability. However, the current study's findings show that TLAM can also produce immediate improvement in ROM in asymptomatic, healthy individuals with no

ankle injury or pathology, as previously reported by Davenport *et al.* (2013) and Ritter (2019). This is important as the current study involved asymptomatic club-level cricket pace bowlers. Furthermore, Davenport *et al.* (2013), Ritter (2019), and the current study used standard goniometers, while Fryer *et al.* (2002) employed motion analysis software to measure ankle ROM, which may explain the differing results. The slight differences in reported dorsiflexion values across studies can be attributed to variations in measurement conventions and test positions (Bohannon and Tiberio 1997). In the current study, ankle sagittal motion was measured using a standard universal goniometer in a non-weight-bearing (supine) position, with the stationary arm aligned along the fibula and the moving arm aligned along the fifth metatarsal. Under this convention, movement of the foot towards the tibia (greater dorsiflexion) reduces the measured angle; consequently, an improvement in dorsiflexion is expressed as a negative pre-post change, whereas an improvement in plantarflexion (movement away from the tibia) appears as a positive change (Norkin and White 2016). By contrast, studies that (a) use a goniometer, but record angular displacement “from the start” (i.e., from the neutral start position rather than the absolute angle between goniometer arms) (Ritter 2019), or (b) quantify dorsiflexion using alternative anatomical landmarks and photographic analysis (Fryer, Mudge and McLaughlin 2002), will report positive values for increased dorsiflexion. The choice of the goniometer for the ankle ROM used in the current study was appropriate, as standard goniometers have demonstrated excellent intra- and inter-rater reliability for ankle sagittal ROM (ICC > 0.90) (Konor *et al.* 2017), making them the appropriate choice for measuring ROM in this study. These methodological choices explain why the current study’s increased dorsiflexion was reported as a negative mean difference. When interpreting the results, once measurement geometry (absolute angle of the goniometer vs. displacement angle of the goniometer) and landmark conventions (fibula, lateral malleolus and fifth metatarsal vs. fifth metatarsal, lateral malleolus and heel) are established, the direction and magnitude of the change observed (dorsiflexion: -9° and plantarflexion: $+7.1^{\circ}$) are consistent with prior evidence showing immediate, improved effects of TLAM on ankle sagittal motion in asymptomatic cohorts (Bohannon and Tiberio 1997; Davenport *et al.* 2013; Ritter 2019).

The observed increase in dorsiflexion and plantarflexion ROM is likely due to the mechanical effects of TLAM. TLAM may restore the posterior glide of the talus within the talocrural joint (Cosby and Grindstaff 2012), thereby reducing joint restriction and allowing greater sagittal plane motion, consistent with the arthrokinematic principle that the talus must glide posteriorly within

the ankle TCJ (Vinenzino *et al.* 2006). Beyond the mechanical restoration of talar glide, the immediate ROM improvements observed may also be influenced by neurophysiological mechanisms outlined by Pickar (2002) and Bialosky *et al.* (2009), who propose that manipulation alters peripheral neurophysiological responses (reduced mechanoreceptor sensitivity) and modulates central processing to produce short-term increases in joint mobility.

No significant ROM changes were observed in the back foot of the control group. However, Group A showed a slight (four times less than front foot plantarflexion) but statistically significant increase in back foot plantarflexion ($+1.7^\circ$, $p = 0.025$). However, this did not remain significant in the GLM multivariate analysis ($F = 1.6$, $p = 0.208$). This indicates that TLAM primarily affected the manipulated (front) ankle, which is expected given the target nature of the intervention.

Importantly, no adverse events were reported immediately after the intervention or in the weeks following, highlighting the safety of TLAM. In summary, these findings demonstrate that TLAM can safely and significantly increase ankle sagittal ROM in club-level cricket pace bowlers.

4.3 CRICKET PACE BOWLING SPEED AND BIOMECHANICAL IMPLICATIONS

In the current study, a significant mean increase in bowling speed of $5.4\text{km}\cdot\text{h}^{-1}$ ($p < 0.001$) was found in the TLAM group. In contrast, no significant change was observed in the sham laser control group (**Table 3.5**). These results agree with earlier studies reporting improved bowling speed following joint manipulation. Sood (2008) found a significant $2.0\text{km}\cdot\text{h}^{-1}$ ($p < 0.001$) increase following combined lumbar and thoracic spine manipulation, and Levine (2016) reported a $5.2\text{km}\cdot\text{h}^{-1}$ increase following full spinal manipulation. However, unlike those studies (Sood 2008; Levine 2016), which focused on spinal manipulation, this is the first known study to link ankle joint manipulation to a pace bowling performance metric such as bowling speed.

Levine (2016) used a Juggs Pro-Sports Radar Gun, whereas Sood (2008) used the same SpeedTrac X™ Radar Gun (EMG Companies Incorporated, Prescott, United States of America) used in the current study. This methodological consistency enables comparability across studies and reinforces the validity of the current study's results. The SpeedTrac X™ device used in the current study operates on Doppler-based tracking technology comparable to the Stalker Pro II (Stalker

Radar, Oregon, United States of America) cited by Callaghan *et al.* (2021). Abdioglu *et al.* (2022) validated the SpeedTrac X™ radar, showing excellent concurrent validity with another Doppler-based radar gun ($r = 0.932$, $ICC = 0.964$, $p < 0.001$) for measuring tennis ball speed. Furthermore, the standardised testing in this study, including consistencies in the ball type, delivery distance, and radar gun positioning, further minimised measurement error and ensured reliable data collection.

The observed increase in bowling speed following TLAM supports the hypothesis that improving ankle sagittal motion can increase bowling speed in club-level cricket pace bowlers. It can be explained by the biomechanical role of the ankle during the FFC phase of pace bowling. Several studies (Worthington *et al.* 2013; King *et al.* 2015; Felton *et al.* 2020; Felton *et al.* 2023) have reported that a dorsiflexed heel-strike at FFC facilitates a larger stride length and optimised plant angle, which in turn increases horizontal impulse. This variable was significantly associated with higher bowling speeds ($r = -0.484$, $p = 0.031$), accounting for approximately 33% of the variance in bowling speed (King *et al.* 2015). Improved front ankle dorsiflexion may allow for enhanced heel-strike landing position, which King *et al.* (2015) found to promote a greater horizontal impulse. In the current study, the observed 9° increase in dorsiflexion ROM likely allowed for a more biomechanically favourable FFC position, enabling the pace bowler to plant his front foot in an improved heel-strike position, thus allowing a greater horizontal impulse to be produced. The larger the horizontal impulse, the more effective the linear momentum from the run-up is transferred into angular momentum, through the trunk, and ultimately culminating in faster arm speed at ball release (King *et al.* 2015).

