THE EFFICACY OF A COMMUNITY BASED ECCENTRIC HAMSTRING STRENGTHENING PROGRAM IN PERI-URBAN BLACK SOUTH AFRICAN SOCCER PLAYERS

BY

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THESIS

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ABSTRACT

Introduction: Hamstring injury prevalence in soccer remains a major concern. Research in this context has focused on Caucasian populations with little attention given to other ethnic groups. The compatibility and applicability of such research to the South African context, particularly at an amateur level, may be minimal due to fundamental differences in physical characteristics, as well as complexities with regards to implementation. The aim of this investigation was therefore twofold. 1) Identify the lower extremity strength and performance profile of Peri-urban Amateur South African Players, and 2) Assess the efficacy of a community based intervention through the use of the Nordic Hamstring Exercise. **Methods:** 19 Black male Eastern Cape amateur players participated in a 12 week randomly controlled trial (9 = Control, 10 = Intervention). All participants completed regular training, while the intervention group, in addition, performed the Nordic Hamstring exercise post warm up. The incremental program design was taken from Mjolsnes *et al.* (2004), with a progressive increase in both sets and repetitions. Compliance was defined as completion of the required exercises for that session. Isokinetic strength evaluations (at $60°.s^{-1}$ and $180°.s^{-1}$) including assessment of peak torque and total work, as well as performance measures of countermovement and squat jump, were completed pre and post intervention, with the profile of the Peri-urban player the combined responses of both groups at baseline. Additionally, both the functional ratio (Eccentric Hamstrings/Concentric Quadriceps) and eccentric utilization ratio (Countermovement Jump/Squat Jump) were calculated. **Results:** Concentric quadriceps peak torque at baseline reported values of 195 (±22) Nm and 141 (±21) Nm at $60°.s^{-1}$ and $180°.s^{-1}$. Values of 162 (±21) Nm were observed for peak torque of the eccentric hamstrings at $60°.s^{-1}$, while 157 (±18) Nm was indicated at $180°.s^{-1}$. Mean functional ratio responses were observed as 0.83 (±0.11) and 1.12 (±0.16) for $60°.s^{-1}$ and $180°.s^{-1}$ respectively. Additionally, the eccentric utilization ratio responses were recorded as 1.04 (±0.08). Regarding the intervention, concentric quadriceps total work of the dominant limb significantly improved over the time course of experimentation within the intervention group. Other quadriceps variables, concentric hamstrings, squat jump capability and performance measures all reported no significant changes ($p>0.05$) over the course of assessment when compared to the control. Eccentric hamstrings peak torque observed significant improvements ($p<0.05$) of between 5.72 and 12.82 % within the intervention group, while the countermovement jump indicated a significant 15.59 % increase ($p<0.05$). Additionally, the functional ratio and the eccentric utilization ratio both indicated no significant changes ($p>0.05$), with a 2.48-7.66 % and 5.33 % improvement noted following completion of assessment. **Conclusion:** Isokinetic responses at baseline observed decreased quadriceps strength, and increased hamstring strength when compared to both amateur and professional populations examined in previous studies, for both isokinetic testing speeds. Additionally, performance measures indicated similar responses to other amateur populations. Regarding the intervention, significant improvements in eccentric hamstring peak torque and countermovement jump indicate the partial success of the present intervention. Additionally, while the functional ratio and eccentric utilization ratio reported no significant changes, improvements were noted within the intervention group while the control noted no change. The Nordic hamstring lower therefore resulted in strength improvements within the eccentric hamstrings, reported as a significant factor for injury risk, however, such changes were not sufficient to significantly impact the functional ratio. It can be concluded that community based programs within South Africa have the potential to be effective; however, there are many barriers to implementation, including, language, ethnic and cultural differences, while a lack of resources and infrastructure play a significant role in a lack of development. More research of this nature is required to provide scientific support for structures and guidelines for the peri-urban community based South African player, to ensure the efficacy of internationally successful interventions such as the Nordic exercise.

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CHAPTER I

INTRODUCTION

BACKGROUND TO THE STUDY:

Soccer or football is the most popular sport worldwide, with a 2007 survey conducted by the Fédération Internationale de Football Association (FIFA) indicating that over 265 million players participate at a variety of competitive levels. Due to this popularity and the high profile nature of elite soccer, related research has grown substantially over the last 20 years, attempting to optimise performance (Carling, 2005) and reduce injury (Olsen, 2004). Considering such aims, a fundamental aspect of this soccer specific research was to establish the relative demands placed on the player.

Using the technique of time motion analysis, Jen Bangsbo and colleagues (1994) observed that soccer has a unique intermittent, non-continuous activity profile, with a change in activity every four seconds. The predominant activity is running, however, other ball related activities such as tackling, shooting, heading, passing and running with the ball are crucial to performance, and contribute to the development of fatigue (Mohr e*t al.,* 2005). Additionally, over the duration of match-play, players typically cover between 9 and 12 km over a 90 minute game, depending on the level of play (Mohr *et al.,* 2005). Players must therefore be competent in multiple aspects of fitness such as aerobic and anaerobic power, muscular strength, flexibility and agility (Svensson and Drust, 2005).

These associated demands affect the rate of fatigue of the player and relative performance over the duration of match-play. More specifically, fatigue is especially prevalent during the later stages of each half (Rahnama *et al.,* 2002 & Mohr *et al*., 2005). This is referred to as the corresponding fatigue profile and has vital implications for both performance and injury risk. For instance, this unique soccer specific fatigue profile has a time dependant relationship with injury, indicated in studies by Rahnama *et al.* (2002) and Greig *et al.* (2006).

The intermittent demands of soccer therefore result in a high frequency of soccer related injury as observed by Ekstrand *et al.* (2011). Of particular interest are injuries to the thigh region which according to these authors, account for 23% of all soccer related injuries. Furthermore, Hawkins *et al*. (2001) notes that 81% of these thigh injuries are muscular strains, of which 67% can be attributed to the hamstring muscle group. Multiple studies (Askling *et al.*, 2003; Mjølsnes *et al.*, 2004; Arnason *et al.*, 2008) have indicated that such an injury most often occurs during eccentric activity of the hamstrings, particularly during the later swing phase of the running gait (Pinniger *et al.*, 2000; Small *et al.,* 2010). This is reasonable, as the predominant activity in soccer is running (Bangsbo *et al.*, 2006). Due to this high risk of hamstring injury and the popularity of soccer, greater insight is needed in this area. Therefore the current study was designed to further develop the understanding of hamstring injuries and the prevention thereof.

Researchers have placed high importance on understanding hamstring injury causation (Söderman *et al.*, 2001; Arnason *et al.,* 2004; Small *et al.,* 2008). This is necessary as hamstring injuries are not only common, but also highly prone to re-injury (Croisier, 2004). Although muscular fatigue is a significant factor, it is now thought that hamstring strain causality is multifactorial in nature (Worrell and Perrin, 1992; Croisier*.,* 2004). Such factors can be split into two distinct aspects: modifiable and non-modifiable factors. Modifiable factors include flexibility (Witvrouw *et al.,* 2003), muscular strength balances (Clark *et al,* 2005), such as the functional hamstring to quadriceps ratio, warm up techniques (Taylor *et al,* 1990), previous injury and insufficient recovery (Arnason *et al.,* 2004). It is important to note that while re-injury is an important consideration, the primary aim of this thesis is injury prevention, and the research is approached from this paradigm. Non-modifiable factors noted include age (Orchard, 2001) and particularly ethnicity (Woods *et al.,* 2004).

A combination of these factors is a potential contributor to injury risk within the hamstring muscle group (Worrell, 1994). However, the understanding of the interaction between such factors is limited. This is an interesting consideration when viewing the literature specific to soccer. Although there is a high number of interacting factors identified, related research has predominantly focused on European (Tourny-Chollet *et al.*, 2000; Cometti *et al.,* 2001; Rahnama *et al.*, 2003; Witvrouw *et al.,* 2003; Croisier, 2004; Zakas *et al.*, 2006; Croisier *et al.,* 2008; Greig, 2008; Greig & Siegler, 2009; Magalhaes *et al.,* 2010; Small *et al.*, 2010; Delextrat *et al.,* 2010; Robineau *et al*., 2012; Lovell *et al.,* 2013) and to a lesser extent on North American (Worrell *et al.,* 1994) and South American (Da Silva *et al.*, 2008; Cohen *et al.,* 2014) populations. Minimal studies have focused on the African player and more specifically, Southern African players of Bantu descent, despite ethnicity being shown to be an important risk factor (Opar et al., 2012). This is an important consideration in South Africa, as 76.4 % of the population are of Bantu descent (CENSUS, 2011). Of particular interest for the current study was therefore the impact of race, or rather ethnic origin on player capabilities.

This is a crucial consideration, as each population of interest has different physiological, biomechanical and anthropometric characteristics (Gallagher *et al.,* 1997; Looker, 2002; Carroll *et al.,* 2008). It is difficult to say whether such differences are relevant within an African soccer context as minimal research has been conducted. However, inference can be drawn from studies on general African athletes, such as endurance runners, with Coetzer *et al.* (1993) and Larsen *et al.* (2005) both noting that such ethnic differences are important performance and injury risk factors. For example, running economy and oxygen utilization, effectively explain Kenyan dominance in endurance running when compared to their European counterparts (Larsen, 2003), while the contribution of genetic factors to performance, is identified in a study by Tucker *et al.* (2013). The impact of ethnicity within a soccer context is indicated in a hamstring injury audit of English professional football, conducted by Woods et al. (2004), stating that players of black ethnic origin are at greater risk of hamstring injury,

Subsequently, these inherent ethnic differences may further influence responses within a South African soccer context. However, due to a lack of soccer specific research, it is difficult to identify the extent of such inherent variations. Most importantly, the unique population at play within this context, namely Southern African footballers, may have a different response and fatigue profile. This is intimated in a study by Coetzer *et al.,* (1993), who established fundamental differences between white and black runners. Furthermore, Jones *et al*. (2015) identified the upper thigh isokinetic profile of black South African players in response to match-play simulation. The authors noted that black university students may be at a greater risk of hamstring injury, due to a greater reduction in hamstring strength over the time course of simulated match play.

Although these physical parameters are vitally important, factors such as socio-economic status also play a fundamental role in physical capacity (Mayosi *et al.,* 2009). This is especially prevalent in South Africa at a Peri-urban level, due to the high levels of poverty, unemployment, disease and HIV, amongst this community based population (Bradshaw & Steyn, 2001). Additionally, the majority of the playing population within the South African context are from this lower socio-economic bracket. It is integral that such factors are considered when engaging with the South African population. Unfortunately, no studies have identified the effect of these factors on performance and injury risk within this context. This has direct implications for soccer training techniques, which are therefore adopted from varying populations.

This is a vital aspect of the present study. It is simplistic to extrapolate fundamental findings across populations, as this assumes similar responses and thus, injury risk and performance characteristics. Furthermore, the lack of research on the Peri-urban South African soccer player places a great disadvantage on the most significant player population. The unique characteristics of the population at play may result in a unique soccer-specific response profile, due to both modifiable and non-modifiable factors. Therefore the first aim of the current study was to establish the strength and performance profile of the community based Peri-urban South African player, a population currently understudied.

Not only is it important to acknowledge the unique characteristics/profile of a particular population, but also to investigate the efficacy of interventions strategies within this context. As previously identified, hamstring injury is the most prevalent soccer related injury (Ekstrand *et al.,* 2011). Recent research has therefore attempted to establish intervention programmes that aim to increase the relative strength of the hamstrings in footballers (Mjølsnes *et al.,* 2004; Gabbe *et al.,* 2006; Arnason *et al.,* 2008; Croisier *et al.*, 2008). Multiple exercises and exercise regimes (Mjølsnes *et al.,* 2004; Gabbe *et al.,* 2006; Petersen *et al.,* 2011) have been employed in an attempt to reduce injury risk. Such exercises include box jumps, hamstring curls and downhill running. Currently, the most effective hamstring strengthening exercise is the Nordic hamstring lower, employed in a variety of studies (Mjolsnes *et al.,* 2004; Gabbe *et al.,* 2006; Petersen *et al.,* 2011). However, the effectiveness of each individual exercise is still highly contentious as these exercises have been employed in a variety of contexts, and on varying populations (Mjolsnes *et al.,* 2004; Gabbe *et al.,* 2006), predominantly in Europe(Engebretzen *et al.,* 2008; Arnason *et al*., 2008; Croisier *et al.,* 2008; Petersen et al., 2011).

The efficacy of intervention strategies such as the Nordic hamstring lower have therefore not been explored within the unique South African context at a community soccer level. As a result, it is unknown whether such intervention strategies are effective within this context. The secondary aim of the present study was therefore to establish the efficacy of an eccentric hamstring strengthening intervention within the Peri-urban South African context, in order to provide a reference and foundation for future community based soccer specific South African research.

STATEMENT OF THE PROBLEM:

Although soccer specific research has grown substantially over the last 20 years, the majority of said research has focused on the elite player and European populations. Furthermore, endurance running research indicates that inherent differences between populations results in differing performance characteristics, which may influence the soccer specific fatigue and injury risk profile of the South African player. Additionally, modifiable factors such as nutrition and socio-economic status also play a significant role in soccer specific performance and injury risk. Thus, currently the knowledge base regarding the unique South African soccer player profile is very limited, having concomitant impact on both performance and risk of injury in South African community based soccer programmes. Furthermore, although the Nordic hamstrings intervention has been shown to be effective in several European contexts, its efficacy within the South African context, particularly at the community based soccer level, has not been adequately explored. It is imperative that the efficacy and barriers to implementation be investigated in order to identify the effectiveness of such interventions within this context.

The aim of this thesis was therefore two fold; Firstly, to develop the strength and performance profile of the amateur Black South African player within the Rural

Eastern Cape context. Secondly, to assess the efficacy of an eccentric hamstring-strengthening programme on this unique population of community based Black Southern African soccer players.

STATISTICAL HYPOTHESIS

<u>Hypothesis 1</u>: The first null hypothesis proposed is that there will be no differences in physical responses between pre and post assessment for both control and intervention group

H_o: µResponses $T_{Pre\ (Con,\ Int)}$ = µResponses $T_{Post\ (Con,\ Int)}$

H_a: µResponses $T_{Pre\ (Con,\ Int)}$ ≠ µResponses $T_{Post\ (Con,\ Int)}$

Where:

µResponses = Isokinetic Peak Torque, Work, Power, Angle of Peak Torque, Time to Peak torque, Squat Jump Height, Countermovement Jump Height, Eccentric Utilization Ratio, Functional Ratio, 10m Sprint, Yo-Yo Shuttle Test

T= Time (Pre or Post Intervention)

Con/Int = Control Group or Intervention Group

Hypothesis 2: The second null hypothesis proposed is that there will be no differences in physical responses between the Control and Intervention groups, pre and post the 10 week Nordic intervention.

H_o: $\mu CONResponses\ T_{(Pre,\ Post)} = \mu INTResponses\ T_{(Pre,\ Post)}$

H_a: $\mu CONResponses\ T_{(Pre,\ Post)} \neq \mu INTResponses\ T_{(Pre,\ Post)}$

Where:

µResponses = Isokinetic Peak Torque, Work, Power, Angle of Peak Torque, Time to Peak torque, Squat Jump Height, Countermovement Jump Height, Eccentric Utilization Ratio, Functional Ratio, 10m Sprint, Yo-Yo Shuttle Test

T= Time (Pre or Post Intervention)

CON/INT = Control Group or Intervention Group

Hypothesis 3: The third null hypothesis proposed is that there will be no interaction between time and group for physical responses, pre and post the 10 week Nordic intervention.

H_o:$(\mu Responses_{(Con,Pre)} - \mu Responses_{(Con,Post)}) = (\mu Responses_{(Int,Pre)} - \mu Responses_{(Int,Post)})$

H_a:$(\mu Responses_{(Con,Pre)} - \mu Responses_{(Con,Post)}) \neq (\mu Responses_{(Int,Pre)} - \mu Responses_{(Int,Post)})$

Where:

µResponses = Isokinetic Peak Torque, Work, Power, Angle of Peak Torque, Time to Peak torque, Squat Jump Height, Countermovement Jump Height, Eccentric Utilization Ratio, Functional Ratio, 10m Sprint, Yo-Yo Shuttle Test

T= Time (Pre or Post Intervention)

Con/Int = Control Group or Intervention Group

RESEARCH HYPOTHESIS

Hypothesis 1

The Nordic Hamstring intervention strategy will result in no change in relative hamstring strength and performance indicators over time, for the control and intervention groups.

Hypothesis 2

There is no difference in relative hamstring strength and performance indicators between the intervention and the control group over the duration of the intervention

Hypothesis 3

There is no interaction between time and group for relative hamstring strength and performance indicators over the duration of the intervention

CHAPTER II

REVIEW OF LITERATURE

Soccer or football is the most popular sport world-wide, with a reported 265 million players participating at a number of different competitive levels. Furthermore, these differing levels can be categorized by the level of professionalism, financial investment, training and fitness requirements, as well as natural skill and talent (Small, 2008). Examples of these levels of play include amateur, tertiary, semi-professional, professional and elite. Additionally, due to increased media exposure and high levels of financial investment, the world wide appeal of the game has grown exponentially in recent years. This has placed great focus on maximising player potential (Williams *et al.,* 1993), particularly at an elite level, as well as reducing the prevalence of injury (Olsen *et al.,* 2004).

SOCCER SPECIFIC PROFILE

In order to facilitate such goals, understanding the characteristics of soccer match-play, and furthermore, understanding the demands placed on the player, is of paramount importance. To isolate this nature of soccer, initial researchers monitored the demands using the technique of time motion analysis. Such profiles identified are population specific, but do however present a basis for understanding the nature of match-play. Significant authors in the field such as Bangsbo (1994) and Reilly (1997), have therefore established this profile, ensuring the complete understanding of the demands of the game.

Table I: Definition of Locomotor Intensities (Bangsbo, 1994)

Category	Speed (km.h-1)
Standing	< 0.5
Walking	5
Jogging	10
Cruising/Striding	17
Sprinting	>23

Soccer is a predominantly intermittent activity, as the player is required to change activity every 4-6s (Bangsbo, 1994). A top-class player thus performs around 1350 activities during the game (Bangsbo, 1994), with the most common activity being running (Reilly, 1997). Due to the intermittent nature, associated running can be further categorized by the different intensities (as listed in Table I above). Additionally, the relative percentage time spent in each locomotor category, has been indicated by Mohr *et al.* (2003) and can be seen in Figure 1. These categories were deemed appropriate by initial researchers such as Bangsbo (1994); Reilly (1997) & Krustrup *et al.* (2003). Furthermore, this differentiation of speeds has been adopted in multiple studies since (Rahnama *et al.*, 2002; Williams, 2007; Greig, 2008; Small, 2008), and is employed in validation of soccer simulation protocols.

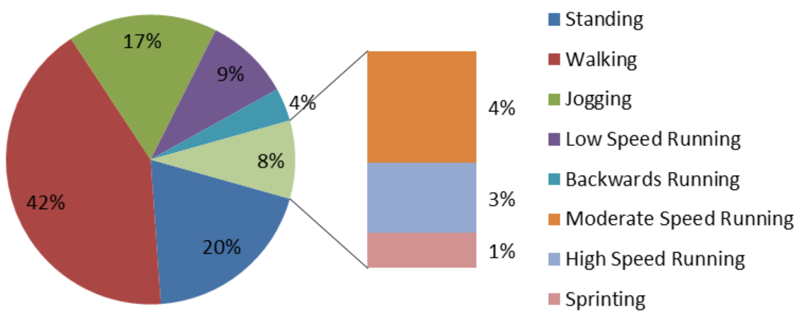

Figure 1: Percentage time in each locomotor category associated with soccer match-play (Mohr *et al.,* 2003)

Over the duration of soccer match play, players typically cover a total distance of 9 – 12 km (Bangsbo, 1994; Krustrup *et al.*, 2003; Mohr *et al.*, 2004), with distance varying according to the playing level (Mohr *et al.,* 2003), style of play and position (Rampinini *et al.,* 2007). An example of these differing demands across positions was established by Bloomfield (2007), who performed time motion analysis on English Premier League matches. As indicated in Table II, midfielders experience significant demands across the categories of jogging, running and sprinting when compared to other positions.

Table II: Percentage time activity profile across positions taken from Bloomfield (2007) (Data are Mean (SD))

	STRIKER	MIDFIELDER	DEFENDER
Standing	5.3 (3.5)	2.1 (1.6)	6.3 (2.5)
Walking	14.1 (3.8)	12.8 (4.2)	15.8 (4.5)
Jogging	24.7 (8.7)	28.3 (12)	31.5 (6.8)
Running	11.1 (4.5)	14.6 (9.2)	7.6 (3.6)
Sprinting	5.5 (3.3)	6.4 (3.1)	2.5 (1.3)
Skipping	8.3 (2.8)	9.1 (3.8)	12.3 (6.2)
Shuffling	9.5 (1.6)	7.9 (2.1)	10.5 (3.2)
Other	21.5 (7.7)	18.8 (5.6)	13.6 (8)

Besides running, other soccer related activities such as dribbling, tackling, heading and kicking, further contribute to the overall demands of match play (Mohr *et al.,* 2005). The demands of this unique intermittent profile result in an average aerobic loading during the game of 75% of typical maximal oxygen uptake (Bangsbo, 1994). Although aerobic metabolism accounts for much of the energy demands associated with soccer, increased levels of lactic acid have been reported (Krustrup, 2003) following soccer match-play. It was therefore construed that the anaerobic system is highly taxed during intense periods of the game (Mohr *et al.,* 2005). As a result, it is necessary for players to be hardened to the unpredictable demands of soccer match-play.

