RELATIONSHIPS BETWEEN HIP RANGE OF MOTION, SPRINT KINEMATICS AND KINETICS IN TRACK AND FIELD ATHLETES

Brodie Hewlett

A thesis submitted to Auckland University of Technology in partial fulfillment of the requirements for the degree of Master of Sport and Exercise (MSpEx)

2013

School of Sport and Recreation

Table of Contents

List of Figures

List of Tables

Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Signed: 

Date: 9 May 14

Acknowledgements

I would firstly like to acknowledge my primary supervisor Prof. Mike McGuigan for his expert guidance and valuable contributions to this thesis. In particular, thank you for addressing issues and reviewing draft chapters promptly, it was hugely appreciated. Also, to my secondary supervisor Dr. Matt Brughelli, thank you for your expertise and input towards this research.

I would like to give special thanks to Matt Cross. Your contributions to the collection and analysis of data were invaluable and I look forward to more collaboration in the future. I would also like to thank Prof. Will Hopkins for use of his spreadsheets in the data analysis.

I also wish to thank the athletes that participated in this research, without your contribution this research would not be possible.

To my family, friends, work colleagues, and everyone else that supported me throughout this year, and over my entire academic journey, thank you.

Finally, I would like to dedicate this thesis to my late father, Des Hewlett. Thank you for everything you have given and taught me over the years.

Ethical Approval

Ethical approval for this research was obtained from the AUT Ethics Committee (reference 12/338) on the 19th December 2012 (see Appendix 1).

Abstract

Hip range of motion (ROM) may influence movement kinematics and kinetics during sprinting. The purpose of this research was to investigate the relationships between hip ROM and measures of sprint kinematics and kinetics in track and field athletes, and to assess changes in these variables at different stages of the athletics season. Nineteen national-level track and field athletes undertook testing procedures for kinematic and kinetic assessment. Twelve participants returned to the laboratory 12 weeks later to carry out the same testing procedures. Clinical assessments of static and active hip ROM were conducted using a Thomas test and the active straight-leg raise. The kinematic data were collected from over-ground 40 m sprint trials recorded at 240 Hz and the kinetic data were obtained from a non-motorised treadmill with in-built load cells. The reliability of these assessments were analysed via intraclass correlation coefficients and typical error. Pearson correlation coefficients were used to examine the relationships between the kinematic and kinetic variables and the change scores between testing occasions were analysed by calculating the percentage change and effect sizes to make magnitude-based inferences. The results showed that all assessments had good reliability apart from hip extension (HE) angular velocity. Correlational analysis revealed very large correlations between dynamic hip flexion (HF) ROM and HE angular velocity ($r = 0.76$), and very large negative correlations between dynamic HF ROM and pelvic angle at peak HE ($r = -0.71$), as well as peak running velocity and ground contact time ($r = -0.73$). There was also a large correlation shown between dynamic HE ROM and pelvic angle at peak HF ($r = 0.55$), and large negative correlations shown between angular HF velocity and contact time ($r = -0.61$), and angular HE velocity and pelvic angle at peak HE ($r = -0.69$). Changes in the kinematic and kinetic variables were shown to be trivial between testing occasions. In conclusion, the high reliability shown for clinical measures of hip ROM and assessment of sprint kinematics and kinetics makes these tests useful for researchers and practitioners. Furthermore, the observed correlations between measures of hip ROM and sprinting kinematics and kinetics have implications for the development of technical sprinting abilities such as achieving a high degree of dynamic HF ROM to maximize HE angular velocity. The correlations between dynamic hip ROM and pelvic angle during running may also have implications for reducing vertebral impingement and hamstring strain injuries.

Chapter 1: Introduction

There is considerable interest as to whether increased flexibility will improve sports performance. Previous reviews have concluded that pre-exercise stretching and regular flexibility training promotes better sports performance (Shellock & Prentice, 1985; Shrier, 2004) but this notion has been subject to much conjecture with Blum and Beaudoin (2000) arguing that it is likely dependent on the sport and playing position in question. Muscle flexibility represents the extensibility of a muscle-tendon unit when stretched and stretching techniques are accepted as the most effective method for developing flexibility. A clinical assessment of muscle flexibility typically involves measuring joint range of motion (ROM) with the assumption that peak ROM is limited by muscle extensibility. Numerous studies have highlighted this dependence by showing improved ROM following both acute (McChellan, Padua, Guskiewicz, Prentice, & Hirth, 2004; McNair & Stanley, 1996; Whatman, Knappstein, & Hume, 2006) and chronic (Hortobagyi, Faludi, Tihanyi, & Merkely, 1985; LaRoche & Connolly, 2006; Mahieu et al., 2007; Marshall, Cashman, & Cheema, 2011; Meroni et al., 2010; Nakamura, Ikezoe, Takeno, & Ichihashi, 2012; Reid & McNair, 2004) doses of stretching. Because most joints have more than one muscle passing over the articulation, ROM measures generally reflect the extensibility of a muscle group or complex rather than a single isolated muscle.

There are several different types of flexibility, which include static, dynamic, passive and active flexibility. The relationships between each type of flexibility are still unclear, however the available data suggests each type may exhibit some independence (Young, Clothier, Otago, Lyndell, & Liddell, 2003). Indeed it has been shown that changes to specific ROM measures are best achieved by applying the relevant type of stretching (Meroni et al., 2010), that is, active stretching will improve active ROM more than static stretching, and vice-versa.

Flexibility Training, Performance and Muscle Function

The importance of flexibility training is obvious when sport success is explicitly dependent on achieving high degrees of joint ROM, hence flexibility was shown to be positively correlated to success in rhythmic gymnastics (Hume, Hopkins, Robinson, Robinson, & Hollings, 1993). Aside from increasing ROM, there are data showing the benefits of stretching for enhancing athletic performance (Kokkonen, Nelson, Eldredge, & Winchester, 2007; Shrier, 2004). In practice though, many athletes and coaches appear to place a low emphasis on flexibility and seldom include specific flexibility training in the structured training routine. Consequently, anecdotal evidence suggests that athletes often neglect stretching, particularly when training time is limited. However, studies have shown that static and passive stretching can acutely alter the viscoelastic behaviour of a muscle-tendon unit (Bressel & McNair, 2002; Cornwell, Nelson, & Sidaway, 2002; Hobara, Inoue, Kato, & Kanosue, 2011; Kato, Kanehisa, Fukunaga, & Kawakami, 2010; Kubo, Kanehisa, Kawakami, & Fukunaga, 2001; Nordez, Cornu, & McNair, 2006; Whatman et al., 2006) and this appears detrimental to performance tasks that have high force and fast contraction speed characteristics. Indeed, sprinting and jumping demand both high forces and fast contraction speeds; hence sprint and jump performance are often decreased immediately after lower body static stretching (Fletcher & Anness, 2007; Fletcher & Jones, 2004). However, a recent review showed that the detrimental effects of pre-exercise static stretching may only be realised when the stretch duration is longer than 60 seconds (Kay & Blazevich, 2012), suggesting that the effects may be dose dependent.

Chronic doses of stretching also appear to cause changes to the viscoelastic properties of muscles and tendons (Mahieu et al., 2007; Marshall et al., 2011; Nakamura et al., 2012; Reid & McNair, 2004) but, paradoxically, produce confounding effects on explosive performance outcomes, with improvements (Gajdosik, Vander Linden, McNair, Williams, & Riggin, 2005; 2007), reductions (Fletcher & Anness, 2007; Fletcher & Jones, 2004) and no changes (Bazett-Jones, Gibson, & McBride, 2008; Yuktasir & Kaya, 2009) in sprinting, jumping and agility performances all reported in the literature. The reported performance improvements may be due to enhanced muscle function. Hortobagyi and colleagues (Hortobagyi et al., 1985) showed that regular and chronic passive stretching can increase both the force development and contraction speed of muscle. The more recent work of Kokkonen and colleagues supports this notion by showing that large doses of static stretching considerably improved muscle strength (Kokkonen et al., 2007; Kokkonen, Nelson, Tarawhiti, Buckingham, & Winchester, 2010; Nelson et al., 2012), and one of the studies also reports a small improvement in sprint performance following 10 weeks of lower-extremity stretching (Kokkonen et al., 2007). Thus it is imperative that we advance our understanding of how muscle flexibility affects high force/contraction speed tasks such as sprinting.

Hip Range of Motion and Sprinting Kinematics

Anecdotally it appears common for sprinters to have limited static ROM around the hip joint. It is known that the hip muscles contribute significantly to the propulsive forces generated during running (Sozen, 2010) so athletes with limited static hip ROM may be negatively affected if there are changes in muscle functionality. Few efforts have been made to determine the influence of hip flexibility on measures of sprint performance. In one study, six weeks of hamstring stretching did not improve 55-metre sprint times (Bazett-Jones et al., 2008). In contrast, Kokkonen et al. (2007) found that 10 weeks of static stretching resulted in a significant 1.3% improvement in 20-metre sprint performance with a concomitant 18.1% increase in flexibility. Meanwhile, Meckel, et al. (1995) found no differences in hamstring flexibility between sprinters at different performance levels.

While research on the relationships between hip ROM and sprint times is limited and equivocal, the relationships between clinical hip ROM measures and sprinting biomechanics have received even less attention. Furthermore, most sprinting studies (Bazett-Jones et al., 2008; Meckel et al., 1995) have focused on hamstring flexibility only, while little attention has been paid to the hip flexors. It would be useful for researchers and practitioners to know whether clinical measures of hip ROM strongly relate to sprinting kinematics and kinetics to further understand the implications of flexibility training on sprint performance.

Additionally, maintaining or improving flexibility is often a training objective of athletic programmes. Gleim and McHugh (1997) suggest that flexibility may be largely determined by the nature of training undertaken for a specific sport. As long as the training modes that improve flexibility offset the activities that reduce it then a net gain in flexibility will result. For example, taekwondo training has been shown to improve flexibility (Hyun-Bae, Stebbins, Joo-Hee, & Jong-Kook, 2011) probably because the training includes a relatively large volume of stretching that offsets the other training activities that reduce ROM. However, when multiple fitness components are trained at once, the overall effect on flexibility may be diverse because within a training programme, some of the training activities improve flexibility, some decrease flexibility and some may have no effect at all. Most importantly, there appear to be some interactions between different fitness components trained simultaneously and flexibility. Nóbrega et al. (2005) brought to light these interactions by showing that flexibility training alone improved ROM 33% while resistance training alone did not change ROM, but the same stretching and resistance training combined only increased ROM by 18% i.e. to a lesser extent than flexibility training alone. Thus, while some training activities such as stretching may increase flexibility, other activities such as resistance training may negate the flexibility gains when the two activities are combined within sessions or within training days/weeks, even though resistance training or other particular training modes do not necessarily reduce flexibility when trained in isolation.

Athletic training programmes often include numerous different training activities performed in different combinations making the overall effect on flexibility difficult to forecast. For example, a 10-week football (soccer) training programme that predominantly included running and excluded a structured stretching routine improved sit and reach test scores by 6% (Miranda, Antunes, Pauli, Puggina, & da Silva, 2013). Track and field athletes also typically undergo a wide variety of combined training activities within an annual training programme, including weight training, sprinting, running, plyometrics, core strengthening, stretching, and co-ordination drills. While some of these training modes have been shown in the literature to exhibit independent effects on flexibility (Kwang-Jun, 2010; Nóbrega et al., 2005), the effect of these training activities in different combinations is relatively unknown.

Training-Related Changes in Range of Motion

If the nature of the training activities influences flexibility then ROM may change across different training phases, because training activities usually change between macrocycle and mesocycle phases. Gaining insight into the seasonal (macro and mesocycle) changes in flexibility would inform coaches whether more or less stretching and flexibility training should be included in the training programme in order to maintain or improve ROM at certain time-points. Changes in flexibility across or within the training mesocycles of a track and field programme have not been extensively researched. Makaruk and Makaruk (2009) monitored the hamstring flexibility of a group of sprinters within the specific preparation training period and observed that ROM changed significantly during the nine week training period. A secondary finding of these authors was that flexibility was at its lowest when the amount of high intensity (anaerobic) exercise was greatest thus underlining the influence of training activities on flexibility. At present, there are no additional studies that support these findings, therefore further research is vital to advance understanding in this area.

Research Questions

This research project will investigate the relationships between clinical measures of hip ROM and sprinting kinematics and kinetics. The second study will assess these measures in a group of sprinters at different stages of the sprint season to observe the changes. This approach will advance our understanding as to whether relationships between hip ROM and sprinting kinematics and kinetics are of practical significance, and whether these measures change at different time-points. It is also hoped the information yielded from this research will direct and drive subsequent human experiments and biomechanical modeling research, to help further understand the relevance of flexibility in sprint performance.

There are some specific issues that these studies will address; the first is whether relationships of a large magnitude exist between clinical measures of static and active hip ROM and the ROM used during sprinting. There is likely to be an optimal amount of dynamic ROM that sprinters move through to produce the most efficient movement and the optimal ground reaction forces (i.e. direction and magnitude), but it is not conclusive whether the dynamic ROM achieved by track sprinters is dependent on static and/or active ROM. There is a paucity of data comparing ROM qualities measured clinically to dynamic ROM during sprinting.

Another question that needs answering is whether there are strong relationships between ROM measures and other kinematic measures during sprinting. It is suggested that limited static hip extension ROM (caused by tight hip flexors) is a potential cause for increasing anterior pelvic tilt and this appears to restrict dynamic hip extension during running (Schache, Blanch, & Murphy, 2000). Such restrictions in hip extension ROM could adversely affect stride length and other kinematic measures, but evidence to support this stance is needed.

It is unknown whether dynamic hip ROM during sprinting influences ground reaction forces. Altering the amount of hip flexion and extension could change both the magnitude and direction of the forces that are applied. It is plausible that a greater dynamic hip extension ROM could increase the magnitude and direction of horizontal force applied to the ground. On the contrary, the increased ground contact time may offset the benefits if little additional force is produced (Weyand, Sternlight, Bellizzi, & Wright, 2000). There is no data showing the relationships between dynamic hip ROM and ground reaction force characteristics during sprinting, thus investigation of this is worthwhile.

Consideration must be given to whether sprinters have similar hip ROM and sprinting mechanics during the in-season and the off-season. The observation that sprinters have relatively little static hip ROM may be a consequence of the type of training undertaken (Makaruk & Makaruk, 2009). Sprinters' training regimes are typically predominated by sprinting, plyometrics and weight training. Studies have shown that heavy resistance exercise (Albracht & Arampatzis, 2013; Burgess, Connick, Graham-Smith, & Pearson, 2007) and plyometric training (Burgess et al., 2007; Ducomps et al., 2003; Four, Nordez, Guette, & Cornu, 2009) increase muscle-tendon stiffness. Because changes in stiffness seem to coexist with changes in ROM (Nakamura et al., 2012; Whatman et al., 2006), hip ROM in sprinters may change depending on the stage of the season and associated phase of training. More specifically, during the competitive season when the imposed training demands are high, hip ROM may be expected to decrease due to increased muscle-tendon stiffness, whereas following the transition phase at the start of the off-season, the muscles may gain compliance and increase ROM accordingly. To that end, it would be valuable to see whether hip ROM measured during the competition season differs to that measured in the off-season.

Purpose Statement

The purpose of this research is two-fold; 1) to examine the magnitude of the relationships between measures of hip ROM and sprint kinematics and kinetics in track and field athletes, and 2) to assess changes in hip ROM during and after the sprinting season.

Significance of the Research

Practitioners involved in the assessment and implementation of athletic training programmes are concerned with identifying and improving the factors that limit performance. This investigation will add knowledge in this research area by firstly outlining the relationships between clinical ROM measures and sprinting kinematics and kinetics. The significance of this to practitioners is that it will help them develop best practice in the assessment and monitoring of hip ROM. Secondly; the research will examine the correlations between the hip ROM measures and selected biomechanical measures of sprinting. These data are of significance to practitioners as biomechanical measures such as joint angles, ROM, force production and body position provide limitations to performance. Providing practitioners with this information will help them determine appropriate interventions seeking specific mechanical and/or physiological changes to ultimately improve performance. Finally, comparing the ROM measures during and after the competitive season will determine whether or not ROM changes in competitive sprint athletes.

Study Limitations

The limitations of the study are:

1. The sample size is small, due to a limited amount of track and field athletes available to study.
2. The kinetic data were obtained from treadmill sprinting and therefore may have limitations in the generalisability to overground sprinting due to slight kinematic differences in running technique.
3. The videographic data were obtained in 2-D limiting measurement to the sagittal plane only.

Study Delimitations

The study is delimited to:

1. Male and female track and field athletes aged 14-30 with at least one year of experience in structured sprint training and free from injury and illness. The generalisability of the results is therefore limited to a small population.
2. The kinematic data were obtained from overground sprinting rather than treadmill sprinting. This was done to improve the validity to overground sprint running.
3. Clinical measures of static and active ROM; measures of dynamic ROM, pelvic angle, angular hip velocity, contact time, and maximal running velocity during overground sprinting; and vertical ground reaction forces and horizontal forces during non-motorised treadmill sprinting. Other kinematic and kinetic measures were not considered.

Chapter 2: Literature Review: The Influence of Hip Range of Motion on Human Movement

Introduction

Many physiological and mechanical factors influence movement quality in sport, but some factors are better understood than others. One factor that remains poorly understood is joint ROM, and specifically, how it influences movement kinematics. Understanding the effect that joint ROM has on movement is critical to fully elucidate the importance of developing or maintaining muscle flexibility and joint ROM to perform sporting tasks most effectively and/or efficiently.

A lack of hip joint ROM in particular could affect a number of important kinematic variables during movement. In performing movements such as running, jumping and kicking – which are common movements in sports – hip ROM is of particular interest given the large ROM that this joint moves through and the contribution that the surrounding hip muscles make in executing these movements (Debaere, Delecluse, Aerenhouts, Hagman, & Jonkers, 2013; Sozen, 2010). Furthermore, the dependence between hip joint motion and the lumbo-pelvic complex (Crosbie & Vachalathiti, 1997) may have important implications for the prevention and rehabilitation of dysfunction and injury in the lumbar-pelvic-hip region.

A greater knowledge of this topic will advise clinicians and other practitioners of the relative significance of hip-joint ROM in influencing lower-body movement quality, thus guiding practice to improve the effectiveness of flexibility assessment and physical training programmes. Therefore, the purpose of this review is to present the current evidence regarding how measures of hip ROM influence lower-body movement.

Relationships Between Different Measures of Range of Motion

It is important that the differences between the various types of flexibility be distinguished. Range of motion can be measured in a number of ways including static, dynamic and active measurement. Static flexibility refers to the possible ROM around a joint during a passive movement requiring no voluntary muscular activity, while dynamic flexibility refers to the available joint ROM during active movement and therefore requires voluntary muscle activation (Baechle & Earle, 2008). Active flexibility is similar to dynamic flexibility but involves more controlled movement and requires the end ROM to be held for a short period of time (Meroni et al., 2010). In relation to sports performance, static, active and dynamic ROM all seem applicable to the execution of specific tasks; for example, many kicking tasks require a high degree of dynamic hip ROM, while gymnastics and ballet routines generally require a large amount of active and static ROM.