Similarly, Felton *et al.* (2023) reported an increase in bowling speed (17.28km·h⁻¹) when all lower limb kinematics at FFC were theoretically optimised. While this increase in bowling speed is greater than that of the current study, Felton *et al.* (2023)'s theoretical model optimised multiple joints simultaneously, whereas the current study focused only on the effect of the front ankle. Interestingly, a single-joint intervention resulted in a 5.4km·h⁻¹ increase in bowling speed, which underscores the ankle's biomechanical importance. Given the biomechanical context that a lower dorsiflexion angle equals greater ROM, the negative correlation suggests that as ankle dorsiflexion ROM improves (angle decreases), bowling speed increases.

The mechanical basis for the improvement in front ankle dorsiflexion and plantar flexion is that TLAM may improve the amount of posterior talar glide within the talocrural joint (Vincenzino *et al.* 2006; Cosby and Grindstaff, 2012), thereby enhancing sagittal plane motion. This facilitates the critical transition from dorsiflexion to plantarflexion during FFC, allowing the ankle to act as an efficient force transmission point within the kinetic chain (Worthington *et al.* 2013). The current study's findings that TLAM may restore talar motion within the mortise, thereby increasing ankle sagittal ROM align with the mechanism proposed by Pellow and Brantingham (2001). This improved joint mobility likely contributed to the observed increase in bowling speed by facilitating a more biomechanically advantageous position at FFC. Although the current focussed only on the sagittal motion of the ankle, the findings do strengthen the biomechanical evidence reported by Almansoof, Nuhmani and Muaidi (2023), where improved ankle dorsiflexion facilitates quadriceps and core musculature activation, enhances power generation, and promotes efficient energy transfer through the lower-limb kinetic chain. Similarly, they found that improved ankle mobility enhanced arm swing efficiency during vertical jumping in volleyball athletes, a movement pattern biomechanically similar to pace bowling. Collectively, this supports the premise that improved ankle mobility, such as that observed following TLAM, may enhance kinetic chain efficiency and contribute to increased bowling velocity. Importantly, the sham laser group did not experience significant improvements in ROM or bowling speed, reinforcing the conclusion that mechanical ankle joint manipulation, rather than the placebo effect, was responsible for the observed increase in bowling speed.

Notably, the significant bowling speed gains in the TLAM group occurred despite unmeasured variations in run-up velocity, which can influence ball release (Ferdinands *et al.* 2010; Worthington *et al.* 2013; Kiely *et al.* 2021; Ramachandran *et al.* 2021). This suggests that the improved ankle function was a key contributor to increased pace bowling speed, independent of other technical variations. This is evident in the multivariate GLM analysis, presented in **Table 3.5**, which showed significant between-group differences in front foot dorsiflexion, front foot plantarflexion, and bowling speed between Groups A and B. The results demonstrate that TLAM had an intervention effect compared to sham laser, particularly on front foot ankle mechanics and bowling speed.

The relationship between TLAM and enhanced athletic performance is further supported by Kamali *et al.* (2017), who reported significant improvements ($p < 0.001$) in functional tests (single-leg hop, 24m sprint, Y-balance) following TLAM in athletes with chronic ankle instability. Although their population differed from that of the current study, the findings collectively suggest that TLAM has the potential to produce measurable improvements in sport-specific performance, such as athletics and pace bowling in cricket.

In summary, TLAM produced significant improvements in bowling speed in club-level cricket pace bowlers, likely via improved biomechanics during the FFC phase, which allowed for greater horizontal impulse generation and more efficient energy transfer through the kinetic chain. These findings address the study objective relating to bowling speed, supporting the hypothesis and providing the first documented evidence that a lower limb manipulation intervention can directly improve a pace bowling performance outcome.

4.4 IMPACT OF THE STUDY

The current study is the first investigation to examine the immediate effects of lower limb manipulation, specifically TLAM, on bowling speed in cricket pace bowlers. By finding statistically significant increases in both ankle sagittal motion and bowling speed following TLAM intervention, the study contributes new insights into the functional role of the ankle in cricket pace bowling. While previous research has primarily focused on spinal interventions (Sood 2008; Levine 2016), this study highlights that ankle mobility can directly influence performance-related outcomes, such as bowling speed.

These findings have several practical implications. For sports chiropractors and medical staff working with cricket teams, TLAM may serve as an effective, non-invasive, and safe technique for enhancing ankle joint mobility and improving performance outcomes. From a coaching and biomechanical perspective, this study emphasises the importance of ankle and lower limb function in optimising FFC mechanics and generating greater bowling speed. While research and coaching strategies often focus on upper body mechanics (Glazier *et al.* 2000; Portus *et al.* 2010; Johnstone *et al.* 2014; Ferdinands 2015; Feros *et al.* 2020), the findings of the current study suggest that the under-explored lower limb may hold the key to unlocking further performance gains in pace

bowlers. Feros *et al.* (2020) identified bowling speed as a critical determinant of performance, as it directly reduces the batter's reaction time and enhances wicket-taking potential. Consequently, the mean increase of $5.4\text{km}\cdot\text{h}^{-1}$ observed following TLAM may, therefore, represent a meaningful improvement in pace bowling performance. The increase in ball velocity will shorten the batter's reaction time and may increase the likelihood of inducing a technical error that leads to a wicket (Feros *et al.* 2020).

Furthermore, this research expands the scope of chiropractic involvement in sports performance management, particularly of the ankle, as part of pre-performance preparation or ongoing athlete management. This rationale highlights the role a chiropractor can have within a team's structure, specifically the medical staff of a cricket team.

The relevance of this study extends across the different levels of cricket. While the research was conducted on club-level (amateur) pace bowlers, the biomechanical principles should also apply to professional players. At the amateur level, the study provides a promising performance enhancement that can benefit the majority of cricket bowlers. In professional teams, where cricket is played at a highly competitive level and marginal performance gains are significant, the application of these findings may offer a competitive edge. These results lay a foundation for future research investigating the intermediate and long-term effects of talocrural manipulation on the bowling speed at the professional level of cricket.

Beyond its clinical relevance, the study also lays the groundwork for future research into the impact of chiropractic intervention and peripheral joint manipulation on pace bowling. These findings can guide future investigations into the impact of chiropractic interventions or long-term management strategies aimed at enhancing performance, thereby expanding the evidence base within the chiropractic and sports science communities.