With knowledge of the intermittent activity pattern associated with soccer match-play, it is vital to identify the effects of such demands on the player. This is known as the soccer specific fatigue response profile and is highly associated with injury risk.

INJURY PROFILE

As discussed, soccer has large associated physical demands that are placed on the player over the duration of soccer match-play. Combined with large player numbers (FIFA, 2007), there is a high frequency of muscular injuries (Ekstrand *et al.,* 2011). Furthermore, with the inherent risk associated with semi-contact intermittent sport, soccer related injury is therefore an important factor when evaluating the player (Fuller *et al.,* 2006). Within this soccer context, injury is especially prevalent in the lower extremities (Wong and Hong, 2005), due to the characteristics of bipedal human locomotion. An injury audit conducted by Ekstrand *et al.* (2011) indicated that the most frequent muscular injuries associated with match play are hamstring, quadriceps, hip/groin and calf strains. Importantly, contact injuries are not included in such analysis, due to their random nature. The frequencies of such injuries are reported in Figure 2 below, categorized by age group. Such lower extremity injuries tend to occur in the latter stages of both halves of play (Hawkins *et al.*, 2001; Rahnama *et al.,* 2003), noting the causal relationship between fatigue and injury risk.

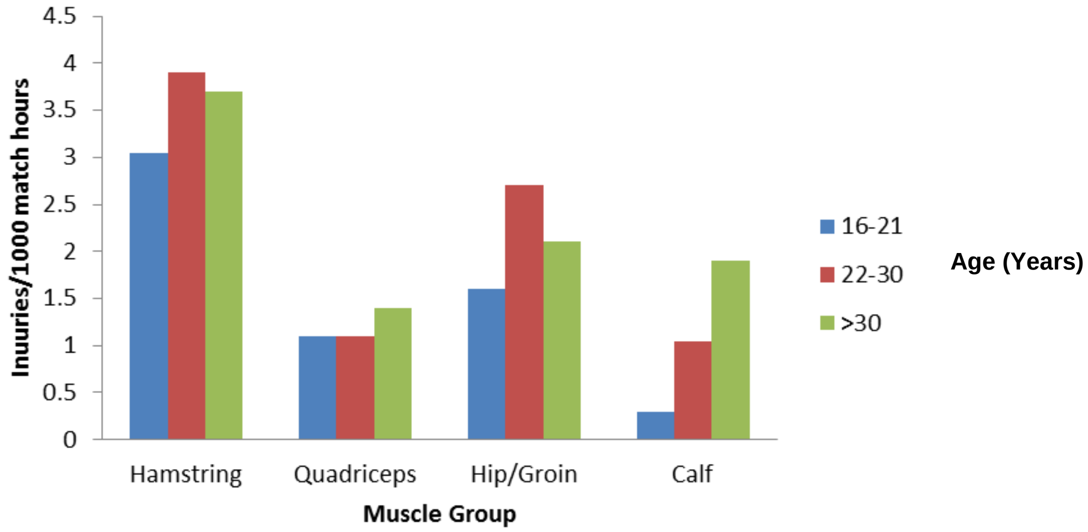

Figure 2: Match incidence of 4 most common muscle strain injuries in age groups 16 to 21 years, 22 to 30 years and >30 years (Ekstrand *et al.,* 2011)

Additionally, the intermittent nature of soccer results in varying degrees of risk regarding injury (Witvrouw *et al.,* 2003). Activities such as running, twisting, turning, jumping and landing have been reported by Wong and Hong (2005), as the most common mechanisms for injury. The thigh, and more specifically the hamstring muscle group, is reported to be the most frequently injured anatomical structure, as a result of these soccer specific demands (Ekstrand and Gillquist, 1983; Arnason *et al.,* 2004, Ekstrand *et al*., 2011).

According to Hawkins *et al.* (2001), muscle strains account for 81% of all thigh injuries and 94 % of hamstring injuries (Woods *et al.,* 2004). Additionally, this frequency of hamstring injury is reported as 3:1 when compared to the quadriceps muscle group (Small, 2008), placing greater focus on hamstring capability to develop force. Additionally, the biceps femoris muscle is the most frequently injured, accounting for 53% of hamstring strains (Woods *et al.,* 2004, Opar *et al.,* 2012). This should, however, be treated with caution, as 19% of hamstring injuries within the study conducted by Woods *et al*. (2004), were unspecified in their diagnosis.

It is important to note, that most research regarding hamstring injury, and subsequently hamstring strength, have predominantly been conducted on European (Tourny-Chollet *et al.,* 2000; Cometti *et al.,* 2001; Rahnama *et al.,* 2003; Witvrouw *et al.,* 2003; Zakas *et al*., 2006; Croisier *et al.,* 2008; Greig, 2008; Greig and Siegler, 2009; Small *et al.,* 2010; Lovell *et al.,* 2013), and to a lesser extent North American (Worrell, 1994), and South American (Da Silva *et al.,* 2008) populations. The populations of interest are indicated in Table III. However to date little research has focused on African players, and more specifically on Southern African players, despite the known biomechanical and physiological differences between African and European populations within an athletic context (Larsen, 2003).

Table III: Hamstring related research and populations of interest

	Country
Tourney-Cholet *et al.* (2000)	France
Cometti *et al.* (2001)	France
Rahnama *et al.* (2003)	England
Witvrouw *et al*. (2003)	Belgium
Zakas *et al.* (2006)	Greece
Greig (2008)	England
Greig and Siegler (2009)	England
Brughelli *et al.* (2010)	Spain
Small *et al.* (2010)	England
Worrell *et al.* (1994)	America
Silva *et al*. (2008)	Brazil

Such anthropometric (Carroll *et al.,* 2008), biomechanical (Looker, 2002) and physiological differences (Gallagher *et al.,* 1997) may be present in the unique Southern African Black population, and furthermore, may have a significant influence on capability and performance within a soccer context (Larsen, 2003). Additionally, hamstring injury is especially prevalent within the South Africa context, as reported by Calligeris *et al.* (2015. The authors noted that 21% of all soccer specific injuries were to the thigh region when establishing injury incidence of a South African Premier Soccer League team in 2015. As a result, any research on the risk of thigh injury conducted in European and American regions may not be relevant to the population of African soccer players.

A vital characteristic regarding hamstring related research is therefore the focus on specific populations. However, it is important to establish the knowledge of hamstring injury epidemiology and epistemology in order to evaluate the current state of hamstring related research. The following is therefore a review of such content, in order to establish the importance of hamstring strain injuries within a soccer specific context. This will then be related to the specific population of interest namely: Southern African Players.

HAMSTRING VULNERABILITY

The hamstring muscle group consists of three muscles, namely; Biceps femoris, semitendinosus and semimembranosus. The primary function of the hamstring muscle group is extension of the hip and flexion of the knee (Totora & Derrickson, 2006). This is particularly relevant within the gait cycle, constantly active during soccer match-play due to the high frequency of running (Small *et al.,* 2010). Multiple authors (Rahnama *et al*., 2002; Greig *et al.,* 2006; Small, 2008) have investigated the vulnerability of hamstrings to injury during the soccer match-play, particularly during the later stages (Ekstrand *et al*., 2011). The activity profile, unique to soccer, induces a significant risk in the hamstring muscle group (Small, 2010), with sprinting described as a primary mechanism for injury in soccer (Woods *et al.,* 2004).

Concerning the epidemiology of hamstring muscle injuries, the overall frequency of hamstring strains may be due to the increased popularity of soccer (Small, 2008). This has led to an increased number of such injuries within the sport (Olsen *et al.* 2004), specifically an increase in the number of hamstring strains associated with the later stages of match-play (Greig, 2008). To establish the specific incidence of hamstring strain, soccer injury audits have been employed at a number of competitive levels. In the early 1980's, it was reported that hamstring strains had a prevalence rate of 6 % (Ekstrand and Gillquist, 1983). However, the hamstring strain rate had more than doubled over the following two decades, amounting to 13-15% of all injuries (Woods *et al.*, 2003).

Thus, hamstring muscular strains have become a major concern due to financial implications, as well as time spent away from the pitch (Chomiak *et al.,* 2000). As such, it has been suggested that more effective prevention programmes be developed to minimize risk of injury (Rahnama *et al.,* 2002; Greig *et al.,* 2006; Small, 2008). Additionally, Hawkins *et al.* (2001) reported that 35% of total injuries in English professional football were hamstring related injuries, placing even greater importance on the understanding, and prevention of such injuries, as well as the development of effective prevention programmes.

MECHANISMS OF INJURY

It has been proposed that the increased risk within the hamstrings may be due to the eccentric actions associated with the rapid extension of the knee, decelerating the lower leg during the final phase of the running gait (Croisier *et al.,* 2008). This demonstrates the relationship between sprinting and injury. However, multiple authors have contended that the mechanism of hamstring injury is multifactorial in nature (Worrel and Perrin, 1992; Croisier *et al,* 2004; Croisier *et al.,* 2008), and thus remains controversial as to the extent that such factors contribute to injury.

Temporal Pattern of Hamstring Injuries

The pattern of injury can be investigated concerning the timing of injury over the playing season and within individual match-play. Most injuries occur during preseason or following the closed season (Hawkins *et al.,* 2001). This is associated with a loss of fitness due to rehabilitation time (Croisier *et al*., 2004), and thus the player is less able to withstand the stresses associated with pre-season training. This places large emphasis on appropriate programmes and reintegration techniques to ensure player conditioning is appropriate. Furthermore, Woods *et al.* (2004) observed a high proportion of hamstring strain during the later stages of the season. Cumulative fatigue and reduced emphasis on player conditioning may explain such a finding (Small, 2008).

Within the context of individual match-play, as previously discussed, 47% of injuries occur during the later third of both halves (Woods *et al.,* 2004). Fatigue is thus a crucial factor concerning injury, as the experience of fatigue may alter the complex neuromuscular co-ordination pattern that occurs during running (Verrall *et al.,* 2001). However, such injuries are multifactorial in nature and should be approached holistically (Woods *et al.,* 2004).

Hamstring Injury Risk Factors

Hamstring strains are associated with asynchrony of individual muscles (Woods *et al.,* 2004), with strains accounting for 37% of all injuries in professional soccer (Hawkins *et al.*, 2001). Such strains are categorized according to a 3 grade model with grade 1 (mild), grade 2 (moderate) and grade 3 (severe) dependant on the extent of muscular damage (Ekstrand et al., 2012). Importantly, the activity of any muscle can be defined as either passively stretched or activated during stretch (Zarins and Ciullo, 1983). Most clinicians agree that muscle strains most often occur during such activities. Thus, muscular fibres have a particular strain threshold for both activity modes. Excessive stretch or stress while activated may therefore result in injury (Kirkendall and Garrett, 2002).

It has been established that hamstrings are at a high risk of injury during the later stages of each half of soccer match-play (Greig *et al.,* 2006). Due to the intermittent profile of soccer, particularly the different activity modes, understanding the contributing factors to hamstring injury is complex. The following factors have been established as contributors to the occurrence of hamstring injury, but must be considered with caution as any interaction between these factors is poorly understood

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Fatigue

Although fatigue is not the key focus of the current study it is an important component of both performance and injury risk within soccer. Therefore the review will briefly introduce the concept of fatigue as it provides important background to hamstring injury causation, but it will not be covered in its full scope.

The unique intermittent profile of soccer match-play results in a higher proportion of injury during the final third of each half (Hawkins *et al.,* 2001). Physiological changes within the muscle fibres may therefore be directly associated with injury risk, as a result of the experience of fatigue. Mohr *et al.* (2005) identified the effect of fatigue on performance during the later stages, while a study conducted by Ekstrand *et al*. (2011) reported the high frequency of injuries at this time. Furthermore, Hawkins *et al.* (2001) and Rahnama *et al.* (2002), have identified that to resist fatigue, players are able to continue performing sub-maximally, while the ability to perform maximally is diminished. Injury may occur while players are attempting to perform maximally during the later stages. This is indicated by the higher proportion of hamstring injuries occurring as a function of time (Woods *et al.,* 2004).

The experience of soccer related fatigue and the relating effects on performance have been well documented by Mohr *et al.* (2005) & Rampinini et al. (2008). Such studies indicate that the amount of sprinting, high intensity running, and distance covered are lower during the second half of match-play when compared to the first (Bangsbo 1994, & Mohr *et al.,* 2003). Thus, decreased performance is associated with the experience of fatigue. This is further epitomized by a progressive decline in relevant force producing capabilities across both halves (Small, 2008; Greig *et al.,* 2006). This reduction in capacity is synonymous with the risk of injury (Rahnama *et al.,* 2002), and is a crucial component in injury prevention strategies.

Fatigue is a complex aspect of human performance and remains highly contentious (Macintosh *et al.,* 2002). In order to dissect and unpack the current understanding of soccer-specific fatigue this review will look at temporary fatigue (which occurs at all stages following high intensity activity), followed by cumulative fatigue which generally occurs during the later stages of both halves.

Temporary Fatigue

An interesting aspect of fatigue is the sensation of temporary fatigue. Established through the use of time motion analysis (Mohr *et al.,* 2003), a reduced performance was indicated following a period of intense exercise. Furthermore, Mohr *et al.* (2003) observed that the amount of intense running performed following the most intense period of the match, was observed to be less than the average observed throughout the game. Similar findings were noted in repeated sprint performance (Mohr *et al.,* 2005). Following the most intense period of the first half, sprint performance was lowered by up to 30% (Krustrup *et al.,* 2003). However, the associated repeated sprint ability had recovered by the end of the first half (Krustrup *et al.,* 2003). Players therefore experience a temporary reduction in capability, termed 'temporary fatigue', which is recovered over the duration of the half (Mohr *et al.,* 2005).

Cumulative Fatigue

The experience of cumulative fatigue has been well established by multiple authors within the context of intermittent sports (Mohr *et al.,* 2003; Twist & Highton, 2013; Granatelli *et al.,* 2014; Waldron *et al.,* 2014). Specifically within soccer match-play, as reported by Bangsbo (1994) and Mohr *et al.* (2003), the amount of high intensity exercise declines towards the end of the game. Furthermore, Mohr *et al.* (2003) reports that the amount of high intensity running is reduced during the final 15 minutes of play, while Mohr *et al.* (2003b) indicated that exercise intensity declines during the final third of the second half. Additionally, repeated sprint ability was reported to be reduced when comparing before and after match-play valuations (Krustrup *et al.,* 2003; Mohr *et al,* 2004). With regards to the effect of cumulative fatigue on injury risk, a significant study is that of Marshall et al. (2014) who examined changes in hamstring muscle torque producing capabilities in response to a simulated soccer match. It was reported that reductions in maximal voluntary torque and rate of torque development occur towards the end of each half. Such reductions may indicate the inherent hamstring injury risk as a result of soccer related fatigue.

Fatigue therefore plays a significant role in performance and consequently, injury risk. The specific demands of soccer-match-play evoke a unique fatigue profile, which must be considered when assessing player capacity (Mohr *et al.,* 2005). As fatigue is such a crucial factor in soccer performance, it is important to understand the mechanisms, which may play a role in the development of fatigue. This area of research is still controversial, and must be assessed critically.

Muscle Strength and Balance

Strength deficiencies relating to dominant and non-dominant hamstrings, as well as between quadriceps and ipsilateral hamstring muscles has been reported as having a high correlation to hamstring weakness from as early as Burkett (1970). Furthermore, according to Clark *et al.* (2005), the hamstring length-tension relationship during eccentric contractions plays a vital role in hamstring injury risk.

In order to better understand predisposition to injury, recent research has established the importance of the ratio between hamstrings and quadriceps with regards to relative strength, noting its importance in identifying hamstring risk factors (Rahnama *et al.,* 2002; Greig *et al.,* 2006). Two such ratios have been established, namely, the traditional and functional ratios.

- Traditional H:Q (Concentric Hamstrings: Concentric Quadriceps)
- Functional H:Q (Eccentric Hamstrings: Concentric Quadriceps)

Traditionally, the ratio between concentric hamstrings and concentric quadriceps was employed in assessing the capacity of the upper thigh (Figoni *et al.,* 1988). However, researchers have noted (Aagaard *et al.,* 1998 & Croisier *et al.,* 2002) that this ratio is not representative of functional action, as concentric quadriceps are not antagonistic to concentric hamstrings. Recently, the functional ratio has therefore become of greater interest. This is due to its more accurate representation of the muscular action of the upper thigh, as eccentric hamstring activation is antagonistic to the concentric quadriceps (Croisier *et al.,* 2002). The functional H: Q ratio is regarded as an effective indicator regarding the effect of soccer-specific fatigue on relative strength, as it is more representative of functional action (Aagaard *et al*., 1998 &

Dauty *et al.,* 2003). Additionally, Rahnama *et al.* (2002) and Greig *et al.* (2006) found a time dependant progressive reduction in the functional H: Q ratio, implying insufficient hamstring strength to counteract the force produced by the quadriceps during the late swing phase of the gait cycle. This has been identified as a significant risk factor for injury (Aagaard *et al.,* 1998; Croisier *et al.,* 2008Opar *et al.,* 2012).

Body Mechanics and Dysfunction

Comerford and Mottram (2001) have previously indicated the contribution of body mechanics to hamstring injury risk. They reported that the restriction or tension in one part of the kinetic chain may create an increased load on other parts of the chain. This may result in either, macro trauma or cumulative micro trauma, which both results in strain as reported by Small (2008). Hennessey and Watson (1993) further hypothesized that this may be true of the hamstring muscle group, with the impact of lumbar lordosis and lumbar pelvic mechanics playing an important role in hamstring strength capacity. However, further prospective studies are needed to investigate the impact of body mechanics on performance and injury within a soccer specific context (Small *et al.,* 2009).

Warm-up

A common aspect of injury investigation is the impact of the warm-up. It has long been viewed that increased muscle temperature prevents muscular strain (Garret, 1990). Furthermore, the capability of the musculo-tendinous unit to absorb force is directly proportional to resting length and muscle temp according to Taylor *et al.* (1990). Dynamic stretching and other such warm up techniques have therefore become commonplace pre-game. There are however, conflicting reports regarding the efficacy of such techniques. Interestingly, an investigation by Lovell *et al*. (2013) established the effects of whole body vibration, passive half time and intermittent exercise half time regimes. A passive half time had a negative effect on sprint and jump performance while the other strategies had minimal effect. Further research must be conducted, however, it can be tentatively suggested that a passive half time has negative performance effects and therefore the inclusion of a warm up is an important consideration.

Flexibility

It has been reported that 11% of all soccer injuries are related to muscle tightness (Ekstrand and Gillquist, 1983) or a lack of flexibility. Two studies using multivariate analyses, found that players with reduced hamstring muscle flexibility are at significantly higher risk for injuries (Witvrouw *et al.,* 2003; Henderson *et al.,* 2010). Other studies, however, reported contradictory findings (Orchard *et al.,* 1997; Arnason *et al.,* 2004; Engebretsen *et al.,* 2010; Fousekis *et al.,* 2010). Related literature regarding flexibility as a factor therefore remains contentious, and more research in this area is required (Small, 2008).

Age

It has been observed that the occurrence of injury and re-injury occur as a function of age (Orchard, 2001). Furthermore, Orchard (2001) noted that for players aged 23 years and up, injury is significantly more likely. Similar observations were made by Keller *et al.,* (1987) within the soccer specific context. This may be associated with age related spinal degeneration, as reported by Orchard (2001). Aspects such as Nerve impingement and hamstring fibre denervation have been reported as a bi-product of aging. This is especially prevalent with Type II fibres, due to their relative increased modes of activity (Liu et al., 2012).

Race/Ethnicity

The importance of race or ethnicity with regards to injury risk is a significant consideration within the context of interventional research. A study by Verrall *et al.* (2001) indicated that within a sample of Australian Rules football players, participants of aboriginal descent were at a greater risk of injury. Furthermore, an investigation by Woods *et al.* (2004) observed that players of Bantu ethnic origin are at greater risk of hamstring injury. The researchers attributed this greater risk to a greater proportion of Type II fibres. Within the context of this study, such hypotheses are important. The local South African population are predominantly black and therefore warrant further investigation to assess whether an increased risk is truly prevalent. Additionally, Calligeris *et al.* (2015) observed injury frequency within the South African soccer league, intimating similar injury frequency to European populations. However, it is simplistic to categorize players according to race. There are a number of contributing factors which influence physiological, biomechanical and anthropometrical characteristics. A more effective term is ethnicity which includes aspects such as historical geographical location and inherent genetic factors (Tucker *et al.,* 2013). The importance of population specific assessment will be further discussed in due course.

<u>Sprinting</u>

Hamstring muscle activation during sprinting is a vital aspect of injury risk as noted by Pinniger *et al*. (2000). The action of decelerating the thigh and lower leg prior to toe strike, places the hamstring under high eccentric demand (Agre, 1985). Furthermore, stabilisation of the knee during stance phase is crucial while assisting in hip extension during the push-off phase, increasing the relative demands of eccentric action of the hamstrings (Agre, 1985). Consequently, sprinting is a high risk activity with regards to potential hamstring injury, particularly within an intermittent sport context.