Unfortunately it is not uncommon for practitioners to confuse the various types of flexibility, particularly with respect to the measurement of static and active ROM. Moreover, the associations between each of these ROM measures are often misunderstood, where static ROM measurement is sometimes interpreted to reflect active ROM measurement, and inferences are also made about dynamic ROM from the results of static and active ROM assessment data. Such inferences need to be carefully considered as the available correlational data indicates that each type of flexibility is a somewhat independent measure (Moscov, Lacourse, Garhammer, & Whiting, 1994; Schache et al., 2000). The correlation data however, is scarce, and limited to static and dynamic ROM comparisons only; Schache et al. (2000) found no significant correlation (R^2 = 0.004) between static hip extension measured using a Thomas Test, and dynamic hip extension ROM during running on a treadmill. Meanwhile, research on female ballet dancers of varying levels revealed only low correlations (r = 0.33) between static hip extension and flexion, and dynamic ROM of the hip joint during dance performance (Moscov et al., 1994). On the other hand, a study conducted on AFL players revealed significant correlations between static hip extension ROM, measured in a Thomas test, and maximal hip extension (r = 0.65) during a maximal drop-punt kick (Young et al., 2003).

Several reasons could be speculated to explain the inconsistencies in the correlations. A simple explanation could be put down to the movement task used in the dynamic ROM assessment, and whether it requires maximal joint ROM. For example, dynamic ROM during submaximal running at 20 km/h on a treadmill as measured by Schache et al. (2000) does not necessarily require maximal hip extension, in fact, the amount of hip extension only needs to be sufficient to produce the propulsive forces required to maintain that speed. Young et al. (2003) on the other hand, measured dynamic ROM during a maximal kicking task where maximal hip extension is desired to achieve a more powerful kick. Discrepancies in ROM findings may also be attributed to the familiarity of the exercise mode used in testing. It would be expected that the elite runners used by Schache et al. would undertake very little, if any, treadmill running in their typical training regime. This is unlike the AFL players (Young et al., 2003) and gymnasts (Moscov et al., 1994) who were assessed during tasks they are likely to perform regularly. From this standpoint, it would be interesting to investigate whether hip ROM differs between overground running and treadmill running in elite runners at both maximal and submaximal speeds.

Somewhat surprising is the fact that the relationship between active and dynamic hip ROM has not been investigated. Hypothetically, active ROM should have more similarity with dynamic ROM compared to static ROM because both active and dynamic ROM assessment involves movement that is limited by the strength of the agonist and the extensibility of the antagonist muscles. In other words, an increase in hip flexor strength is expected to increase active and dynamic hip-flexion ROM without a concomitant change in hip extensor muscle extensibility, due to the increased capacity of the hip flexors to overcome the stretch-imposed resistance produced by the antagonistic extensor muscles. Furthermore, both active and dynamic stretching techniques are based on reciprocal inhibition where a contraction of the agonist should theoretically inhibit the antagonist allowing it to relax during stretch (Meroni et al., 2010). It is clear that further research is needed to examine the relationship between active and dynamic ROM.

Despite the lack of correlational data between static, active and dynamic ROM, insights into the inter-relationships of these measures can be gleaned from experimental research, by determining whether a specific mode of stretching affects multiple ROM measures, or whether the different ROM measures change concurrently during and following specific stretching interventions. Some longitudinal studies have shown that chronic adaptation to a particular stretching intervention (static, active or dynamic) is fairly specific (Meroni et al., 2010; Youdas, Krause, Egan, Therneau, & Laskowski, 2003). For example, performing active stretching of the hamstrings results in greater improvements in the active knee extension test compared with static stretching (Meroni et al., 2010). Meanwhile, six weeks of static calf stretching performed for two minutes daily, failed to improve active dorsiflexion ROM (Youdas et al., 2003). In contrast to Youdas et al. (2003), other data have revealed changes in active ROM following a static stretching intervention (McChellan et al., 2004) although static ROM wasn't concurrently measured to determine whether the change scores for each ROM measure were similar. Taken together, the limited data suggests that static and active ROM are relatively independent qualities with perhaps only a minimal or moderate transference between them.

The relationship between static and dynamic ROM may be different. Caplan, Rogers, Parr, and Hayes (2009) showed that 5-weeks of static hamstring stretching resulted in a 4.9% gain in dynamic hip-flexion ROM during high-speed running. It is possible that a stronger relationship exists between static and dynamic ROM compared with static and active ROM, but it could also be speculated that changes in ROM might be realised more during explosive lower-body movements rather than in isolated ROM tests. Unfortunately, the authors (Caplan et al., 2009) did not measure the concurrent changes in static ROM throughout the intervention and no control group was used for comparison, therefore claiming a cause-and-effect relationship between static stretching and dynamic ROM in this study is problematic.

Data from acute training studies could also be considered to determine whether stretching that acutely increases one measure of ROM also affects another measure of ROM. Again, most studies are limited to static and dynamic ROM measures. Cronin, Nash, and Whatman (2008) found a 2% increase in dynamic knee ROM immediately following an acute bout of static hamstring stretching. In contrast, Young, Clothier, Otago, Bruce, and Liddell (2004) found no differences in dynamic hip ROM during football kicking when they compared a warm-up that included static stretching of the hips with a warm-up consisting of running only. Similarly, a static stretching warm-up resulted in no increase in hip-joint range of motion during instep kicking in football (Amiri-Khorasani, Abu Osman, & Yusof, 2011). A possible explanation for the lack of ROM changes in these studies is that the short bout of static stretching failed to improve static ROM enough to influence dynamic ROM. Indeed, the warm-up prescribed by Young et al. (2004) resulted in no change to static ROM when measured before and after the warm-up. However, further examination of the changes in ROM following acute bouts of stretching is required.

When interpreting data relating to dynamic ROM, further consideration must be given to the method of dynamic ROM assessment used. Dynamic ROM can be measured in one of two ways; either as the greatest degree of joint ROM achieved during a movement task i.e. a football kick – sometimes termed functional ROM (Alter, 1997) – *or* as the maximal joint ROM measured during an isolated dynamic movement such as a swinging the leg back and forth as high as possible. In relation to this topic – and any research seeking to uncover the links between dynamic ROM and movement quality – it seems intuitive that measuring the ROM within the specific context of the sports task is the most worthwhile measure. This is because the specificity of the measurement should relate strongly to other kinematic and kinetic measures during performance, at least compared to measuring maximal dynamic ROM in an isolated movement. In obtaining this information though, measuring dynamic ROM in an isolated movement may be more logistically feasible, and yield greater reliability when using repeated measures, which is particularly appealing to researchers.

Influence of Hip ROM on Human Movement

Joint kinematics can affect athletic performance in several ways. The joint ROM used to perform many specific sports tasks is ideally that which results in the most powerful, yet efficient, coordinated movement. Powerful movement results from optimising the force and velocity components of a joint of segment action, while minimising the amount of energy used during these actions increases movement efficiency. An additional consideration is the minimisation of injury during such movements. For these reasons, athletes train to develop both physical and technical abilities. In terms of these abilities, the static or active hip ROM that an athlete possesses in isolation is viewed as a physical ability while the ROM that an individual moves through during a performance task can be viewed as both a physical and/or technical ability. Nevertheless, these ROM variables may be implicated in optimising lower body kinematics during movement.

Joint Angular Velocity

In sport, movement quality is often quantified by the speed at which a force is applied to an external object or the ground (i.e. power), and in turn this determines how far or how fast a projectile or person travels. Joint angular velocity is one kinematic measure that can be used to assess movement quality during dynamic movements. For example, the angular velocity of the hip during hip extension in sprinting and jumping is a determining factor of performance (Hamilton, 1993), and the same applies during the rapid hip flexion performed in kicking movements (Ball, 2008).

Generating the largest angular velocities cannot be achieved over a relatively small ROM because velocity is determined by the amount of acceleration applied over a given time. Thus, obtaining a greater angular velocity around a joint is achieved by accelerating the joint through a greater dynamic ROM to allow a longer time to accelerate the limb. Supporting this, Baker and Ball (1996) showed that longer kickers of the football had greater knee flexion ROM than the shorter kickers in the Australian Football League (AFL) probably because greater limb velocity was achieved on foot contact. Also, a reduction in the dynamic ROM of the dorsiflexors is also reported to be highly correlated ($r = 0.80$) to a reduction in ankle angular velocity during repeated isolated dynamic contractions (Cheng, Davidson, & Rice, 2010), although the reduced ROM and velocity could be attributed to fatigue in this study design. In contrast, only low to moderate correlations were observed between shank angular velocity and the starting position ($r = 0.49$) and range and motion ($r = 0.32$) of the knee joint in an isolated knee extension task (Bober, Putnam, & Woodworth, 1987).

Nonetheless, dynamic hip ROM appears to influence movement quality during coordinated sports tasks when measuring performance outcome variables; for example, a greater hip ROM (Effect Size [ES] = 1.2) and hip angular velocity (ES = 0.77) were observed in the non-preferred kicking leg compared to the preferred leg during forward swing in the AFL punt kick (Ball, 2011). It is also clear through visual observation, but supported by empirical evidence (Levanon & Dapena, 1998), that football players use a greater hip extension ROM when they attempt to kick the ball for distance using a full instep kick as opposed to executing a short pass kick. Indeed, an analysis of these two kicking techniques confirms that a greater ball velocity on foot contact is accomplished with the full in-step kick (Hiroyuki, Asai, Ikegami, & Sakurai, 2002), and the angular velocity of the thigh is reported to be the main mechanical determinant of ball velocity (De Witt & Hinrichs, 2012). Collectively, these data highlight the importance of dynamic hip ROM for increasing hip joint angular velocity to produce powerful dynamic movements.

While it is evident that functional dynamic ROM is important for generating a high angular velocity, the influence of static and active ROM has not been directly investigated. However, evidence exists to suggest that static and active flexibility may affect the ability to rotate a joint at the highest possible velocity via an enhancement in muscle contraction speed (Hortobagyi et al., 1985). Indeed, significant improvements in concentric contraction speed have been reported following seven weeks of stretching that induced greater ROM (Hortobagyi et al., 1985). The stretch-related physiological mechanisms to explain the improved contraction speed remain unclear though. One possible mechanism is through a change in muscle geometry, as longer fascicles have been associated with faster contraction speeds (Abe, Kumagai, & Brechue, 2000; Kumagai et al., 2000). Despite popular belief, a chronic dose of stretching does not appear to increase fascicle length, even in the face of observed increases in ROM (Nakamura et al., 2012; Samukawa, Hattori, Sugama, & Takeda, 2011). Thus, it seems unlikely that static and active hip ROM affects hip angular velocity by increasing fascicle length. A more likely mechanism for improving contraction speed lies in altered viscoelastic properties of the muscle. Shrier (2004) suggested that increased muscle stiffness in the antagonist muscle could limit force and contraction speed of the agonist muscle because there is greater passive resistance to overcome thus requiring more energy to move the limb. Muscle stiffness is often represented by the passive torque (stress) required for a given amount of deformation (strain) in the muscle-tendon unit. It has been shown that the passive torque measured at a given joint angle is reduced following both acute (Bressel & McNair, 2002; Cornwell et al., 2002; Kato et al., 2010; Kubo et al., 2001; Magnusson et al., 1996; Nordez et al., 2006; Whatman et al., 2006) and chronic (Mahieu et al., 2007; Nakamura et al., 2012) static stretching interventions. Moreover, the concurrent increases in ROM in the longitudinal studies (Mahieu et al., 2007; Nakamura et al., 2012) suggest that increased ROM can at least be partly attributed to reductions in muscle-tendon stiffness, along with increased stretch tolerance (LaRoche & Connolly, 2006; Reid & McNair, 2004). If this is the case, then ROM improvements could yield benefits for athletes seeking faster contraction speeds and high joint velocities. However, with the limited evidence available, these relationships are still unknown.

Pelvic Tilt

Anecdotally, excessive anterior pelvic tilt is commonly observed in sprint-sport athletes. Because it is shown that pelvic tilt influences lumbar spine posture (Bridger, Orkin, & Henneberg, 1992), some suggest that greater anterior pelvic tilt is associated with a higher incidence of lower back injury. Specifically, increased anterior pelvic tilt causes greater lumbar lordosis and hyperextension of the lumbar spine (Bridger et al., 1992) which reportedly leads to repetitive impingements on the vertebral facets during running (Slocum & James, 1968). Because sprinting involves high forces being transferred through the lumbar-hip-pelvis complex, the stresses placed on these structures are likely to be magnified during sprints. Furthermore, it is suggested that lumbar-pelvic kinematics may also be implicated in resolving chronic hamstring strains (Panayi, 2010) due to the origin of the biceps femoris attaching to the ischial tuberosity of the pelvis (Abebe, Moorman, & Garrett Jr, 2009). Hamstring strains are the most prevalent injury in sprint sports (Orchard, 2001) thus it is imperative that the determinants of such injury are known.

It is purported that hip flexor and extensor flexibility has a major influence on pelvic positioning during relatively static postures (Bridger et al., 1992). Numerous studies have demonstrated that hip extension ROM influences posterior pelvic tilt during hip flexion tasks such as touching toes (Gajdosik, Hatcher, & Whitsell, 1992), sit-and-reach (Muyor, Alacid, & López-Miñarro, 2011), supine leg raise (Congdon, Bohannon, & Tiberio, 2005) and manual handling (Carregaro & Gil Coury, 2009). In addition, López-Miñarro, Muyor, Belmonte, and Alacid (2012) found that acute hamstring stretching can effectively increase anterior pelvic tilt during sit-and-reach. During forward bending tasks, anterior pelvic tilt aids in the maintenance of a neutral lumbar lordosis which is accepted as the most stable spinal position for lifting, therefore tight hamstrings that inhibit anterior pelvic tilt may predispose individuals to lower back injury. However, not all data is unanimous on this contention because Norris and Matthews (2006) found no association between hamstring length and pelvic tilt during forward bending in their study. The discrepancy in results could be due to the forward bending task used in the study because Norris and Matthews (2006) measured pelvic tilt during forward bending at a submaximal ROM, while Gajdosik et al. (1992), Muyor et al. (2011), and López-Miñarro et al. (2012) all measured pelvic tilt during maximal flexion (toe-touch or sit-and-reach), and Congdon et al. (2005) measured pelvic tilt at various trunk flexion angles up to maximal. These data imply that limited hip flexion ROM may only affect pelvic tilt when individuals are subjected to postions that are close to reaching the maximal extensibility of the hamstrings. However, the manual handling task used by Carregaro et al. (2009) only involved submaximal hip flexion ROM yet these authors still found differences in pelvic angle between individuals with flexible and inflexible hamstring muscles. Providing another explanation for the different findings are the fact that Norris and Matthews (2006) used the active knee-extension test to determine hamstring flexibility while the active or passive straight-leg raise test was used by all of the other researchers. The key difference between these two assessments is that, unlike the straight-leg raise assessment, the active knee-extension test does not provide a measure of maximal hip joint ROM, but rather it measures knee joint ROM in a fixed (90°) hip position and assumes hamstring extensibility as the limiting factor. Therefore, it is speculated that the limiting factor of the active knee-extension test is not necessarily the extensibility of the same muscles that influence pelvic tilt.

In contrast to postures involving maximal hip flexion, standing pelvic posture appears to be unaffected by hip ROM. Neither Congdon et al. (2005) or Muyor et al. (2011) found any correlations between straight-leg raise assessments and pelvic tilt during standing. Likewise, López-Miñarro et al. (2012) found that standing pelvic tilt was unchanged following acute hamstring stretching. Similar findings have been observed for the anterior hip muscles whereby Heino, Godges, and Carter (1990) found no correlations between hip extension ROM and standing pelvic tilt. In explaining these findings, Norris and Matthews (2006) suggest that the hip moment generated by the hamstrings may be insufficient to posteriorly rotate the pelvis in a standing posture because the line of action of the hamstrings is more or less vertical, and has a small moment arm in relation to rotating the pelvis. Further confounding the issue, the balance of activation between the hip and trunk muscles are also shown to affect pelvic tilt when lying prone (Tateuchi, Taniguchi, Mori, & Ichihashi, 2012), therefore muscle inflexibility may only be one of several factors influencing pelvic tilt when considering standing postures.

The relationships between hip ROM measures and pelvic tilt may be different when dynamic movements are considered. Schache et al. (2000) examined relationships between clinical hip extension ROM and anterior pelvic tilt during running and found no statistically significant correlation. Supporting data were reported by Watt et al. (2011b) who found that 10 weeks of hip flexor stretching did not decrease the anterior pelvic tilt in frail elderly individuals during walking, however this is probably because the reduced hip extension and increased anterior pelvic tilt in elderly is shown to be a dynamic rather than postural characteristic (Lee et al., 2005). Although, in a similar experiment using non-frail elderly individuals, the same 10-week hip flexor stretching protocol reduced anterior pelvic tilt by 3.8° (Watt et al., 2011a), however a statistically significant decrease in anterior pelvic tilt was also observed in the control group, bringing the quality of the study into question.

While the evidence suggests that clinical ROM has no association to pelvic tilt during running, significant correlations (R^2 = 0.70-0.80) have been reported between reduced dynamic hip extension and increased anterior pelvic tilt during running (Franz, Paylo, Dicharry, Riley, & Kerrigan, 2009; Schache et al., 2000). Importantly, the measurement of hip extension in these studies is taken as the angle of the femur relative to the pelvic angle i.e. a line drawn through the anterior and posterior iliac spines, which suggests that individuals who display reduced hip extension (relative to the pelvic angle) achieve the same amount of absolute hip extension by increasing the amount of anterior pelvic tilt. Based on this finding, pelvic tilt rather than dynamic hip ROM is more likely to be affected in those with reduced static and/or active hip ROM.

Conclusion

From the research to date, there is a lack of correlational studies examining the relationship between the different measures of hip ROM, especially between static and active ROM, and active and dynamic ROM. It is apparent though, that one type of flexibility may not necessarily be indicative of another, thus ROM assessment data should be interpreted within its specific context. In other words, a static ROM assessment may give little information on one's active ROM, while an active ROM assessment may not be reflected in a dynamic ROM assessment. Furthermore, most longitudinal studies have not assessed multiple measures of ROM, making it difficult to determine whether cause-and-effect relationships exist across various ROM measures. What is more, the applicability of data from acute stretching studies remains questionable given that residual ROM can remain unaffected with only brief one-off bouts of stretching. It is clear that further research is needed to determine the relationships between ROM measures, especially between static and active ROM and measures of dynamic ROM during specific performance tasks. In addition, longitudinal studies that assess multiple ROM measures before, during and after a stretching intervention would enable further insights into the cause-and-effect relationships between changes in one type of flexibility and another, which would further enhance our understanding of the topic.

There is a paucity of data investigating the relationships between hip joint ROM and human lower-body movement. Relationships between dynamic hip ROM and hip angular velocity have only been investigated during kicking tasks. In kicking, greater hip extension appears to be a prerequisite to maximising ball velocity at foot contact, this is because greater ROM allows more time to accelerate the limb. At present, no studies have investigated the relationships between dynamic ROM and hip angular velocity during other explosive lower-body movements such as sprinting, hence this could be a focus for future research. Moreover, the influence of clinical ROM measures on human movement also remains largely unknown. A limited amount of data suggests that increased muscle flexibility may improve muscle-shortening velocity, but whether that translates to higher joint velocities during complex dynamic movements also remains unknown.