4.5 STRENGTHS AND LIMITATIONS OF THE STUDY

The strengths of this study include its pre-post intervention experimental design, with random allocation of participants to the intervention and control groups, as well as a homogeneous sampling method using asymptomatic male club-level bowlers, with 90% of the prospective

participants participating in the study. A further strength was that all data collection took place in an indoor facility, which prevented several factors, such as wind, significant variations in environmental temperature and humidity, that could have influenced the results. The significant improvements observed after a single intervention highlight TLAM's potential for immediate impact. The limitations include a small sample size (mainly due to funding constraints), no inter-rater reliability testing could be done for goniometer readings as only the researcher conducted the ROM assessments, and the effect of manipulation on ankle dorsiflexion, plantarflexion, and bowling speed, beyond a few minutes, is not possible to describe. Further limitations of the current study include the restriction of the sample to male pace bowlers between the ages of 18 and 50 years, excluding female bowlers, spin bowlers, and participants with acute or chronic ankle injuries. As a result, the findings may not be generalisable to all cricket populations or to bowlers outside this age range.

4.6 CONCLUSIONS

The primary aim of this study was to determine the immediate effect of talocrural joint manipulation on ankle sagittal motion and bowling speed in club-level cricket pace bowlers. The findings revealed that TLAM significantly improved dorsiflexion and plantarflexion in the front foot ankle, and these changes were accompanied by a statistically significant increase in bowling speed. A moderate negative correlation was observed between the increased ankle dorsiflexion and bowling speed, suggesting that improved ankle mobility may facilitate a more optimal biomechanical position during FFC; however, caution should be noted as the significance was marginally below 0.05. These findings align with the specific objectives of this study.

Regarding the associated hypotheses established at the start of the study, the following alternative hypotheses (H_a) are accepted:

1. There was a significant difference in ankle dorsiflexion range of motion compared to sham laser immediately after TLAM.
2. There was a significant difference in ankle plantarflexion range of motion compared to sham laser immediately after TLAM.

3. There was a significant difference in bowling speed compared to sham laser immediately after TLAM.

As the first study to examine the effect of lower limb manipulation on performance-specific outcomes such as bowling speed, this research broadens the understanding of the kinetic chain during pace bowling. It emphasises the importance of the ankle during pace bowling and the effect every joint has on the complex biomechanics of pace bowling. Furthermore, the findings highlight the potential role of chiropractic intervention in the performance management of cricket pace bowlers.

4.7 RECOMMENDATIONS

Based on the findings of this study, several recommendations are proposed for future research:

- Conduct a similar study in female pace bowlers to determine potential gender differences in ankle range of motion and bowling performance (Felton *et al.* 2019).
- To investigate the effect of TLAM on GRFs and bowling speed to better understand the impact of TLAM during the FFC phase of pace bowling (Worthington *et al.* 2013).
- To examine the effect of TLAM, ankle sagittal motion and bowling should include an inter-rater method of goniometer measurements or more sensitive measurement instruments.
- The current study and previous research (Sood 2008; Levine 2016) only investigated the effect of manipulation on pace bowling speed. A future study should investigate the impact of manipulation on spin-bowling performance metrics such as spin and bounce.
- Conduct a crossover study in which the control group receives the TLAM intervention, with bowling speed and ankle ROM reassessed after an appropriate washout period. This design would allow the duration and time-dependent effects of TLAM on ankle sagittal motion and bowling performance to be more accurately determined.

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CHAPTER FIVE: MANUSCRIPT

Manuscript (unpublished): Submitted to Journal of Sports Science (Appendix 7)

Ankle Mobility for Increased Performance: The Impact of Talocrural Manipulation on Bowling Speed in Cricket Pace Bowlers

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Jason Vermaak: conception or design of the work; interpretation of data for the work; drafting the work or revising it critically for important intellectual content; final approval.

Junaid Shaik: interpretation of data for the work; drafting the work or revising it critically for important intellectual content; supervision; final approval.

Shereen Currie: interpretation of data for the work; drafting the work or revising it critically for important intellectual content; supervision; final approval.

Conflicts of interest: None

Declaration of funding: Jason Vermaak was awarded a National Research Foundation (NRF) First-time Master's Research grant to conduct the research study

Abstract

The study investigated the immediate effect of talocrural long-axis manipulation (TLAM) versus sham laser on bowling speed and sagittal ankle range of motion (ROM) in club-level pace bowlers in the eThekweni Municipality, South Africa. Fifty-four bowlers were randomly allocated into two groups ($n = 27$ each). Group A received TLAM of the front ankle, while Group B received a sham laser placebo. Pre-intervention bowling speed was recorded as the average of three deliveries. Outcomes measured included bowling speed ($\text{km}\cdot\text{h}^{-1}$) using a SpeedTrac X radar gun and ankle sagittal motion ($^{\circ}$) using a goniometer. Data were analysed using SPSS version 31. Significant improvements in ankle ROM, with increased dorsiflexion (-9.0° , $p < 0.001$) and plantarflexion ($+7.1^{\circ}$, $p = 0.001$), as well as increased bowling speed ($+5.4 \text{ km}\cdot\text{h}^{-1}$, $p = 0.003$) were found in Group A. A borderline significant negative correlation ($r = -0.484$, $p = 0.049$) was observed between the change in front foot dorsiflexion and the increase in bowling speed. Conversely, Group B showed no significant changes in either ankle ROM or bowling speed. These findings suggest that talocrural long-axis manipulation may enhance ankle mobility and improve pace bowling performance, offering potential benefits for cricket athletes seeking immediate performance gains.

Word count: 200

Keywords: pace bowling, bowling speed, ankle dorsiflexion, ankle plantarflexion, manipulation, ankle joint

Introduction

Cricket is a bat-and-ball sport that originated in England during the 16th century and has since evolved into one of the most popular sports globally, particularly in countries such as India, Australia, South Africa, and England (Naha and Malcolm 2021). The game is structured around two key disciplines, viz., batting and bowling. Batting involves players attempting to score runs by striking the ball and running between the wickets, while bowling refers to delivering the ball

towards the batter to dismiss them or limit scoring (Bhandurge *et al.* 2024). Bowling is broadly categorised into two types: pace bowling, which relies on speed and bounce, and spin bowling, which uses ball rotation and variation to deceive the batter. Bowling speed is considered a key determinant of pace bowling performance, as it directly influences the batter's reaction time and the bowler's ability to take wickets (Feros, Young and O'Brien 2020).