Injury to the upper thigh is most likely to occur during sprinting, when flexibility demands are the highest and the forces involved are at their maximum (Agre, 1985 & Pinneger *et al*. 2000). A further important consideration is quadriceps flexibility. Increased forward acceleration of the lower limb forces the hamstrings to counteract eccentrically, resulting in reduced knee flexion (Gabbe *et al.* 2005). Furthermore, gait dynamics such as decreased stride length as the game continues, results in mechanical adaptation and an increased hamstring risk (Hanon, 2005). This adaptation is exhibited by rectus femoris and biceps femoris, which show the earliest signs of fatigue, and thus limit stride length (Hanon, 2005). As a result, hamstring injury most commonly occurs during the late swing phase of sprinting, when the deceleration of the quadriceps requires greater eccentric force production of the hamstrings. This contribution of sprinting to hamstring fatigue and injury risk is complex and therefore requires consideration.

Hamstring muscle strains predominantly occur during non-contact activities such as sprinting and jumping (Stanton and Purdam, 1989). Additionally, an investigation by the English Football association reported that 57% of all hamstrings injuries are a result of running or sprinting (Woods *et al.,* 2004).It is important to note that running may be used as an all-encompassing term, involving activities such as twisting, turning or stretching. It must be used with caution, as further research is needed to isolate the impact of different soccer related activities. However, Rahnama *et al.* (2002) and Greig *et al.* (2006) report that injuries typically occur when demands placed on the muscle group exceed their capabilities i.e. following the development of fatigue.

Previous injury and Insufficient Recovery and Rehabilitation

A vital factor relating to muscular injury is the increased risk of re-injury, as reported by Small (2008). A study conducted by Hawkins *et al.* (2001) reported that recurrent injuries account for over 7% of all soccer related injuries. This is due to pre-existing muscular weakness due to previous injury, and thus only requires subsequent minor trauma to result in injury (Woods *et al.,* 2004). This increased risk of injury during non-contact activities (such as running), may indicate insufficient recovery and rehabilitation techniques. In order to reduce the prevalence of re-injury, rehabilitation and specific return to play criteria must be established (Hawkins *et al.,* 2001). However, rehabilitation should not be the concern here. Primary prevention of the initial injury must be the priority (Arnason *et al.,* 2004)

As discussed above, there is a high prevalence of hamstring injury due to the unique activity profile of soccer (Ekstrand *et al.,* 2011). Furthermore, there are many contributing factors to hamstring injury development and occurrence. Accordingly, multiple researchers (Worrell, 1994; Tourny-Chollet *et al.,* 2000; Cometti *et al.,* 2001; Da Silva *et al.,* 2008 Greig, 2008; Small *et al.,* 2010; Lovell *et al.,* 2013) have investigated the fatigue and injury risk profiles of certain populations (European, North and South American) to understand the demands placed on the player. However, Africans and particularly Southern Africans remain significantly understudied.

This is a substantial issue with regards to assessment and recommendations for players within this context. Research conducted on varying populations has ensured the development of a significant body of knowledge, which has been standardized and applied world-wide. However, there is often an assumption made by coaches that all players carry similar levels of injury risk, and similar characteristics relating to performance. It can be said definitively that this is not the case, as indicated in studies such as Hamilton (2000) who investigated East African dominance in endurance running events. It was deduced that aspects such as physiology, environment, psychology and social aspects, all play a significant role in performance related factors. Thus varying populations have unique characteristics which affect performance. Furthermore, these inherent differences may result in a differing injury risk profile.

It is therefore vital to identify the unique factors that may affect the strength and fatigue profile of local Grahamstown players. These factors can then be used to improve our understanding of hamstring injury prevalence within this context, as it cannot be assumed that the degree of hamstring injury risk is comparative to other populations.

UNDERSTANDING DIFFERENCES BETWEEN POPULATIONS

When analysing any population of interest, it is important to note that specific environmental factors and influences may affect overall capacity (Tucker *et al.,* 2013). This may in turn have an effect on soccer match-play performance, particularly the experience of fatigue and inherent injury risk. However, understanding the unique characteristics of African soccer players is difficult due to the lack of relevant research in this area. In order to investigate potential factors which affect performance and may influence injury risk, inference may be drawn from studies which have assessed African athletes within an endurance running context. This will allow for insight into the biomechanical and physiological aspects of these athletes, when compared to their Caucasian counterparts.

To understand the interaction of such factors, it is imperative to take a holistic approach when identifying the unique characteristics of Southern African Players. As such, the unique context of Grahamstown players will be analysed through 4 encompassing factors namely; Physical, Environmental, Psychological and Socio-Economic. These have been established from a study by Hamilton (2000) as vital aspects of performance, and consequently, injury risk.

Issue 1: Physical Factors

Firstly, it is well known that African long distance runners out perform their Caucasian counterparts (Larson, 2003). In order to understand this phenomenon, multiple authors have investigated the anthropometrical, biomechanical and physiological differences of Africans compared to Caucasian athletes.

An initial study by Weston *et al.* (1999) compared South African black and Caucasian runners. The author observed that South African runners' exhibit greater fatigue resistance, lower lactate accumulation, and higher oxidative enzyme activity. Furthermore, black African runners had a greater capacity to sustain high intensity endurance exercise. Furthermore, a similar study by the same author (Weston *et al.* 2000) analysed the running economy of African and Caucasian distance runners. It was reported that African distance runners exhibit greater running economy and higher fractional utilization of VO2 peak. Thus such endurance runners are more adept at optimizing oxygen utilization as well as energy conservation through their economy of movement.

Similar findings were established by Larsen (2003) who noted that Kenyan endurance performance can be attributed to a higher fractional utilization of VO2 max. Furthermore, BMI, body shape and leg anthropometry could be advantageous and an important factor in performance. Following such insight, a study by Marino *et* *al.* (2004) investigated the effect of environmental conditions on relative performance. The finding that African runners ran faster only in the heat despite similar thermoregulatory responses as Caucasian runners suggests that the larger Caucasians reduce their running speed to ensure an optimal rate of heat storage without developing dangerous hyperthermia. As such, it was deduced that genetic and environmental factors play an important role in the evolution of performance.

Further investigations into genetic factors have been completed by Scott (2005) and Tucker *et al.* (2013). Scott reports that environmental factors and perhaps polymorphisms in the nuclear genome are important in running success while Tucker states that performance and physiology has a complex polygenic nature. The fundamental importance of genetics is well illustrated by Broos *et al.* (2015) who determined the influence of ACTN R577X polymorphism on muscle strength and muscular endurance. The authors reported improved strength performance of RR compared to XX genotype during power oriented sports. Additionally, soccer players tend to have an ACTN3 genotype (Santiago *et al.,* 2008). Favourable genetic variants therefore result in relative athletic dominance. To date, little research has focussed on understanding how these factors affect the African athlete within the soccer context or even the intermittent sports context more broadly.

Furthermore, the phenotypic variation present in Africa is substantial as indicated in the Human Genome Project (Gomez *et al,* 2014; Gurdasani *et al.,* 2015). African populations are therefore severely underrepresented in terms of genetic adaptations (Campbell and Tishkoff, 2010). This is significant for researchers from an evolutionary and performance perspective. It is vital to assess individual populations due to their different evolutionary histories (Lambert and Tishkoff, 2009). Consequently, generalisations across different populations should be made with extreme caution as each population will present with a unique set of attributes affecting both the performance characteristics and the risk of injury. These studies support the notion that soccer research needs to take cognisance of the historical geographical location of the players. As the present study focussed on the unique responses of the peri-urban Black South African soccer player, findings will hopefully add unique insights to the body of knowledge.

As discussed above, a variety of factors can explain the dominance of African endurance athletes. This indicates that inherent differences within the athlete result in different performance characteristics. Aspects such as physiology, biomechanics and anthropometrics play a significant role in the relative capacity of the athlete. The importance of these ethnic differences within a soccer context are indicated by Woods et al. (2004), who identified ethnicity as an important factor for injury risk. It is therefore important to appreciate the unique physical profile of the population at play. If such differences exist, it is sensible to be cautious when applying standardized interventions and training programs to various populations, as capacity and relative injury risk may be significantly different. Research must first establish the characteristics of the population of interest in order to maximise the effect of any intervention.

Issue 2: Environmental Factors

Although physical factors play a significant role in performance, an understanding of environmental influences is important in order to identify the aspects that form an athlete’s development and eventual capability. Geographical location is one such factor. An example is the comparison between relative dominance of East African long distance runners, and West African sprinting dominance. This illustrates that those factors inherent to the environment may influence relative performance parameters (Hamilton, 2000).

A significant study within this paradigm is that of Onywera *et al.* (2006), who investigated demographic characteristics of elite Kenyan endurance runners. It was established that Kenyan runners are from a distinctive environmental background in terms of geographical distribution, ethnicity and travel to school. Thus, influences such as training rate and relative demands associated with geographical location influence success of the athlete. These findings highlight the importance of environmental and social factors (influenced by the environment) in performance.

This perspective is supported by Marino *et al.* (2004) who noted the vital impact the environment plays in the evolution of performance. When comparing African and Caucasian runners, Africans recorded comparatively superior running performance when exposed to warm conditions. Geographical location therefore resulted in a performance enhancing evolutionary trait. Such a finding concurs with a study by Scott (2005) exploring the fundamental impact of environmental factors on Elite Ethiopian runners genetics, and performance. It is evident that historical geographical location is an important consideration with regards to soccer specific research, and is therefore a primary purpose of the current study.

Issue 3: Psychological Factors

When considering the athlete as a whole, a crucial element is the mind or the related psychological influences. With such high variability in mood and external influence, such a factor must be acknowledged as playing an important role in performance. A study completed by Baker (2003) indicates that the psychological atmosphere the athlete is presented with has direct influence on performance. Furthermore, the atmosphere during training, and the relative dedication to improvement, plays a role in capacity and performance. A further study (Gillet *et al.,* 2009) notes the impact of the coach in terms of motivation. The levels of training achieved are often guided by the coach. As such, their impact cannot be over stated as they guide the athlete's potential and have great influence over eventual capacity. Finally, a report by Gee (2010) investigated the nature of sports psychology. They reported that mental preparation is a key to performance and sport psychology is esoteric in nature. The mental element is often the greatest barrier, particularly in optimising performance.

Issue 4: Socio-Economic Factors

South Africa is especially unique (concerning socio-economic stresses) as it is part third world, and part western world. This is the case socially, economically and industrially, with a split between modern and traditional techniques as well as outlooks and expectations (Bradshaw *et al.* 2003). This is further differentiated by the vast income gap experienced, characterized by Grahamstown with a beautiful university campus juxtaposed with abject poverty, less than 2 kilometres away. Such rates of Poverty are the direct result of poor education, employment and income.

These factors play a vital role in what is commonly known as the cycle of disease (seen in Figure 3).

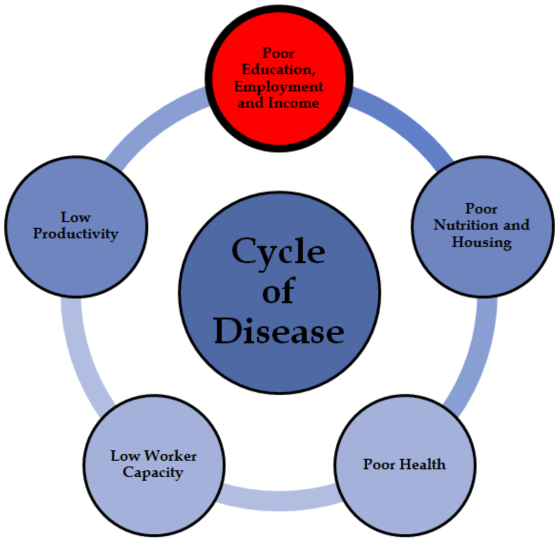


Figure 3: The cycle of disease

This cycle has important implications for the context of African players, with multiple factors contributing to poverty rates. Furthermore, many South Africans live below the ‘breadline’, with common occurrences of under nutrition and malnutrition (Mayosi *et al.,* 2009), which has a direct impact on the strength profile of the South African Footballer. Although it is understood that those athletes that compete in soccer match-play have a certain level of nutrition and physical capability, such factors are important to acknowledge as they may further influence the capacity of the hamstrings to produce force, further heightening potential injury risk (Kirkendall, 1993). As such, it is important to understand the health risks at play for our specific population.

To establish health risks, health organisations refer to the triple burden of disease facing the particular country of interest (Bradshaw *et al.,* 2003). However, in South Africa, the unique status quo regarding HIV, places greater load on the population. It has therefore been isolated as its own factor, resulting in the quadruple burden of disease (Econex, 2009 – South Africa’s Burden of Disease).

The first factor to be discussed is HIV/AIDS. HIV has a unique impact on the strength profiles of African players with a high prevalence in the lower class population. South Africa has an exceptionally high HIV rate, placing an unusually large burden on society (Bradshaw *et al.,* 2003; Mayosi *et al*., 2009; Kleinert, 2009). Although this may not directly affect players, HIV is highly likely to affect some aspect of their lives, which may understandably influence motivation and dedication

The second factor is non-communicable or chronic disease, which are non-infectious and non-transferrable. Diseases such as cancer, cardiovascular disease, diabetes and other chronic disease account for 29 million deaths each year in low to middle-income countries (WHO, 2013). The World Health Organisation (2013) sites four risk factors (tobacco use, alcohol abuse, poor diet and physical inactivity) as modifiable factors for disease risk

The third factor is communicable disease, particularly relevant amongst the lower income bracket. The increase in relevant risk factors such as health education, maternal and perinatal conditions, poor hygiene and health standards, results in the potential for contagious disease (Mayosi *et al.,* 2009). This has direct implications for the quality of life experienced by South Africans. Furthermore, poverty factors such as nutrition and monetary responsibility play a role in the strength status of players, as well as access to training and facilities. Additionally, nutrition issues stem from socio-economic inequality and result in higher risk for communicable disease, and potentially non-communicable (Kirkendall, 1993). Nutrition may be the most prominent socio-economic issue for the South African soccer player, as inadequate nutrition has a direct effect on endurance capacity (Kirkendall, 1993), and in turn, injury risk (Reilly *et al.,* 2003).

The final factor is violence. In a country with such high levels of unemployment and poverty, local players endure a variety of social conditions, which may result in injury. Whether this be intimate-partner, political or spontaneous violence, for obvious reasons this has a direct effect on a players ability to perform maximally.

Moving away from the burden of disease, one can isolate additional factors which may influence the capacity of the South African footballer. As a third world nation, access to facilities is a fundamental problem for any player from a poverty stricken background. This inhibits ability to optimise performance and places the player at a disadvantage. Traditional intervention strategies may not consider such aspects, and assume prior knowledge and certain performance related parameters. Furthermore, aspects such as training and advice are minimal for players in such circumstances. Players must therefore endure significant challenges when attempting to adopt soccer as a profession within the South African context.

As indicated above, all populations have unique characteristics that influence capacity and performance. Furthermore, the factors affecting South African players are highly variable and highly influential. It is therefore vital to understand these factors in order to generate effective and appropriate conditioning, training and intervention procedures. The differences are vast between the populations, and applying standards based on analysis of different players may not only be inaccurate, but may even be dangerous.

Therefore, the Southern African and particularly the Eastern Cape player population may have differing strength characteristics and therefore a unique injury risk profile, particularly concerning the hamstring muscle group. Identifying the strength characteristics of players in such circumstances is therefore vital in order to develop an understanding of the unique characteristics of the population at play. The first aim of this study has therefore been identified: The assessment of the soccer specific strength and performance profile of the amateur Eastern Cape player.

LOWER EXTREMITY ASSESSMENT

Due to the nature of soccer match-play, assessment of lower extremity strength is of the utmost importance (Greig, 2008). As indicated by Mohr *et al.* (2005) the soccer specific fatigue profile has direct implications for performance and injury risk, and so the identification and measurement of strength characteristics plays an important role in understanding player responses (Rahnama *et al.,* 2003).

Lower extremity assessment has become commonplace within a soccer context (Greig *et al.,* 2006), however, there remain areas of contention. In order to dissect such areas, it is vital to understand the fundamentals regarding assessment of the lower extremity.

Muscle Activation

The human muscular-skeletal system is exceptionally intricate due to the complex nature of multiple muscles across multiple planes. Activation or contraction of muscle fibres implies shortening, however, it rather refers to the generation of tension using motor neurons (Totora *et al.,* 2011). Muscle activation has a number of different ways to generate force (Windhorst, 1996).

Isotonic activations occur when the tension remains unchanged while the length of the muscle changes. Lifting an object at a constant speed is an example of isotonic muscle activation, as the muscle changes in length during activation. There are two types of isotonic activations, namely concentric and eccentric (Tortora *et al.,* 2011).

Concentric is the most typical type of activation associated with exercise. The external force on the muscle is less than the force the muscle is generating, otherwise known as a shortening contraction. This occurs when one lifts a load less than the max capability of said muscle group. The second activation type is eccentric muscle activity. The muscle lengthens due to the resistance being greater than the force the muscle is producing. An appropriate example is during the later phase of the swing gait, where eccentric activity of the hamstring controls the lowering of the lower extremity (Windhorst, 1996). Additionally, as running is the most common activity associated with soccer, this eccentric hamstring activation is an important consideration with regards to injury risk (Greig, 2006).

There are two main features regarding eccentric muscle activity. Firstly, the absolute tension can be very high relative to maximum tension generating capacity. This is because we can lower a much heavier object than we can lift. Secondly, the absolute tension is relatively independent of lengthening velocity, i.e. skeletal muscle is very resistant to lengthening and thus can generate high levels of tension (Windhorst, 1996 & *Totora et al., 2011*). A further type of muscle activation is isometric where the muscle is held at a fixed length, the same distance and not moving. An example of this is merely holding an object such as a tennis racket. The force produced exactly counteracts the force generated by the object.

The figure below indicates the Force-Velocity Curves associated with the different muscle activity modes. As previously indicated, eccentric muscle activity is capable of far greater levels of force generation, while concentric activity has relatively low force producing capabilities.

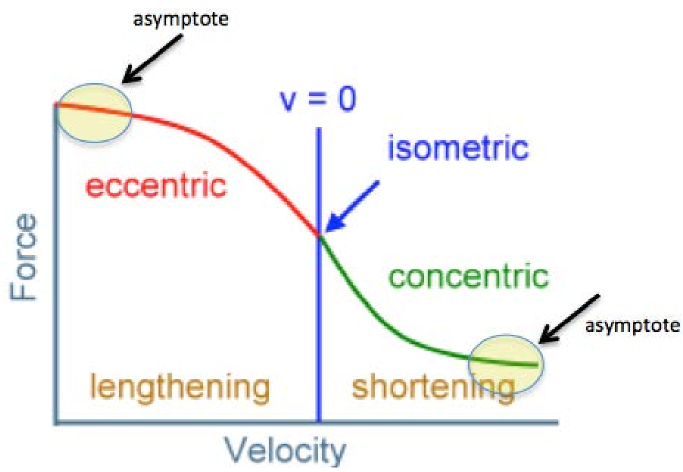


Figure 4: Force Velocity Curve of a Muscle

In order to isolate the characteristics of these different muscle activation modes within an individual, isokinetic assessment was developed in order to assess muscle activity. This has become a cornerstone of lower extremity assessment (Greenberger, 1995; Lephart *et al.,* 2002; Kim *et al.,* 2003), particularly within a soccer context (Rahnama *et al.,* 2002; Greig *et al.,* 2006).

Isokinetic Assessment

Isokinetic dynamometry is widely used for muscular function studies, because it facilitates a dynamic, objective, accurate and reproducible evaluation (Siqueira *et al.,* 2002). Although manual testing (strength dynamometers etc.) is cheap and easier to use, the results are less objective as sub-maximal effort is difficult to identify. With resistance relative to the force applied, the isokinetic dynamometer is highly effective at identifying sub-maximal effort. Therefore, results regarding muscle performance parameters are more reliable, with a high test re-test index (Baltzopolous *et al.,* 1989).

Isokinetics has therefore become a standard technique to indicate muscular performance. Especially prevalent in a clinical setting (due to relative resistance), further applications such as sport science, and particularly soccer research have benefitted. Multiple studies (Cometti *et al.,* 2001; Roos *et al.,* 1998; Soderman *et al.,* 2001) have investigated muscular responses in football players using isokinetics; particularly around the knee joint (Rahnama *et al.,* 2002).

Definition of Isokinetics

Isokinetic strength testing has been extensively used to determine participant or patient capacity, as well as having applications within a rehabilitation context (Greenberger *et al*., 1995). During the contraction, the resistance applied by the device is equal to the applied muscular torque, allowing for dynamic muscular contraction when the velocity of movement is controlled (Baltzopolous *et al.,* 1989). Therefore, an increase in muscular torque results in an equal resistance provided by the isokinetic dynamometer (Moffroid *et al.,* 1969). As a result, practitioners can establish force production curves to assess strength characteristics.

It is well known that muscular force varies at different joint angles. If maximal force is applied over a range of movement, isokinetic assessment offers optimal loading of the muscles in dynamic conditions (Baltzopolous *et al.,* 1989). During isokinetic movements, the resistance is equal to muscular capacity, and so muscular loading is maximal at points where mechanical advantage is maximal. This is a more functional assessment than isotonic muscular activity (Hislop and Perrine, 1967).

Within a soccer context, and due to the bipedal nature of human locomotion, the lower extremities are the most susceptible to fatigue (Mohr *et al.,* 2005). As such, they carry higher injury risk, indicated by the high frequency of hamstring strain and knee ligament injury (Ekstrand *et al*., 2011). When discussing assessment methods the focus will therefore be on lower extremity assessment, as it is most relevant within this context.