Pelvic angle appears to be implicated in lower back and hamstring injuries. During forward bending tasks involving maximal trunk flexion, there is evidence to suggest that limited hip flexion ROM influences pelvic tilt. However, relationships between both hip flexion and extension ROM and pelvic tilt are not evident during standing, probably because the hip muscles are not lengthened considerably in this posture. Finally, the limited evidence suggests that clinical ROM measures may not relate to pelvic tilt during dynamic movements, but on the other hand dynamic ROM and pelvic tilt during running appear to have some association. It is clear that a greater body of research is required to gain a more complete understanding of these relationships.

Chapter 3: Methodology

Participants

The participants' characteristics for the various studies are presented in Table 1. Nineteen track and field athletes (13 males, 6 females) aged 14-28 years were recruited to participate in the descriptive observational studies approved by the AUT University Ethics Committee (see Appendix 1). All participants gave their written informed consent (see Appendices 3-5) prior to partaking in the research. The inclusion criteria for the descriptive studies required participants to: (i) be between 14-35 years old; (ii) have at least one year of training experience in a structured athletics programme that included regular sprint training; and, (iii) be free of injury with no known musculoskeletal injuries as determined by a pre-screening questionnaire (see Appendix 6). Participants for the observational studies were recruited from athletics clubs via email (Appendix 7), and a website advertisement and a media release through Athletics NZ (Appendices 8 and 9).

An additional 10 healthy and active individuals (8 males, 2 females) aged 20-28 years also gave consent to participate in a reliability study. All participants completed the same pre-screening questionnaire to ensure they were healthy and free of any lower body injury that might affect their sprint performance. The participants were predominantly recruited from the School of Sport and Recreation at AUT University.

Table 1: Participant characteristics

Characteristic	**Study 1[a]**	**Study 2[b]**	**Study 3[c]**
n	10	19	12
Age (yr)	23.2 ± 2.7	20.4 ± 3.9	18.7 ± 3.0
Height (cm)	177.4 ± 11.6	178.0 ± 9.4	177.9 ± 10.2
Body Mass (kg)	80.6 ±16.4	72.1 ± 12.1	71.4 ± 14.3
Training Years[§]	-	5.7 ± 3.3	5.2 ± 2.7
100-m Season's Best (s)	-	11.8 ± 0.8	11.8 ± 0.9
100-m Personal Best (s)	-	11.6 ± 0.8	11.7 ± 0.9

Values are means ± SD

[a]Reliability study [b]Cross-sectional study [c]Prospective study

[§]Training years in a structured athletics programme

Study Design

Reliability Study

A test-retest design was undertaken to determine the intra-and inter-session reliability for all measurement variables. To determine the test re-test reliability of each assessment, the participants completed two formal testing sessions, each separated by 2-3 days to avoid any residual effects from the previous session. The testing was conducted within the same 4-hour period of the day on each separate testing occasion, as diurnal variation has been shown to effect hip flexibility measures (Guariglia et al., 2011). To obtain the intra-session reliability data, the participants performed four trials of each test.

Cross-sectional Study

This investigation was conducted to determine the influence of hip ROM on sprint kinematics and kinetics in track and field athletes. A cross-sectional analysis was undertaken to examine the relationships between hip ROM and the kinematic and kinetic variables. Specifically, correlations were calculated between clinical hip ROM measures, sprint kinematics (dynamic hip ROM, pelvic angle, angular hip velocity, contact time and 0-40 m peak running velocity) and sprint kinetics (mean peak vertical force and mean peak horizontal force relative to body mass) during maximal speed sprinting. Participants were required to perform three trials on all tests apart from the clinical ROM tests where two trials were performed; the reason for this was to avoid increases in ROM during subsequent trials. The decision was made to include three trials for the kinematic and kinetic measures rather than two trials in an attempt to account for movement variability leading to large differences between two individual trials.

Prospective Study

A prospective cohort study was carried out to investigate changes in hip ROM during and after the competitive athletics season. Twelve of the participants involved in Study 2 returned to the laboratory 9-12 weeks later to complete a follow-up testing session. On each testing occasion, the same protocol used in Study 2 was completed.

Testing Procedures

All three studies required the participants to complete the testing battery shown in Figure 1. The testing procedures involved the collection of descriptive data, static and active ROM assessments, 40-m overground sprint trials and treadmill sprint trials.

Descriptive Data

On the first testing occasion, descriptive data was obtained for every participant (see Appendix 6) including height, body mass, training background and injury history.

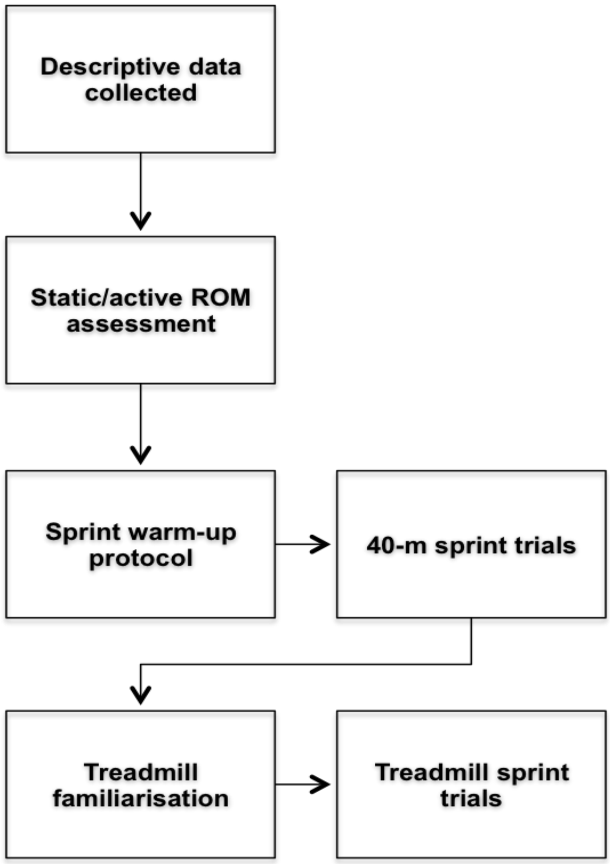

Figure 1: Overview of testing procedures

Static and Active Hip ROM Assessment

Prior to the ROM assessments, the participants were instructed to refrain from any stretching or warm-up activity as both modes of exercise are shown to improve ROM (DePino & Webright, 2000; Wenos & Konin, 2004). Before commencing the ROM testing, retroreflective markers were placed on the greater trochanter of the femur (hip), lateral epicondyle of the tibia (knee) and lateral maleolus (ankle) to identify anatomical landmarks allowing the measurement of hip ROM. Static hip extension ROM was measured using a Thomas Test as described by Harvey (1998). For this test, the participants lay in a supine position on the end of a plinth while holding both knees into the chest tightly to ensure the pelvis was tilted posteriorly. Once they had adopted this position, the command was given for the participants to lower the leg down towards the floor in a relaxed position whilst continuing to hold the contralateral limb tightly (see Figure 2A). Between each trial, the participants sat up on the edge of the plinth for a period of 30-s before lying back down to repeat the test. Active hip flexion ROM was assessed using an active straight leg raise as described by Ylinen, Kautiainen and Hakkinen (2010). The participants lay in a supine position with both legs extended, and were then instructed to move their left ankle into plantarflexion, and contract their left quadriceps to achieve full extension at the knee. From this position, the left leg was raised as high as possible by flexing at the hip in a controlled manner until they achieved maximal ROM (see Figure 2B). During the test, a research assistant placed their hands on the contralateral thigh to ensure it did not lift off the plinth while the participant flexed the opposite hip. Once maximal ROM was reached, the participants were required to hold the leg stationary for 3-s, this was to ensure they could not bounce to the end ROM in a ballistic fashion. A modified version of this test has previously been shown to have high reliability e.g. ICC = 0.97, CV = 1.2% (Bozic, Pazin, Berjan, Planic, & Cuk, 2010). Between each trial, the participants remained in the supine start position for 30 s.

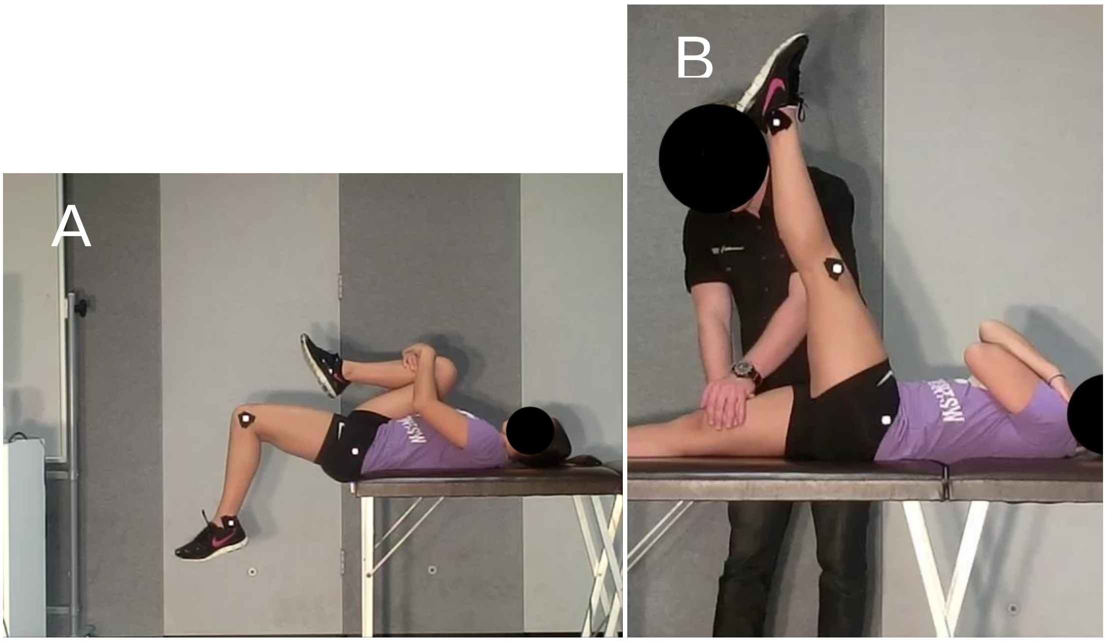

Figure 2: Assessment of hip ROM: (a) Thomas test; (b) active straight leg raise

Sprint Kinematics Assessment

Dynamic hip flexion and extension ROM, pelvic angle, angular hip velocity, contact time and maximum running velocity were all assessed during 3 maximal 40-m sprint trials. The sprints were performed overground as differences have been reported compared to treadmill sprinting for some kinematic variables such as pelvic angle (Chockalingam, Chatterley, Healy, Greenhalgh, & Branthwaite, 2012). The distance of 40-m was chosen because during pilot testing it was deemed that the sprinters would attain (or get very close to) maximal speed whilst being able to safely decelerate within the spatial constraints of the indoor track. Prior to the sprints, additional retroflective markers were added to the anterior (ASIS) and posterior (PSIS) suprailiac spines. Participants were then taken through a standardised warm-up protocol consisting of a 3-minute jog followed by four 40-metre run-throughs that progressively increased in intensity from 65% to 95% of their estimated maximal running speed. This warm-up protocol was constructed to provide a warm-up sufficient for maximal speed sprinting but kept brief to minimise the effect on ROM (Wenos & Konin, 2004). Following the warm-up, a 3-minute recovery was allocated before the maximal sprint trials were performed. Each sprint trial was separated by 5-minutes of passive rest allowing full recovery between trials. The sprints were performed from either a standing or crouch stance as preferred by the participants, and initiated on the signal of a starter.

Sprint Kinetics Assessment

Vertical ground reaction forces and horizontal forces were collected during maximal sprinting on a Woodway non-motorised treadmill (Force 3.0, Eugene, OR USA). Prior to the maximal treadmill sprint trials, participants were put through a familiarisation protocol consisting of a 1-minute jog and two submaximal sprints. For the submaximal sprints, participants were instructed to accelerate smoothly up to a pre-determined speed where once reached it would be verbally communicated that they hold that speed for 3-s until told to slow down to a stop. The speed of the submaximal familiarisation sprints were calculated by firstly converting the participants 100 m season's best time into an average velocity and then setting each intensity at 40% and 50% of the calculated maximal velocity respectively. These warm-up speeds were determined subsequent to pilot testing where it was found that 40-50% of maximum overground sprinting velocity related to approximately 70-80% maximal speed on the treadmill due to the resistance of the treadmill belt. In the case of the reliability study where data on the participants' 100 m season's best were unknown, arbitrary speeds of 3 $m.s^{-1}$ and 3.5 $m.s^{-1}$ for females and 3.5 $m.s^{-1}$ and 4 $m.s^{-1}$ for males were prescribed. These speeds were set based on pilot testing conducted with non-sprint athletes and represented a conservative speed that most individuals could easily exceed. During the maximal treadmill sprint trials, participants accelerated smoothly and quickly until maximum velocity was reached, as observed by a plateau in the speed output signal (see Figure 8). Once the speed was seen to plateau, participants continued for an additional 3 s until the command was given to slow down. The 3-s duration at maximal speed was chosen because pilot testing determined this was a sufficient amount of time to collect data from 10 steps while the participants were running at maximal speed. Five minutes of passive rest was allocated between each sprint trial to ensure full recovery.

Instrumentation and Data Analysis

Clinical ROM Assessments

The static and active ROM assessments were recorded using a digital video camera (Casio Exilim EX-ZR100, Casio Computer Co., Tokyo, Japan) sampling at 25 Hz placed 5-m perpendicular to the plinth. A spirit level was used to ensure the camera was horizontal. Once captured, the video data were exported to PC and analysed on software (Kinovea, version 0.8.15) to measure the joint angles. From the 3 s of video data, the joint angles were measured at the point of peak ROM, subject to the ROM being sustained for a minimum of 1 s. Static hip extension and active hip flexion ROM were measured by centring the protractor tool in the software over M_{Hip} and recording the angle between a line connecting the M_{Hip} to M_{Knee} in relation to a horizontal reference line (Figure 3A and 3B).

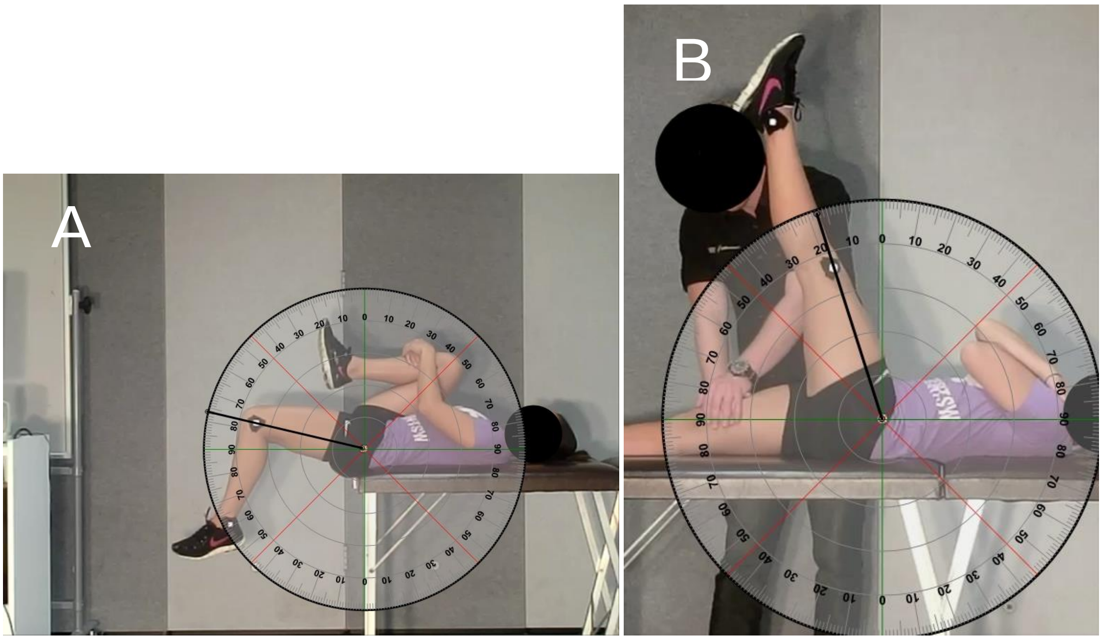

Figure 3: Measurement of hip ROM: (a) static HE; (b) active HF

Sprint Kinematics

Video data was captured for each sprint trial using a high-speed 2-D video camera (Casio) recording at a sampling rate of 240 Hz to assess sprint kinematics. The camera was placed perpendicular to the participants' running plane at the 35-m mark and positioned at a distance of 4-m from the running lane (Figure 4). A large spirit level was used to align the video camera before every testing session and two portable 2-beam light clusters were placed alongside the camera to provide an external light source. Following data acquisition, the video data was transferred onto a computer and exported into a software programme (Kinovea) for subsequent analysis. All trials were assessed and the average score of three or four trials were used for analysis in each respective study. Dynamic hip ROM measures were calculated by placing a line connecting the hip and knee markers, and measuring the angle of this line in relation to a vertical reference line (Figure 5). Peak hip flexion ROM was defined as the greatest angle achieved in the stride cycle, while hip extension ROM was defined as the amount of hip extension at toe-off. Pelvic angle was measured during peak hip flexion and at toe-off by placing the centre of the protractor on the ASIS marker and measuring the angle between a line running through the PSIS marker and a horizontal reference line (Figure 6). The angular hip velocity (ω) during HF was calculated as the angular displacement (θ) of the hip divided by the change in time (t), thus $\omega = \theta/t$. Contact time was calculated as the period between touchdown and toe-off during the ground support phase.

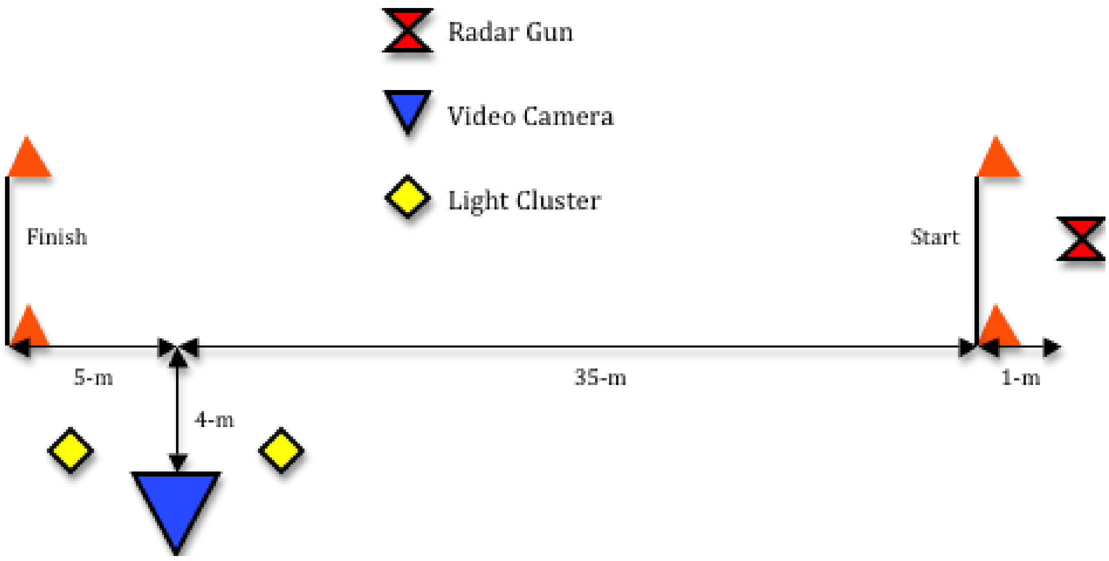

Figure 4: Instrument positioning for 40-m sprint trials

Maximum Sprint Velocity

A Stalker ATS^{TM} radar system (Radar Sales, Minneapolis, MN, USA) with a sampling frequency of 50 Hz was placed at a distance of 1 m behind the start line (Figure 4) to measure running velocity. The sprint data were then imported into custom Stalker ATS software and cropped of any data points where the participants were stationary. The outliers showing a velocity of zero were then deleted and the data were exported to Excel files for subsequent analysis in a custom software package (LabVIEW™, National Instruments, version 11.0.1, USA). Maximum sprinting velocity was calculated by fitting an exponential decay curve to the data set (Figure 7) and recording the peak velocity from the highest point of the fitted curve.