Pace bowling involves a series of biomechanical phases (Kiely *et al.* 2021). It begins with the run-up, where the bowler accelerates towards the crease, building momentum (Purohit and Vijayvargia 2012). This is followed by the back foot contact phase, marking the first point of ground contact after the run-up, and thereafter the front foot contact (FFC) phase (Olivier *et al.* 2023). At FFC, the bowler's front foot contacts the ground, acting as a strut over which the upper body pivots (Purohit and Vijayvargia 2012). The FFC phase is crucial for transferring kinetic energy from the run-up through the lower limbs and trunk to the bowling arm, culminating in the ball-release phase (Purohit and Vijayvargia 2012).

Previous research has examined upper body mechanics, including shoulder alignment, trunk rotation, and spinal kinematics, identifying them as key contributors to bowling speed (Portus *et al.* 2010; Ferdinands 2015). Additional factors, such as anthropometric characteristics (Glazier, Paradisis and Cooper 2000; Johnstone *et al.* 2014) and upper body muscular strength (Feros, Young and O'Brien 2019; Feros *et al.* 2020; Ramachandran *et al.* 2021; Felton *et al.* 2025), have been shown to influence bowling performance.

Recently, research has shifted focus to the role of the lower limb, particularly the ankle, during the FFC phase of pace bowling, which is integral for transferring momentum through the kinetic chain (Worthington, King and Ranson 2013; King, Worthington and Ranson 2015; Felton *et al.* 2020; Felton *et al.* 2023). Worthington *et al.* (2013) and King *et al.* (2015) identified two key

kinematic parameters that significantly affected bowling speed: heel-strike technique and the front foot plant angle. Kinetic variables such as horizontal impulse ($r = 0.574, p = 0.008$) and horizontal loading rates ($r = -0.484, p = 0.031$) were also positively associated with faster bowling speeds, indicating that a gradual application of horizontal force (rather than an abrupt force) may be more effective in generating ball velocity. Interestingly, a significant positive correlation was found between these kinetic parameters and front foot plant angle. These findings suggest that a heel-strike landing with an extended stride length facilitates a more effective conversion of linear momentum into angular momentum during FFC, ultimately contributing to increased bowling speed. Notably, King *et al.* (2015) found that horizontal impulse explained 33% of the variance in bowling speed, with 50% of this variance linked to the plant angle, a position dependent on dorsiflexion of the front ankle. Felton, Yeadon and King (2020) and Felton *et al.* (2023) further explored these mechanics using a 3D torque-driven simulation model, demonstrating that optimising FFC biomechanics can lead to a 13.5% increase in bowling speed.

Based on the work of Worthington *et al.* (2013), King *et al.* (2015), Felton *et al.* (2020) and Felton *et al.* (2023), it can be theorised that the front ankle may serve as a crucial link in the pace bowling action suggesting that a pace bowler needs to adequately dorsiflex the front ankle to maximise the conversion of momentum generated during the run-up into ball speed. Therefore, the ankle plays a pivotal role in optimising biomechanical efficiency and facilitating effective energy transfer through the kinetic chain.

Interventions that can enhance dorsiflexion may hold potential for improving bowling performance. One such intervention is the talocrural long-axis manipulation (TLAM), a manual therapy technique proposed to improve ankle joint mobility (Beazell *et al.* 2012). Joint manipulation, particularly high-velocity, low-amplitude (HVLA) thrust techniques, are commonly

used in manual medicine to improve joint mobility and potentially enhance athletic performance (LaPelusa and Bordoni 2023). While spinal manipulation has been studied in cricket (Sood 2008; Levine 2016), no research has examined the impact of ankle manipulation on performance outcomes, such as bowling speed.

TLAM is hypothesised to increase sagittal ankle ROM (Cosby and Grindstaff 2012; Davenport *et al.* 2013; Ritter 2019), which may allow pace bowlers to adopt more biomechanically advantageous positions during FFC, thereby enhancing energy transfer and bowling speed. Therefore, this study aimed to investigate the immediate effects of talocrural long-axis manipulation on ankle sagittal range of motion and bowling speed in club-level cricket pace bowlers.

Methods

Study design and research procedure pre-intervention

The research paradigm was a quantitative, experimental investigation with a pre-post-test design. A purposive homogeneous sampling method, with participants randomly allocated to groups, was used in this study (Etikan, Musa and Alkassim 2015). Fifty-four amateur, club-level cricket players participated in this study. Ethical approval was obtained from the Institutional Research Ethics Committee of the Durban University of Technology (IREC 243/24). The participants were recruited from amateur cricket clubs in the eThekweni Municipality, Durban, South Africa, from March 2025 to May 2025. The study was conducted on the premises of the local cricket clubs after permission was obtained. The inclusion criteria required participants to be male cricket pace bowlers aged 18-50 years, actively playing for a cricket club during the 2024/2025 season, and able to bowl at speeds of $100\text{km}\cdot\text{h}^{-1}$ or more during warm-up. The age range was chosen to minimise the risk of selecting participants with degenerative joint conditions (Paget, Tol and

Reurink 2021), and a homogeneous male sample was used to minimise sex-based differences in bowling mechanics and speed (Felton *et al.* 2019). To ensure that asymptomatic participants with no ankle injury or pathology were included, the exclusion criteria included any history of ankle or lower limb fracture, surgery, or sprain within the past 12 months, as well as the presence of contraindications to manipulation, such as deep vein thrombosis (Raymond 2021). Once written informed consent was obtained, participants were randomly assigned to one of the two groups (Group A, the TLAM intervention; and Group B, the sham laser intervention). A medical history and an orthopaedic examination of the ankles were conducted for each participant to minimise extraneous variables that could affect ankle range of motion, such as joint swelling, as well as minimise the risk of contraindication to joint manipulation. All participants were required to bowl three balls as a warm-up. Thereafter, ankle dorsiflexion and plantarflexion were assessed using a short-arm analogue goniometer (HiTech, Durban, South Africa) according to the technique described by Fong *et al.* (2011) and Cosby and Grindstaff (2012). The pre-intervention bowling speed was recorded as an average of three deliveries using a SpeedTrac X™ Radar Gun (EMG Companies Incorporated, Prescott, United States of America). The device was set up at the bottom of the cricket pitch, behind protective netting and calibrated according to the manufacturer's guidelines.

Intervention:

For the sham laser, the participants were instructed to lie supine on the portable chiropractic table and observe as the researcher switched on the laser device (Globus, Codogné, Italy). The treatment protocol was set on the laser to authenticate the procedure; however, the laser was deactivated when the participant wore the protective eyewear, and therefore, produced no therapeutic benefit to the participant. The head of the laser was directed along the TCJ for 30 seconds, but no contact was made with the participant's skin to prevent tactile stimulation. For the procedure to mimic

regular laser therapy, the participant and clinician wore protective eyewear. The procedure produced no change in temperature, sound, or vibration (Cotler *et al.* 2015), and the placebo intervention did not pose any adverse effects to the participants.