The effect of Gravity

When performing movements in the vertical plane, a gravitational force is obviously applied. Thus, the registered force must be adjusted to isolate the true muscular force applied (Herzog, 1988). A gravitational error factor has therefore been established (Winter *et al.,* 1981), and is included within the mechanism to isolate true muscular torque.

Inertial effects on Isokinetic Movement

Sapega *et al*. (1982) identified that during isokinetic movements the torque output demonstrates a prominent initial spike, otherwise known as torque overshoot. The dynamometer is not activated if the velocity of movement is lower than the pre-set angular velocity (Baltzopolous *et al*., 1989). The limb therefore accelerates, as there is no resistance. The velocity of the limb is above the pre-set velocity (Sapega *et al.,* 1982).

The overshoot is the reaction of the dynamometer to the over speeding limb-lever arm (Baltzopolous *et al.,* 1989). The extent of overshoot depends on aspects such as greater limb mass, longer distance between axis of rotation and Centre of Mass, as well as the mass of the lever arm of the dynamometer itself (Baltzopolous *et al.,* 1989). This overshoot is therefore important to consider when assessing torque production curves.

Isokinetic Parameters

During assessment, it is imperative to take a holistic approach to ascertain the true characteristics of the relevant muscle group. These parameters combined, provide a more comprehensive picture and influence our understanding of muscular function.

Maximum Torque

Maximal or peak torque refers to the highest singular torque value (Baltzopolous *et al*., 1989) produced during muscle activation. The position of this maximal torque value is vital and provides information regarding mechanical properties of the relevant muscle group. Therefore the angle of this maximal torque is important to include. This is particularly relevant for the hamstrings where hamstring injury commonly occurs during late swing phase, and so the ability of the hamstrings to act eccentrically at these angles is an important consideration (Rahnama *et al.,* 2002). Peak torque mean values has been identified as ineffective if the specific angular position is not consistent (Osternig, 1975), and is therefore an important characteristic.

The measurement of the muscular force is applied within dynamic conditions. Protocols to determine maximum torque are well established, with main contention being the number of repetitions required to develop maximal torque. Perrin (1986) suggested four max repetitions while a testing protocol for knee extensors and flexors developed by Jenkins *et al.* (1984) consisted of five max reciprocal repetitions.

Angular Velocity

Multiple studies (Barnes, 1980; Osternig *et al.,* 1983; Jones *et al.,* 2015) have indicated that the muscular torque exerted during isokinetic testing decreases with increasing angular velocity of movement. This is attributed to different neurological patterns of motor units at these different velocities. As such, one can predict the force production curve at different speeds to isolate any pre-existing weaknesses and evaluate optimum joint angle for maximal muscular force.

Reciprocal Muscle Group Ratio

The ratio between agonist and antagonistic muscles is an indication of muscular balance or imbalance around a joint (Aagaard *et al.,* 1998), which is particularly relevant for the knee. The functional hamstrings to quadriceps ratio (H: Q) is of the utmost importance as the knee is one of the largest and most complex joints (Baltzopolous *et al.,* 1989). According to Campbell and Glenn (1982) the ratio is more important than maximal torque with regards to effective inference.

Typically, hamstrings and quadriceps have been measured concentrically and then compared. This traditional ratio has been used to identify absolute strength. However, functional muscular contraction evokes opposite function of the antagonistic muscle i.e. when hamstrings are active eccentrically, quadriceps are acting concentrically. Therefore, the traditional ratio has been replaced with a more functional ratio between eccentric hamstrings and concentric quadriceps (Aagaard *et al.,* 1998; Rahnama *et al.,* 2003; Greig *et al.* 2006). This is otherwise known as the dynamic control ratio (Impellizzeri *et al.,* 2007; Holcomb *et al.,* 2007)

Multiple studies have investigated baseline measures of the ratio about the knee. High school football players ratios have been observed as 0.60 - 0.7, while 0.56 – 0.62 in untrained subjects. Furthermore, Aagaard *et al.* (1998) reported that the ratio increased as the velocity of movement increased. Multiple factors affect this strength ratio such as sex, age, activity, nutrition, previous injury etc. (Henderson *et al.,* 2010 & Kim *et al.,* 2011).

These ratios are a well-established technique for identifying strength capability as well as strength imbalances around the knee joint (Soderquist, 2014; Zebis *et al.,* 2011; Rahnama *et al.,* 2005). Knapik *et al.* (1991) reported that strength imbalances of greater than 15% result in a 2.8 times greater risk of injury, while multiple studies have identified eccentric activity of the hamstrings as synonymous with injury, within a soccer specific context (Hibbert *et al.,* 2008; Greig *et al.,* 2006).

Therefore, the functional ratio is an important measure to identify potential risk, and isolate muscle strength. Within in intervention context, the ratio may identify any changes in relative strength and within the ratio following an intervention strategy (Holcomb *et al.,* 2007).

<u>Torque Acceleration Energy</u>

This is defined as the work performed in the first one-eighth second of torque production (Perrin *et al.,* 1987). It can be useful as an indicator of maximum torque production if plotted against various velocities (Osternig, 1986). Importantly within a clinical context, weaker muscles (potentially due to neuromuscular facilitation) show peak torque later in range of motion as has been demonstrated by Kannus and Jarvinen (1990). The reliability of this measure is often very low (Kannus, 1994) and is made worse by repeated tests according to Chan and Maffulli (1996).

Time Rate of Torque Development

This outcome parameter of isokinetics is the time it takes to reach peak torque (Baltzopolous *et al.,* 1989). This can be used as an indication of strength imbalance, as well as improvements in the ability to develop force. This typically refers to the upward slope of the torque curve, particularly the initial third of the force velocity curve. A prolonged initial phase infers a problem in developing force within the muscle.

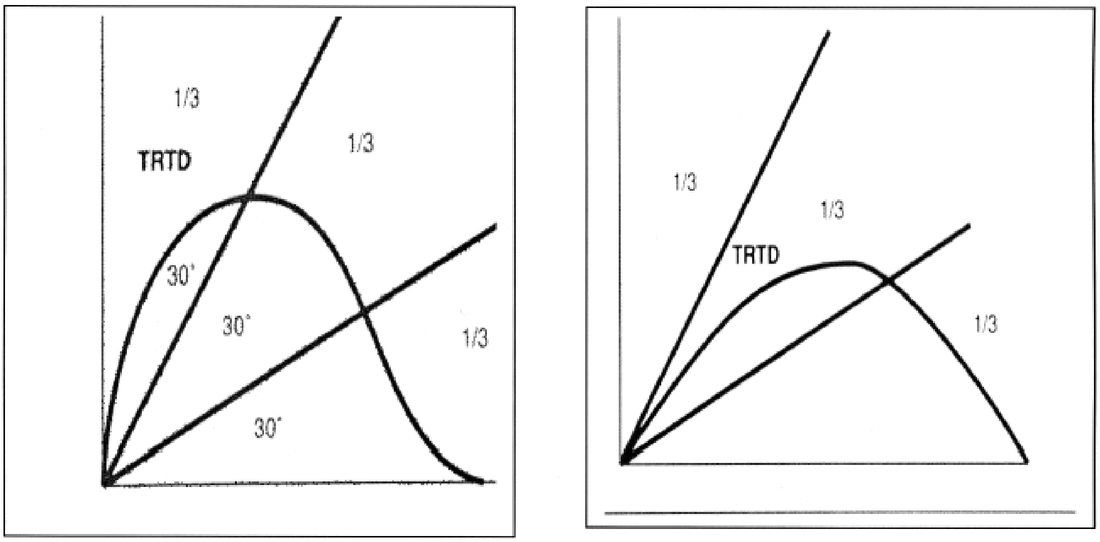


Figure 5: Typical and Atypical Time Rate of Torque Development Graph

Applications of Isokinetics

Rehabilitation and Assessment

An advantage of Isokinetics is the variable resistance equal to the applied muscular force, as well as constant preselected velocities (Baltzopolous *et al.,* 1989). Safety is ensured, even for those with inherent weaknesses. This allows for rehabilitation of muscular imbalances or ligamentous injuries (Croisier *et al.,* 2001). These clinical applications are not relevant for this study, although their importance in athlete rehabilitation cannot be greater stressed. Identification of any participants with underlying weakness is an additional application within this context.

The efficacy and reliability of Isokinetic assessment was investigated by Armstrong *et al*. (1983), in patients with multiple sclerosis. Test-retest reliability was reported as 0.99 ($p<0.001$). Maximal torque however, may not reflect an improvement as a potential learning effect must be considered. However, it is well established that Isokinetics is a highly effective tool for rehabilitation.

Isokinetic Training

The ability of the dynamometer to provide constant preselected velocities during isokinetic movements allows for effective training and improvement of muscular performance. This is a well-established technique, with early studies such as Lesmes *et al.* (1978) using isokinetic training and specific angular velocities to increase the maximum torque of the involved muscle groups. Furthermore, a transfer effect at other velocities has also been noted (Coyle *et al.,* 1981; Lesmes *et al.,* 1978) with higher velocity training ($240°.s^{-1}$) having a greater transfer effect over the lower velocities. This adaptation of motor units within the muscle explains this training effect (Milner Brown 1975; Sale *et al.,* 1983) and indicates the benefits of isokinetic training for dynamic movements. Isokinetic training has been used in a variety of contexts, and has been observed to effectively increase the relative strength (Siquira *et al.,* 2002; Jones *et al.,* 2002; Brown *et al.,* 2003; Beebe *et al.,* 2013; Milot *et al*., 2013).

Injury Prevention

A further application within a clinical setting is the Identification of muscular imbalances, whether it is between dominant and non-dominant limbs or within particular muscle groups and their antagonistic muscles (Grace, 1988). Multiple studies have investigated strength imbalances within a soccer specific context (Siqueira *et al.,* 2002; Newton, 2006; Croisier *et al.,* 2008) with such imbalances indicated as a vital factor for injury risk (Rahnama *et al.,* 2002). According to Croisier et al. (2008), the correction of such imbalances through the use of isokinetic training, results in a significant reduction in injury occurrence. Isokinetics as an injury prevention tool is therefore highly effective,

Isokinetic Testing Speeds

Researchers have employed a range of isokinetic testing speeds in order to assess the force producing capabilities of the lower limbs. With regards to isokinetic testing speeds within a soccer assessment paradigm, comparisons between the available studies investigating soccer-specific strength characteristics are difficult. Previous studies regarding the isokinetic evaluation of the lower limbs in soccer players have employed a large range of isokinetic speeds for both eccentric and concentric modalities. Greig (2008) and Greig and Siegler (2009) utilised isokinetic speeds of 60º.s-1, 180º.s-1 and 300º.s-1, while a large number of studies utilised isokinetic speeds of 60º.s-1 and 120º.s-1 (Tourny-Chollet *et al.,* 2000; Kellis *et al.,* 2001; Croisier *et al.,* 2008; Small *et al*., 2009; Small *et al.,* 2010; Lovell *et al.,* 2013). Definitive isokinetic testing speeds are therefore contentious, as studies have used a range of values. However, according to Perrin (1993) it is beneficial to assess both strength (60°.s^{-1}) and power (180°.s^{-1}). These are vital attributes for soccer performance due to its intermittent nature (Jones *et al.,* 2015)

Although such speeds have been employed to assess muscular function, whether these speeds are truly representative of functional actions remains uncertain. Actions during soccer match-play far exceed the capabilities of isokinetic dynamometer systems. However, it is seen as the gold standard (Perrin, 1993) in terms of performance assessment, as the most effective method available.

Vertical Jump

Another common form of lower extremity assessment is the vertical jump. This dynamic movement is often viewed as more effective than Isokinetics, to establish dynamic muscle performance (Cochrane *et al.,* 2004). Jumping is a natural human activity, and a common motion associated with soccer match play. The vertical jump therefore has high validity in representing the amount of power or the force capability of the lower extremity, although replicability due to factors such as motivation is a vital consideration (Cochrane *et al.,* 2004; McGuigan *et al.,* 2006).

Research within the South African context must provide sustainable, replicable solutions. The vertical jump is effective in this context as no expensive apparatus is needed. The ability to measure jump height is all that is required. A significant issue relating to vertical jump is reliability, as effectiveness is highly dependent on procedure and techniques (Moir *et al.,* 2008). Habituation and consistency is therefore a vital concern.

<u>Jump Types</u>

There are different jumping techniques, which may be employed, to represent different muscular characteristics. There are 2 jump types, namely:

- Squat Jump
- Countermovement Jump

The squat jump indicates concentric strength of the leg extensors (Young *et al.,* 1995) while the countermovement jump measures the reactive strength of the lower body, indicating slow SSC (Stretch Shortening Cycle) ability (McGuigan *et al.,* 2006). Values for the squat jump are typically lower than the countermovement jump (Bobbert *et al.* 1996) due to this eccentric contribution.

Average values for the countermovement jump have been established as 45.1 (±1.7) cm while average squat jump are indicated as 44.1 (±1.3) cm (Sporis *et al.,* 2009). The ratio between these jump types isolates the SSC activity to indicate eccentric capabilities in the upper thigh (Cochrane *et al.,* 2004; McGuigan *et al.,* 2006). This is known as the eccentric utilization ratio (EUR). The EUR is of particular interest in soccer assessment, due to the high rate of hamstring muscle injury (McGuigan et al. 2006)

The vertical jump is therefore a cost effective technique, which is crucial within the Southern African context, where access to expensive facilities such as Isokinetics is often difficult. If vertical jump technique is consistent, this measure can be extremely important within this context and can be readily applied to other low income areas.

PERFORMANCE IMPORTANCE

The identification of strength characteristics and their relation to injury is of vital importance (Croisier *et al.,* 2008). However, soccer research predominantly has a two prong approach: To reduce injury and to increase performance (Arnason *et al.,* 2004). Performance is therefore a vital aspect of any soccer specific research as a main outcome associated with match-play. The identification of performance characteristics of the Eastern Cape player population is an important consideration when assessing the unique profile of these players.

Assessment of strength capabilities through the use of Isokinetics and vertical jump is an effective method to infer performance (Greig *et al.,* 2006 & Cochrane *et al.,* 2004). However, such actions are not representative of the dynamic demands associated with soccer match-play, such as sprint ability and intermittent endurance (Chaouachi *et al.,* 2010). These are both deemed relevant fitness prerequisites for any player.

Sprint Times

The most common form of performance identification within a soccer context is sprint ability. Short duration sprints with minimal recovery are very common in intermittent sports (Bishop *et al.,* 2011). Identification of such sprint ability over 10m (Buchheit *et al.,* 2010) and/or 20m (Gabbett, 2010) is therefore a common form of performance testing. Furthermore, sprint ability is often used to assess the effect of soccer specific interventions or performance pre, during and post season (Chaouachi *et al.,* 2010).

Additionally, the ability of the player to produce the best average sprint performance over a series of sprints is a vital performance and fitness component of soccer (Dawson *et al.,* 1993). Repeated sprint ability (RSA) with minimal recovery between sprints, is therefore a further aspect of sprint performance that has garnered particular attention. Training studies indicate that RSA training has a positive effect on intermittent high intensity performance (Impellizzeri *et al.,* 2008). 30m sprints are typically used for RSA protocols (Impellizzeri *et al.,* 2008 & Reilly *et al.,* 2000). An important aspect of such testing is to ensure an appropriate length of test to induce required fatigue, but not excessive unnecessary sprinting (Chaouachi *et al.,* 2010).

Shuttle Runs

The profile of soccer requires players to constantly change activity throughout the game (Bangsbo, 1994). As the most predominant activity is running (Reilly, 1997), relative intermittent high intensity endurance capability is an important fitness characteristic. This is due to the high aerobic demands associated with soccer (Mohr *et al.,* 2005). As such, multiple shuttle run protocols have been developed to assess intermittent endurance capability. The most common shuttle tests used are the Yo-Yo intermittent endurance and intermittent recovery tests (Bangsbo *et al.,* 2008). The Yo-Yo tests were introduced by Jens Bangsbo and colleagues who questioned the relevance of the VO_{2max} test. Such tests include 20m shuttle runs with incremental difficulty due to time constraint. Endurance tests are more aerobic than recovery tests due to the 5m recovery jog afforded after each shuttle (Krustrup *et al.,* 2003). Players are rated according to the final stage completed before exhaustion. The Yo-Yo tests have been repeatedly validated (Thomas *et al.,* 2006; Souhail *et al.,* 2010; Martinez-Lagunas *et al.,* 2014) and have consistently been employed in a soccer context to assess intermittent endurance capabilities.

HAMSTRING STRENGTH INTERVENTIONS

As previously discussed, hamstring injuries are the most prevalent injury associated with soccer match-play (Ekstrand *et al.,* 2011). Such injuries are highly prone to re-injury due to factors such as insufficient rehabilitation and early return to the game (Croisier *et al.,* 2008). Furthermore, hamstring injuries place high stress on the players, teammates and the support staff as absence of the player from training and competitive play impacts the tactical strategies and team dynamics (Arnason *et al.,* 2004). Additionally, costs of rehabilitation and the inherent costs of missing important players, results in high financial implications. For instance hamstring injuries cost the English Premier League and associated clubs in the region of £270 million in 2012 due to the rehabilitation costs, loss in viewer ratings and significant reduction in the quality of play. The indirect effects of hamstrings injuries at lower levels of play are far more poignant. Players at an amateur level, particularly those from a low socio-economic class use football as a social outlet and an opportunity to escape daily routine (Nicholson *et al.,* 2008). Financial incentives are not possible at such a level and as a result, the loss of a player to injury places high financial burden (due to a lack of access to medical aid) on the family and isolates the player. Furthermore, in South Africa, amateur players do not have access to effective rehabilitation (See Table XXXIII), and/or do not have the financial support to recover from these injuries.

Therefore, reactive strategies are not particularly effective within this context due to a lack of infrastructure and investment for these players. Injury prevention must therefore be proactive (Heiderscheit *et al.,* 2010). This is a common outlook throughout world soccer, and multiple hamstring exercises have been developed (Mjolsnes *et al.,* 2004; Engebretsen, 2008; Aquino *et al.,* 2010), attempting to reduce the extent of injury. As previously highlighted, hamstring injuries are most likely to occur during the late swing phase of the running gate, during eccentric action (Chumanov *et al.,* 2011). Focus of hamstring injury prevention strategies has therefore been on eccentric exercises (Goode et al., 2015).

In order to assess any exercise, two major outcomes have traditionally been employed. Firstly related research identifies statistics regarding reduction in injury frequency (Askling *et al.,* 2003 & Arnason *et al.,* 2008). However, such statistics require longitudinal studies, typically at least a season, in order to accurately assess the effect of any intervention (Petersen *et al.,* 2011). Another outcome typically employed is the effect of the exercise on the relative strength of the hamstrings (Clark *et al.,* 2005).

. To enable co-ordinated movement, bipedal locomotion and effective energy conservation, the hamstring acts eccentrically to decelerate the limb during the late swing phase (Tortora *et al.,* 2011). Injury typically occurs when the hamstrings are not able to decelerate the limb during the gait cycle. The ratio between the concentric capabilities of the quadriceps and the eccentric capabilities of the hamstrings is therefore crucial (Aagaard *et al.,* 1998). The hamstring must be capable of counteracting the force in the lower extremity, generated by the quadriceps (Croisier *et al.,* 2008). The ideal ratio is therefore 1 or higher, as the hamstrings are capable of equal force generation as the concentric quadriceps, when acting eccentrically (Aagaard *et al.,* 1998). An increase in hamstring eccentric strength suggests an increased capability to decelerate the lower limb during the late swing phase, significantly reducing injury risk (Clark *et al.,* 2005). The relative strength of the hamstrings is therefore a vital indicator of any intervention and its relation to injury risk (Opar *et al.,* 2014).

It is important to note that when looking at players, one must look on an individual level and not generalize across the board. Each player may possess specific strength imbalances, which must be identified and prioritized.

Interventions

Due to the relative risk of hamstring injury, preventative interventional research has been employed, establishing the effect of eccentric exercises on relative hamstring strength (Rahnama *et al.,* 2002). The most effective technique to improve relative strength is isokinetic dynamometry. Systems such as the Biodex, allow for the complete isolation of specific muscle groups, and allow for testing and training at constant velocity. Multiple muscle actions and multiple speeds can be used to improve both strength and power characteristics (Perin, 1994). As an intervention technique a study conducted by Croisier *et al.* (2008) reported that isokinetic strength training reduced muscle injury incidence, while Brugelli *et al.* (2009) reported an altering of the optimum angle of peak torque. Isokinetics is viewed as the 'gold standard' for both assessment and rehabilitation. Its application as a training technique is safe and highly effective (Brugelli *et al.,* 2009)

However, such systems cost in excess of R1 million. Although highly valid and reliable, solutions must be both practical and sustainable. More cost effective solutions are needed within the context of South Africa.

Leg Curl

The most commonly known hamstring strengthening exercise is the leg curl. A study by Aquino *et al.* (2010) investigated the strengthening effects of this exercise using the leg curl bench (Masters Equipment). Participants performed the leg curl in lengthened position both concentrically and eccentrically. Isokinetic assessment was then performed to identify any changes in hamstring strength characteristics. Results from this study demonstrated that strengthening in a lengthened position produced a significant shift of the torque–angle curve, which suggests an increase in muscle length. The hamstrings were therefore able to create peak torque at an angle closer to extension, indicating an increased ability to counter act the quadriceps during the late swing phase. Interestingly, Mjolsnes *et al.* (2004), noted that the Nordic hamstring exercise is more effective. More research is required to truly identify the practical value of this exercise within this context.