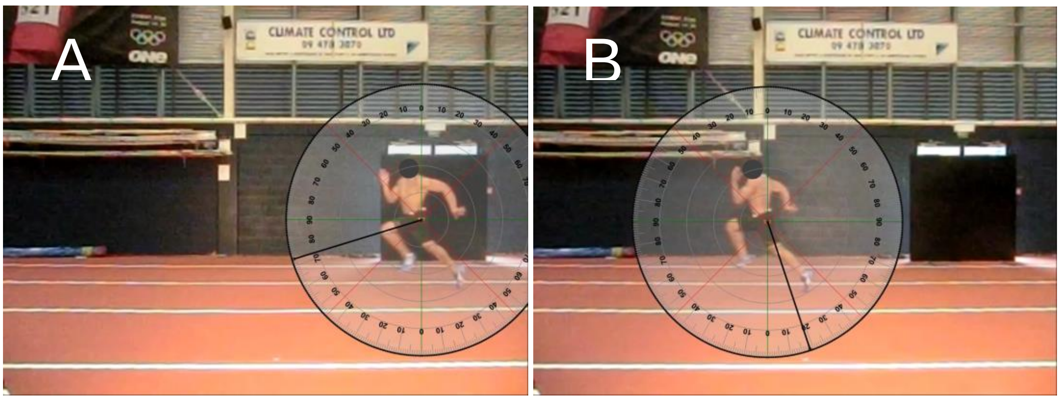

Figure 5: Measurement of dynamic hip ROM: (a) HF; (b) HE

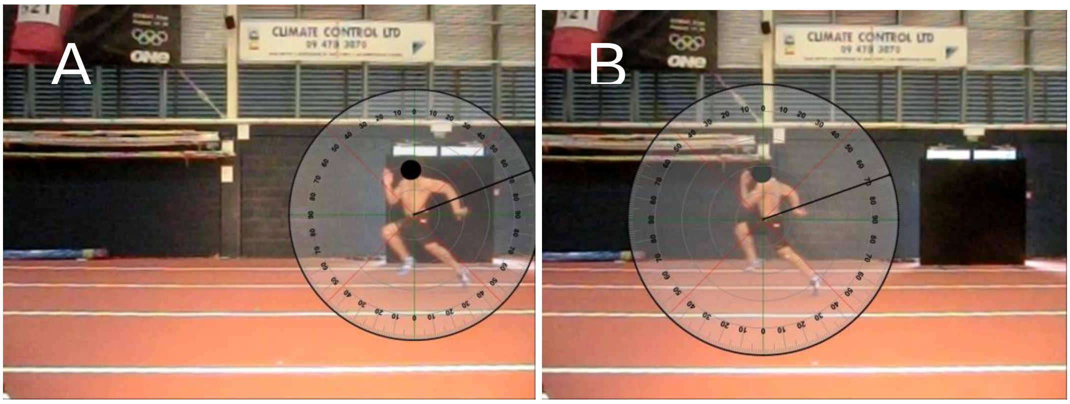

Figure 6: Measurement of pelvic angle: (a) HF; (b) HE

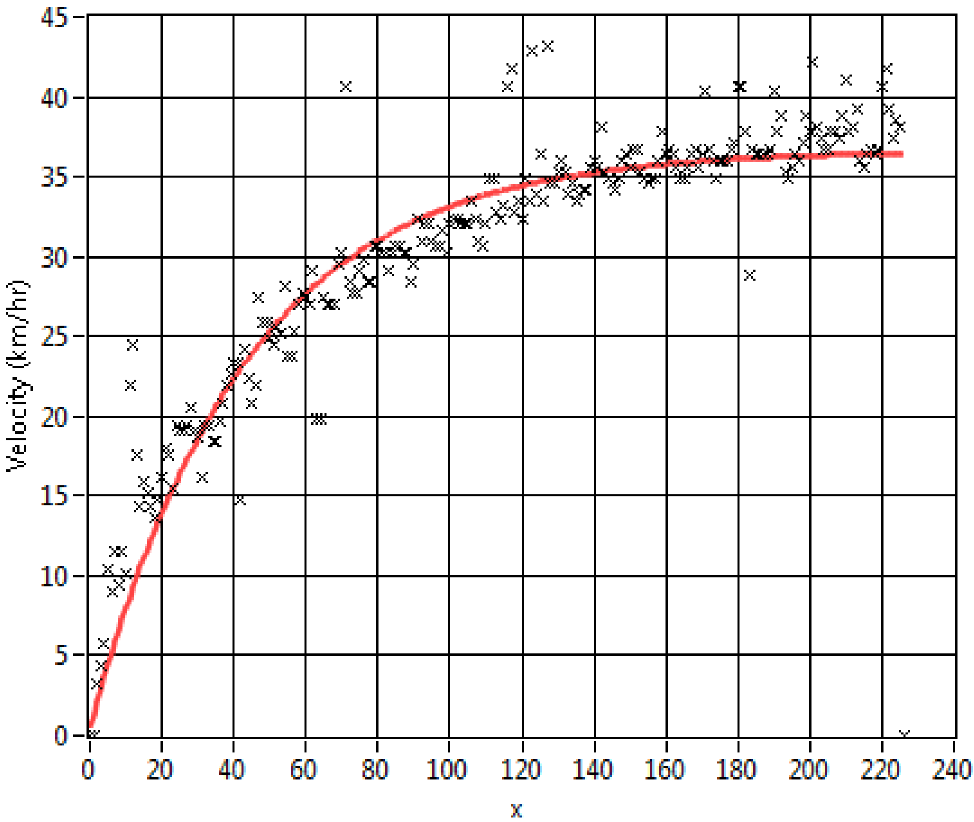

Figure 7: Exponential decay curve fitted to raw data points

Sprint Kinetics

A non-motorised treadmill (Woodway) with an in-built force plate embedded underneath the belt recorded vertical ground reaction forces to the computer at 200 Hz. In addition, the participants wore a harness that was attached via a non-elastic tether to a height-adjustable strain gauge and load cell mounted to a fixed vertical stanchion. The load cell and strain gauge recorded the horizontal forces at a sampling rate of 200 Hz. The sliding strain gauge was adjusted according to the participants' waist height so that the tether was horizontal to the load cell. Once positioned, the tether was locked into place to avoid any movement during testing. The in-built force plate and load cell were both calibrated before each testing occasion by placing two different weights of known quantities on each instrument to gain a calibration factor. Following data acquisition, the kinetic data were exported to Microsoft Excel files and analysed using custom software (LabVIEW). The treadmill's speed output signal was analysed visually to identify the area where the participants were at a sustained maximal running velocity (Figure 8). The average of ten steps (5 right, 5 left) during sustained maximal velocity and were used to calculate the peak vertical ground reaction forces and horizontal forces (Figure 9).

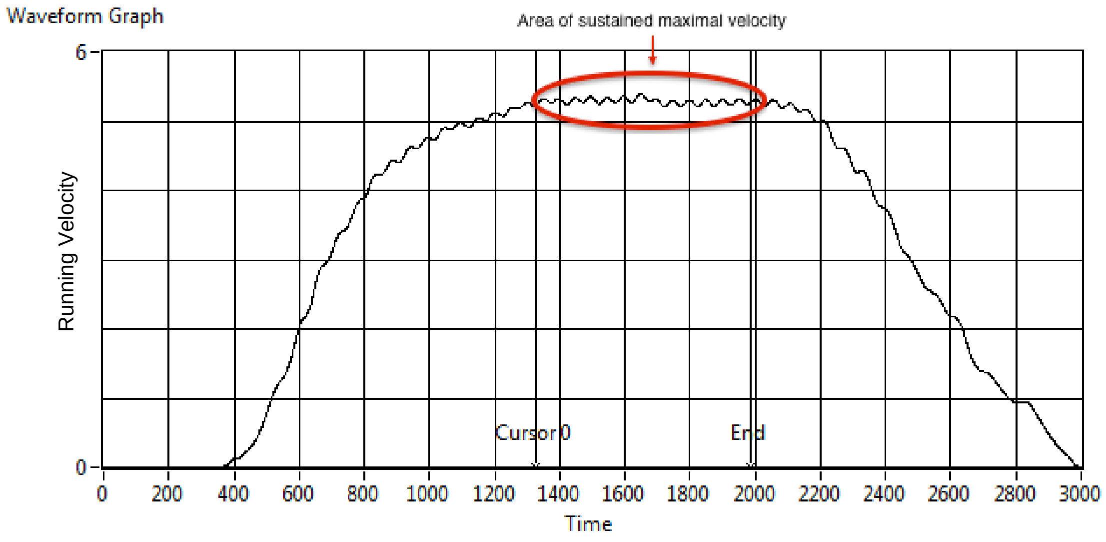

Figure 8: Identification of maximal sprint velocity from the velocity-time curve. The steps in the area of sustained maximal velocity are used in the analysis of vertical and horizontal force outputs (see Fig. 9)

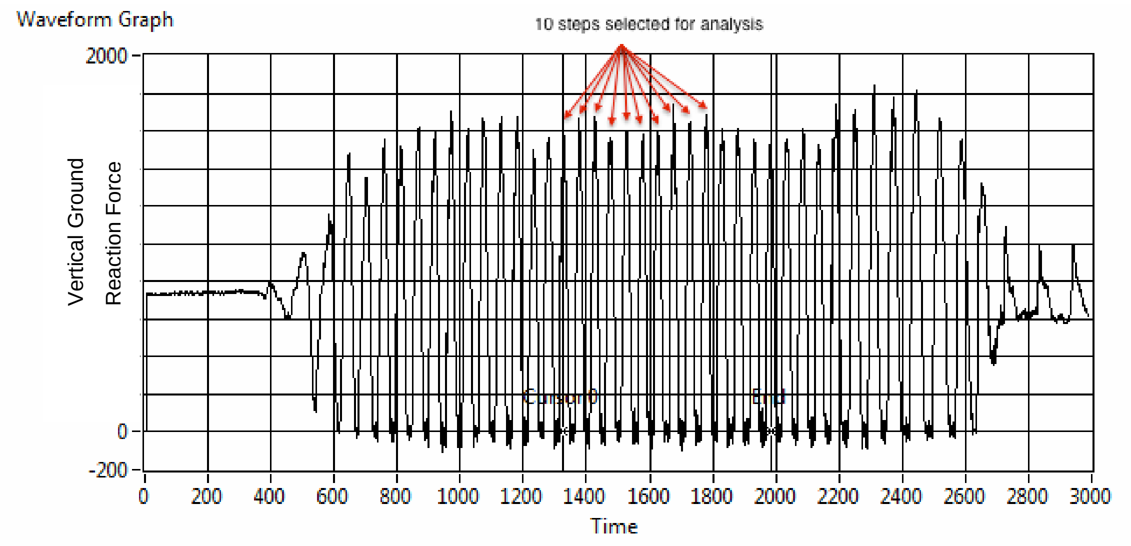

Figure 9: Identification of the 10 steps used to calculate the force outputs by matching the force-time signal to the area of sustained maximal velocity from the velocity-time signal

Statistical Analysis

Intra-session and test-retest reliability are expressed as the intra-class correlation coefficient (ICC) and standard error of measurement (typical error, or coefficient of variation [CV] where logarithmic transformation is appropriate), as suggested by Hopkins, Marshall, Batterham, and Hanin (2009). The spreadsheets used for this analysis were provided by Hopkins (2011) and the level of acceptance for reliability was set at CV < 10% and ICC > 0.70. Pearson's correlation coefficients were used to calculate the relationships between the measurement variables in the cross-sectional study. The magnitude of correlations were interpreted as trivial (0-0.1), small (0.1-0.3), moderate (0.3-0.5), large (0.5-0.7), very large (0.7-0.9) and nearly perfect (0.9-1.0) as defined by Hopkins (2002). These correlations were calculated in Microsoft Excel. Changes in the kinematic and kinetic measures were determined by assessing the change in the mean score of each outcome variable with 90% confidence limits (CL) using the excel spreadsheet developed by Hopkins (2006). The smallest worthwhile change for the kinematic and kinetic variables was calculated in standardised (Cohen) units as 0.20 of the between-subject standard deviation from the data collected on the first testing occasion (Hopkins et al., 2009). The statistical data in the spreadsheets were also used to make magnitude-based inferences on the change score. The inferences were derived by calculating the probabilities of a positive, negative, or trivial change in each variable, and a qualitative statement was then provided based on the following probability scale for changes: <0.5%, most unlikely; 0.5-5%, very unlikely; 5-25%, unlikely; 25-75%, possibly; 75-95%, likely; 95-99.5%, very likely; >99.5%, almost certainly (Hopkins et al., 2009).

Chapter 4: Results

Reliability Study

The intra-session and test-retest reliability for the ROM variables are provided in Table 2. The ROM measures all produced acceptable intra-session reliability with the exception of pelvic angle at peak hip extension (ICC = 0.68). Clinical measures of static and active ROM produced high intra-session reliability with ICC's of 0.88 and 0.97 and a TE of 2.0-2.5° between trials respectively. Between testing sessions, static and active ROM were also found to have good reliability (ICC = 0.81-0.90, TE = 2.2-4.0°). The dynamic ROM variables measured during sprinting showed high intra-session reliability with ICC's in the range of 0.83-0.89 and a typical error of ~2°. However, of the dynamic ROM measures during running, hip flexion (HF) ROM showed good test-retest reliability but hip extension (HE) ROM revealed unacceptable reliability (ICC = 0.40). Measurements of pelvic angle yielded slightly lower intra-session reliability (ICC = 0.68-0.80, TE = 3.4-3.8°) between consecutive trials. Pelvic angle measured at peak HF was highly reliable between testing sessions, however pelvic angle measured at peak HE produced poorer test-retest reliability (ICC = 0.48).

Table 2: Reliability statistics for ROM variables

	Intra-session		Test-retest	
Measure	**ICC**	**Typical Error** (°)	**ICC**	**Typical Error** (°)
Static HE ROM	0.88	2.0	0.81	2.2
Active HF ROM	0.97	2.5	0.90	4.0
Dynamic HE ROM	0.83	2.0	0.40	3.9
Dynamic HF ROM	0.89	2.1	0.85	2.3
Pelvic angle at peak HE	0.68	3.8	0.48	4.1
Pelvic angle at peak HF	0.80	3.4	1.00	0.5

ICC, intraclass correlation coefficient
HE, hip extension; HF, hip flexion

The intra-session and test-retest reliability statistics for the kinematic and kinetic measures are presented in Table 3. The intra-session reliability for all variables was shown to be acceptable. Both measures of angular velocity produced acceptable reliability between trials, however the CV for mean angular HE velocity was approaching the acceptable limit of 10%. Mean angular HF velocity also showed superior test-retest reliability, and in fact, the day-to-day CV for HE velocity was shown to be unacceptable (~15%). Ground contact time measures demonstrated good reliability between trials and excellent reliability (ICC = 0.99, CV = 1.0) between testing days. Measurement of peak velocity showed high reliability, both within and between testing sessions. Likewise, the sprint kinetic measures of horizontal and vertical force also produced acceptable intra-session reliability and very good test retest reliability with ICC's of 0.94 for both force measures and a CV of between 1.5-3.3%.

Table 3: Reliability statistics for kinematic and kinetic variables

	Intra-session		Test-retest	
Measure	**ICC**	**CV (%)**	**ICC**	**CV (%)**
Mean angular HF velocity	0.86	4.5	0.89	3.8
Mean angular HE velocity	0.91	9.5	0.79	15.4
Contact time	0.81	3.9	0.99	1.0
Peak running velocity	0.96	1.4	0.92	1.9
Peak horizontal force	0.92	4.1	0.94	3.3
Peak vertical force	0.81	2.5	0.94	1.5

ICC; intraclass correlation coefficient; CV, coefficient of variation
HE, hip extension; HF, hip flexion

Cross-sectional Study

Pearson correlations between each of the paired variables are shown in the Table 4. A very large correlation (r = 0.76) was revealed between dynamic HF ROM and angular HE velocity during running, and a large correlation (r = 0.55) was shown between dynamic HE ROM and pelvic angle at peak HF (Figure 10). Very large negative correlations (Figure 11) were found between dynamic HF ROM and pelvic angle at peak HE during running (r = -0.71), and between ground contact time and peak running velocity (r = -0.73), while large negative correlations were found between angular HF velocity and contact time (r = -0.61), and between angular HE velocity and pelvic angle at peak HE (r = -0.69).