Front foot ankle joint manipulation was performed with participants lying supine on the portable chiropractic table and holding onto the edge to stabilise their lower extremities. The hands of the researcher were positioned around the ankle so that both fifth digits were in contact with the dorsal aspect of the talus, and the thumbs rested on the plantar surface of the foot. The joint was distracted, and a single HVLA thrust in the caudal direction was performed in accordance with the technique described by Sillevs, Regalado and Shamus (2022).

Post-intervention assessment:

Ankle dorsiflexion and plantarflexion were then assessed and recorded. The participants were then required to bowl as fast as possible three times, and the average of the bowling speeds was recorded. A time frame of one to five minutes post-intervention was considered as immediate, for the purpose of this study.

Data analysis

Version 31 of the Statistical Package for the Social Sciences (SPSS) was used to analyse the data. Before conducting inferential analyses, the data were tested for normality using the One-Sample Kolmogorov-Smirnov test (KS) with Lilliefors Significance Correction and Monte Carlo approximation. The results indicated that most variables did not significantly deviate from a normal distribution ($p > 0.05$), supporting the use of parametric statistical tests for subsequent analyses. A paired sample *t*-test was used to compare the intra-group results, analysing the changes from pre-test and post-test results within each group. To evaluate the collective influence of the intervention type (Group A: TLAM; Group B: sham laser) on changes in ankle joint ROM and

bowling speed, a GLM multivariate analysis was conducted. Spearman's correlation was used to analyse the relationship between outcome variables, such as changes in bowling speed, ankle dorsiflexion, and ankle plantarflexion. An alpha level of 0.05 was set to determine statistical significance; therefore, a p -value of <0.05 was considered statistically significant.

Results

Ankle range of motion

Intra-group findings

In Group A, the front foot dorsiflexion pre- and post-intervention means $\pm$ SD were $110.9^\circ \pm 5.7^\circ$ and $101.9^\circ \pm 7.7^\circ$, respectively, with a significant mean change of -9.0° ($p < 0.001$). The front foot plantarflexion with a pre- and post-intervention means $\pm$ SD were of $152.9^\circ \pm 9.1^\circ$ and $160.0^\circ \pm 7.3^\circ$, respectively, with a mean change of $+7.1^\circ$ ($p < 0.001$). In contrast, the front foot dorsiflexion pre- and post-intervention means $\pm$ SD in Group B were of $110.3^\circ \pm 7.0^\circ$ and $109.3^\circ \pm 6.4^\circ$ ($p > 0.15$), respectively, with a mean change of -1.0° , while the front foot plantarflexion pre- and post-intervention means $\pm$ SD were $152.0^\circ \pm 7.4^\circ$ and $153.2^\circ \pm 6.9^\circ$, respectively, with a mean change of $+1.2^\circ$ ($p > 0.15$). Interestingly, in Group A, the back foot plantarflexion pre- and post-intervention means $\pm$ SD were $154.1^\circ \pm 8.2^\circ$ and $155.8^\circ \pm 7.0^\circ$, respectively, with a significant mean change of $+1.7^\circ$ ($p = 0.025$). The change in mean, SD, 95% confidence intervals and p -values are presented in **Table 5.1** for both groups.

Bowling speed

Intra-group Findings

Group A experienced a significant increase in bowling speed, with a mean improvement of $+5.4\text{km}\cdot\text{h}^{-1} \pm 7.2$ ($p < 0.001$). Group B showed no significant change ($+0.3\text{km}\cdot\text{h}^{-1} \pm 4.7$, $p = 0.775$). The mean bowling speeds pre- and post-intervention, along with the change in mean, 95%

confidence intervals, and p -value, are tabulated in **Table 5.2**.

Correlation between bowling speed and ankle ROM

In Group A, the change in bowling speed correlated inversely with the change in front foot dorsiflexion, with a Spearman's correlation coefficient of -0.484 ($p = 0.049$) (**Figure 5.1**). Given the biomechanical context that a lower dorsiflexion angle equals greater ROM, this negative correlation suggests that as dorsiflexion ROM improves (angle decreases), bowling speed increases.

Multivariate analysis: Combined influence of TLAM on outcomes

A GLM revealed that intervention type had a significant influence on the combined outcomes of ankle ROM and bowling speed (Pillai's Trace = 0.488, $p < 0.001$; **Table 5.3**), whereas age was not a significant covariate ($p = 0.907$). Univariate analyses confirmed significant between-group differences in front foot dorsiflexion ($p < 0.001$), front foot plantarflexion ($p < 0.001$), and bowling speed ($p = 0.003$) (**Table 5.4**). No significant between-group differences were observed for back foot dorsiflexion ($F = 2.3$, $p = 0.133$) or back foot plantarflexion ($F = 1.6$, $p = 0.208$), indicating that TLAM primarily affected the manipulated (front) ankle.

Discussion

This study aimed to investigate the immediate effects of TLAM on ankle ROM and bowling speed in cricket pace bowlers. These findings demonstrated a statistically significant improvement in both ankle dorsiflexion and plantarflexion in the TLAM group. These improvements were accompanied by a significant increase in bowling speed. A moderate inverse correlation was found between the change in front foot dorsiflexion and the change in bowling speed. In contrast, no significant changes were observed in the control group, reinforcing the hypothesis that TLAM can

positively influence bowling speed in cricket pace bowlers.

Ankle ROM significantly increased following TLAM, with a mean change of 9.0° in dorsiflexion. Notably, the control group did not experience a significant change in ROM, further supporting the effect of TLAM. No significant ROM changes were observed in the back foot of the control group. However, Group A showed a slight (four times less than front foot plantarflexion) but statistically significant increase in back foot plantarflexion. However, this did not remain significant in the GLM multivariate analysis and is considered an anomalous finding. This indicates that TLAM primarily affected the manipulated (front) ankle. The mechanical basis for the improvement in front ankle dorsiflexion and plantar flexion is that TLAM may improve the amount of posterior talar glide within the talocrural joint (Vincenzino *et al.* 2006; Cosby and Grindstaff 2012), thereby enhancing sagittal plane motion. This facilitates the critical transition from dorsiflexion to plantarflexion during FFC, allowing the ankle to act as an efficient force transmission point within the kinetic chain (Worthington *et al.* 2013). This finding aligns with previous literature suggesting that talocrural joint ROM, particularly dorsiflexion, increases following manipulation therapy (Cosby and Grindstaff 2012). During FFC, the bowler's body pivots over the front ankle, and a restriction in the ankle ROM can potentially alter the force that is transmitted through the kinetic chain and potentially negatively affect the bowling speed. The present findings suggest that improved ankle mobility may contribute to optimising the biomechanics during the FFC phase of pace bowling and ultimately improve bowling speed.