Flexibility

Poor flexibility has been cited previously as a significant risk factor for hamstring injury (Witvrouw *et al.,* 2003; Henderson *et al.,* 2010). Intervention strategies have therefore aimed at improving muscle flexibility in an attempt to reduce injury. In 2010, Aquino and colleagues investigated the effect of flexibility training on hamstring injury. No modifications in torque producing capabilities were observed following a stretching program. Furthermore, Arnason *et al.* (2008) reported that no reduction in injury frequency was noted following a flexibility program alone. Further research is therefore required to better understand the contribution of flexibility to hamstring injury risk.

Balance Board Hamstring Lowers

A further method of improving eccentric strength of the hamstrings is through the use of the balance board. An investigation conducted by Soderman *et al.* (2001) indicated that eccentric actions are at high risk due to the act of controlling or resisting motion. The focus of such an exercise was therefore to improve the length tension relationship. The authors employed hamstring lowers, using a customized board. The board provides an unstable surface, encouraging constant lower limb muscle activation. The use of hamstring lowers with this board allows for the isolation of the upper thigh and particularly, the knee flexors. Both single and double exercise bouts were completed with a training effect noted within the muscle fibre of the hamstring. The authors reported a small transient change, indicating the benefits of hamstring training strategies. However, the sample size was small within the investigation, while Engebretsen *et al.* (2008) recorded poor compliance and limited effectiveness for the balance board. Further research is therefore needed to understand the inherent benefits.

Proprioceptive Training

A further avenue of investigation is the effect of proprioceptive training on injury risk. It has been suggested by Kraemer *et al.* (2009) that poor balance plays a significant role in lower extremity injuries, particularly in females. The authors established a proprioceptive balance training program over a 3 year period. It was reported that hamstring strain injury rate decreases in relation to the duration of balance training. However, a study conducted by Hupperets *et al.* (2010) reported poor compliance with regards to a balance training program. There is therefore insufficient evidence to suggest the true efficacy of proprioceptive training.

Nordic Hamstring interventions

Currently, the most accepted eccentric training exercise is the Nordic Hamstring lower. This exercise has been cited since the 1880s (as indicated in the figure) however, it has risen to prominence in recent years due to the high frequency of hamstring injuries in intermittent sport.

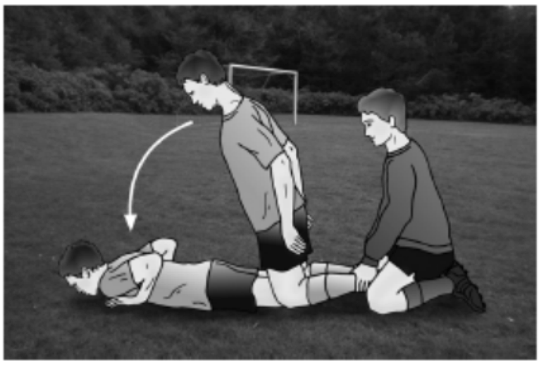


Figure 6: Image from Mjolsnes et al. (2004) demonstrating the exercise. The Nordic lower is an eccentric hamstring strengthening exercise. The participant starts in a kneeling position with the lower body and torso as rigid as possible. Pressure is applied to the ankle to ensure constant ground contact, either through partner or strapping. The upper body is slowly lowered with the hamstrings maximally loaded in the eccentric phase.

To establish the efficacy of the exercise, Mjolsnes *et al.* (2004) conducted a 10 week randomized controlled trial, comparing the traditional hamstring curl to the Nordic exercise. The program design adopted was incremental, with a progressive increase in both sets and repetitions over the ensuing weeks. This was done to reduce the risk of injury as the exercise places significant strain on the hamstring muscle group. Following isokinetic assessment, the authors reported an 11% and 7% increase in eccentric hamstring torque at 60 and $90°.s^{-1}$. This increase was significantly greater than that observed for the traditional hamstring curl. It was therefore suggested to develop maximal eccentric hamstring strength in soccer players. Additionally, Clark *et al.* (2005) reported favourable neuromuscular adaptations for the potential prevention of hamstring injuries, as well as enhancing performance in untrained males, in a similar program. The authors further stated that the exercise beneficence is due to its simplicity. This a crucial consideration within the South African context, due to the lack of facilities and equiptment.

Multiple studies have further investigated the exercise. Peterson *et al.* (2011) established that in male professional and amateur players, additional eccentric hamstring exercise decreased the overall rate of new and recurrent hamstring injuries, while Arnason *et al.* (2008) observed that eccentric strength training lowered the incidence of hamstring injury when partnered with a warm-up. Contrastingly, Gabbe *et al.* (2006) proposed eccentric training as a potential preventative strategy and cited that the simple eccentric intervention may reduce injury incidence, however, that compliance is the key difficulty to overcome. This is supported by Anastasi & Hamzeh (2011) with the authors reporting that control and adherence is crucial for such interventions. This is a constant issue within the relevant literature as authors fail to report the compliance of their participants and so true efficacy is poorly understood (Goode *et al.,* 2015). However, a more recent study by Van der Horst *et al.* (2013) recorded a reduction by up to 70% in hamstring injury incidence, following a season long intervention study, while an editorial by Thorborg (2012) provides a concise view on the benefits of Nordic hamstrings, in a variety of contexts. Currently, the Nordic Hamstring lower is therefore seen as the most effective eccentric strengthening exercise.

Multi-Activity Interventions

Although singular exercises have often been employed to improve relative hamstring strength, multi-activity interventions have been used in a number of contexts. These aim to improve the player in a number of domains, with eccentric training as a component. The most well-known is the ‘11’ injury prevention programme to reduce injury prevalence. An evaluation by van Beijsterveldt *et al.* (2012) reports that while the ‘11’ program focuses on core stability, effective warm-up, eccentric training of thigh muscles, proprioceptive training, dynamic stabilisation and plyometrics, there was no significant reduction in injury following implementation. Identification of the effects of multi-exercise intervention is difficult as the individual effects of each exercise are unknown. Further research is therefore required to establish any interactional effects between exercises.

Although numerous studies have investigated hamstring strengthening programs, the efficacy of hamstring intervention programs is limited, due to methodological differences, non-compliance of participants (Goode *et al.,* 2015), and the use of multi-exercise interventions. Further research is therefore needed within this area to identify efficacy across populations and skill level. A second aim of this study has therefore been identified. Establish the efficacy of a hamstring intervention within the context of amateur South African players.

SUMMARY

It is evident that injury to the hamstring muscle group is a vital consideration regarding soccer specific research. Furthermore, intervention strategies such as the Nordic hamstring lower that have been employed to increase the relative strength of the hamstrings and reduce overall frequency of injury, have been successful within certain populations. However, there is a distinct lack of soccer specific research regarding the South African player. The efficacy of such interventional research within this unique context is therefore unknown. The current study is therefore aimed at quantifying the unique characteristics of the South African player, and determining the efficacy of interventional research within this context.

CHAPTER III

METHOD

INTRODUCTION

The objectives of the current study were two-fold; firstly to establish the lower extremity strength and performance profile of peri-urban community based amateur soccer players and then secondly, to investigate the efficacy of a hamstring intervention programme within this context. In order to achieve these objectives the following methods were established.

EXPERIMENTAL DESIGN

Design Matrix

There were two components to the current research project:

1. Profile of Peri-Urban Black South African soccer players

In order to establish the strength and performance characteristics of the present population, baselines measures for both the control and intervention groups were combined, in order to formulate the overall profile of the peri-urban community based player.

Thus the profile was incorporated as part of the initial evaluation for the intervention in the above mentioned way and the remainder of the methods will discuss the second component of the present study, namely:

2. The Efficacy of a Nordic hamstring intervention in Peri-urban Black South African soccer players

The design for this project included two independent variables, namely time and the sample groups. For two of the dependent variables, namely strength and performance characteristics, the time frame involved assessment on two occasions while for the remaining variable (vertical jump responses) the total number of assessments was four. The justification for the use of these independent and dependent variables is further elucidated in the following sections.

- 2 by 2 (Isokinetic Dynamometry and Performance Characteristics)

Group	**Time**	
	Pre (Week 0)	Post (Week 12)
Control		
Intervention		

- 2 x 4 (Vertical Jump)

Group	**Time**			
	Pre (Week 0)	Week 4	Week 8	Post (Week 12)
Control				
Intervention				

Figure 7: Design matrices for the present investigation

THE SOUTH AFRICAN CONTEXT

A primary aim of the present study was the efficacy of interventional research within the unique South African context. Therefore, before the intervention can be proposed, it is necessary to place this project within its South African context in order to contextualize intervention design.

As the largest playing population, an important aspect of the current study was to identify the characteristics of the amateur South African player. Within the South African context, the majority of this population live in transitional zones where urban and rural areas mix (Lehohla, 2006). These peri-urban areas are a result of peri-urbanization that creates hybrid landscapes of fragmented urban and rural characteristics. Players were therefore selected from this demographic to represent the amateur community based South African playing population. This context is associated with low income and low socio-economic status, a fundamental aspect of the current South African climate. It is imperative that soccer specific research engage with the majority of the playing population and the unique context within which they live. Furthermore, participants of the present study were recruited from the local amateur Grahamstown soccer league, a peri-urban environment within the Eastern Cape, South Africa.

JUSTIFICATION OF INTERVENTION

The introductory chapter (page 1) provides clear justification for the need to investigate the efficacy of hamstring intervention strategies within the South African peri-urban context. The following section provides further motivation for the selection of the Nordic hamstring exercise as the intervention of choice in the current study. Numerous exercise techniques have all been shown to be effective strategies for increasing hamstring strength, which has been identified as a crucial indicator for hamstring injury risk (Mjølsnes *et al.* 2004). Reasons for exclusion will be further elucidated.

Eccentric Strengthening Exercises

Hamstring intervention strategies are popular within recent soccer related research due to the high frequency of hamstring injury associated with match-play (Ekstrand *et al.* 2011). As such, intervention strategies that employ multiple exercises have been developed in an attempt to increase the relative strength of the hamstrings and reduce injury. However, combined exercise regimes are limited in terms of identifying the efficacy of specific exercises, as it is uncertain which exercise has caused the effect. Therefore, one exercise was employed within the present study to isolate and identify its unique effects on relative hamstring strength of the peri-urban South African population.

Eccentric hamstring strengthening exercises such as isokinetics, leg curls and balance board lowers have all been shown to be effective (to varying degrees) at reducing the incidence of hamstring injuries (Croisier *et al.,* 2008; Engebretsen *et al.*, 2008; Aquino, *et al*. 2010). Within the South African peri-urban context, however, there is an understanding that interventions must be cost effective. As most of the intervention strategies outlined above require equipment, such exercises may not be accessible to the general player within a Southern African context, and was thus excluded.

Nordic Hamstring Lowers

The Nordic hamstring lower is the most popular eccentric hamstring strengthening exercise and has been employed in a number of studies such as Mjølsnes *et al.* (2004), Clark *et al.* (2005), Gabbe *et al.* (2006), Arnason *et al.* (2008), and Van der Horst *et al.* (2015). A significant benefit of the Nordic hamstring procedure is that it requires no equipment to perform the intervention. Costs are therefore minimal and the exercise is simple to perform if explained effectively (Peterson *et al.,* 2011). This is extremely relevant for the South African context where access to facilities and training methods is a fundamental failing, particularly within a soccer context. The efficacy of this particular exercise has been extensively reviewed on page 47.

Furthermore, the Nordic hamstring exercise has been used in a variety of contexts such as Australia, Norway and the Netherlands. Importantly, however, these contexts do not include South Africa or furthermore the per-urban community based soccer players used in the current study.

Additionally, an important factor is the issue of compliance, as outlined in a systematic review by Goode *et al.* (2015). An important characteristic of the present study was therefore to identify how hamstring strength training relates to the context described above. Although the Nordic hamstring lower is the most popular eccentric hamstring training technique, its efficacy and retention rates within the peri-urban South African context has not been explored. The Nordic hamstring exercise was therefore selected as the exercise of choice for this intervention.

Program Design

Table IV: The incremental design of the Nordic hamstring intervention program

Week	Sessions Per Week	Sets and Repetitions
1	1	2 X 5
2	2	2 X 6
3	3	3 X 6-8
4	3	3 X 8-10
5-10	3	3 sets, 12-10-8 reps
10+	1	3 sets, 12-10-8 reps

The intervention followed the above study design (Table IV), as employed by *Mjølsnes et al*. (2004). Mjolsnes *et al*. (2004), was the first study to assess the efficacy of the Nordic hamstring lower using a randomly controlled trial. This design has been adopted in similar studies investigating the efficacy of the Nordic hamstring lower (Arnason *et al*., 2008; Petersen *et al.*, 2011), and was therefore selected for inclusion within the present study.

The Nordic hamstring exercise technique

It is a partner based exercise, involving the stabilization of the ankle by the partner in order to isolate the hamstring muscle group. Participants are instructed to assume the starting position of kneeling with trunk extended. Players are encouraged to ensure their back and upper thigh is in line, as indicated in Figure 8 below. Players are then instructed to lean forward, ensuring smooth controlled movement, keeping the back and hips extended. The goal is to work at resisting the forward fall for as long as possible, to ensure maximal loading of the hamstrings during the eccentric phase. Once the participant lands on their hands, they continue until their chest touches the ground, at which point they must forcefully push off into the starting kneeling position, ensuring minimal concentric effort by the hamstrings. The load is increased by resisting the fall for longer periods. Once players can withstand 12 repetitions through the entire range of motion, adjustments can be made by adding speed to the starting phase or additional load with an assistant placing pressure at the back of the shoulders. Adjusted from Bahr & Mæhlum (2004)**.**

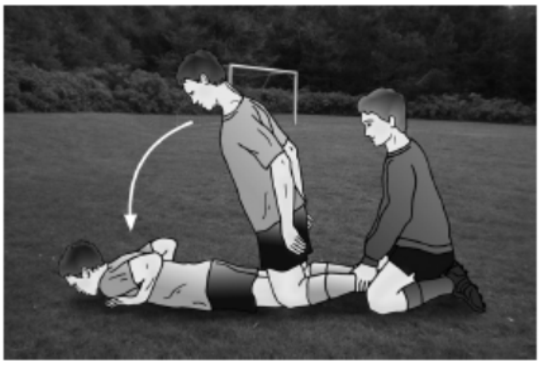


Figure 8: Graphical representation of the Nordic hamstring lower

Training Program

The sample population participated in soccer specific training four times a week, while also engaging in match-play once a week, typically on Saturday afternoon. Players were therefore habituated to the relative demands of consistent training and match-play. The Nordic Lower programme (approximately 15 minutes in length) was in addition to regular training, incorporated by the relevant coaches and supervised by the relevant researcher. The exercise session was performed after the comprehensive warm-up. The additional programme was incremental, allowing for habituation to the relative demands. This minimized the risk of hamstring injury. Participants were encouraged to abstain from practice if they experienced severe post-match or post training pain or soreness.

SELECTION OF INDEPENDENT VARIABLES

In order to evaluate the efficacy of the Nordic hamstring intervention strategy a research design as outlined in Figure 7 was established. The time frame used and selection of the control and experimental groups is outlined below.

Time

To establish the effect of an eccentric training program, relative hamstring strength related performance measures were measured over the duration of the programme. The eccentric hamstring intervention programme lasted 12 weeks. This was conducted during the second half of the 2014/2015 season. During this experimentation period, two weeks of intervention requirements were missed due to poor weather and the Easter break (See appendix B for full compliance data). A 10 week programme was therefore completed over this period. Within similar soccer related studies (Askling *et al.*, 2003; Gabbe *et al.*, 2006; Arnason *et al.,* 2008; Petersen *et al.*, 2011) intervention length has typically been 10 or more weeks. Furthermore, McArdle *et al.* (2006) states that to establish the true effect of an intervention, the duration is required to be 8 weeks or more. 12 weeks (with an actual 10 week intervention) was therefore adequate time for effect and is consistent with similar studies. Three key factors were investigated over this time frame. These were tested at different times over the duration of the intervention.

Group Assignment

In order to facilitate the randomly controlled trial design of the current study experimentation incorporated a two–group experimental design i.e. a Control vs. Experimental group (Refer to Figure 7). Within the context of soccer specific research, this is a common methodology to isolate the effect of an intervention (Mjolsnes *et al.* 2004; Arnason *et al.,* 2008; Croisier *et al.,* 2008; Petersen *et al.* 2011). The purpose of such experimental design is to enable comparisons to be drawn between these groups, ensuring that any effects identified were due to the intervention applied, rather than extraneous variables. Participants assigned to the control group were fully informed regarding the need to abstain from the exercise, in order to establish any effect.

Initially, 32 players were recruited to attend habituation sessions. Two squads of players were included, to ease experimental procedures, and to reduce random error due to multiple squads with differing fitness regimes. These squads were MARU FC (n=20) and Shooting Stars FC (n=12). Prior to baseline assessment, four players reported with injury during the previous 6 months and were therefore excluded. Over the course of the intervention period, nine players were removed from the study due to non-compliance, non-attendance of practices, or an inability to complete isokinetic assessment. Compliance was defined as the completion of the daily exercise session, with players excluded from the study if they completed 50% or less of the required sessions. Following completion of the experimental period, 19 players were therefore eligible for inclusion, with 9 participants within the control group, and 10 in the intervention group.

SELECTION OF PARTICIPANTS

The aim of the present study was to identify the strength and performance profile of community based South African players, and secondly, to establish the efficacy of a hamstring intervention within this context. Importantly, multiple studies have indicated that there are performance and injury differences between races (Bosch *et al.*, 1990; Coetzer *et al.*, 1993; Weston *et al.*, 1999). This aspect of the study is comprehensively discussed on page 24. With this in mind, only Black African participants of Bantu descent were selected to represent this demographic. Additionally, soccer related research has utilized solely European (Cometti *et al.*, 2001; Croisier *et al.*, 2008; Greig & Siegler, 2009; Lovell *et al.*, 2013), North American (Worrell, 1994) and South American participants (Da Silva *et al.*, 2011; Cohen *et al.*, 2014). As a result, data relating to Black African players will allow the development of a succinct profile, and improved understanding regarding the efficacy of interventional research in this context.

Participants were selected from the local Grahamstown soccer league, Eastern Cape, South Africa. The male soccer league is far more prominent within this context, and so males were selected allowing for easier participant recruitment and ensuring sufficient numbers. Furthermore, relevant comparative literature within hamstring research focuses on males (Rahnama *et al.*, 2003; Mjølsnes *et al.,* 2004; Greig *et al.*, 2006).

The 18 week experimentation period occurred during the 2014/2015 local league season, from February to April 2015. Participants selected had experienced match-play during the 2013/2014 season, as well as at the end of 2014, and so were well habituated to the demands of seasonal play. Both squads included had similar training regimes, with practices from Monday to Thursday each week (5 pm - 7:30 pm), with match-play on Saturday afternoons. All experimentation associated with the present study was conducted during these training times due to large variability in availability of participants. Additionally, soccer-specific research suggests players between the ages of 18 and 35 are able to perform successfully at the levels required in the various amateur soccer leagues around the world (Tourny-Chollet *et al.*, 2000; Kellis *et al.,* 2001; Croisier *et al.,* 2008; Small *et al.*, 2009; Lovell *et al.*, 2013). As a result, the above age range was utilised for the present study. Additionally, defensive, midfield, and attacking players were recruited as all outfield players experience similar levels of fatigue and are susceptible to injury (Tourny-Chollet *et al*., 2000).

SOCIO ECONOMIC QUESTIONNAIRE

A unique aspect of the present study was the population of interest. In order to accurately represent the peri-urban context, a socio-economic questionnaire was developed and administered to participants of this study. This is an important component of the study as a primary aim was to investigate the efficacy of interventional research within this context. It was therefore deemed important to identify the socio-economic condition, in order to ascertain its unique effects on efficacy. The questionnaire was developed using questions and aspects identified as influential in the South African General Household survey (http://sada-data.nrf.ac.za/handle/10956/5). The CENSUS survey has been previously validated, and identifies vital household, work related, social, economic and familial factors, which influence socio-economic status. This in turn allows for the identification of the unique influences experienced by the South African peri-urban player population. The questionnaire was not employed to definitively identify factors of interest, relevant to the population. It was rather used to generate a description of the population of interest. The administered survey can be found on in Appendix A.

DEPENDANT VARIABLES

Lower Extremity Strength

The lower extremity strength profile is a crucial characteristic of the soccer player (Cometti *et al.*, 2001), due to the nature of soccer-specific demands. Furthermore, the lower extremities and more specifically the thigh have consistently been found to be the most frequently injured structure during competitive soccer match-play (Hawkins & Fuller, 1999; Hawkins *et al*., 2001; Wong and Hong, 2005; Ekstrand *et al.*, 2011). Therefore, the knee flexors and extensors of the leg were chosen as the muscles to measure rather than other, less frequently injured areas.

In order to establish the effects of an eccentric hamstring strengthening intervention, eccentric hamstring strength parameters were measured to identify any strength improvements. A further consideration is muscular imbalance, indicated as a vital factor in hamstring strain injury (Croisier *et al.,* 2008). As a result, concentric hamstrings strength was measured to identify any effect of an eccentric strengthening regime on the relative concentric strength profile of the hamstrings. Functionally speaking, eccentric hamstring activation carries the greatest risk of injury (Ekstrand *et al.,* 2011). Eccentric activation of the hamstrings occurs when slowing the lower extremity, a result of concentric action of the quadriceps. Therefore the antagonist relationship between eccentric hamstring capabilities and concentric quadriceps capabilities is an important consideration, as indicated in numerous studies (Aagaard *et al.*, 1998; Holcomb *et al.,* 2007; Costa *et al.*, 2013; Jones *et al.,* 2015). To establish the relative capabilities of the upper thigh, concentric quadriceps strength capabilities were identified. This relationship is otherwise known as the functional ratio, which is an effective identifier of hamstring injury risk (Small *et al.*, 2010).