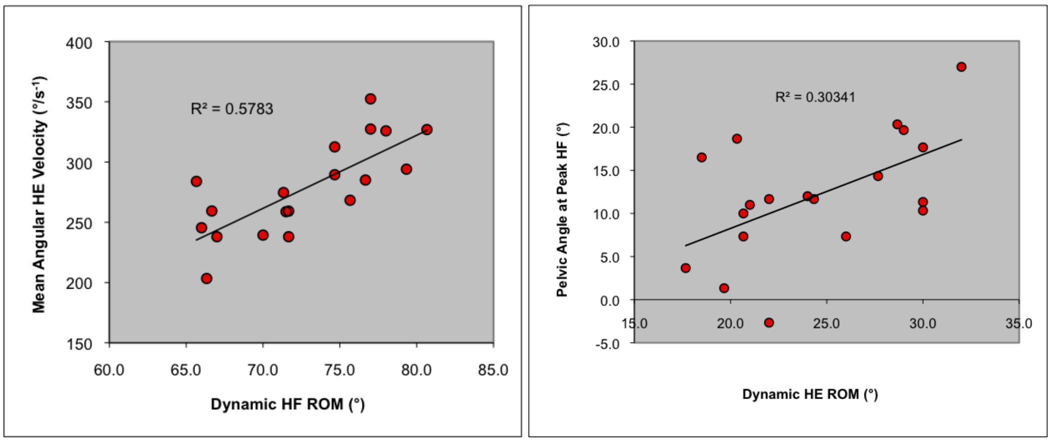

Figure 10: Correlation scatterplots showing positive correlations of large or very large magnitude between dynamic hip ROM, HE angular velocity, and pelvic angle during running

Table 4: Correlation matrix

	Static HE ROM	Active HF ROM	Dynamic HE ROM	Dynamic HF ROM	Angular HF Velocity	Angular HE Velocity	Pelvic Angle[1]	Pelvic Angle[2]	Contact Time	Running Velocity	Horizontal Force
Static HE ROM (°)	-	-	-	-	-	-	-	-	-	-	-
Active HF ROM (°)	0.23	-	-	-	-	-	-	-	-	-	-
Dynamic HE ROM (°)	0.32	0.32	-	-	-	-	-	-	-	-	-
Dynamic HF ROM (°)	0.12	-0.27	-0.48	-	-	-	-	-	-	-	-
Mean angular HF velocity (°.s^{-1})	0.34	0.00	0.06	0.43	-	-	-	-	-	-	-
Mean angular HE velocity (°.s^{-1})	-0.02	-0.34	-0.42	**0.76**	0.38	-	-	-	-	-	-
Pelvic angle at peak HE (°)	-0.09	0.33	0.17	**-0.71**	-0.33	**-0.69**	-	-	-	-	-
Pelvic angle at peak HF (°)	-0.29	0.19	**0.55**	-0.49	-0.16	-0.45	0.27	-	-	-	-
Contact time (ms)	0.12	-0.06	-0.10	-0.35	**-0.61**	-0.17	0.11	-0.30	-	-	-
Peak velocity (m.s^{-1})	-0.45	-0.20	-0.02	0.41	0.37	0.19	-0.35	0.36	**-0.73**	-	-
Peak horizontal force (N.kg^{-1})	-0.46	0.12	0.17	-0.05	0.00	-0.02	0.08	0.11	-0.28	0.46	-
Peak vertical force (N.kg^{-1})	0.04	0.21	-0.01	0.44	0.35	0.27	-0.44	-0.17	-0.25	0.28	0.38

HE, hip extension; HF, hip flexion
[1]Pelvic angle at peak HE; [2]Pelvic angle at peak HF
Correlations are as follows: 0-0.1, trivial; 0.1-0.3, small; 0.3-0.5, moderate; 0.5-0.7, large; 0.7-0.9, very large; 0.9-1.0, nearly perfect

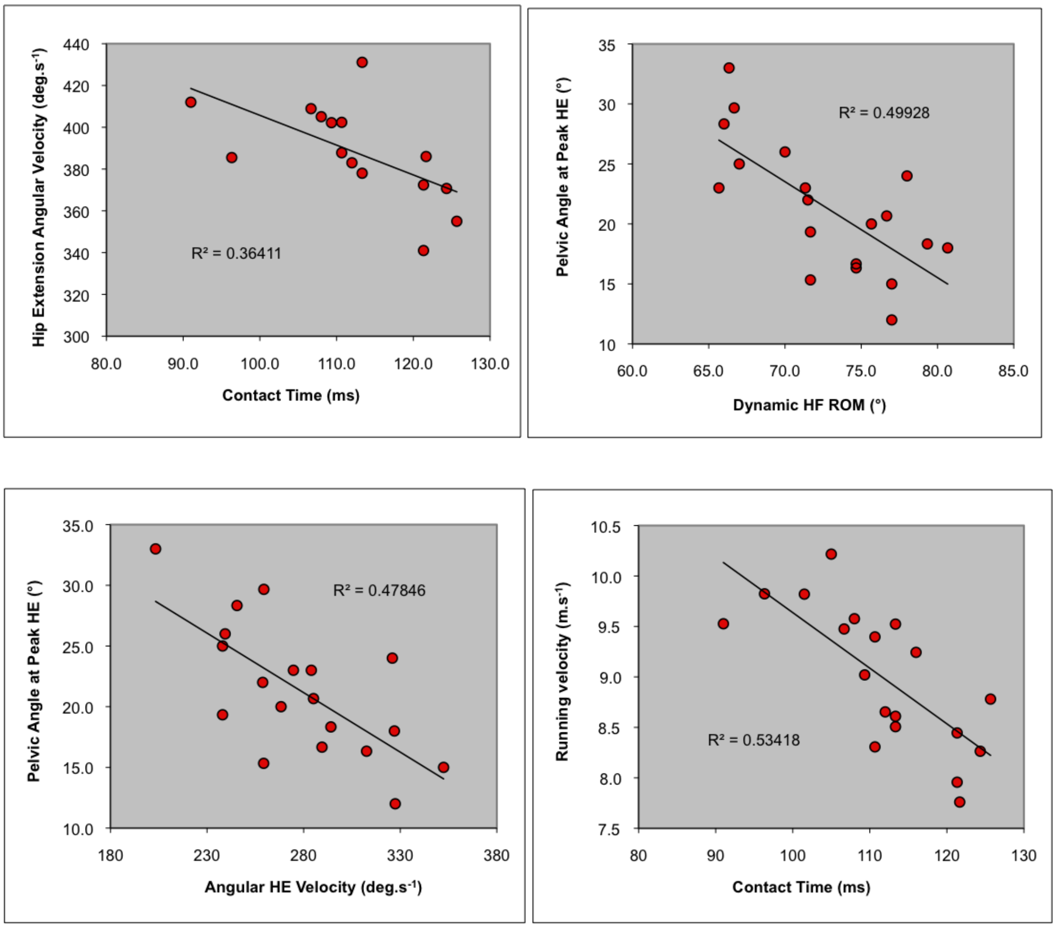

Figure 11: Correlation scatterplots showing negative correlations of large or very large magnitude

Prospective Study

Changes in the ROM, kinematic and kinetic variables from the in-season to post-season are displayed in Table 5. Apart from dynamic HF ROM, all measured variables showed only small variation (-2.0-3.0%) with trivial effect sizes (0.03-0.18) between the two measurement occasions. Dynamic HF ROM underwent a mean change of -2.0% with an effect size (ES) of 0.26 (small), the quantitative analysis of probabilities shows that the effect is possibly negative and possibly trivial.

Table 5: Changes in ROM, kinematic and kinetic variables

Measure	In Season	Post Season	Effect Size	Mean Change ± 90% CL (%)	Qualitative Assessment
Static HE ROM (°)	172.5 ± 11.1	172.0 ± 11.1	0.05	-0.3 ± 1.5	Likely trivial
Active HF ROM (°)	77.9 ± 10.3	79.7 ± 10.2	0.17	2.3 ± 4.0	Possibly positive, possibly trivial
Dynamic HE ROM (°)	23.2 ± 5.3	23.8 ± 4.9	0.13	3.0 ± 10.9	Possibly trivial
Dynamic HF ROM (°)	74.3 ± 7.1	72.7 ± 5.3	0.26	-2.0 ± 2.7	Possibly negative, possibly trivial
Pelvic angle at peak HE (°)	20.7 ± 5.4	21.1 ± 5.4	0.08	2.0 ± 10.9	Possibly trivial
Pelvic angle at peak HF (°)	10.8 ± 9.0	10.3 ± 7.8	0.07	0.2 ± 36.4	Possibly trivial
Mean angular HF velocity ($°.s^{-1}$)	381.8 ± 20.6	385.6 ± 26.8	0.16	0.9 ± 2.9	Possibly positive, possibly trivial
Mean angular HE velocity ($°.s^{-1}$)	296.9 ± 59.7	288.6 ± 35.2	0.18	-1.6 ± 8.6	Possibly negative, possibly trivial
Contact time (ms)	109.3 ± 8.2	110.3 ± 8.3	0.11	0.8 ± 2.6	Possibly trivial
Peak velocity ($m.s^{-1}$)	8.91 ± 0.76	9.00 ± 0.71	0.12	1.0 ± 1.4	Likely trivial
Peak horizontal force ($N.kg^{-1}$)	4.17 ± 0.48	4.08 ± 0.47	0.18	-2.0 ± 3.5	Possibly negative, possibly trivial
Peak vertical force ($N.kg^{-1}$)	26.0 ± 3.1	26.1 ± 2.8	0.03	0.5 ± 3.2	Likely trivial

HE, hip extension; HF, hip flexion; CL, confidence limits
Effect sizes (ES) were described as follows: >1.2, large; 0.6-1.2, moderate; 0.2-0.6, small; <0.2, trivial
Qualitative assessment was determined as follows: <1%, almost certainly not; 1-5%, very unlikely; 5-25% unlikely; 25-75% possibly; 75-95%, likely, 95-99%, very likely; >99%, almost certainly

Chapter 5: Discussion

The purpose of this research was to investigate the relationships between measures of hip ROM and sprint kinematics and kinetics in track and field athletes, and to assess changes in these measures at different stages of the athletics season. The first study was conducted to examine the intra-rater reliability of the kinematic and kinetic measures, which generally revealed high reliability across the spectrum of variables analysed. The second study was conducted to examine the relationships between clinical measures of hip ROM, sprint kinematics and sprint kinetics. Correlational analysis revealed very large correlations between several paired variables. Finally, the third study was conducted to investigate the changes in these kinematics and kinetic measures at different stages of the athletics season. The results from this study revealed mostly trivial changes in the selected variables, although individual variability was observed.

Reliability Study

The reliability observed for clinical measures of static and active hip ROM in the current study was very good. In particular, the test-retest reliability of the Thomas test (ICC = 0.81, TE = 2.2°) was generally higher than has been previously reported (ICC = 0.52-0.86, TE = 2-7°) when assessing healthy individuals (Gabbe, Bennell, Wajswelner, & Finch, 2004; Peeler & Anderson, 2008; Peeler & Anderson, 2007). The higher reliability may be because previous researchers opted to use goniometry to measure ROM (Gabbe et al., 2004; Peeler & Anderson, 2008; Peeler & Anderson, 2007) whereas the current study collected video data that was analysed using motion analysis software. Several researchers have drawn attention to the high reliability of video analysis methods for assessing joint ROM (Cronin, Nash, & Whatman, 2006; Mier, 2011; Robinson, O'Connor, Shirley, & MacMillan, 1993) and the results of the current study provides further evidence that video analysis offers a superior alternative for measuring joint ROM. Using the testing procedures described in the current study, a TE of ~2° was observed, therefore a change score of at least 3° provides a conservative reference in determining worthwhile changes between repeat testing occasions.

Several researchers have reported excellent reliability for the passive straight leg raise test (PSLR), which involves increasing joint ROM manually (Askling, Nilsson, & Thorstensson, 2010; Bozic et al., 2010). However, very few studies have investigated the reliability of the active straight leg raise (ASLR). One study described a novel variation to the traditional ASLR whereby the tested leg was raised in a ballistic manner, i.e. as fast as possible (Askling et al., 2010). While this variation showed very high intra-rater reliability (ICC = ≥0.95, CV ≤ 2.7%), no studies were identified that reported the reliability of the active straight leg raise conducted at a controlled tempo. Nevertheless, using video analysis, the controlled ASLR assessment for assessing active hip flexion ROM revealed good reliability both within and between sessions (ICC = 0.90-0.97, TE = 2.5-4.0°). Moreover, the reliability obtained is highly comparative to the ballistic technique developed by Askling et al. (2010) as the CV of up to 2.7% found in their study corresponds to a TE of ~3°. The TE of 4° between test days for the ASLR in the current study was slightly higher than for the Thomas test. Therefore a threshold of 5° is recommended for determining changes in hip flexion ROM using the ASLR technique described.

During overground sprint running, dynamic ROM variables were shown to have high reliability. In fact, the TE between measurements were similar to the static and active ROM tests, that is, ~2° between consecutive trials and between ~2-4° between testing days. Given the high angular velocity of the lower limbs during sprinting, the fact that these movements have biological variability comparable to static and active ROM measurements is an interesting finding. Moreover, repeated measures of dynamic HF ROM had high reliability (ICC = 0.85, TE = 2.3°) that compares favourably to previous studies (Cronin et al., 2006). The reliability values obtained in the current study indicate a change score as low as ~3° could be considered worthwhile. On the other hand, the test-retest reliability for dynamic HE ROM was lower (ICC = 0.40, TE ≈ 4°). Nevertheless, a TE of ~4° provides a similar 5° threshold as the ASLR for determining ‘true’ changes in dynamic HE ROM. The ICC is a measure of relative reliability or “the degree to which individuals maintain their position in a sample with repeated measures” (Cronin et al., 2006, p. 193), thus small variability in the data and a low sample size greatly affect the ICC (Bland & Altman, 1990), the latter of which is more likely skewing the results in this study.

Compared to the ROM measures, pelvic angle was shown to have greater variability between consecutive trials (TE ≈ 3.5°). Because of the variability observed for pelvic angle measurements in overground sprinting, further research could focus on determining the number of trials required to gain a representative mean value when measuring pelvic angles. Ironically, the reliability for pelvic angle was shown to be excellent when measured at peak HF but poor at peak HE. The most obvious explanation is that there were less data for pelvic angle at peak HE due to several trials being excluded because the markers were occluded. To overcome this issue in future 2-D investigations, researchers have since suggested an alternative method for the placement of pelvic markers which was shown to reduce marker occlusion and improve reliability (Borhani, McGregor, & Bull, 2013). However, despite the relatively small amount of data, other studies have also observed questionable reliability for measurements of pelvic angle during gait (Laroche et al., 2011) despite the excellent reliability that pelvic angle measures have shown during static postures (Azevedo, Santos, Carneiro, & Andrade, 2013; Gilliam, Brunt, MacMillan, Kinard, & Montgomery, 1994). Aside from the data limitations, explaining the variability is difficult. It may be that further variability is induced when placing the marker set on the anterior (ASIS) and posterior (PSIS) supra-iliac spines of the pelvis between testing occasions. On the other hand, the ASIS and PSIS landmarks are relatively simple to identify unless assessing overweight individuals (Moriguchi et al., 2009). The participants in the current study were relatively lean, thus a more plausible alternative explanation for the variability lies in the increased movement variability involved in high-speed movement around the hip joint (Kivi, Maraj, & Gervais, 2002). However, further research using a larger sample and the new marker set techniques described by Borhani et al. (2013) may reveal higher reliability for measures of pelvic angle during sprinting.

Paradoxically, HF angular velocity appeared to be highly reliable, while HE angular velocity had approximately 10% error between trials and 15% between testing occasions. These differences could be linked to the similar disparity observed for pelvis angle measurements i.e. movement involving hip extension may simply be more variable than hip flexion. Another issue is that the hip extension movement used to calculate HE angular velocity was shorter compared to the hip flexion movement, this resulted in less frames of video data being collected for hip extension and may have resulted in lower reliability. The number of frames of data needed to get an accurate representation of angular velocity may need to be determined. These points aside, it remains difficult to speculate why the observed variability for angular HE and HF velocity is considerably different, especially given that both movements were similarly un-resisted in the flight phase of the gait cycle. While mixed reliability (ICC = 0.50-0.96) has been reported for joint angular velocity measures using gyro-sensors (Arai et al., 2008) and motion analysis (Mueller & Norton, 1992), no other studies were found that report the reliability for measurements of hip angular velocity during sprinting using motion analysis techniques. Notwithstanding, Mueller and Norton (1992) found notable variability for angular velocity measures when comparing individual trials, with ICC values as low as 0.50 and CV’s in the range of 17-76%. The authors suggest that errors in angular velocity are expected to be higher than for joint positional measures due to the fact that the values are derived from the products of angular position and time. Therefore, a small error in either the positional measures or the time measure is compounded into a larger error for angular velocity. However, the authors found that indexes of reliability were markedly improved when using the mean of three (ICC ≥ 0.95) or five (ICC ≥ 0.99) trials hence they suggest the analysis of at least 3 trials are necessary in practice (Mueller & Norton, 1992).

Ground contact time was determined from analysing the 2-D video data and calculating the time between touchdown and toe-off by observing foot deformation. Despite the use of similar techniques in the literature (Lockie, Murphy, Jeffriess, & Callaghan, 2013), the reliability for this method has not been reported, perhaps because the majority of studies have calculated contact time by analysing force signals (Tukuafu & Hunter, 2010), which currently serves as the gold standard. However, using this video analysis technique, the data were exceptionally reliable, especially between testing occasions (ICC = 0.99, TE = 1.0%). Although the issue of validity still needs addressing, this preliminary data suggests that motion analysis offers a reliable alternative for measuring ground contact time. Furthermore, motion analysis is particularly useful for studies of overground sprinting where force signals from consecutive steps are difficult to obtain. Further research comparing contact time data obtained from video to data obtained from force signals during treadmill and overground running is needed to determine the validity of the motion analysis technique used in the current study.

The reliability of peak running velocity was measured using the Stalker ATS radar system. The current study revealed very high reliability for peak velocity during sprinting with ICC's of >0.90 and a CV of <2% both within and between testing occasions. The reliability of sprint performance measures using radar gun technology are not previously documented, however the reliability obtained from this instrument is very similar to that reported for timing gates (Waldron, Worsfold, Twist, & Lamb, 2011). Therefore, the radar gun seems to provide a reliable alternative for measuring sprint velocity, at least over distances of up to 40-m. Aside from the good reliability observed, the radar gun offers some distinct advantages over timing gates. One of these advantages lies in the ability to calculate instantaneous velocities over the spectrum of the distance measured, thus allowing peak velocity and rates of acceleration and deceleration to be easily determined. In addition, the acceleration data makes the calculation of a horizontal force-velocity-power profile possible, once the subjects' mass and drag coefficient are known (Samozino et al., 2013). Practically, the radar gun provides a reasonably sensitive field measurement tool for detecting changes in sprint velocity whereby a change of 2% or more is likely to reach significance. It is worth noting, however, that different data filtering and smoothing methods can be used to obtain a peak velocity value from radar gun data. In the current study, an exponential decay curve was fitted to the velocity data set, but this method appears to slightly underestimate the peak velocity. Comparing this technique to alternative data processing methods such as taking the average of the twenty highest data points could be done to examine the criterion-related validity of fitting an exponential decay curve.

Finally, peak horizontal forces and peak vertical ground reaction forces measured on the Woodway NMT only showed a small amount of variation between trials (≤4.1%) and were highly reliable between testing sessions (ICC = 0.94, CV = 1.5-3.3%). The reliability of the force data attained from the Woodway NMT in this study is similar to what is reported by Hughes, Doherty, Tong, Reilly, and Cable (2006) and compares favourably to the work of others using the same or similar ergometry (Hopker, Coleman, Wiles, & Galbraith, 2009; Tong, Bell, Ball, & Winter, 2001). Interestingly, horizontal forces were consistently noisier than vertical forces. The greater error observed could simply be due to differences in the instrument (load cells) used for measurement, although, each had the same sampling rate. However, despite the familiarisation protocol, it was more than likely that some participants experienced further learning effects, albeit to a small extent. Nonetheless, the general trend of higher horizontal forces with subsequent trials may be due to the participants becoming more accustomed to the NMT allowing them to sprint faster. Moreover, the learning effects could have been augmented by the visual feedback of performance that the participants received from the on-screen display between trials, as well as the encouragement provided from the researchers to ensure their best performance was given in each trial. On the other hand, the higher typical error in the horizontal force data might be due to the quick development of sprinting technique to maximise horizontal force, and as a result, the belt velocity of the NMT. Indeed, it has been demonstrated that the peak velocity attained in both overground sprinting (Morin et al., 2012; Morin, Edouard, & Samozino, 2011) and on the NMT (Brughelli, Cronin, & Chaouachi, 2011) are determined by the net horizontal forces developed, thus the participants in this study may have been able to quickly improve their technical ability to attain better performance on the NMT with each successive trial.

Cross Sectional Study

In agreement with previous research (Moscov et al., 1994; Schache et al., 2000), only a small correlation (r = 0.32) was found between the clinical measure of static HE ROM and dynamic HE ROM during sprinting. The correlation found in the current study on sprinters was almost identical (r = 0.33) to that reported between static ROM and the dynamic ROM measured during ballet dancing (Moscov et al., 1994). Similarly, the small negative correlation (r = -0.27) between active and dynamic HF ROM found in the current study provides evidence of the equally independent nature of these measures. Collectively, these findings suggest that the dynamic ROM used in sprinting is not heavily influenced by either static or active ROM qualities. There is, however, the possibility of a non-linear relationship existing between these measures that would be missed using a correlational analysis, that is, there could be a cut-off point where less than a certain amount of static or active ROM could negatively impact dynamic ROM. Such analysis could be a focus of future research in this area.