Additionally, a significant increase in bowling speed ($5.4\text{km}\cdot\text{h}^{-1}$) was observed in Group A. This supports the biomechanical premise that a greater ankle ROM may contribute to an increase in bowling speed. The moderate negative correlation between dorsiflexion and bowling speed ($r = -0.401$, $p = 0.049$) indicates that improving ankle ROM may promote a more

biomechanically advantageous position during FFC. Felton *et al.* (2020) proposed that a heel strike, requiring dorsiflexion, is the optimal position at FFC, aligning with the improvements observed in this study.

Previous studies (Sood 2008; Levine 2016) have explored the effect of manipulation of other regions of the body on bowling speed, but this study was the first to investigate the effect of ankle manipulation on bowling speed. These findings contribute to a growing body of evidence suggesting that manipulation may be a valuable tool for performance enhancement in cricket pace bowling.

These findings have practical implications for sports chiropractors and coaching staff. Incorporating manipulation, specifically TLAM, in pre-match or as part of ongoing player management may provide a non-invasive method to improve ankle function and potentially enhance pace bowling performance. Given that pace bowling involves complex coordination across the kinetic chain, even the smallest improvement in joint function may yield important differences in performance. The relevance of this study extends across the different levels of cricket. While the research was conducted on club-level (amateur) pace bowlers, the biomechanical principles apply to professional players as well. At the amateur level, the study provides a promising performance enhancement that can benefit the majority of cricket pace bowlers. In professional teams, where cricket is played at a highly competitive level and marginal performance gains are significant, the application of these findings may offer a competitive edge. These results lay a foundation for future research investigating the intermediate and long-term effects of talocrural manipulation on the bowling speed at the professional level of cricket.

A strength of this study was the use of a homogeneous sample and the inclusion of a control, which strengthens the validity of the interventional group. Additionally, the significant

improvements observed following a single TLAM session highlight the potential for immediate performance benefits.

However, there are a few limitations which should be noted. The study assessed only the immediate post-intervention effects; the duration of these observed benefits remains unknown. The study employed a single-rater method for measuring ankle ROM. Furthermore, the study only examined the effect of TLAM on male cricket pace bowlers, and the findings cannot be applied to female cricket until further research is conducted. While the sample size was appropriate for the eThekweni Municipality and provided preliminary findings, additional research with larger cohorts is warranted to confirm the findings across the broader cricket population. Future research should investigate the impact of ankle manipulation on the sagittal motion and performance of female pace bowlers, and include an inter-rater method of goniometer measurements or more sensitive measurement instruments

Conclusion

This study was the first to investigate the effect of TLAM on cricket pace bowling speed and its relationship with ankle ROM. Significant results were observed in the intervention group, with an increase in bowling speed and ankle ROM in both dorsiflexion and plantarflexion. No significant differences were observed in the control group for either bowling speed or ankle ROM. Furthermore, the backfoot of the participants in Group A, which did not receive the intervention, also showed no significant increase in ankle ROM.

The results are likely to be useful for sports chiropractic management of cricket pace bowlers and highlights the essential role chiropractors can have within a cricket team's management and medical staff. Future research should focus on further understanding the ankle's

role during the FFC phase of pace bowling and explore the effect of ankle manipulation intervention on female pace bowling performance.

Acknowledgments

- Dr Prasanthi Nayager (private practice) for her time and off-campus supervision for this study.
- Mr Deepak Singh for his assistance with statistical analyses used in this study.
- Every cricket club, cricket coach, and club management staff for their assistance in recruiting players and providing venues for data collection.
- All the participants of this study.

Disclosure Statement

Jason Vermaak was awarded the NRF First-time Master's Research Grant to conduct the research study.

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Funding Details

This work was supported by the National Research Foundation and awarded to Jason Vermaak under Grant Number: PMDS23041593168

Appendices (As Appropriate); Table(S) With Caption(S) (On Individual Pages); Figures

Table 5.1. Ankle Range of Motion Data Analysis.

Group	ROM	Mean from pre- to post-intervention $\pm$ SD (°)	95% Confidence intervals		<i>p</i> -value
			Lower	Upper	
A	Dorsiflexion FF	-9.0 $\pm$ 6.7	11.6	-6.4	<0.001
	Dorsiflexion BF	-1.3 $\pm$ 4.9	-3.3	0.6	0.173
	Plantarflexion FF	7.1 $\pm$ 6.8	4.5	9.9	<0.001
	Plantarflexion BF	1.7 $\pm$ 3.6	0.2	3.1	0.025
B	Dorsiflexion FF	-1.0 $\pm$ 3.7	-2.5	0.4	0.152
	Dorsiflexion BF	0.9 $\pm$ 6.0	-1.5	3.2	0.484
	Plantarflexion FF	1.2 $\pm$ 5.2	-0.9	3.2	0.266
	Plantarflexion BF	0.3 $\pm$ 4.0	-1.2	1.9	0.665

Correlation is significant at the 0.05 level (two-tailed)

FF = Front Foot

BF = Back Foot

Table 5.2. Bowling Speed Data Analysis.

Group	Mean $\pm$ SD (km·h ⁻¹)	95% Confidence intervals		<i>p</i> -value
		Lower	Upper	
A	5.4 $\pm$ 7.2	2.6	8.3	<0.001
B	0.3 $\pm$ 4.7	-1.6	2.1	0.775

Correlation is significant at the 0.05 level (two-tailed)

Table 5.3. Multivariate tests for a combined set of dependent variables.