In order to establish an idea of the lower extremity strength profile the following variables were considered to be of importance: Peak hamstring and quadriceps torque, functional hamstrings to quadriceps peak torque ratios, work done, average power per repetition, time rate of torque development and angle of peak torque, in both the dominant and non-dominant legs. According to Baltzopoulos *et al.* (1983), peak torque identifies the highest muscular force output, while angle and time to peak torque represent the location within the range of motion, and time taken to produce relative force. These torque related factors represent the maximal capabilities of the muscle group in question, and the location of peak torque within the range of motion. Within a soccer context, this has implications for hamstring injury risk (Greig, 2006; Jones, 2012), and are typical outcomes with regards to isokinetic assessment. Additional parameters include work, whichrepresents functional performance of torque summed through the range of motion, while power identifies how effectively the muscle can perform work over time (Baltzopoulos *et al.,* 1983). Such factors are important when analysing the relative capabilities of the muscle group in question, and were selected for inclusion within the present study.

Isokinetic evaluation is the ‘gold standard’ for muscular assessment (Perrin *et al.,* 1993). Furthermore, numerous studies have employed isokinetic dynamometry when identifying the strength capabilities of soccer players (Cometti *et al.*, 2001; Rahnama *et al.*, 2003; Greig *et al.*, 2006; Zakas, 2006; Croisier *et al.*, 2008; Jones *et al.*, 2015;), and was therefore deemed an appropriate method to accurately and reliably assess torque production capabilities of the upper thigh.

Previous literature regarding isokinetic assessment of the lower limbs in soccer players have utilised a large range of isokinetic speeds for both eccentric and concentric activation. Greig *et al.* (2006) and Greig & Siegler (2009) utilised isokinetic speeds of $60°.s^{-1}$, $180°.s^{-1}$ and $300°.s^{-1}$, while a large number of studies utilised isokinetic speeds of $60°.s^{-1}$ and $120°.s^{-1}$ (Tourny-Chollet *et al.*, 2000; Kellis *et al.,* 2001; Croisier *et al.*, 2008; Small *et al.*, 2009; Small *et al*., 2010; Lovell *et al.*, 2013). The present study utilized isokinetic testing speeds of $60°.s^{-1}$ and $180°.s^{-1}$ in order to accurately and safely assess the muscular changes associated with the intervention. These isokinetic testing speeds were chosen as according to Perrin *et al.* (1993) they represent the most appropriate testing speeds to test both strength ($60°.s^{-1}$) and power ($180°.s^{-1}$). Strength is an important characteristic of muscular performance

(Cronin & Hansen, 2005), while the power related speed is more representative of functional action associated with the gait cycle (Jones *et al.,* 2015).

Additionally, both the dominant and non-dominant limbs were tested. Multiple studies report strength asymmetries between the limbs (Fowler & Reilly, 1993; Roos *et al.,* 1998; Rahnama *et al*., 2005). Furthermore, asymmetry is a high risk factor for injury (Croisier *et al.,* 2008). It was therefore necessary to ascertain the strength profile of both limbs to identify inherent discrepancies, and to note the effects of an eccentric strengthening regimen on both the dominant and non-dominant limbs. The limb to be tested first, either dominant or non-dominant, was randomly assigned.

With regards to the intervention, the current investigation focused on the time dependant changes in peak hamstring and quadriceps torque, quadriceps to hamstrings ratios, work done, average power, time to peak torque and angle of peak torque, in both the dominant and non-dominant limbs, prior to and following the intervention period. Isokinetic parameters were taken before and after the intervention period, consistent with studies such as Mjølsnes *et al.* (2004), Croisier *et al.* (2008) and Small *et al.* (2009). This was completed to note any changes in the strength profile over the duration of the programme (Refer to Figure 7).

Performance Characteristics

<u>Vertical Jump</u>

An important aspect of the present study was applicability to the peri-urban context. Cost effective solutions are an important consideration in a country with high levels of poverty and poor infrastructure. Vertical jump was therefore employed as an effective performance measurement; and technique to establish eccentric capabilities in the thigh (Cronin & Hansen, 2005). Two types of vertical jump were employed: the Countermovement Jump (CMJ) and the squat jump (SJ). During a CMJ, the player begins in an upright position; bends to a predetermined optimal eccentric depth then immediately jumps vertically (Hunter and Marshall, 2001). This CMJ incorporates the eccentric component associated with lower limb activation. During the SJ, the player holds a knee angle of 90 degrees for 3 seconds, followed by a vertical jump (Bobbert et al., 1996). The SJ is therefore purely concentric, indicating concentric capabilities of the lower limb. The ratio between techniques isolates the eccentric component, a representation of the eccentric capabilities of the hamstrings.

- EUR = CMJ Height/ SJ Height

This eccentric utilization ratio (EUR) is calculated to represent the utilization of the stretch shortening cycle during hamstring activity. A high EUR represents a player with a high capacity to store potential energy. Vertical jump was therefore employed to represent lower limb capabilities, prior and following the intervention. Vertical jump measures were performed prior to, at week 4, at week 8, and post intervention to identify changes over the duration of the intervention, (see Figure 7 on page 52 for details).

<u>Sprint Times</u>

A critical factor in hamstring injury is the contribution of sprinting biomechanics (Small *et al.,* 2009). Furthermore, sprinting is an important component of soccer at any level, and therefore the effects of an eccentric intervention on sprint ability are an imperative consideration. In order to get a representation of performance, a 10m sprint time test was selected for inclusion. The 10m sprint time protocol has been reported as a good indicator of sprint ability by Mirkov *et al.* (2008). Additionally, the sprint has been employed in a number of studies including Cometti *et al.* (2001), Wisloff *et al.* (2004), Buchheit *et al.* (2010), Waldron *et al.* (2011), Spencer *et al.* (2011), and Green *et al.* (2013), and is the most common sprint test in soccer. Furthermore with minimal time to perform and low impact on fatigue associated with the test, the 10m sprint test was selected for inclusion within this study. Comparison was therefore made pre and post intervention to indicate changes in these performance characteristics

Intermittent Capability

As soccer is an intermittent sport (Bangsbo, 1994), it is important to consider the effects of any intervention strategy on intermittent performance. Typically, such protocols are generally for all intermittent sports and not specific to soccer (Bangsbo *et al*., 2008). The intermittent endurance test selected for inclusion was the Yo-Yo Intermittent Recovery Test (Bangsbo *et al.,* 2008). This test is used to measure aerobic capacity and has a large construct and concurrent validity (Krustrup *et al*., 2003; Bangsbo *et al*., 2008; Mohr *et al*., 2010). Furthermore, this is a more precise measure of intermittent capability (Mohr, 2013), and to date is the most commonly used test. Multiple studies have employed this shuttle test in soccer specific investigations (Krustrup *et al*., 2003; Castagna *et al.,* 2006; Rampinini *et al*., 2010). Due to these factors it was selected for inclusion to profile the cabiltiies of the selected population. Additionally, it was employed to identify whether an eccentric hamstring intervention affects intermittent capability. To assess the impact of the intervention on performance characteristics, relevant measures were performed before and after the investigation period (Refer to Figure 7). This is consistent with a comparable study by Steffen *et al.* (2008) assessing the impact of a similar soccer specific intervention.

MEASUREMENT AND EQUIPMENT

During experimental testing sessions, it was extremely important that accurate and reliable data were continually collected from each participant. All equipment utilised during experimentation was therefore correctly set up, calibrated, fitted to the participant and correctly operated. The following equipment was required in order to collect anthropometric and biomechanical responses:

Anthropometric Measures

Body mass: Toledo™ scale

The body mass of each participant was measured to the nearest 0.01 kg using a calibrated Toledo™ electronic scale. Each participant was required to remove their footwear and wear minimal clothing during measurement. The researcher requested the participant to stand still, in the centre of the scale, with body mass distributed evenly between the feet. Mass was recorded once a stable recording could be obtained.

Stature: Harpenden™ Stadiometer

Stature was obtained using a Harpenden Stadiometer and recorded to the nearest millimetre (mm). Participants wore light clothing, were required to remove their shoes, and stood on the Stadiometer in an upright position facing forward with their heels against the base of the Stadiometer. Stature was measured from the floor to the vertex in the mid-sagittal plane.

Physical Parameters

Isokinetic Strength Testing: BIODEX System 4 PRO Isokinetic Dynamometer

Isokinetic assessment provides a highly controlled evaluation in which the neuromuscular performance of a joint system can be safely stressed (Svensson & Drust, 2005). Additionally, isokinetic dynamometry accurately assesses the balance of strength between the hamstrings and the quadriceps (Pincivero *et al*., 1997), evoking useful data regarding physical fitness, and indications for injury.

Isokinetic dynamometry measures the dynamic muscular force of action when the velocity of movement is controlled (Perrin *et al.,* 1989). Muscle function was measured using a BIODEX System 4 PRO Isokinetic Dynamometer (BIODEX, Biodex Medical Systems, Inc., Ramsey Road, New York 11967). The isokinetic dynamometer was set up to suit each participant, following the guidelines provided by the manufacturers and a soccer specific assessment procedure by Greig *et al*. (2006). This set up was maintained for both pre and post assessment, in order to reliably identify the effects of an eccentric focused intervention.

Procedure for the Assessment of the Upper thigh (Greig *et al.,* 2006)

- The subject is seated on the dynamometer (with hip joint at approximately 90 degrees of flexion) with the body stabilized by several straps around the thigh, waist, and chest to avoid compensation.
- The range of knee motion will be fixed at 90° of full extension.
    - The gravitational factor of the dynamometer's lever arm and lower leg-segment ensemble will be compensated for during the measurements.
- ISOKINETIC TESTING SPEEDS
    - Two testing speeds will be used. According to Perrin *et al.* (1993), these speeds indicate Strength (60°.s^{-1})and Power (180°.s^{-1})
- 3 maximal repetitions will be completed at each speed and for each muscle mode.
- All sets of testing will be separated by 1 minute of rest.
- Before assessment, adequate habituation was completed.
- Oral encouragement given
- Performed for both legs

The dynamometer's lever arm was correctly secured around the participant's ankle using appropriate strapping, proximal to the lateral and medial malleoli. Restraints were applied across the participant's chest and across the thigh ensuring activity was not restricted. Range of motion varies across participants (Perrin *et al.,* 1993) and so range of motion was self-selected, and kept consistent for pre and post assessment. This was to ensure minimal influence for total work and average power responses.

As previously discussed, correction for gravity is an important consideration (Li *et al*., 1996) in the case of knee extension and flexion testing. The Biodex S4 identifies the mass of the limb through voluntary relaxation of the leg in the extended knee position (Svensson & Drust, 2005). This was completed during prior to experimental protocol. The importance of complete relaxation was emphasized to the participant.

Each participant was required to perform three repetitions, performed on both the dominant and non-dominant legs, at isokinetic speeds of $60^{o}.s^{-1}$ and $180^{o}.s^{-1}$, in both eccentric and concentric modalities. Three repetitions were selected to increase the reliability of muscular responses whilst reducing the effects of fatigue (Greig *et al.*, 2006). Limb dominance was self-selected.

Rest periods of 30 seconds were employed between each set of repetitions, in order to reduce the impact of fatigue. Participants were instructed that each repetition should be a maximal contraction throughout the entire range of motion. To ensure that the data collected was reliable and valid, torque production curves with a coefficient of variation (CV) of greater than 20% were excluded from the data set, or alternatively repeated by the participant. This was done to ensure maximal effort through testing. Furthermore, 20% was selected upon recommendations from the manufacturer for large muscle groups. No visual feedback was afforded to the participant but verbal encouragement was provided by the researcher. The verbal encouragement provided was consistent across the board. Isokinetic dynamometer set up was kept consistent for pre and post assessment for each participant in order to ensure reliability of responses.

A vital aspect of isokinetic assessment is habituation to procedures. This is particularly relevant within the peri-urban context, where players are not exposed to equipment of this nature. Prior to assessment, all participants therefore attended the Human Kinetics and Ergonomics Department at Rhodes University to habituate to the BIODEX S4. Multiple sub-maximal repetitions were completed in all activity modes and at both speeds. Following completion, maximal assessment was performed to ensure full comprehension. Such sessions were conducted on days prior to experimentation to remove the effects of fatigue.

Performance Indicators

Vertical Jump: Self Made

Systems such as the Jump Meter (Takei Kiki Kogyo Co. Ltd, Japan) are highly reliable as they automatically record jump height when touched. The value is then displayed on the accompanying screen. However, such vertical jump measurement devices are often wall mounted, and are also reasonably expensive. This is a limitation within the South African peri-urban context, due to a lack of resources and infrastructure available to community based players. However, the principle established through such systems is simple. All that is required is a record of jump height. A more effective solution was therefore employed with the following directives: cheap, portable and reusable. This was a crucial element of the present study due to its field based nature. Equipment was transported to the participants, and so ease of transport and assembly was a critical consideration.

Figure 9: Images to show the self-made vertical jump meter employed within this study.

The electrical touch-sensitive jump meter device was replaced with a board of plywood. This board was covered in black board paint, with white lines painted, consistently representing 1 cm intervals. This board was attached to an adjustable bracket. This bracket is then supported by an accompanying stand with concrete base. During experimentation, the participant fully extends their arm upwards and the vertical jump board is then adjusted up or down to suit the reach of the player. Relative heights can then be achieved. Participants applied minimal white chalk powder to their middle fingers, before completing the jump. The chalk leaves an indication of the vertical jump height achieved. The self-made apparatus was checked through comparisons to the Jump meter developed by Takei Kiki Kogyo Co. Ltd. Pilot studies were completed prior to experimentation. Multiple participants performed vertical jumps using both apparatus's, with jump height comparisons made. It was concluded that the self-made device accurately replicated results from the Takei Jump Meter. It was therefore deemed an acceptable measurement device, as a cost effective, portable and sustainable solution.

Each jump type was performed 3 times at each measurement point and an average was taken. According to Church *et al.* (2001), Knudson (2001) and Cochrane *et al.* (2004), this is an appropriate method to establish a reliable jump height and eccentric utilization ratio. Each individual jump was separated by a 20-second waiting period, while the two broader jump categories were separated by 1 minute. This was done to reduce the impact of fatigue. This is recommended by Cochrane *et al*. (2004) as an appropriate delay between measures.

10m Sprint: Casio Stopwatch

The 10m distance was measured using a tape measure, and the distance was indicated using simple cones. From a standing start, participants completed the sprint, with their time being measured with the use of a Casio stop watch *(HS-80TW-1)*. Initiation of the test was indicated using a whistle. The best of three sprints was chosen, in line with a study by McGawley (2013). A two minute rest period was employed between each repetition.

Yo-Yo Intermittent Recovery Test: Bleep Test App for iPhone

The audio prompts associated with the Yo-Yo test intermittent recovery test were delivered through the use of the IPhone Bleep Test application. The accompanying 20m shuttle and 5m recovery course were established through the use of a tape measure and standard cones. The audio was initiated with the researcher using a whistle to further indicate the points of the test. Participants were required to maintain pace with the audio prompts, and were requested to stop the test if they missed two of said prompts. To reduce the effects of random error, the same researcher observed and recorded all sprinting trials. These sprints were completed on the same level turf surface.

EXPERIMENTAL PROCEDURE

The experimentation for this study was divided into three main phases. The initial phase involved the introduction and habituation of participants to the present study, particularly to procedures such as Isokinetics. During this session, participants were presented with an outline of the focus and purpose of the study and were familiarized with the experimental procedures including technique for vertical jump, Isokinetics, performance measures and the Nordic hamstring lowers exercise. The length of the habituation period varied according to participant, due to the foreign nature of isokinetic procedures within this context. Following adequate habituation, informed consent was obtained (appendix A). Anthropometric and baseline values were then obtained for all dependant variables, at least 48 hours following habituation.

The second phase required participants assigned to the intervention group, to perform the Nordic hamstring intervention program on a weekly basis. This was in addition to regular training. Participants of the control group continued with regular training. Following the intervention period, the third phase was initiated, with isokinetic, vertical jump and performance measures being taken. Isokinetic assessment was conducted in the Human Kinetics and Ergonomics department at Rhodes University, Grahamstown, South Africa. Vertical jump and performance measures were conducted at either Rhodes University playing fields, or municipal playing fields.

Session 1: Introduction, Habituation and Baseline Assessment

Initially, participants were informed of the nature and aspects of the study at an introductory session. Procedures pertaining to the study were explained to the participants both verbally and in writing (Appendix A). This session served to familiarize the participants with the different vertical jump types, procedures for 10m sprint and the Yo-Yo Intermittent Recovery Test, isokinetic assessment and the Nordic hamstring exercise. Once queries had been addressed, participants were required to sign an informed consent form before any data was obtained. Basic demographic and anthropometric data were acquired, including; age, stature, mass, playing position, years of experience and injury history. Participants of this study were included if they were not injured or under the influence of medication over the course of the intervention period. Participants were excluded if they had suffered a lower extremity injury in the previous 6 months.

Players included in the study were then habituated to the BIODEX S4 isokinetic dynamometer. Adequate time was taken to familiarize participants with equipment, technique and procedures. During this habituation session, participants were exposed to the speed of $60°s.^{-1}$, before the faster speed of $180°s.^{-1}$. This allowed for an easier learning experience as a slower speed is easier to perform due to greater movement control. The necessity for maximal effort was stressed to the participant. Players were then habituated to the procedures for vertical jump and the performance measures. Participants were encouraged to practice the protocols, to ensure adequate familiarization.

Baseline Assessment

Following the introductory session, participants were required to present themselves at the HKE department for assessment. Participants were encouraged to adorn regular soccer attire, excluding shin pads due to requirements of isokinetic assessment. Prior to testing, participants performed a standardize warm-up including a five minute cycle ergometer ride at 60 Watts and 5 minutes of static and dynamic stretches for the lower extremity (Small *et al.,* 2009; Lovell *et al.,* 2013). Players were encouraged to perform any additional warm-up if it was deemed necessary.

Participants were then re-familiarized with the performance, vertical jump and isokinetic measures.

Participants attended the department in groups of four, to reduce the length of the testing period, increasing reliability of results. Following randomization into two groups of two, players performed both performance testing and vertical jump, followed by isokinetic assessment, or vice versa to reduce variability. The performance of selected tests in a fatigued state was justified due to the time constraints of both the players and research itself. Performance and vertical jump procedures were performed on the Rhodes University playing fields. The 10m sprint was completed three times, with a two minute rest in-between repetitions. A minimum 10 minute break was then employed for adequate recovery. Participants then completed the Yo-Yo intermittent recovery test with audio prompts, followed by a 15 minute rest period. Participants were provided with water at all times and hydration was self-selected. Following adequate recovery, participants completed the 6 vertical jumps. These were separated by 30 seconds between each jump, and two minutes between the sets. Additionally, isokinetic assessment was completed on both legs, with the first limb to be tested randomized. This was maintained for both pre and post assessment. Participants performed muscle function testing at the required isokinetic speeds with 30 seconds rest intervals between each set of three repetitions. This was completed for all contraction modes.

Session 2 - Intervention

Following completion of baseline assessment, players were randomly assigned to either the control, or intervention group. The was done using a random number generator. Participants randomly assigned to the intervention group were re-familiarized with the Nordic hamstring lower. Players were encouraged to partner up, to improve adherence. Over the following 12 week period, the Nordic hamstring lower program was completed. Each session was observed and monitored by the researcher, and performed after warm up.. Adherence was recorded for each session. At weeks four and eight, vertical jump procedures were performed for both groups. These procedures were identical to baseline testing procedures.

Session 3 – Post Assessment

Following completion of the intervention period, both the control and intervention groups attended the HKE department to perform the test battery. The procedures were identical to those performed prior to the testing period. Additionally, participants completed a socio-economic questionnaire (Appendix A).

The same researcher and testing assistants were present for all testing sessions. Roles performed were identical for habituation, baseline testing and post assessment. This ensured the standardization of testing throughout the study period.

ETHICAL CONSIDERATIONS

Prior ethical approval from the Rhodes University Research Ethics Committee was a prerequisite for the implementation of testing procedures.

Informed Consent

All participants were informed both verbally and in writing of the nature of the present study (Appendix A). The purpose of the study, including aims, expectations and any associated risks or benefits, as well as the procedures that were to be carried out, were explained. All participants were informed that they were free to abstain from the study at any point. Voluntary, written consent was given by all participants without any pressure from coaching staff, team captains, or other team members. Upon completion of the study, all participants were provided with detailed feedback regarding their results, as well as the overall outcomes of the study. Photographs of the testing procedures were only taken with the consent of the participant.

Privacy and anonymity of results

A coding system was used to ensure any information and data obtained during experimental testing could not be traced back to the participants. The name on each data sheet (Appendix A) was used for record purposes only, and the participants were informed that their data would be held on file for statistical analyses and be deleted following the completion of the study, with only one copy being stored in the Department of Human Kinetics and Ergonomics, Rhodes University, for archive purposes.