Interestingly, moderate correlations were found between static HE ROM and peak velocity (r = -0.45) and peak horizontal force (r = -0.46) suggesting that faster sprinters tend to have less static HE ROM. One possible reason for this finding is that the faster athletes have accumulated more training hours, which has contributed to those athletes having less joint ROM. Indeed, prolonged football training (De Castro, Machado, Scaramussa, & Gomes, 2013) and increased anaerobic running (Makaruk & Makaruk, 2009) have both been associated with reduced hip ROM.

The strongest relationship between two variables was shown between dynamic HF ROM and mean angular HE velocity during sprinting (r = 0.76). This finding was not unexpected as a higher dynamic ROM has been shown to be a factor in producing a higher angular limb velocity in other lower body movements (Baker & Ball, 1996). However, the current study is the first to demonstrate this relationship during overground sprinting. A kinematic analyses of competitive sprinting previously found dynamic HF ROM to be a determining factor of 100-m sprint performance (Ansari, Paul, & Sharma, 2012), but relationships between other kinematic or kinetic variables were not investigated. Interestingly, dynamic HF ROM was found to have a moderate correlation with peak vertical force (r = 0.44). I was certainly observed anecdotally in the current study that those runners who produced a high amount of dynamic HF ROM typically ran with a larger displacement of their centre of mass i.e. they had a 'bouncier' action, which would explain the increase in vertical force, however research is needed to provide empirical evidence.

During sprinting, dynamic HF ROM was also found to have a negative correlation (r = -0.71) to the pelvic angle measured at peak hip extension. In contrast, a large correlation (r = 0.55) was also observed between dynamic HE ROM and pelvic angle at peak HF. These findings suggest that the position of the pelvis during sprinting is related to technical sprinting abilities, specifically the amount of hip ROM that is used. A greater pelvic angle represents more anterior pelvic tilt while a smaller angle relates to more posterior tilt. Thus, the negative correlation found between dynamic HF ROM and pelvic angle at peak HE suggests that those with high knee lift during the recovery phase will run with the pelvis in a more posterior position throughout the entire stride cycle. On the contrary, those who run with greater dynamic HE ROM are likely to have more anterior pelvic tilt, which is maintained when the contralateral hip is flexed. To that end, it was interesting to see a moderate negative correlation (r = -0.48) shown between dynamic HF and HE ROM, indicating that sprinters who run with relatively more dynamic HF ROM will typically have less dynamic HE ROM and vice-versa. This certainly raises the question as to whether there is an optimal amount of dynamic hip ROM with regards to the balance of HE and HF ROM.

The large negative correlation coefficient (r = -0.69) shown between HE angular velocity and pelvic tilt at peak HE is somewhat puzzling. It is possible that the correlation between these variables is related back to the fact that those producing larger angular velocities are doing so by having more dynamic HF, which is where the increased posterior pelvic tilt likely stems from.

Another interesting finding was the large negative correlation found between HF angular velocity and ground contact time (r = -0.61). This correlation might be explained by anthropometric differences between the sprinters. That is, those athletes with shorter levers may accomplish higher joint angular velocities due to the decreased moment of inertia of that joint. Additionally, for a given joint angular velocity, a shorter lever would reduce the angular displacement at the distal aspect of the moving limb and allow a higher movement frequency (Mei, 1989; Pelayo, Sidney, Kherif, Chollet, & Tourny, 1996). In the case of sprinters, a reduced angular displacement of the leg would lead to less foot displacement during the stance phase, and in turn could reduce ground contact time. Previous studies have found anthropometric difference to be a poor predictor of sprint performance (Kukolj, Ropret, Ugarkovic, & Jaric, 1999) however it worthwhile to know what kinematic variables are affected by anthropometric factors to ensure appropriate comparisons are being made between individuals.

Comparative with previous research (Brughelli et al., 2011; Kivi et al., 2002), a large negative correlation (r = -0.73) was found between peak running velocity and ground contact time. This finding further supports the contention that faster runners have shorter ground contact times (Kunz & Kaufmann, 1981). Furthermore, the correlation shown in the current study was similar to that reported (r = -0.61) by Coh, Jost, and Stuhec (1998) in their investigation of female sprinters. The need for shorter ground contract times with increasing velocity is purported to allow for the faster repositioning of the legs (Brughelli et al., 2011) although others suggest it may be attributed to a decrease in thigh angle at foot touchdown (Kunz & Kaufmann, 1981) i.e. a shorter landing distance. However, another possibility is that the diminishing time afforded in the stance phase is a consequence of, rather than a requisite for, an increased horizontal velocity of the centre of mass, but further research is needed to verify this standpoint.

Finally, a moderate correlation (r = 0.46) was found between peak horizontal force from treadmill running and peak overground running velocity. This finding is in agreement with the correlation (r = 0.47) reported by Brughelli et al. (2011) but lower than the correlation (r = 0.78) found by Morin et al. (2011). The difference in findings between studies may be related to the instrument used to collect data. Both the current study and Brughelli et al. (2011) collected horizontal force data via a non-elastic tether that was fixed to the participants' waist and mounted to a load cell placed behind the runner, while Morin et al. (2011) collected the horizontal ground reaction forces directly via a force plate mounted underneath a treadmill. It may be that horizontal ground reaction forces differ from the horizontal forces collected in the current study. In any case, this study provides additional data to support the hypothesis that sprint performance is determined by the technical ability to apply more forward oriented horizontal forces rather than the physical ability of producing large overall forces.

Prospective Study

The clinical measures of static and active hip ROM remained largely unchanged between the two testing occasions with a -0.3% change recorded for static HE ROM and a 2.3% change recorded for active HF ROM. While a qualitative assessment of the change in HF ROM was 'possibly positive and possibly trivial', the observed 2.3% change are within the typical test-retest error observed in the reliability study, thus these changes are not likely substantial. These findings differ from previous observations that have shown changes in ROM at different stages of a training mesocycle in track sprinters (Makaruk & Makaruk, 2009). The changes observed by Makaruk and Makaruk (2009) were no greater than 3° which represented a relatively small change in joint ROM, and one that is comparable to that observed in the current study. However, their study included a standardised training schedule including stretching. In contrast, the athletes' training schedules in the current study were not standardised making it impossible to quantify how uniform the training was with regards to the balance of training modalities. Nonetheless, as the participants were all national-level athletes, it is reasonable to expect that the overall focus of the programme was largely similar with regards to peaking within the time-frame of the domestic competition calendar i.e. all of the athletes were aiming to peak at the national championships. Even so, some individual variation was evident as several athletes had positive or negative changes in active HE ROM of ~5-6°. These changes are thought to reflect alterations in hamstring muscle extensibility and/or hip flexor strength, thus it is expected that some athletes undertook conditioning activities that elicited larger changes in these qualities.

Dynamic ROM variables were also relatively similar between the two testing occasions. Dynamic HF ROM decreased slightly with the -2° mean change found to have a small ES (0.26). It is certainly plausible that dynamic HF ROM was reduced following the competitive season because retaining a high HF ROM requires technical ability and hip flexor strength and endurance; some of which may have been lost in the post-season transition period. Dynamic HE ROM on the other hand, increased 3%, but with individual variation of ±11% (90% CL) factored in, the result is possibly trivial.

The mean changes for pelvic angle measurements were also small and trivial. Despite this, a large amount of individual variation was observed for both pelvic angle measures, especially at peak HF. Regardless of the measurement error, pelvic angle would be expected to have greater variability than other kinematic variables, given the complexity of the factors influencing pelvic position (Chockalingam et al., 2012). For example the degree of hip flexion ROM during standing influences the pelvic angle (Azevedo et al., 2013) thus the same is expected during sprinting.

Measures of hip angular velocity also did not change substantially. The mean angular HF velocity in particular had <1% change, and the range of ± 2.9% (90% CL) shows there was a surprisingly small amount of individual variation between testing occasions. On the other hand, angular HE velocity had a -1.6 ± 8.6% (90% CL) change, which again indicates much larger variability for movement involving HE. The lack of change in angular velocity measures suggests that the neuromuscular characteristics of the lower body muscles, such as contraction speed, may have been maintained between testing sessions to allow similarly high movement velocities.

The associated variables of peak running velocity and ground contact time underwent little change between testing occasions with the mean values of each changing by no more than 1%. The similar values observed for these measures further suggest that the training status of the sampled athletes was similar between testing occasions, a surprising result given that the follow-up testing was conducted 4 weeks after the domestic season concluded. It could therefore be suggested that 4 weeks is not a long enough time period to see a regression of sprint performance. However, more comparisons need to be made to gain a full understanding of the residual effects of sprint training on these kinematic variables.

The changes in the kinetic outputs of the participants were also trivial. The small 2% decrease in peak horizontal force values was possibly negative and possibly trivial as defined by the qualitative analysis. Considering the change scores collectively, it would be prudent to view this result as typical error, as the mean change is indeed within the 3.3% TE shown in the reliability study. Preceding data analysis, it was anticipated that the horizontal force outputs would decrease at follow-up testing due to some deterioration in the participants' physical or technical ability to produce high horizontal forces. However, in the absence of any meaningful changes, it appears as though these technical sprint abilities were maintained.

It is interesting that no clear changes in hip ROM, or sprint kinematic and kinetics were observed between testing conducted in the competition season to testing conducted following the competition season. It is possible that more repeated measures taken at different time points are required to gain a complete understanding of these changes.

Chapter 6: Summary and Practical Applications

The purpose of this research was to investigate the relationships between hip ROM and kinematic and kinetic variables during sprinting, and to examine the changes in these variables at two different stages of the athletics season. Both acute and chronic doses of stretching have previously been shown to affect sprint performance (Fletcher & Anness, 2007; Fletcher & Jones, 2004), therefore clinical and dynamic measures of hip ROM may relate to sprint measures. However, because a myriad of other factors influence sprint performance (Comyns, Harrison, & Hennessy, 2010; Cronin, Green, Levin, Brughelli, & Frost, 2007; Deane, Chow, Tillman, & Fournier, 2005; Guskiewicz, Lephart, & Burkholder, 1993; Satkunskien, Rauktys, & Stanislovaitis, 2009), a biomechanical approach was taken in this research to give insights into the mechanical factors that are related to hip ROM.

The kinematic and kinetic assessments used in the studies were assessed for reliability. The procedures described for these studies generally had very good reliability across the spectrum of measures and compared favourably with other relevant literature. The kinematic assessment procedures used in this study could be easily replicated in subsequent research and is therefore useful to academics. Some of the assessment procedures are also highly applicable in the practical setting. For example, practitioners can reliability implement clinical assessments of hip ROM into their practice. The assessment of sprint kinetics involved sprint trials on a NMT, and in line with previous findings (Hughes et al., 2006), these measures also had high reliability. The advantage of the NMT is that data from multiple steps can be analysed which is appealing to both researchers and coaches. The high reliability of the NMT data makes this apparatus a viable option for sports scientists wishing to assess kinetic outputs during sprinting.

The correlational study revealed several novel findings including a very large relationship between dynamic HF ROM and angular HE velocity during running. This association has previously been shown for kicking tasks (Ball, 2011), but until now has not been documented for sprinting. Track coaches often advocate that athletes should sprint with a high degree of hip flexion to produce more favourable lower body mechanics, however the empirical evidence for this concept was lacking. This finding provides biomechanical evidence to support such practice and informs those coaches currently not aware of this concept. However, further research is now needed to support this contention, and in particular, intervention studies would provide insights into the cause-and-effect relationship between these variables.

It was also shown that dynamic ROM and pelvic angle during sprinting are highly related. Furthermore, an inverse correlation was shown between dynamic HF and HE ROM. Therefore, practitioners need to be aware that an intervention to change one of these variables may result in an alteration in the other, with the possible performance implications ensuing. Future research should investigate the cause and effect relationship between these variables and examine the implications of these postural variations on performance and injury risk factors.

The very large correlation shown between peak sprinting velocity and ground contact time supports previous findings (Brughelli et al., 2011; Kivi et al., 2002) and reinforces the importance of producing propulsive forces within a very short time to attain higher running velocities. As such, conditioning exercises for sprint athletes need to reflect these demands so training stimulus that require brief ground contact times and high forces are recommended.

The prospective study was carried out to measure the changes in the kinematic and kinetic variables at different stages of the athletics season. However, no meaningful changes were observed when these variables were measured during the season and four weeks post-season. Previous research reported changes in hamstring flexibility during different phases of a preparation mesocycle (Makaruk & Makaruk, 2009), however the current study was carried out during and after the competition phase. The lack of changes raise the question of how long the residual effects of sprint training last as this has implications for providing optimal tapering strategies; this question hopes to stimulate future research.

Collectively, the studies undertaken in this research have addressed some important questions. Firstly, the reliability of many kinematic and kinetic measures using video data and motion analysis procedures were established. These findings will aid researchers and practitioners in the selection of appropriate assessment procedures pertinent to the laboratory or clinical setting. Secondly, the relationships between hip ROM, sprint kinematic and kinetics were described. This analysis revealed several novel findings that provide insights into the interdependence of various kinematic and kinetic measures. Ultimately, the correlational data raise questions as to how technical sprint coaching concepts affects other important aspects of lower body movement. Finally, the changes in these kinematic and kinetic variables were assessed at two different time-points in the athletics season. It was determined that the stage of the athletics season did not affect these measures in any meaningful way.

Research Limitations

There are a several limitations to this research that warrant discussion. Firstly, a relatively small sample was recruited. This research was carried out to provide applicability to high-level track sprinters; hence the selection of experienced national-level track and field athletes was crucial. Moreover, it was thought that a lack of technical sprinting knowledge on behalf of the participants would provide a confounding factor in determining the relationships between sprint kinematics and kinetics. That is, participants who are regularly coached on running technique should have more of an awareness of optimal sprinting technique, thus their sprinting kinematics and kinetics were more likely influenced by physical characteristics. However, recruiting a large number of high-level track sprinters was difficult for several reasons; 1) the population of sprinters is relatively small; 2) injury prevalence in this population is notoriously high, causing many athletes to withdraw from the study following successful recruitment; 3) some coaches did not consent to their athletes participating in the research because it was viewed as an additional training load during an important time in the competition year. However, a reasonable number of athletes were sampled to provide some novel insights into the relationships between kinematic and kinetic variables during sprinting.

Further limitations were imposed because the kinematic sprint data were collected from overground sprint trials using 2-D video cameras. The kinematic analysis was limited to only several steps and restricted to movement in the sagittal plane, thus the potential for a small amount of parallax error. Furthermore, the retroflective markers on the pelvis could not be identified in a small number of trials, usually because a small amount of rotation occurred thus reducing the amount of comparisons that could be made for some measures. However, unlike the available treadmill ergometry, overground sprinting allowed the participants to sprint without limiting maximal velocity. Also, treadmill ergometry is known to alter dynamic ROM and other kinematic values during sprint trials (McKenna & Riches, 2007) thus overground sprint trials improve the validity of the data, possibly even more so in a sample of track and field athletes. Contact time measures were also taken from the video data captured from the overground sprint trials. This technique has its limitations as it can be difficult to determine the exact frame when the foot comes in contact with the ground i.e. the frame rate of the video data was 1/240 s meaning there are 0.004 s between frames, thus error of approximately 1/20 of the magnitude variable is potentially induced for contact times of around 100 ms.

Finally, the athletes' training schedules were not controlled thus several assumptions were made with regard to the results of the prospective study. The ability to control and manipulate the participants' training programme would have enabled a more concise analysis of prospective kinematic and kinetics changes at the different time points of the season, but such control was simply not possible with the selected sample and during the competition season.

References

Abe, T., Kumagai, K., & Brechue, W. F. (2000). Fascicle length of leg muscles is greater in sprinters than distance runners. *Medicine and Science in Sports and Exercise, 32*(6), 1125-1129.

Abebe, E. S., Moorman, C. T., & Garrett Jr, W. E. (2009). Proximal hamstring avulsion injuries: injury mechanism, diagnosis and disease course. *Operative Techniques in Sports Medicine, 17*(4), 205-209.

Albracht, K., & Arampatzis, A. (2013). Exercise-induced changes in triceps surae tendon stiffness and muscle strength affect running economy in humans. *European Journal of Applied Physiology, 113*(6), 1605-1615.

Alter, M. (1997). *Sport Stretch* (2nd ed.). Champaign: Human Kinetics.

Amiri-Khorasani, M., Abu Osman, N. A., & Yusof, A. (2011). Acute effect of static and dynamic stretching on hip dynamic range of motion during instep kicking in professional soccer players. *Journal of Strength and Conditioning Research, 25*(6), 1647-1652.

Ansari, N. W., Paul, Y., & Sharma, K. (2012). Kinematic analysis of competitive sprinting. *African Journal for Physical, Health Education, Recreation and Dance, 18*(4), 662-671.

Arai, T., Obuchi, S., Shiba, Y., Omuro, K., Nakano, C., & Higashi, T. (2008). The feasibility of measuring joint angular velocity with a gyro-sensor. *Archives of Physical Medicine and Rehabilitation, 89*(1), 95-99.

Askling, C. M., Nilsson, J., & Thorstensson, A. (2010). A new hamstring test to complement the common clinical examination before return to sport after injury. *Knee Surgery, Sports Traumatology, Arthroscopy, 18*(12), 1798-1803.

Azevedo, D. C., Santos, H., Carneiro, R. L., & Andrade, G. T. (2013). Reliability of sagittal pelvic position assessments in standing, sitting and during hip flexion using palpation meter. *Journal of Bodywork and Movement Therapies, 18*(2), 1-5.

Baechle, T., & Earle, R. (2008). *Essentials of strength training and conditioning* (3rd ed.). Champaign, IL., USA: Human Kinetics.

Baker, J., & Ball, K. (1996). *Biomechanical considerations of the drop punt*. Canberra: Australian Institute of Sport.

Ball, K. (2008). Biomechanical considerations of distance kicking in Australian Rules football. *Sports Biomechanics, 7*(1), 10-23.

Ball, K. (2011). Kinematic comparison of the preferred and non-preferred foot punt kick. *Journal of Sports Sciences, 29*(14), 1545-1552.

Bazett-Jones, D. M., Gibson, M. H., & McBride, J. M. (2008). Sprint and vertical jump performances are not affected by six weeks of static hamstring stretching. *Journal of Strength and Conditioning Research, 22*(1), 25-31.

Bland, J. M., & Altman, D. G. (1990). A note on the use of the intraclass correlation coefficient in the evaluation of agreement between two methods of measurement. *Computers in Biology and Medicine, 20*(5), 337-340.

Blum, J. W., & Beaudoin, C. M. (2000). Does flexibility affect sport injury and performance? *Parks and Recreation, 35*(10), 40-47.

Bober, T., Putnam, C. A., & Woodworth, G. G. (1987). Factors influencing the angular velocity of a human limb segment. *Journal of Biomechanics, 20*(5), 511-521.

Borhani, M., McGregor, A. H., & Bull, A. M. J. (2013). An alternative technical marker set for the pelvis is more repeatable than the standard pelvic marker set. *Gait and Posture, 38*(4), 1032-1037.

Bozic, P. R., Pazin, N. R., Berjan, B. B., Planic, N. M., & Cuk, I. D. (2010). Evaluation of the field tests of flexibility of the lower extremity: reliability and the concurrent and factorial validity. *Journal of Strength and Conditioning Research, 24*(9), 2523-2531.