Effect	Test	Value	F	Hypothesis df	Error df	<i>p</i> -value	Partial Eta ²
Intercept	Pillai's Trace	0.064	0.7	5.0	47.0	0.664	<0.1
Age	Pillai's Trace	0.032	0.3	5.0	47.0	0.907	<0.1
Group	Pillai's Trace	0.488	9.0	5.0	47.0	< 0.001	0.5

Computed using alpha = 0.05

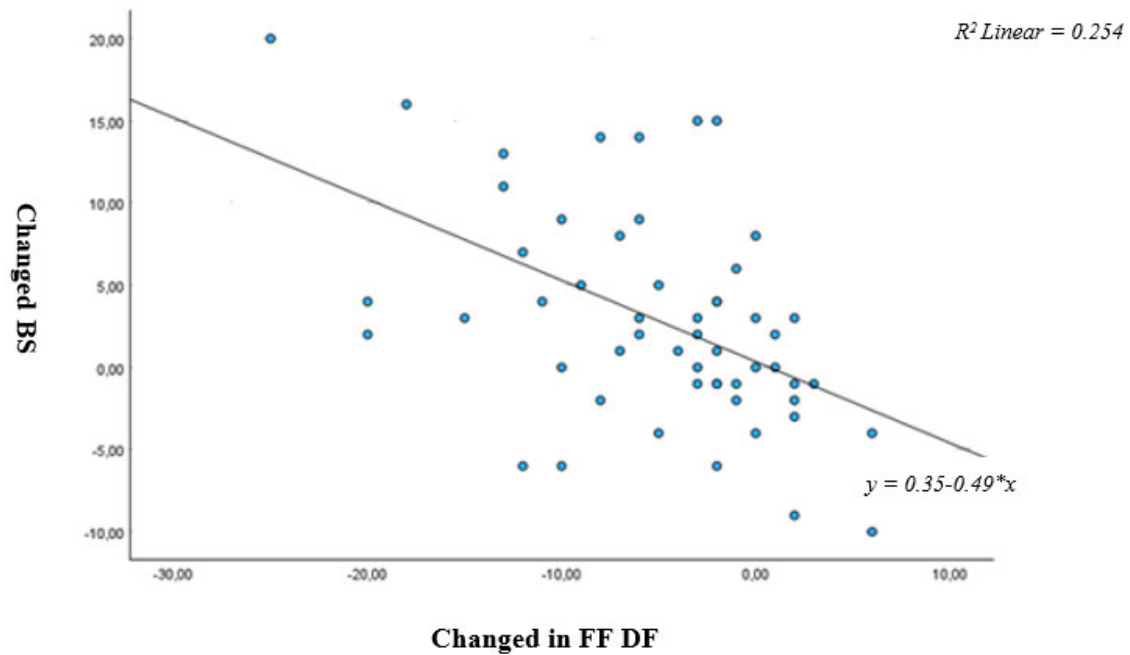
* = Significant value

Table 5.4. ANOVA test of between-participant effects for key outcomes.

Dependent variable	Mean square	F	<i>p</i> -value	Partial eta squared
Change in Front Foot Dorsiflexion	856.3	29.1	<0.001*	0.4
Change in Front Foot Plantarflexion	497.4	13.2	0.001*	0.2
Change in Back Foot Dorsiflexion	69.4	2.3	0.133	<0.1
Change in Back Foot Plantarflexion	23.9	1.6	0.208	<0.1
Change in Bowling Speed	355.5	9.5	0.003*	0.2

Computed using alpha = 0.05

Figure 5.1. Scatterplot with trendline of the correlation between the change in bowling speed and the change in front foot dorsiflexion ROM.



Key: BS = Bowling speed
FF = Front Foot
DF = Dorsiflexion

Word Count

Report: 3032

Total: 3819

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APPENDIX 1: ETHICS CLEARANCE NUMBER



Institutional Research Ethics Committee
Research and Postgraduate Support Directorate
2nd Floor, Berwyn Court
Gate 1, Steve Biko Campus
Durban University of Technology
P O Box 1334, Durban, South Africa, 4001
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www.dut.ac.za

19 March 2025

Mr J Vermaak
3 Van der Stel Avenue
Kenridge
Cape Town

Dear Mr Vermaak

The immediate effect of long-axis talocrural manipulation and sham laser on sagittal motion of the ankle joint and bowling speed of club cricket pace bowlers in the Ethekwini Municipality
Ethical Clearance number IREC 243/24

The DUT-Institutional Research Ethics Committee acknowledges receipt of your gatekeeper permission letters.

Please note that FULL APPROVAL is granted to your research proposal. You may proceed with data collection.

Any adverse events [serious or minor] which occur in connection with this study and/or which may alter its ethical consideration must be reported to the DUT-IREC according to the DUT-IREC Standard Operating Procedures (SOP's).

Please note that any deviations from the approved proposal require the approval of the DUT-IREC as outlined in the DUT-IREC SOP's.

It is compulsory for a student or researcher to apply for recertification on an annual basis. The failure to do so will result in withdrawal of ethics clearance. It is the responsibility of the researcher and the supervisor to apply for recertification.

Please note that you are required to submit a Notification of Completion of Study form together with an abstract to the DUT-IREC office on completion of your study.

Yours Sincerely

Dr T E Khoza
Deputy Chairperson: DUT-IREC

APPENDIX 2: LETTER OF INFORMATION



LETTER OF INFORMATION

Title of the Research Study: The immediate effect of long-axis talocrural manipulation and sham laser on sagittal motion of the ankle joint and bowling speed of club cricket pace bowlers in the Ethekwini Municipality.

Principal Investigator/s/researcher: Jason Vermaak

Co-Investigator/s/supervisor/s: Dr. S. Currie (PhD. Sports Science) and Dr. J. Shaik (M. Tech. Chiro.; M. Med. Sci. (SM))

Brief Introduction and Purpose of the Study: To determine if talocrural long-axis manipulation or laser application has any effect on sagittal ankle motion and bowling speeds in pace bowlers.

Greeting:

Dear participants, I am a 6th year Masters in Chiropractic student that is currently completing a research dissertation and I would like to invite you to participate in the research.

What is Research:

Research is a systemic investigation to acquire new knowledge, establish facts and reach conclusions. The aim of this research is to acquire new information into cricket pace bowling and the factors that affect bowling speed.

Procedure: The consultation: A case history and orthopaedic examination of the ankle will be done behind a screened-off area. After this, you will be assigned to one of two intervention groups depending on which piece of numbered paper you pick from a bag i.e. Group 1 (manipulation) or Group 2 (laser). You will then bowl 6 deliveries as a warm-up. Your ankle's range of motion (or amount of movement) will be measured using a goniometer (a simple non-invasive device). You will then be asked to bowl as fast as you can for 6 deliveries and the speeds will be measured by a bowling speed device (radar). Depending on which group you were allocated to, the appropriate intervention will be applied. Your ankle's range of motion will be measured again as before and you will then be asked to bowl as fast as you can for 6 deliveries and again the bowling speed will be measured. The consultation is expected to last about one and a half hours.

Risks/Discomforts: All consultations are supervised by a registered, qualified chiropractor. Ankle manipulation may cause transient (short interval) discomfort to the ankle. There are no other discomforts expected with this intervention. Laser therapy is completely safe and no side effects are expected.