STATISTICAL PROCEDURES

All data collected was reduced and analysed using Statistica™ 12. Initially, general descriptive statistics were calculated as to provide general information regarding the sample as a whole. Following this, 2 way covariant ANOVAs were calculated. In the event of a main or interaction effect, Tukey post hoc analysis was employed. A 95% confidence level was used, allowing for a 5% chance of a type I error occurring (rejecting a true hypothesis).

CHAPTER IV

RESULTS

INTRODUCTION

The present study established two main aims: Identify the profile of the amateur Black South African Player, and investigate the efficacy of the Nordic hamstring exercise intervention within the peri-urban South African context. These two components of the thesis will be presented in separate sections. Results will be presented graphically, with the use of mean values accompanied by standard deviations and coefficient of variation when applicable. The profile data is the combined responses (n=19) of both the control and intervention groups at baseline. Intervention results from the overall ANOVA regarding the effects of group, time and leg dominance will be stated, with further analysis of statistical differences following.

SUBJECT CHARACTERISTICS

A total of 19 male soccer players were included within the present study, with 9 allocated to the control group, and 10 to the intervention group. The sample group included all outfield positions; therefore no goalkeepers were recruited for participation. All participants represented either MARU FC or Shooting Stars FC, both teams competing in the same local Grahamstown league. No medical examination took place prior to testing; the researcher relied on subjective self-reports in order to establish that all participants were free of illness and musculoskeletal injuries to the lower extremities.

Table V: Demographic information of both the Control and Intervention groups

	Control			**Intervention**		
	Mean	SD	CV	Mean	SD	CV
Age (years)	23.89	5.01	0.21	23.20	4.42	0.19
Stature (cm)	171.60	4.32	0.03	171.11	8.03	0.05
Body Mass (kg)	67.16	9.43	0.14	65.62	9.18	0.14
BMI (kg.m^{-2})	22.81	3.25	0.14	22.42	2.87	0.13

Where: SD= standard deviation, CV= coefficient of variation (%)

PROFILE OF THE AMATEUR BLACK SOUTH AFRICAN PLAYER

Isokinetic Assessment

Data from the isokinetic assessment of muscle strength in soccer players can be employed to determine general muscle strength profiles. This research has identified the knee flexors and extensors as the most relevant to profile, due to the nature of soccer. Isokinetic concentric and eccentric data for each muscle group will be displayed separately. For details regarding selection of isokinetic responses please refer to the method chapter (page 51). Significant differences between limb responses are highlighted in red.

Concentric Quadriceps

Mean, standard deviation and coefficient of variation for all participants for the concentric quadriceps are presented in Table V. This data includes all relevant isokinetic responses such as peak torque, time to peak torque, angle of peak torque, total work and average power.

Table VI: Concentric Quadriceps responses of the Peri-Urban South African amateur player

	60°.s^{-1}		180°.s^{-1}	
	Dominant	**Non-Dominant**	**Dominant**	**Non-Dominant**
Peak Torque (Nm) CV (%)	198.3 (18.7) 9	191.7 (25.5) 13	142.7 (19.8) 14	139.9 (23) 16
Time to Peak Torque (ms) CV (%)	523.1 (119.1) 23	545. 8 (136) 25	341.1 (106.1) 31	349.4 (133.0) 38
Angle of Peak Torque (°) CV (%)	75.9 (10.3) 14	74 (9.1) 12	72.5 (8.7) 12	71.2 (8.4) 12
Total Work (J) CV (%)	344.2 (76.9) 22	322.3 (71.8) 22	234.8 (48.4) 21	2271 (53.4) 24
Average Power (W) CV (%)	125.4 (8.6) 7	122.2 (11.9) 10	**215.3 (18.7)** **9**	**227.1 (23.8)** **10**

Peak torque of the knee extensors is indicated in the table above (Table V). For the strength related speed of 60°.s^{-1}, peak torque values of 198.3(±18.7) Nm and 191.7 (±25.5) Nm were observed for the dominant and non-dominant limbs respectively. While at 180°.s^{-1}, lower values of 142.7 (±19.8) Nm and 139.9 (±23.1) Nm were recorded for dominant and non-dominant legs. With regards to time to peak torque, both limbs elicited similar responses. Values of 523.2 (±119.1) ms and 545.8 (±136) ms were observed at the strength related velocity of 60°.s^{-1} for the dominant and non-dominant limbs respectively. At 180°.s^{-1}, concentric quadriceps time to peak torque was indicated as 341.1 (±106.1) ms and 349.5 (±133) ms for the respective limbs.

Angle of peak torque values for the knee extensors were recorded as 75.9 (±10.3) ° for the dominant limb, and 74 (±9.1) ° for the non-dominant limb at 60°.s^{-1}. For the more functional speed of 180°.s^{-1}, values of 72.5 (±8.7) ° and 71.2 (±8.4) ° were observed for angle of peak torque. Pre-intervention values for total work of the concentric knee extensors are indicated in the table above. Total work responses of 344.2 (±76.9) J and 322.3 (±71.8) J were observed for the dominant and non-dominant limbs respectively for the strength related isokinetic velocity.

Isokinetic responses for 180°.s^{-1}, indicated total work average values for the dominant limb as 234.8 (±48.4) J while the non-dominant limb indicated a mean response of 227.1 (±53.4) J. Responses for average power of the concentric quadriceps were noted at both isokinetic speeds. For the strength related speed of 60°.s^{-1}, average power values of 125.4 (±8.6) W and 122.2 (±11.9) W were recorded for the dominant and non-dominant limbs. 180°.s^{-1} responses, indicated average power as 215.3 (±18.7) W and 227.1 (±23.8) W for the preferred and non-preferred limbs respectively. Values at this functional speed were significantly different (p=0.017).

Eccentric Quadriceps

Mean, standard deviation and coefficient of variation for all participants for the eccentric quadriceps are presented in Table VI. This data includes all relevant isokinetic responses such as peak torque, time to peak torque, angle of peak torque, total work and average power.

Table VII: Eccentric quadriceps responses of the Peri-Urban South African amateur player

	60°.s^{-1}		180°.s^{-1}	
	Dominant	**Non-Dominant**	**Dominant**	**Non-Dominant**
Peak Torque (Nm) CV (%)	**213.9 (26)** **12**	**202.5 (32.2)** **16**	202.6 (32.1) 16	195.2 (30.6) 16
Time to Peak Torque (ms) CV (%)	1165.8 (206) 18	1170 (377.2) 32	727.9 (175.1) 10	787.9 (122.1) 15
Angle of Peak Torque (°) CV (%)	73.1 (8.6) 12	75.1 (8.6) 11	72.6 (8.1) 11	72.6 (8.4) 11
Total Work (J) CV (%)	271.1 (58.3) 22	262.4 (51) 19	259.7 (73.1) 28	267.1 (72.7) 27
Average Power (W) CV (%)	**113.7 (16.6)** **15**	**102.6 (12.2)** **12**	192.7 (25.8) 13	186.8 (28.9) 15

Considering responses at 60°.s^{-1}, peak torque values of 213.9 (±26) Nm for the dominant limb, and 202.5 (±32.2) Nm for the non-dominant limb were observed. Peak torque responses were significantly different (p=0.049) between the limbs. Eccentric peak torque values of 202.6 (±32.1) Nm and 195.2 (±30.6) Nm were recorded for the dominant and non-dominant limbs respectively at the faster isokinetic velocity of 180°.s^{-1}. As indicated in Table VI, time to peak torque responses at 60°.s^{-1} indicate values of 1165.8 (±206) ms and 1170 (±377.2) ms for the dominant and non-dominant limbs respectively. Responses for the isokinetic speed of 180°.s^{-1}, recorded values of 727.9 (±175.1) ms for the preferred limb, while the non-dominant observed values of and 787.9 (±122.1) ms.

Angle of peak torque of the knee extensors were observed at both isokinetic velocities. For 60°.s^{-1}, angle of peak torque values of 373.1 (±8.6) ° and 75.1 (±8.6) ° were recorded for the dominant and non-dominant limbs. Values of 72.6 (±8.1) ° and 72.6 (±8.4) ° were reported for angle of peak torque at 180°.s^{-1}. Considering the strength related speed of 60°.s^{-1}, total work values of 271.1 (±58.3) J for the dominant and 262.4 (±51) J for the non-dominant limbs were recorded.

Isokinetic responses at 180°.s^{-1}, indicated total work achieved by the quadriceps was 259.7 (±73.1) J and 267.1 (±72.7) J for the dominant and non-dominant limbs. With regards to average power capabilities, both limbs elicited similar responses. At 60°.s^{-1}, average power values were significantly different between the limbs (p=0.0002) with values of 113.7 (±16.6) W and 102.6 (±12.2) W observed for the dominant and non-dominant limbs respectively. At the faster speed of 180°.s^{-1}, power capabilities were recorded as 192.7 (±25.8) W and 186.7 (±28.9) W for the dominant and non-dominant limbs respectively.

Concentric Hamstrings

Mean, standard deviation and coefficient of variation for all participants for the concentric hamstrings is presented in Table VII. This data includes all relevant isokinetic responses such as peak torque, time to peak torque, angle of peak torque, total work and average power.

Table VIII: Concentric hamstring responses of the Peri-Urban South African amateur player

	60°.s^{-1}		**180°.s^{-1}**	
	Dominant	**Non-Dominant**	**Dominant**	**Non-Dominant**
Peak Torque (Nm) CV (%)	172.4 (29.9) 17	163.5 (21.1) 13	149.6 (30) 20	148.3 (26.7) 18
Time to Peak Torque (ms) CV (%)	637.2 (134) 21	741.1 (182.6) 25	308.4 (127.6) 41	307.4 (123.1) 40
Angle of Peak Torque (°) CV (%)	56.2 (7.6) 14	55.4 (8.8) 16	57.7 (9.4) 16	59.4 (9.7) 16
Total Work (J) CV (%)	277.8 (79.2) 28	271.3 (67.9) 25	197.3 (59.6) 30	203.5 (56.1) 28
Average Power (W) CV (%)	81.7 (13.6) 17	80.2 (13.1) 16	119.9 (22.1) 18	125.1 (20.3) 16

For the isokinetic velocity of 60°.s^{-1}, peak torque values of 172.4 (±29.9) Nm and 163.5 (±21.1) Nm were observed for the dominant and non-dominant limbs respectively. Values of 149.6 (±30) Nm were noted for the dominant limb, while 148.3 (±26.7) Nm was recorded for the non-dominant limb, at 180°.s^{-1}. Time to peak torque responses of the knee flexors when acting eccentrically indicated time to peak torque values of 673.2 (±134) ms and 741.1 (±182.6) ms for the dominant and non-dominant limbs respectively, at the slower isokinetic speed of at 60°.s^{-1}. 180°.s^{-1} responses reported values of 308.4 (±127.6) ms and 307.4 (±123.1) ms for time to peak torque of the dominant and non-dominant limbs.

Angle of peak torque of the knee flexors recorded at baseline; indicated responses of 56.2 (±7.6) ° and 55.3 (±8.8) ° for the dominant and non-dominant limbs at the strength related velocity of 60°.s^{-1}. For 180°.s^{-1}, values of 57.7 (±9.4) ° and 59.4 (±9.7) ° were noted for angle of peak torque of the dominant and non-dominant limbs. Total work of the knee flexors at isokinetic speeds of 60°.s^{-1} and 180°.s^{-1} are displayed in the table above. Considering 60°.s^{-1}, total work values of 277.8 (±79.2) J for the dominant limb and 271.3 (±67.9) J for the non-dominant limb, were recorded.

For the faster isokinetic velocity of 180°.s^{-1}, values of 197.3 (±59.6) J and 203.5 (±56.1) J indicate the total work capabilities of the relevant limbs. Average power of the knee flexors noted similar responses for both limbs at both speeds. 60°.s^{-1} responses, indicate average power values of 81.7 (±13.6) W and 80.2 (±13.1) W for the dominant and non-dominant limbs respectively. For the isokinetic speed of 180°.s^{-1}, 119.9 (±22.1) W and 125.1 (±20.3) W were recorded for average power of the preferred and non-preferred limbs.

Eccentric Hamstrings

Mean, standard deviation and coefficient of variation for all participants for the eccentric hamstrings are presented in Table VIII. This data includes all relevant isokinetic responses such as peak torque, time to peak torque, angle of peak torque, total work and average power.

Table IX: Eccentric Hamstrings responses of the Peri-Urban South African amateur player

	60°.s^{-1}		180°.s^{-1}	
	Dominant	**Non-Dominant**	**Dominant**	**Non-Dominant**
Peak Torque (Nm) CV (%)	166.3 (21.6) 13	158.7 (21.9) 14	**163.4 (21.9)** **13**	**151.1 (13.5)** **9**
Time to Peak Torque (ms) CV (%)	**1339.5 (214.6)** **16**	**965.3 (251.7)** **26**	564.7 (148.8) 26	528.4 (116.2) 22
Angle of Peak Torque (°) CV (%)	39.1 (7.9) 20	39.3 (10.3) 26	46.2 (9.9) 22	46.8 (7.9) 17
Total Work (J) CV (%)	**279.3 (77.4)** **28**	**245.6 (62.7)** **26**	**274.7 (72.9)** **27**	**244.5 (59.5)** **24**
Average Power (W) CV (%)	97.4 (15.4) 16	94.7 (15.2) 16	**191.9 (38.1)** **20**	**176.1 (32.6)** **18**

Isokinetic evaluation indicated multiple significant differences between the limbs at baseline. Responses at $60°.s^{-1}$, reported peak torque values of 166.3 (±21.6) Nm for the dominant limb, while 158.7 (±21.9) Nm was indicated for the non-dominant limb. At the more functional speed of $180°.s^{-1}$, eccentric peak torque of 163.4 (±21.9) Nm and 151.1 (±13.5) Nm were recorded for the dominant and non-dominant respectively. Such values were significantly different ($p<0.001$). As indicated in Table VIII, significant differences ($p<0.001$) in time to peak torque responses at $60°.s^{-1}$ were noted, with values of 1339.5 (±214.6) ms and 965.3 (±251.7) ms observed for the dominant and non-dominant limbs respectively. Values of 564.7 (±148.8) ms were recorded for the preferred limb, while the non-dominant recorded values of 528.4 (±116.2) ms, at $180°.s^{-1}$.

Angle of peak torque of the knee flexors when acting eccentrically was similar for both limbs, at both isokinetic speeds. For $60°.s^{-1}$, angle of peak torque values of 39.1 (±7.9) ° and 39.3 (±10.3) ° were observed for the dominant and non-dominant limbs. At $180°.s^{-1}$, indicated angles of 46.2 (±9.9) ° and 46.7 (±7.9) ° were observed for angle of peak torque. Total work responses for the eccentric hamstrings indicated a significant difference between the limbs, at both isokinetic speeds ($p=0.011$ and p = 0.<0.001). $60°.s^{-1}$ responses reported total work values of 279.3 (±77.4) J for the dominant and 245.6 (±62.7) J for the non-dominant limbs.

Responses for the more functional speed of $180°.s^{-1}$, reported total work achieved by the eccentric hamstrings as 274.7(±72.9) J and 244.5 (±59.5) J for the dominant and non-dominant limbs respectively. Average power capabilities are indicated in the table above. Findings at $60°.s^{-1}$, reported average power values of 97.4 (±15.4) W and 94.7 (±15.2) W for the dominant and non-dominant limbs respectively. For the power representative velocity of $180°.s^{-1}$, power capabilities were recorded as 191.9 (±38.1) W and 176.1 (±32.6) W for the dominant and non-dominant limbs respectively. Findings at the functional speed were significantly different ($p=0.02$).

Functional Ratio

Table X: Functional Ratio responses of the Peri-Urban South African amateur player

	60°.s^{-1}		180°.s^{-1}	
	Dominant	**Non-Dominant**	**Dominant**	**Non-Dominant**
Functional Ratio CV (%)	0.84 (0.09) 10	0.84 (0.14) 16	1.16 (0.17) 15	1.1 (0.16) 14

Responses for the strength related speed of 60°.s^{-1}, reported functional ratio values of 0.84 (±0.09) for the dominant limb and 0.84 (±0.14) for the non-dominant limbs. At the functional speed of 180°.s^{-1}, values of 1.16(±0.17) and 1.1 (±0.16) were recorded for the functional ratio between eccentric hamstrings and concentric quadriceps, of the dominant and non-dominant limbs respectively.

Performance Measures

Table XI: The performance profile of the South African amateur player

	Mean (SD)
Countermovement Jump (cm) CV (%)	55.9 (8.3) 14
Squat Jump (cm) CV (%)	54 (8.4) 15
Eccentric Utilization Ratio CV (%)	1.04 (0.08) 7.5
10m Sprint (s) CV (%)	1.98 (0.18) 9
Yo-Yo Shuttle Run (Stage) CV (%)	7.8 (1.4) 17

The performance profile of the South African amateur player is indicated in the table above. Vertical height capabilities were recorded for both the countermovement jump and the squat jump. Countermovement jump responses indicated heights of 55.9(±8.3) cm while mean squat jump responses were indicated as 54 (±8.4) cm. The relative eccentric utilization ratio indicated a value of 1.04 (±0.08) at baseline. Soccer specific performance measures of 10m sprint and Yo-Yo shuttle run capability were also recorded. Mean 10m sprint time was recorded as 1.98 (±0.18) s, while the average stage completed during the Yo-Yo shuttle run trail was indicated as 7.8 (±1.4).

EFFICACY OF THE NORDIC HAMSTRING EXERCISE WITHIN THE SOUTH AFRICAN CONTEXT

Results regarding the Nordic hamstring intervention will be displayed graphically, for both the control and intervention groups. Mean and standard deviation values will be used, with brackets indicating significant difference between conditions. Both isokinetic testing speeds will be displayed in the same figure.

Compliance

According to Goode et al. (2014), compliance is a vital issue with regards to the effectiveness of hamstring strengthening exercise interventions. For the purposes of the present study, compliance was defined as the completion of the exercise requirements, prescribed by the program. Participants with a compliance of 50% or less, were removed from the cohort. Compliance for the present study was 67.58 (±6.4) %. For more details see appendix B.

Isokinetic Assessment

<u>Concentric Quadriceps</u>

Torque Related Factors - *Peak Torque*

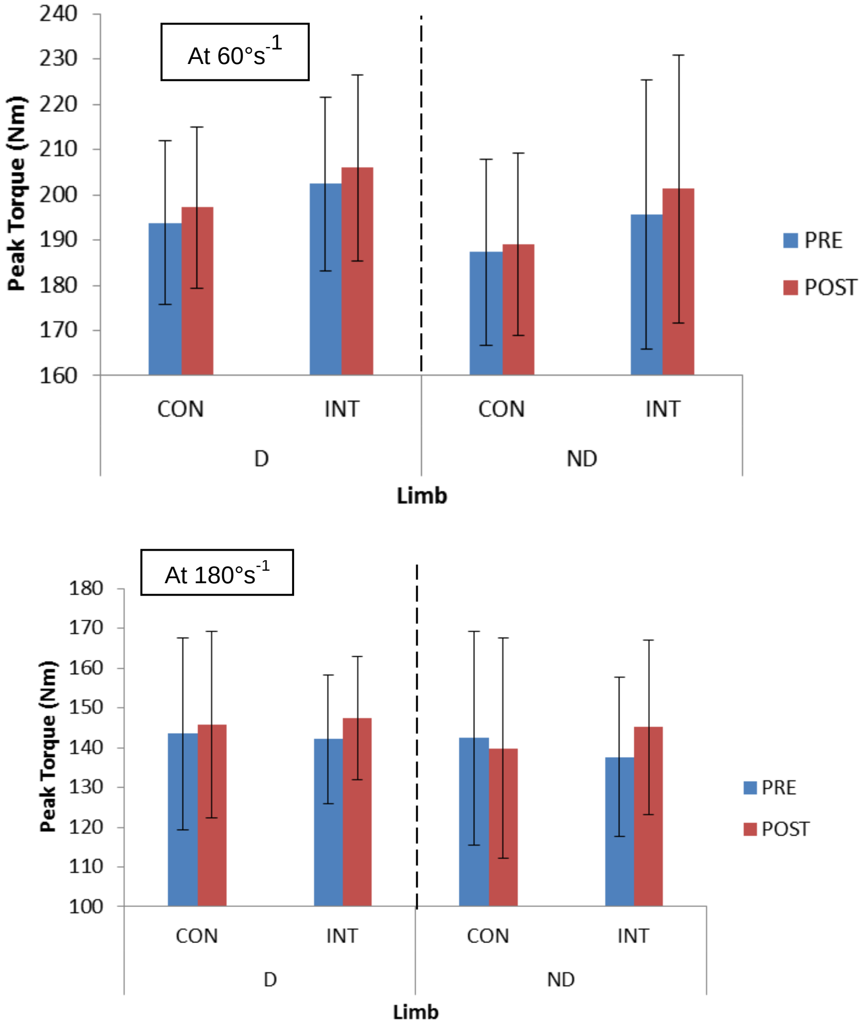


Figure 10: Peak Torque responses of concentric quadriceps in both dominant and non-dominant limbs at 60°.s^{-1} and 180°.s^{-1}

Over the course of the intervention, ANOVA evaluations indicated both a time ($p<0.001$) and limb effect ($p=0.04$) for peak torque of concentric quadriceps at the isokinetic speed of 60°.s^{-1}. Tukey post hoc reported limb differences within the control group at baseline. With regards to the time effect, both groups experienced an increase in peak torque over time. Mean increases in concentric peak torque of 3.4 and 5.6 Nm were observed in the dominant limb of the control and intervention groups respectively. Additionally, a 0.88 and 2.86% increase was noted in the non-dominant limbs of the respective groups. Further analysis indicated no interaction effect between time and group (p=0.395) for peak torque of concentric quadriceps at the isokinetic speed of $60°.s^{-1}$. Increases within the intervention group were therefore not significantly different to those of the control.