Bressel, E., & McNair, P. J. (2002). The effect of prolonged static and cyclic stretching on ankle joint stiffness, torque relaxation, and gait in people with stroke. *Physical Therapy, 82*(9), 880-887.

Bridger, R. S., Orkin, D., & Henneberg, M. (1992). A quantitative investigation of lumbar and pelvic postures in standing and sitting: Interrelationships with body position and hip muscle length. *International Journal of Industrial Ergonomics, 9*(3), 235-244.

Brughelli, M., Cronin, J. B., & Chaouachi, A. (2011). Effects of running velocity on running kinetics and kinematics. *The Journal of Strength and Conditioning Research, 25*(4), 933.

Burgess, K. E., Connick, M. J., Graham-Smith, P., & Pearson, S. J. (2007). Plyometric vs. isometric training influences on tendon properties and muscle output. *Journal of Strength and Conditioning Research, 21*(3), 986-989.

Caplan, N., Rogers, R., Parr, M. K., & Hayes, P. R. (2009). The effect of proprioceptive neuromuscular facilitation and static stretch training on running mechanics. *Journal of Strength & Conditioning Research, 23*(4), 1175-1180.

Carregaro, R. L., & Gil Coury, H. J. C. (2009). Does reduced hamstring flexibility affect trunk and pelvic movement strategies during manual handling? *International Journal of Industrial Ergonomics, 39*(1), 115-120.

Cheng, A. J., Davidson, A. W., & Rice, C. L. (2010). The influence of muscle length on the fatigue-related reduction in joint range of motion of the human dorsiflexors. *European Journal of Applied Physiology, 109*(3), 405-415.

Chockalingam, N., Chatterley, F., Healy, A. C., Greenhalgh, A., & Branthwaite, H. R. (2012). Comparison of pelvic complex kinematics during treadmill and overground walking. *Archives of Physical Medicine and Rehabilitation, 93*(12), 2302-2308.

Coh, M., Jost, B., & Stuhec, S. (1998). Kinematic and dynamic structure of the sprinting stride of top female sprinters. *Biology of Sport, 15*(4), 237-243.

Comyns, T. M., Harrison, A. J., & Hennessy, L. K. (2010). Effect of squatting on sprinting performance and repeated exposure to complex training in male rugby players. *Journal of Strength and Conditioning Research, 24*(3), 610-618.

Congdon, R., Bohannon, R., & Tiberio, D. (2005). Intrinsic and imposed hamstring length influence posterior pelvic rotation during hip flexion. *Clinical Biomechanics, 20*(9), 947-951.

Cornwell, A., Nelson, A. G., & Sidaway, B. (2002). Acute effects of stretching on the neuromechanical properties of the triceps surae muscle complex. *European Journal of Applied Physiology, 86*(5), 428-434.

Cronin, J., Green, J., Levin, G., Brughelli, M., & Frost, D. (2007). Effect of starting stance on initial sprint performance. *Journal of Strength and Conditioning Research, 21*(3), 990-992.

Cronin, J., Nash, M., & Whatman, C. (2006). Assessing dynamic knee joint range of motion using siliconcoach. *Physical Therapy in Sport, 7*(4), 191-194.

Cronin, J., Nash, M., & Whatman, C. (2008). The acute effects of hamstring stretching and vibration on dynamic knee joint range of motion and jump performance. *Physical Therapy in Sport, 9*(2), 89-96.

Crosbie, J., & Vachalathiti, R. (1997). Synchrony of pelvic and hip joint motion during walking. *Gait and Posture, 6*(3), 237-248.

De Castro, J. V., Machado, K. C., Scaramussa, K., & Gomes, J. L. E. (2013). Incidence of decreased hip range of motion in youth soccer players and response to a stretching program: A randomized clinical trial. *Journal of Sport Rehabilitation, 22*(2), 100-107.

De Witt, J. K., & Hinrichs, R. N. (2012). Mechanical factors associated with the development of high ball velocity during an instep soccer kick. *Sports Biomechanics, 11*(3), 382-390.

Deane, R. S., Chow, J. W., Tillman, M. D., & Fournier, K. A. (2005). Effects of hip flexor training on sprint, shuttle run, and vertical jump performance. *Journal of Strength and Conditioning Research, 19*(3), 615-621.

Debaere, S., Delecluse, C., Aerenhouts, D., Hagman, F., & Jonkers, I. (2013). From block clearance to sprint running: Characteristics underlying an effective transition. *Journal of Sports Sciences, 31*(2), 137-149.

DePino, G. M., & Webright, W. G. (2000). Duration of maintained hamstring flexibility after cessation of an acute static stretching protocol. *Journal of Athletic Training, 35*(1), 56.

Ducomps, C., Mauriège, P., Darche, B., Combes, S., Lebas, F., & Doutreloux, J. P. (2003). Effects of jump training on passive mechanical stress and stiffness in rabbit skeletal muscle: role of collagen. *Acta Physiologica Scandinavica, 178*(3), 215-224.

Fletcher, I. M., & Anness, R. (2007). The acute effects of combined static and dynamic stretch protocols on fifty-meter sprint performance in track-and-field athletes. *Journal of Strength and Conditioning Research, 21*(3), 784-787.

Fletcher, I. M., & Jones, B. (2004). The effect of different warm-up stretch protocols on 20 meter sprint performance in trained rugby union players. *Journal of Strength and Conditioning Research, 18*(4), 885-888.

Four, A., Nordez, A., Guette, M., & Cornu, C. (2009). Effects of plyometric training on passive stiffness of gastrocnemii and the musculo-articular complex of the ankle joint. *Scandinavian Journal of Medicine and Science in Sports, 19*(6), 811-818.

Franz, J. R., Paylo, K. W., Dicharry, J., Riley, P. O., & Kerrigan, D. C. (2009). Changes in the coordination of hip and pelvis kinematics with mode of locomotion. *Gait and Posture, 29*(3), 494-498.

Gabbe, B. J., Bennell, K. L., Wajswelner, H., & Finch, C. F. (2004). Reliability of common lower extremity musculoskeletal screening tests. *Physical Therapy in Sport, 5*(2), 90-97.

Gajdosik, R. L., Hatcher, C. K., & Whitsell, S. (1992). Influence of short hamstring muscles on the pelvis and lumbar spine in standing and during the toe-touch test. *Clinical Biomechanics, 7*(1), 38-42.

Gajdosik, R. L., Vander Linden, D. W., McNair, P. J., Williams, A. K., & Riggin, T. J. (2005). Effects of an eight-week stretching program on the passive-elastic properties and function of the calf muscles of older women. *Clinical Biomechanics, 20*(9), 973-983.

Gilliam, J., Brunt, D., MacMillan, M., Kinard, R. E., & Montgomery, W. J. (1994). Relationship of the pelvic angle to the sacral angle: measurement of clinical reliability and validity. *Journal of Orthopaedic and Sports Physical Therapy, 20*(4), 193-199.

Gleim, G. W., & McHugh, M. P. (1997). Flexibility and its effects on sports injury and performance. *Sports Medicine, 24*(5), 289-299.

Guariglia, D. A., Pereira, L. M., Dias, J. M., Pereira, H. M., Menacho, M. O., Silva, D. A., Cyrino, E. S., & Cardoso, J. R. (2011). Time-of-day effect on hip flexibility associated with the modified sit-and-reach test in males. *International Journal of Sports Medicine, 32*(12), 947-952.

Guskiewicz, K., Lephart, S., & Burkholder, R. (1993). The relationship between sprint speed and hip flexion/extension strength in collegiate athletes. *Isokinetics and Exercise Science, 3*(2), 111-116.

Hamilton, N. (1993). Changes in sprint stride kinematics with age in master's athletes. *Journal of Applied Biomechanics, 9*(1), 15-26.

Harvey, D. (1998). Assessment of the flexibility of elite athletes using the modified Thomas test. *British Journal of Sports Medicine, 32*(1), 68-70.

Heino, J. G., Godges, J. J., & Carter, C. L. (1990). Relationship between hip extension range of motion and postural alignment. *Journal of Orthopaedic and Sports Physical Therapy, 12*(6), 243-247.

Hiroyuki, N., Asai, T., Ikegami, Y., & Sakurai, S. (2002). Three-dimensional kinetic analysis of side-foot and instep soccer kicks. *Medicine and Science in Sports and Exercise, 34*(12), 2028-2036.

Hobara, H., Inoue, K., Kato, E., & Kanosue, K. (2011). Acute effects of static stretching on leg-spring behavior during hopping. *European Journal of Applied Physiology, 111*(9), 2115-2121.

Hopker, J. G., Coleman, D. C., Wiles, J. D., & Galbraith, A. (2009). Familiarisation and reliability of sprint test indices during laboratory and field assessment. *Journal of Sports Science and Medicine, 8*, 528-532.

Hopkins, W. (2002). *A scale of magnitudes for effect statistics*. Retrieved 9/7/12, 2012, from http://www.sportsci.org/resource/stats/index.html

Hopkins, W. (2006). Spreadsheets for analysis of controlled trials with adjustment for a predictor. *Sportscience, 10*, 46-50.

Hopkins, W. (2011). Precision of measurement. *A New View of Statistics*. Retrieved from newstats.org/precision.html

Hopkins, W., Marshall, S., Batterham, A., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise, 41*(1), 3-13.

Hortobagyi, T., Faludi, J., Tihanyi, J., & Merkely, B. (1985). Effects of intense "stretching"-flexibility training on the mechanical profile of the knee extensors and on the range of motion of the hip joint. *International Journal of Sports Medicine, 6*(6), 317-321.

Hughes, M., Doherty, M., Tong, R., Reilly, T., & Cable, N. (2006). Reliability of repeated sprint exercise in non-motorised treadmill ergometry. *International Journal of Sports Medicine, 27*(11), 900-904.

Hume, P. A., Hopkins, W. G., Robinson, D. M., Robinson, S. M., & Hollings, S. C. (1993). Predictors of attainment in rhythmic sportive gymnastics. *Journal of Sports Medicine and Physical Fitness, 33*(4), 367-377.

Hyun-Bae, K. I. M., Stebbins, C. L., Joo-Hee, C., & Jong-Kook, S. (2011). Taekwondo training and fitness in female adolescents. *Journal of Sports Sciences, 29*(2), 133-138.

Kato, E., Kanehisa, H., Fukunaga, T., & Kawakami, Y. (2010). Changes in ankle joint stiffness due to stretching: The role of tendon elongation of the gastrocnemius muscle. *European Journal of Sport Science, 10*(2), 111-119.

Kay, A. D., & Blazevich, A. J. (2012). Effect of acute static stretch on maximal muscle performance: A systematic review. *Medicine and Science in Sports and Exercise, 44*(1), 154-164.

Kivi, D. M. R., Maraj, B. K. V., & Gervais, P. (2002). A kinematic analysis of high-speed treadmill sprinting over a range of velocities. *Medicine and Science in Sports and Exercise, 34*(4), 662-666.

Kokkonen, J., Nelson, A., Eldredge, C., & Winchester, J. (2007). Chronic static stretching improves exercise performance. *Medicine and Science in Sports and Exercise, 39*(10), 1825-1831.

Kokkonen, J., Nelson, A. G., Tarawhiti, T., Buckingham, P., & Winchester, J. B. (2010). Early-phase resistance training strength gains in novice lifters are enhanced by doing static stretching. *Journal of Strength and Conditioning Research, 24*(2), 502-506.

Kubo, K., Kanehisa, H., Kawakami, Y., & Fukunaga, T. (2001). Influence of static stretching on viscoelastic properties of human tendon structures in vivo. *Journal of Applied Physiology, 90*(2), 520-527.

Kukolj, M., Ropret, R., Ugarkovic, D., & Jaric, S. (1999). Anthropometric, strength, and power predictors of sprinting performance. *Journal of Sports Medicine and Physical Fitness, 39*(2), 120-122.

Kumagai, K., Abe, T., Brechue, W. F., Ryushi, T., Takano, S., & Mizuno, M. (2000). Sprint performance is related to muscle fascicle length in male 100-m sprinters. *Journal of Applied Physiology, 88*(3), 811-816.

Kunz, H., & Kaufmann, D. A. (1981). Biomechanical analysis of sprinting: Decathletes versus champions. *British Journal of Sports Medicine, 15*(3), 177-181.

Kwang-Jun, K. (2010). Effects of core muscle strengthening training on flexibility, muscular strength and driver shot performance in female professional golfers. *International Journal of Applied Sports Sciences, 22*(1), 111-127.

LaRoche, D., & Connolly, D. (2006). Effects of stretching on passive muscle tension and response to eccentric exercise. *American Journal of Sports Medicine, 34*(6), 1000-1007.

Laroche, D., Duval, A., Morisset, C., Beis, J. N., d'Athis, P., Maillefert, J. F., & Ornetti, P. (2011). Test–retest reliability of 3D kinematic gait variables in hip osteoarthritis patients. *Osteoarthritis and Cartilage, 19*(2), 194-199.

Lee, L., Zavarei, K., Evans, J., Lelas, J., Riley, P., & Kerrigan, D. (2005). Reduced hip extension in the elderly: Dynamic or postural? *Archives of Physical Medicine and Rehabilitation, 86*(9), 1851-1854.

Levanon, J., & Dapena, J. (1998). Comparison of the kinematics of the full-instep and pass kicks in soccer. *Medicine and Science in Sports and Exercise, 30*(6), 917-927.

Lockie, R. G., Murphy, A. J., Jeffriess, M. D., & Callaghan, S. J. (2013). Step kinematic predictors of short sprint performance in field sport athletes. *Serbian Journal of Sports Sciences, 7*(2), 71-77.

López-Miñarro, P. A., Muyor, J. M., Belmonte, F., & Alacid, F. (2012). Acute effects of hamstring stretching on sagittal spinal curvatures and pelvic tilt. *Journal of Human Kinetics, 31*, 69-78.

Magnusson, S. P., Simonsen, E. B., Aagaard, P., Dyhre-Poulsen, P., McHugh, M. P., & Kjaer, M. (1996). Mechanical and physiological responses to stretching with and without preisometric contraction in human skeletal muscle. *Archives of Physical Medicine and Rehabilitation, 77*(4), 373-378.

Mahieu, N. M., McNair, P., De Muynck, M., Stevens, V., Blanckaert, I., Smits, N., & Witvrouw, E. (2007). Effect of static and ballistic stretching on the muscle-tendon tissue properties. *Medicine & Science in Sports & Exercise, 39*(3), 494-501.

Makaruk, B., & Makaruk, H. (2009). Changes to flexibility of the hamstring in sprinters in the context of prevention. *Polish Journal of Sport and Tourism, 16*(3), 152-154.

Marshall, P. W. M., Cashman, A., & Cheema, B. S. (2011). A randomized controlled trial for the effect of passive stretching on measures of hamstring extensibility, passive stiffness, strength, and stretch tolerance. *Journal of Science and Medicine in Sport, 14*(6), 535-540.

McChellan, E. C., Padua, D. A., Guskiewicz, K. M., Prentice, W. E., & Hirth, C. J. (2004). Effects of myofascial release and static stretching on active range of motion and muscle activity. *Journal of Athletic Training, 39*(Supplement 2), 98-99.

McKenna, M., & Riches, P. E. (2007). A comparison of sprinting kinematics on two types of treadmill and over-ground. *Scandinavian Journal of Medicine and Science in Sports, 17*(6), 649-655.

McNair, P. J., & Stanley, S. N. (1996). Effect of passive stretching and jogging on the series elastic muscle stiffness and range of motion of the ankle joint. *British Journal of Sports Medicine, 30*(4), 313-318.

Meckel, Y., Atterbom, H., Grodjinovsky, A., Ben-Sira, D., & Rotstein, A. (1995). Physiological characteristics of female 100 metre sprinters of different performance levels. *Journal of Sports Medicine and Physical Fitness, 35*(3), 169-175.

Mei, X. (1989). The influence of anthropometric measurements and physical qualities on short-distance swimming performance. *Sports Science, 9*(4), 21-24.

Meroni, R., Giuseppe Cerri, C., Lanzarini, C., Barindelli, G., Della Morte, G., Gessaga, V., Cesana, G. C., & De Vito, G. (2010). Comparison of active stretching technique and static stretching technique on hamstring flexibility. *Clinical Journal of Sport Medicine, 20*(1), 8-14.

Mier, C. M. (2011). Accuracy and feasibility of video analysis for assessing hamstring flexibility and validity of the sit-and-reach test. *Research Quarterly for Exercise and Sport, 82*(4), 617-623.

Miranda, R. E. E. P. C., Antunes, H. K. M., Pauli, J. R., Puggina, E. F., & da Silva, A. S. R. (2013). Effects of 10-week soccer training program on anthropometric, psychological, technical skills and specific performance parameters in youth soccer players. *Science and Sports, 28*(2), 81-87.

Moriguchi, C. S., Carnaz, L., Silva, L. C. C. B., Salasar, L. E. B., Carregaro, R. L., Sato, T. D. O., & Coury, H. J. C. G. (2009). Reliability of intra- and inter-rater palpation discrepancy and estimation of its effects on joint angle measurements. *Manual Therapy, 14*(3), 299-305.

Morin, J.-B., Bourdin, M., Edouard, P., Peyrot, N., Samozino, P., & Lacour, J.-R. (2012). Mechanical determinants of 100-m sprint running performance. *European Journal of Applied Physiology, 112*(11), 3921-3930.

Morin, J.-B., Edouard, P., & Samozino, P. (2011). Technical ability of force application as a determinant factor of sprint performance. *Medicine and Science in Sports and Exercise, 43*(9), 1680-1688.

Moscov, J., Lacourse, M. G., Garhammer, J., & Whiting, H. (1994). Predictors of dynamic hip flexibility in female ballet dancers. *International Journal of Dance Science, Medicine and Education, 2*(3), 184-195.

Mueller, M. J., & Norton, B. J. (1992). Reliability of kinematic measurements of rear-foot motion. *Physical Therapy, 72*(10), 731-737.

Muyor, J. M., Alacid, F., & López-Miñarro, P. A. (2011). Influence of hamstring muscles extensibility on spinal curvatures and pelvic tilt in highly trained cyclists. *Journal of Human Kinetics, 29*, 15-23.

Nakamura, M., Ikezoe, T., Takeno, Y., & Ichihashi, N. (2012). Effects of a 4-week static stretch training program on passive stiffness of human gastrocnemius muscle-tendon unit in vivo. *European Journal of Applied Physiology, 112*(7), 2749-2755.

Nelson, A. G., Kokkonen, J., Winchester, J. B., Kalani, W., Peterson, K., Kenly, M. S., & Arnall, D. A. (2012). A 10-week stretching program increases strength in the contralateral muscle. *Journal of Strength and Conditioning Research, 26*(3), 832-836.

Nóbrega, A. C. L., Paula, K. C., & Carvalho, A. C. G. (2005). Interaction between resistance training and flexibility training in healthy young adults. *Journal of Strength & Conditioning Research, 19*(4), 842-846.

Nordez, A., Cornu, C., & McNair, P. (2006). Acute effects of static stretching on passive stiffness of the hamstring muscles calculated using different mathematical models. *Clinical Biomechanics, 21*(7), 755-760.

Norris, C. M., & Matthews, M. (2006). Correlation between hamstring muscle length and pelvic tilt range during forward bending in healthy individuals: An initial evaluation. *Journal of Bodywork and Movement Therapies, 10*(2), 122-126.