Remuneration and Costs: There are no financial or other rewards offered in this study. All subjects will qualify for one free consultation pertaining to a musculoskeletal complaint (e.g. back pain, shoulder pain, knee pain, etc.) within 1 year after participation in this study at the Chiropractic

Day Clinic. There are no costs to you for taking part in this study.

Confidentiality: Your name will not be revealed in the data sheets. All names will be coded and this will be used during data analysis. Only the researcher and his supervisor will have access to the data. If you have any queries about this study, which have not been satisfactorily explained by the researcher, please do not hesitate to contact the supervisor. You are not forced to take part in this study. Participation is purely on a voluntary basis. You may withdraw at any stage of this study with no negative repercussions whatsoever.

Results: The dissertation will be available online for all participants to view.

Research-related Injury: In the unlikely case of injury or adverse reaction a qualified Chiropractic will be onsite to assess the injury. As per remuneration each participant will receive one free treatment at the DUT Chiropractic Day Clinic.

Storage of all electronic and hard copies including tape recordings: All electronic copies of data will be stored on an encrypted hard drive with only the researcher and supervisors allowed access. All hard copies will be stored for a period of five years in a secure location at the Durban University of Technology: Department of Chiropractic.

Persons to contact in the Event of Any Problems or Queries: Please contact the researcher (0761621451), my supervisor (083 779 0358) or the DUT-Institutional Research Ethics Administrator on 031 373 2375. Complaints can be reported to the Acting Director: Research and Postgraduate Support on researchdirector@dut.ac.za

If you agree to participate in this study, please sign the attached informed consent form

APPENDIX 3: INFORMED CONSENT



Full Title of the Study: The immediate effect of long-axis talocrural manipulation and sham laser on sagittal motion of the ankle joint and bowling speed of club cricket pace bowlers in the Ethekwini Municipality.

Names of Researcher/s: Jason Vermaak

Statement of Agreement to Participate in the Research Study:

- I hereby confirm that I have been informed by the researcher, _____ (name of researcher), about the nature, conduct, benefits and risks of this study - Research Ethics Clearance Number: _____.
- 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

I, _____ (name of researcher) herewith confirm that the above participant has been fully

informed about the nature, conduct and risks of the above study.

Full Name of Researcher

Date

Signature

Full Name of Witness

Date

Signature

APPENDIX 4: MEDICAL CASE HISTORY



By signing, you as the participant agree that you have been given a chance for informed consent (to both be assessed and treated) and also to have data collected for the research study you are attending, in respect of your condition(s) to be documented in research – without disclosure of your name or other identifying details.

Signature: _____ Date: _____
 Name: _____ Occupation: _____
 Race: _____ Age: _____ Sex: _____

History of complaint:	Past medical history: Family history: Systems review:
Assessment of findings Physical evaluation:	Ankle regional:
Diagnosis:	
Comments:	

Supervising Chiropractor: _____ Researcher: _____
 Name: _____ Name: _____
 Signature: _____ Signature: _____

APPENDIX 5: BOWLING SPEED RECORD SHEET

Participant no.	Pre-test bowling speed			Post-test bowling speed		
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APPENDIX 6: ANKLE RANGE OF MOTION RECORD SHEET

[illegible]

APPENDIX 7: PROOF OF MANUSCRIPT SUBMISSION TO JOURNAL



Dear Junaid Shaik,

Thank you for your submission.

Submission ID	258433242
Manuscript Title	Ankle Mobility for Increased Performance: The Impact of Talocrural Manipulation on Bowling Speed in Cricket Pace Bowlers
Journal	Journal of Sports Sciences

If you made the submission, you can check its progress and make any requested revisions on the [Author Portal](#)

Thank you for submitting your work to our journal.

If you have any queries, please get in touch with RJSP-peerreview@journals.tandf.co.uk.

Kind Regards,

Journal of Sports Sciences Editorial Office

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APPENDIX 8: COMPARATIVE ANALYSIS OF PARAMETRIC AND NON-PARAMETRIC TESTS

Outcome	Test Type	Group(s) / Comparison	Parametric Test & Result	Non-Parametric Test & Result	Change in Significance
Front-foot dorsiflexion (°)	<i>Within-group</i>	Intervention (TLAM)	Paired t-test $p < 0.001$ ↑ significant increase	Wilcoxon $W = 9.5$, $Z = -4.98$, $p < 0.001$ ↑ significant increase	No change
		Control (Sham)	Paired t $p > 0.05$ – no change	Wilcoxon $W = 88.0$, $p = 0.694$ – no change	No change
	<i>Between-group</i>	Intervention vs Control (change scores)	Independent t $p < 0.001$	Mann–Whitney $U = 83.0$, $p = 0.000001$	No change
Back-foot dorsiflexion (°)	<i>Within-group</i>	Intervention (TLAM)	$p > 0.05$	Wilcoxon $p = 0.162$	No change
		Control (Sham)	$p > 0.05$	Wilcoxon $p = 0.323$	No change
	<i>Between-group</i>	Intervention vs Control	$p > 0.05$	Mann–Whitney $U = 257.0$, $p = 0.062$	No change
Front-foot plantarflexion (°)	<i>Within-group</i>	Intervention (TLAM)	$p < 0.001$ ↑ significant increase	Wilcoxon $W = 17.0$, $Z = 4.03$, $p < 0.001$ ↑ significant increase	No change
		Control (Sham)	$p > 0.05$	Wilcoxon $p = 0.349$	No change
	<i>Between-group</i>	Intervention vs Control	$p < 0.001$	Mann–Whitney $U = 572.5$, $p = 0.000316$	No change
Back-foot plantarflexion (°)	<i>Within-group</i>	Intervention (TLAM)	$p > 0.05$	Wilcoxon $p = 0.754$	No change
		Control (Sham)	$p > 0.05$	Wilcoxon $p = 0.754$	No change
	<i>Between-group</i>	Intervention vs Control	$p > 0.05$	Mann–Whitney $U = 408.0$, $p = 0.454$	No change
Bowling speed (km·h⁻¹)	<i>Within-group</i>	Intervention (TLAM)	Paired t $p < 0.001$ ↑ significant increase	Wilcoxon $W = 50.0$, $Z = 3.19$, $p = 0.001$ ↑ significant increase	No change

		Control (Sham)	$p > 0.05$	Wilcoxon $p = 0.773$	No change
	<i>Between-group</i>	Intervention vs Control	$p = 0.001$	Mann–Whitney $U = 547.0$, $p = 0.0016$	No change

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