Orchard, J. (2001). Intrinsic and extrinsic risk factors for muscle strains in australian football. *The American Journal of Sports Medicine, 29*(3), 300-303.

Panayi, S. (2010). The need for lumbar-pelvic assessment in the resolution of chronic hamstring strain. *Journal of Bodywork and Movement Therapies, 14*(3), 294-298.

Peeler, J., & Anderson, J. (2008). Reliability limits of the modified thomas test for assessing rectus femoris muscle flexibility about the knee joint. *Journal of Athletic Training, 43*(5), 470-476.

Peeler, J., & Anderson, J. E. (2007). Reliability of the Thomas test for assessing range of motion about the hip. *Physical Therapy in Sport, 8*(1), 14-21.

Pelayo, P., Sidney, M., Kherif, T., Chollet, D., & Tourny, C. (1996). Stroking characteristics in freestyle swimming and relationships with anthropometric characteristics. *Journal of Applied Biomechanics, 12*(2), 197-206.

Reid, D. A., & McNair, P. J. (2004). Passive force, angle, and stiffness changes after stretching of hamstring muscles. *Medicine and Science in Sports and Exercise, 36*(11), 1944-1948.

Robinson, M. E., O'Connor, P. D., Shirley, F. R., & MacMillan, M. (1993). Intrasubject reliability of spinal range of motion and velocity determined by video motion analysis. *Physical Therapy, 73*(9), 626-631.

Samozino, P., Morin, J.-B., Dorel, S., Slawinski, J., Peyrot, N., Villarreal, S. d., & Giuseppe, R. (2013). *A simple method for measuring power, force and velocity properties of sprint running*. presented at the meeting of the XXIV Congress of the International Society of Biomechnanics, Brazil.

Samukawa, M., Hattori, M., Sugama, N., & Takeda, N. (2011). The effects of dynamic stretching on plantar flexor muscle-tendon tissue properties. *Manual Therapy, 16*(6), 618-622.

Satkunskien, D., Rauktys, D., & Stanislovaitis, A. (2009). The effect of power training on sprint running kinematics. *Education, Physical Training, Sport*(72), 116-122.

Schache, A. G., Blanch, P. D., & Murphy, A. T. (2000). Relation of anterior pelvic tilt during running to clinical and kinematic measures of hip extension. *Britsh Journal of Sports Medicine, 34*(4), 279-283.

Shellock, F. G., & Prentice, W. E. (1985). Warming-up and stretching for improved physical performance and prevention of sports-related injuries. *Sports Medicine, 2*(4), 267-278.

Shrier, I. (2004). Does stretching improve performance? A systematic and critical review of the literature. *Clinical Journal of Sport Medicine, 14*(5), 267-273.

Slocum, D. B., & James, S. L. (1968). Biomechanics of running. *Journal of the American Medical Association, 205*(11), 721-728.

Sozen, H. (2010). Comparison of muscle activation during elliptical trainer, treadmill and bike exercise. *Biology of Sport, 27*, 203-206.

Tateuchi, H., Taniguchi, M., Mori, N., & Ichihashi, N. (2012). Balance of hip and trunk muscle activity is associated with increased anterior pelvic tilt during prone hip extension. *Journal of Electromyography and Kinesiology, 22*(3), 391-397.

Tong, R. J., Bell, W., Ball, G., & Winter, E. M. (2001). Reliability of power output measurements during repeated treadmill sprinting in rugby players. *Journal of Sports Sciences, 19*(4), 289-297.

Tukuafu, J., & Hunter, I. (2010). The effects of indoor track curve radius on sprint speed and ground reaction forces. *Conference Proceedings of the Annual Meeting of the American Society of Biomechanics*, 936-937.

Waldron, M., Worsfold, P., Twist, C., & Lamb, K. (2011). Concurrent validity and test–retest reliability of a global positioning system (GPS) and timing gates to assess sprint performance variables. *Journal of Sports Sciences, 29*(15), 1613-1619.

Watt, J. R., Jackson, K., Franz, J. R., Dicharry, J., Evans, J., & Kerrigan, D. C. (2011a). Effect of a supervised hip flexor stretching program on gait in elderly individuals. *Physical Medicine and Rehabilitation, 3*(4), 324-329.

Watt, J. R., Jackson, K., Franz, J. R., Dicharry, J., Evans, J., & Kerrigan, D. C. (2011b). Effect of a supervised hip flexor stretching program on gait in frail elderly patients. *Physical Medicine and Rehabilitation, 3*(4), 330-335.

Wenos, D. L., & Konin, J. G. (2004). Controlled warm-up intensity enhances hip range of motion. *Journal of Strength & Conditioning Research, 18*(3), 529-533.

Weyand, P. G., Sternlight, D. B., Bellizzi, M. J., & Wright, S. (2000). Faster top running speeds are achieved with greater ground forces not more rapid leg movements. *Journal of Applied Physiology, 89*(5), 1991-1999.

Whatman, C., Knappstein, A., & Hume, P. (2006). Acute changes in passive stiffness and range of motion post-stretching. *Physical Therapy in Sport, 7*(4), 195-200.

Ylinen, J. J., Kautiainen, H. J., & Hakkinen, A. H. (2010). Comparison of active, manual, and instrumental straight leg raise in measuring hamstring extensibility. *Journal of Strength and Conditioning Research, 24*(4), 972-977.

Youdas, J. W., Krause, D. A., Egan, K. S., Therneau, T. M., & Laskowski, E. R. (2003). The effect of static stretching of the calf muscle-tendon unit on active ankle dorsiflexion range of motion. *Journal of Orthopaedic and Sports Physical Therapy, 33*(7), 408-417.

Young, W., Clothier, P., Otago, L., Bruce, L., & Liddell, D. (2004). Acute effects of static stretching on hip flexor and quadriceps flexibility, range of motion and foot speed in kicking a football. *Journal of Science and Medicine in Sport, 7*(1), 23-31.

Young, W., Clothier, P., Otago, L., Lyndell, B., & Liddell, D. (2003). Relationship between a modified Thomas test and leg range of motion in Australian-Rules football kicking. *Journal of Sport Rehabilitation, 12*, 343-350.

Yuktasir, B., & Kaya, F. (2009). Investigation into the long-term effects of static and PNF stretching exercises on range of motion and jump performance. *Journal of Bodywork and Movement Therapies, 13*(1), 11-21.

Appendices

Appendix 1: Ethics Approval

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

A U T E C
S E C R E T A R I A T

19 December 2012

Michael McGuigan
Faculty of Health and Environmental Sciences

Dear Michael

Re Ethics Application: **12/338 Hip range of motion: Relationships to sprint kinematics and kinetics, and changes across the sprint season.**

Thank you for providing evidence as requested, which satisfies the points raised by the AUT University Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 19 December 2015.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online throughhttp://www.aut.ac.nz/research/research-ethics/ethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 19 December 2015;
- A brief report on the status of the project using form EA3, which is available online throughhttp://www.aut.ac.nz/research/research-ethics/ethics. This report is to be submitted either when the approval expires on 19 December 2015 or on completion of the project.

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this. If your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply there.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

Dr Rosemary Godbold
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Brodie Hewlett brodie.hewlett@gmail.com

Appendix 2: Participant Information Sheet

SPORTS PERFORMANCE
RESEARCH INSTITUTE, NEW ZEALAND
AN INSTITUTE OF AUT UNIVERSITY

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Participant Information Sheet

Date Information Sheet Produced:

20 December 2012

Project Title

Hip range of motion: Relationships to sprint kinematics and kinetics.

An Invitation

I, Brodie Hewlett, am a Masters student based at the Sport Performance Research Institute NZ (SPRINZ) at AUT University in Auckland.

I would like to invite you to participate in a research study using biomechanical analysis to assess athletic performance. Participation is entirely voluntary and you may withdraw at any time without any adverse consequences.

How are potential participants chosen?

Potential participants are chosen if it has been identified that you are a track athlete that participates in sprint or hurdle events. Actual participation in this research is subject to meeting the inclusion criteria of the study.

What is the purpose of this research?

The purpose of this study is to investigate the relationships between hip range of motion and sprinting biomechanics. This is also one of the studies that make up Brodie Hewlett's proposed Masters Degree.

What will happen in this research?

Each session will involve static and active hip-range-of-motion assessments (see figures below), as well as over-ground and treadmill sprints. You will be familiarised with the non-motorised treadmill prior to testing. Reflective biomechanical markers will be placed on your body and you will be filmed with high-speed 2-D cameras during over-ground sprinting. Prior to the sprint testing, you will undertake a standardised warm-up protocol. Each testing session will take approximately 75-mins.

What do I need to wear to the testing sessions?

To allow for accurate placement and identification of the biomechanical markers placed on your body, you should preferably wear short black (or a similar dark colour) sprint tights and a tight fitting singlet. If you don't have any appropriate clothing then some can be provided for you. You should also bring a water bottle to the testing session.

What are the discomforts and risks?

The anticipated discomforts and risks from participating in this testing are similar to that of your regular sport training and testing sessions. You may experience a mild soreness in your legs; this response is normal and triggered by the onset of any exercise. The other possible discomfort is delayed onset of muscle soreness (DOMS) on the day following or subsequent two days after testing. However, you are unlikely to get DOMS after testing, as the activities involved are similar to your normal training.

Discomfort may also occur due to the nature of the testing. See below for information regarding gender matching and the use of a chaperone.

How will these discomforts and risks be alleviated?

You will have the opportunity to familiarise yourself with the testing procedures.
If you do not feel you are able to complete the testing requested, you should notify the researcher immediately and the testing will be terminated.

You should notify the researcher, if you have a current injury or have had an injury within the last four months that might affect your performance, or that might be worsened or aggravated by the required activity. For example, any strains and sprains must be reported, specifically to the hip, knee and ankle.

Participants will be matched for gender where possible or if specifically requested, and a chaperone can also be arranged on request.

What are the benefits?

By participating in this study, you will receive specific information about your hip range of motion (flexibility), your sprinting mechanics and the forces that you exert into the ground during sprinting. You will also improve our understanding of how hip range of motion relates to the biomechanics of sprinting, which will help improve the practice of our coaches and strength and conditioning specialists.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will your privacy be protected?

The identity and results of each participant will be kept confidential and only shared with your coach if you have checked the appropriate box on the consent form. However due to the small number of elite participants that are being recruited for this research, it is possible that people will be able to identify who participants are when the results are published. Only the researcher (Brodie Hewlett) and the primary supervisor (Prof. Mike McGuigan) will analyse your results. You should also be aware that the results from this research may be published in an academic journal and/or presented at a conference in the future.

What are the costs of participating in this research?

There are no costs to participation, apart from scheduling your time (~90 min) to be available for testing.

How do I agree to participate in this research?

If you would like to participate in this research, you need to sign the attached Consent Form, and return it to Brodie Hewlett prior to participating in any of the tests.

If you do not wish to participate in this research, please notify the researcher and understand that you may withdraw at any time without any prejudice.

Will I receive feedback on the results of this research?

Yes, you can receive a summary of individual results once the information is ready for distribution (around one month after completing the study). Please check the appropriate box on the Consent Form if you would like this information.
The results of your testing performance will only be given to your coach (if applicable) with your permission (please check the appropriate box on the Consent Form).

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Prof. Mike McGuigan, michael.mcguigan@aut.ac.nz, or mobile 021 605 179

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Dr Rosemary Godbold, rosemarygodbold@aut.ac.nz, telephone: 09 921 9999, extension 6902.

Whom do I contact for further information about this research?

Please contact the student researcher, Brodie Hewlett, brodie.hewlett@gmail.com, mobile 021 881 590.

Student Researcher Contact Details:
Brodie Hewlett, brodie.hewlett@gmail.com, mobile 021 881 590.

Project Supervisor Contact Details:
Supervisor, Prof. Mike McGuigan, michael.mcguigan@aut.ac.nz, mobile 021 605 179

Approved by the Auckland University of Technology Ethics Committee on 10/12/2012
AUTEC Reference number 12/338

Appendix 3: Participant Consent Form

Consent Form	AUT UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: ***Hip range of motion: Relationships to sprint kinematics and kinetics, and changes across the sprint season.***

Project Supervisor: ***Prof. Mike McGuigan***

Researcher: ***Brodie Hewlett***

○ I have read and understood the information provided about this research project in the Information Sheet dated 20th December 2012

○ I have had an opportunity to ask questions and to have them answered.

○ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.

○ I am not suffering from any injury, heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or any infection that will impair my physical performance (or that might be aggravated by the tasks requested).

○ I agree to take part in this research.

○ I wish to receive a copy of the report from the research (please tick one): Yes○ No○

○ I agree to share the research results with my coach (please tick one): Yes○ No○

Participant's signature: ....………………………………………………………

Participant's name: ....……………………………………….

Participant's Contact Details (if appropriate):

………………………………………………………………………………………..

………………………………………………………………………………………..

………………………………………………………………………………………..

………………………………………………………………………………………..

Date:

Approved by the Auckland University of Technology Ethics Committee on 12th December 2012 AUTEC Reference number 12/338

Appendix 4: Parent Guardian Consent Form

Parent/Guardian Consent Form

Project title: ***Hip range of motion: Relationships to sprint kinematics and kinetics, and changes across the sprint season.***

Project Supervisor: ***Prof. Mike McGuigan***

Researcher: ***Brodie Hewlett***

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 20th December 2012.
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that I may withdraw my child/children and/or myself or any information that we have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- ○ If my child/children and/or I withdraw, I understand that all relevant information including data, transcripts, or parts thereof, will be destroyed.
- ○ I agree to my child/children taking part in this research.
- ○ I wish to receive a copy of the report from the research (please tick one): Yes○ No○

Child/children's name/s:

………………………………………………………………………………………

Parent/Guardian's signature:

...............................……………………………………………………………

Parent/Guardian's name:

.............................……………………………………………………………

Parent/Guardian's Contact Details (if appropriate):

………………………………………………………………………………………..

………………………………………………………………………………………..

Date:

Approved by the Auckland University of Technology Ethics Committee on 12th December 2012 AUTEC Reference number 12/338

Note: The Participant should retain a copy of this form.

Appendix 5: Participant Assent Form

Assent Form

Project title: ***Hip range of motion: Relationships to sprint kinematics and kinetics, and changes across the sprint season***

Project Supervisor: ***Prof. Mike McGuigan***

Researcher: ***Brodie Hewlett***

○ I have read and understood the sheet telling me what will happen in this study and why it is important.

○ I have been able to ask questions and to have them answered.

○ I understand that while the information is being collected, I can stop being part of this study whenever I want and that it is perfectly ok for me to do this.

○ If I stop being part of the study, I understand that all information about me, including the data or any part of them that include me, will be destroyed.

○ I agree to take part in this research.

○ I agree to share the research results with my coach (please tick one): Yes○ No○

Participant's signature: ....

Participant's name: ....

Participant Contact Details (if appropriate):

……………………………………………………………………………………..

……………………………………………………………………………………..

……………………………………………………………………………………..

……………………………………………………………………………………..

Date:

Approved by the Auckland University of Technology Ethics Committee on 12th December 2012 AUTEC Reference number 12/338

Note: The Participant should retain a copy of this form

Appendix 6: Athlete Pre-screening Questionnaire

SPORTS PERFORMANCE
RESEARCH INSTITUTE, NEW ZEALAND
AN INSTITUTE OF AUT UNIVERSITY

Athlete Pre-screening Health Questionnaire

Athlete code: _____

Name: ________________________________ Date: ______________

DOB: _____/_____/_____Age: _____ Gender: ☐ Female ☐ Male

Address: ____

____

Email: ____

Phone: __________________Mobile: __________________

Preferred method of contact: ☐ email ☐ txt ☐ phone other _____

Physical Measures

Height: _________cm Weight: _________ kg

Athlete History

How long have you been doing athletics training? ________________________________

Do you currently participate in any sports other than athletics? ☐ No ☐ Yes

Please give details: ____

____

What is your current primary event? ☐ Sprints ☐ Hurdles ☐ Combined events ☐ Jumps

What are your *Seasons Bests* for sprint events?

Event: **100m** Time: _________

Event: **200m** Time: _________

Event: **400m** Time: _________

Event: _________ Time: _________

What are your *Personal Bests* for sprint events?

Event: **100m** Time: _________

Event: **200m** Time: _________

Event: **400m** Time: _________

Event: _________ Time: _________

Injury History

Are you currently suffering from injuries to your…

☐ Hips ☐ Knees ☐ Ankle

☐ Lower leg ☐ Upper leg ☐ Feet

Other ____

Researcher Notes:

How long prior to follow up testing would you like me to contact you to set up an appointment?

____

How would you like feedback from the testing sessions to be given?

Directly to you ☐ To your coach ☐ Other ______________________________

Coaches details if necessary:

____

____

Other notes:

____

____

____

____

Appendix 7: Recruitment Email to Participants

Dear Athletes,

My name is Brodie Hewlett and I am a Master's candidate in Sports Kinesiology at AUT University, and am currently undertaking research in sprinting.

To complete my study I require as many sprinters as possible to participate in some simple, non-evasive tests at the Sports Performance Research Institute New Zealand (SPRINZ). The specific information about the study is found in the attached Participant Information Sheet, and should you have any questions regarding the nature of this research then please do not hesitate to contact me.

Your participation in this research is absolutely critical to help us sports scientists and coaches understand more about enhancing sprint performance and your contribution towards helping me complete my Masters thesis would be gratefully appreciated. If you have concerns regarding the cost of travel to participate then please contact me, as you may be eligible to receive a contribution towards your transport costs.

If you would like to participate in this study then please contact me by either email at brodie.hewlett@gmail.com, or by phone on 021881590.

Kind Regards,
Brodie Hewlett

Appendix 8: Recruitment Media Release

Released via Athletics New Zealand:

SPRINT RESEARCH PROJECT NEEDS AUCKLAND-BASED ATHLETES!
Original research being carried out at the Sports Performance Research Institute NZ (SPRINZ) is looking for Auckland-based athletes to participate in an exciting new study.

The research project is lead by Brodie Hewlett, a Sports Kinesiology Master's student at AUT University, who will be investigating the links between hip range of motion and sprinting biomechanics in track and field athletes. The results of this research offer numerous benefits to both athletes and coaches looking to enhance sprint performance.

To complete the study, Brodie requires athletes to participate in some simple, non-evasive tests at SPRINZ (based at the Millennium Institute of Sport on the North Shore).

If you think you might like to participate in this study then please express your interest to Brodie at brodie.hewlett@gmail.com to receive further information about the study.

Appendix 9: Recruitment Website Advertisement

Published on the Athletics New Zealand Website:

SPRINTING RESEARCH PROJECT NEEDS AUCKLAND-BASED ATHLETES!
A research project – carried out at the Sports Performance Research Institute NZ (SPRINZ) – is inviting athletes to participate in an exciting new study. The research, led by Brodie Hewlett, a Sports Kinesiology Master's student at AUT University, is investigating the links between hip range of motion and sprinting biomechanics in track and field athletes.

To complete the study, you will be required to undergo some simple, non-evasive tests at SPRINZ (based at AUT Millennium on the North Shore). The first data collection period is scheduled to commence on April 22nd and run until May 3rd and the full testing protocol takes 60-90 minutes to complete.

The results of this research offer numerous benefits to both athletes and coaches looking to enhance sprint performance, and athletes will receive a feedback report on their individual test results.

If you think you might like to participate in this study then please express your interest to Brodie at brodie.hewlett@gmail.com to receive further information about the study.