Table XII: Absolute and percentage changes over the intervention

		Absolute Change (Nm)		% Change	
		D	ND	D	ND
$60°.s^{-1}$	Control	3.4	1.6	1.76	0.88
	Intervention	3.6	5.6	1.77	2.86
$180°.s^{-1}$	Control	2.3	-2.6	1.63	-1.80
	Intervention	5.3	7.5	3.76	5.45

At the more functional speed of $180°.s^{-1}$, a time effect (p=0.41) was noted for concentric peak torque. Post hoc analysis revealed an overall increase in capability from 141.31 to 144.64 Nm. Additionally, a time-group interaction effect was noted (p=0.035), however, such changes were attributed to differences within the intervention group, between post dominant limb and pre non-dominant limb values. Changes were therefore not significantly different between groups.

Torque Related Factors - *Time to Peak Torque*

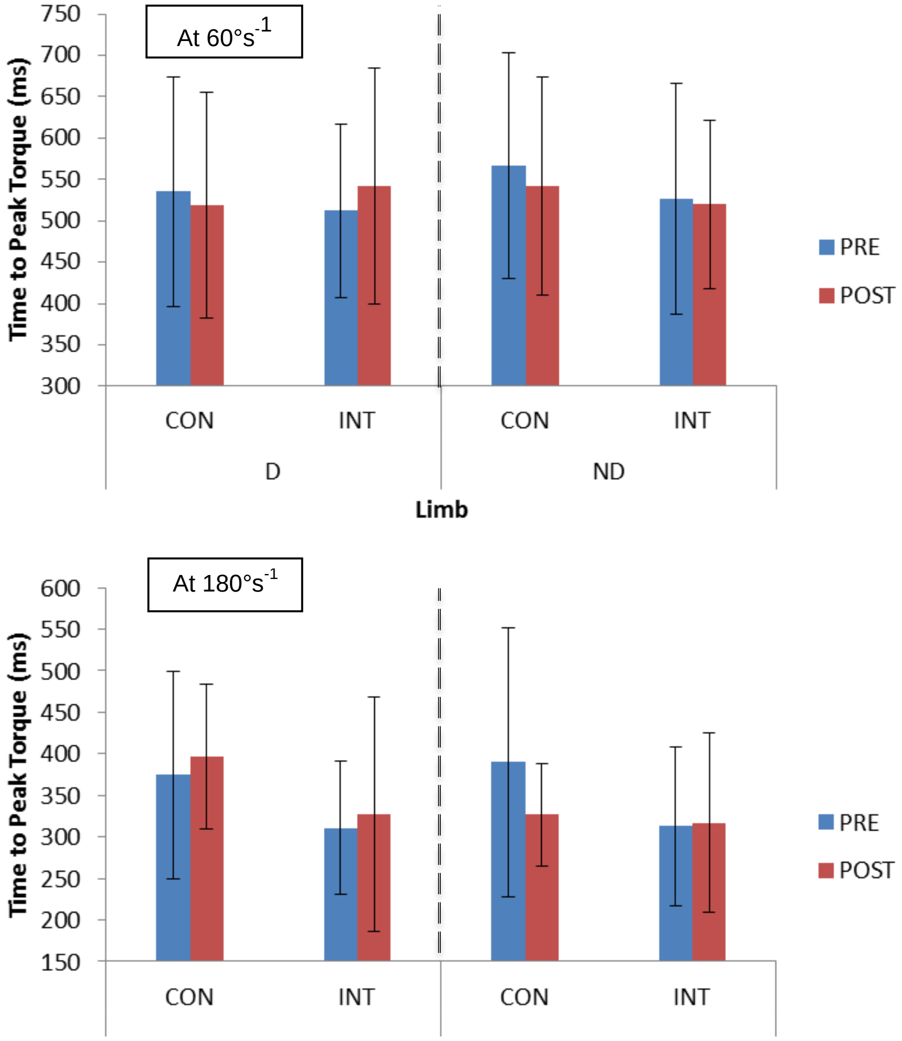


Figure 11: Time to Peak Torque responses of concentric quadriceps in both dominant and non-dominant limbs at 60°.s^{-1} and 180°.s^{-1}

ANOVA evaluations regarding time to peak torque responses of concentric quadriceps at 60°.s^{-1} showed no effect for time (p=0.846), limb (p=0.717) or group (p=0.68) indicating no significant changes between the control and intervention group over the course of the intervention. Minimal changes were noted for all variables of interest.

Table XIII: Absolute and percentage changes over the intervention

		Absolute Change (ms)		% Change	
		D	ND	D	ND
$60°s^{-1}$	Control	-16.6	-24.0	-3.11	-4.31
	Intervention	30.0	-7.0	5.86	-1.33
$180°s^{-1}$	Control	22.2	-63.3	5.93	-16.24
	Intervention	16.0	4.0	5.14	1.28

Overall ANOVA results indicated no time (p=0.8), group (p=0.175) or interaction effects (p=0.485) present for time to peak torque responses at $180°.s^{-1}$. This is despite the fact that there was a 16% decrease in time to peak torque for the control group in the non-dominant limb. This may be partially due to the high inter-subject variability evident within responses.

Torque Related Factors - *Angle of Peak Torque*

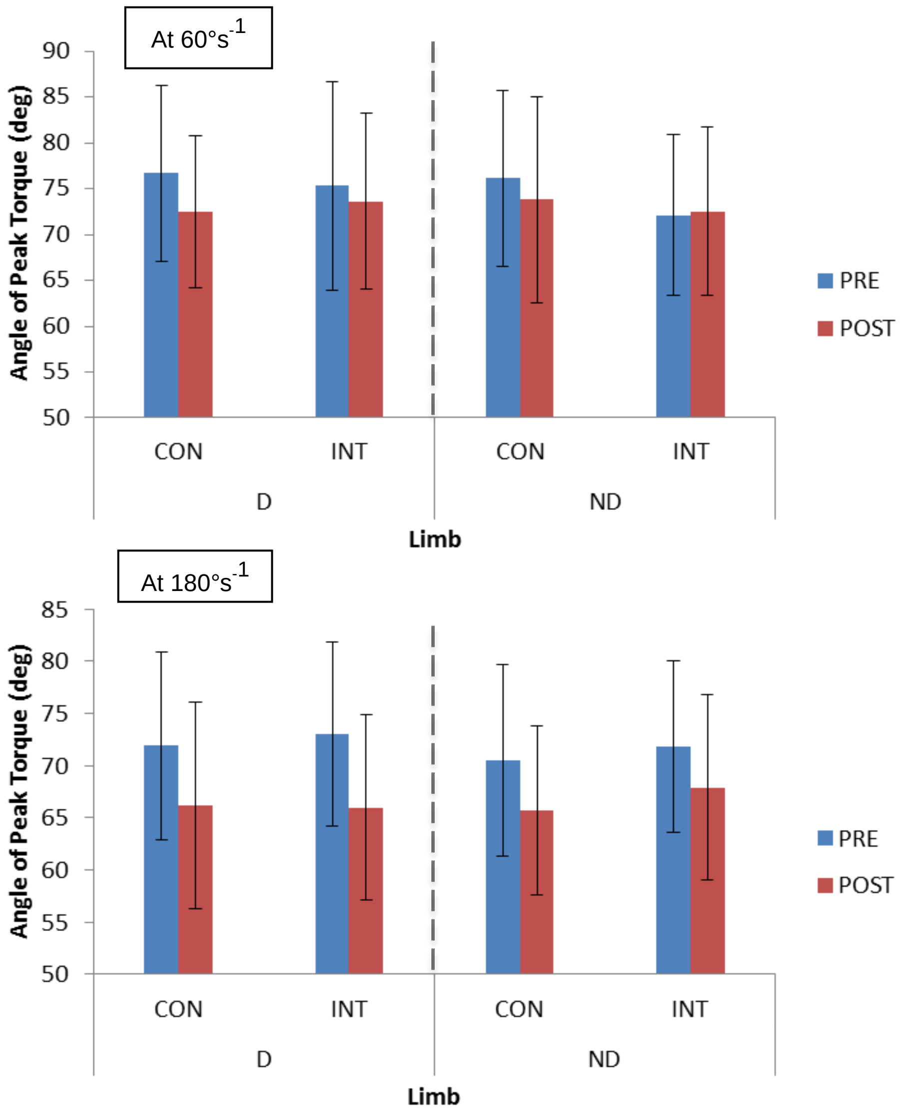


Figure 12: Angle of Peak Torque responses of concentric quadriceps in both dominant and non-dominant limbs at 60°.s^{-1} and 180°.s^{-1}

ANOVA evaluations regarding angle of peak torque indicated no time effect ($p=0.237$) for concentric quadriceps at 60°.s^{-1}. Furthermore, no group effect ($p=0.617$) or interaction between time and group ($p=0.423$) was noted. Pre and post responses observed within both groups were therefore not significantly different over the time course of assessment.

Table XIV: Absolute and percentage changes over the intervention

		Absolute Change (°)		% Change	
		D	ND	D	ND
$60°s^{-1}$	Control	-4.2	-2.3	-5.51	-3.07
	Intervention	-1.7	0.4	-2.26	0.55
$180°s^{-1}$	Control	-5.7	-4.9	-7.88	-6.93
	Intervention	-7.0	-3.9	-9.59	-5.43

For the isokinetic speed of $180°s^{-1}$, ANOVA analysis revealed a time effect (p=0.003) for angle of peak torque of the concentric quadriceps. Combined angle of peak torque responses decreased from 71.8 to 66.5°. Further analysis revealed no interaction between time and group with a p value of 0.957, indicating reductions in angle of peak torque were similar for both groups.

Total Work

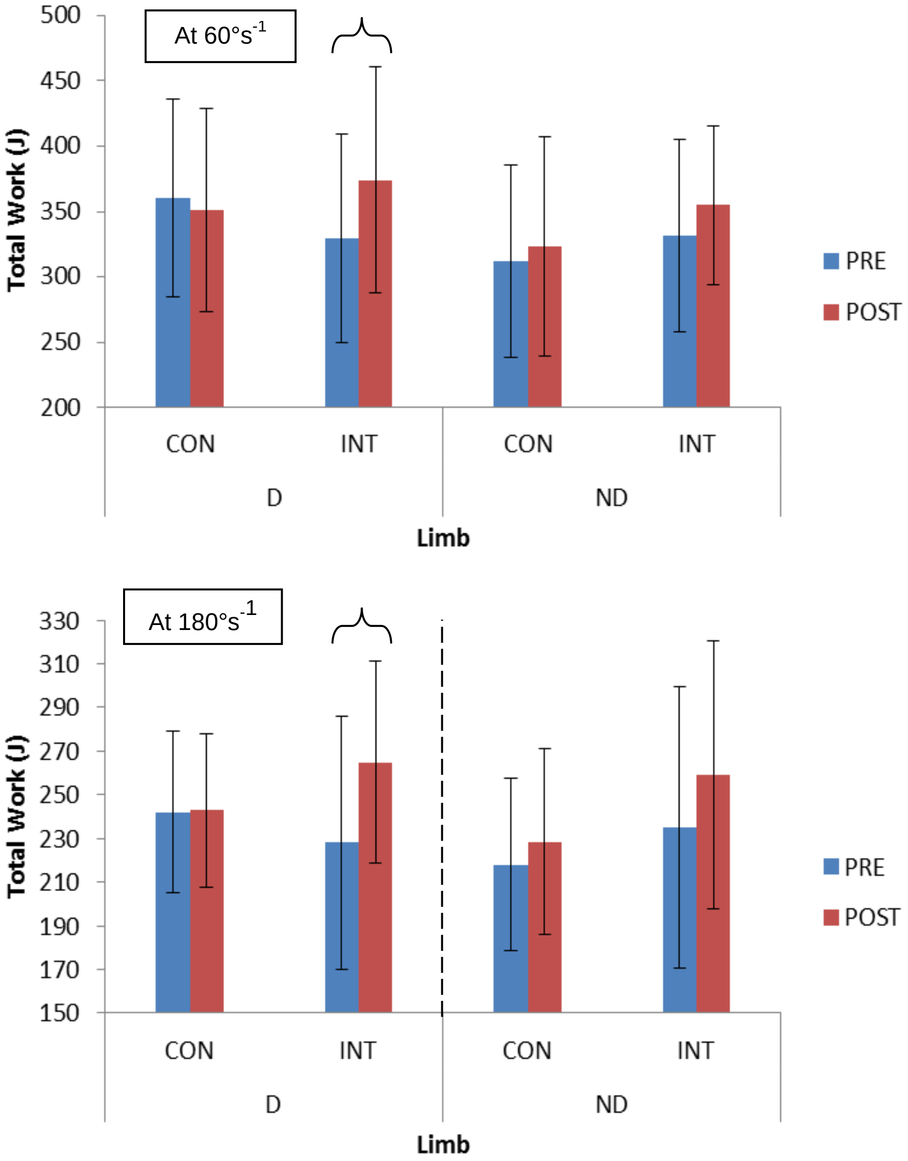


Figure 13: Total Work responses of concentric quadriceps in both dominant and non-dominant limbs at 60°.s^{-1} and 180°.s^{-1} (brackets indicate significant difference between conditions)

Analysis of variance regarding total work responses, indicated a time by group by limb interaction effect (p=0.013) for total work of concentric quadriceps at the isokinetic speed of 60°.s^{-1}. Post hoc analysis indicated increased total work within the intervention group for the dominant limb amounting to a significant 13.49% (44.5J) increase. Although the non-dominant limb noted a 7.11 % increase, it was not statistically significant. Similarly for the control group a reduction in work of 9.8 J for the dominant limb and an 11.2 J increase in the non-dominant limb were found to not be significant.

Table XV: Absolute and percentage changes over the intervention (red values indicate significant differences)

		Absolute Change (J)		% Change	
		D	ND	D	ND
$60°s^{-1}$	Control	-9.82	11.2	-2.72	3.60
	Intervention	44.5	23.6	13.49	7.11
$180°s^{-1}$	Control	0.7	10.4	0.28	4.78
	Intervention	36.7	23.9	16.09	10.18

At the more functional velocity of $180°.s^{-1}$, ANOVA analysis indicated a time effect ($p<0.001$) over the duration of the intervention, with both groups demonstrating an increase in total work. Further analysis revealed a time-group interaction effect ($p=0.014$), with post hoc analysis indicating a significant increase for the dominant limb of the intervention group. The preferred limb experienced a significant increase of 16.09%, while the non-dominant limb experienced a non-significant 10.18% increase over the intervention. Additionally, the control group reported insignificant changes, with an increase within the dominant limb of 0.28%, and 4.78 % for the non-dominant limb.

Average Power

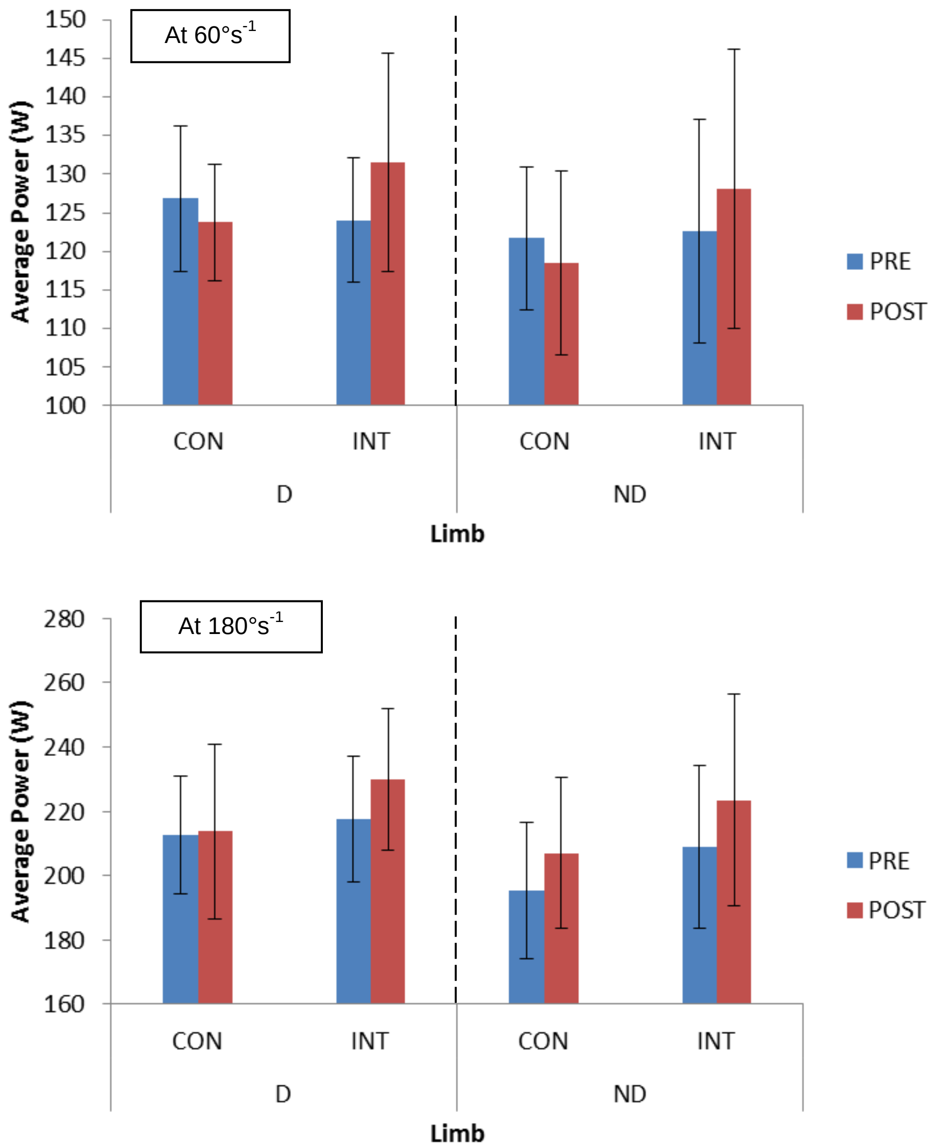


Figure 14: Average Power responses of concentric quadriceps in both dominant and non-dominant limbs at 60°.s^{-1} and 180°.s^{-1}

Following completion of the intervention period, no time (p=0.41) or group (p=0.406) effect was noted for average power of the concentric quadriceps at 60°.s^{-1}. Interestingly, a time by group interaction effect was reported (p=0.024), however, Tukey Post hoc analysis indicated no significant differences between the groups across the intervention (See appendix B). No significant changes were therefore observed for average power, with the intervention group experiencing a 7.5 and 5.5 W increase in the dominant and non-dominant limbs, while the control group noted reductions in average power of 2.46 and 2.67% over the time course of investigation.

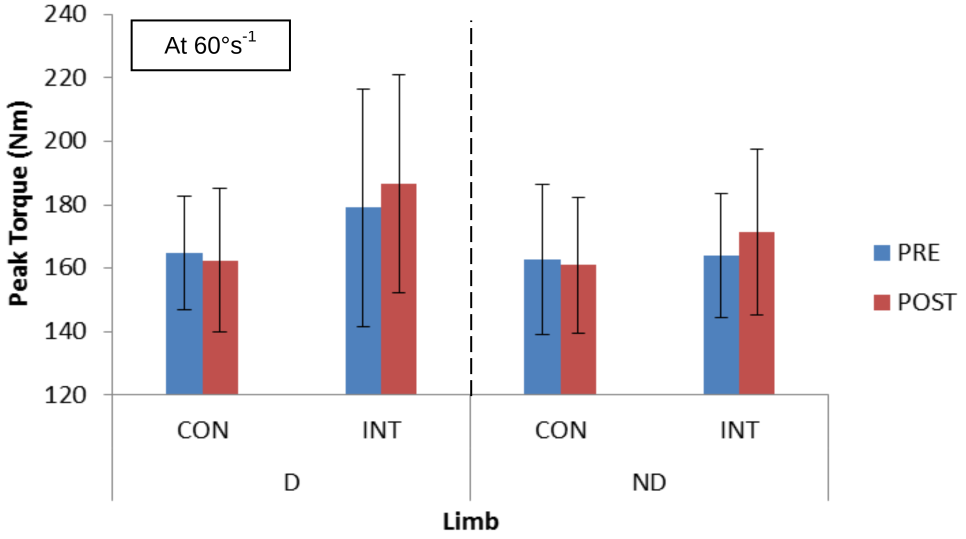
Table XVI: Absolute and percentage changes over the intervention

		Absolute Change (W)		% Change	
		D	ND	D	ND
$60°s^{-1}$	Control	-3.1	-3.3	-2.46	-2.67
	Intervention	7.5	5.5	6.05	4.48
$180°s^{-1}$	Control	1.0	11.6	0.49	5.94
	Intervention	12.4	14.6	5.69	6.97

At $180°.s^{-1}$, ANOVA analysis indicated a time effect ($p<0.001$), with a combined increase in average power from 208.9 to 218.9 W. Further analysis revealed no time by group interaction effect ($p=0.114$), with no significant differences between groups. Although the figure above may indicate substantial increases within the intervention group, such changes were not significant. Increases of 12.4 W and 14.6 W were noted in the dominant and non-dominant limbs while the control group experienced increases of 0.49 % and 5.94% for the relevant limbs, which were not significant.

Concentric Hamstrings

Torque Related Factors - *Peak Torque*



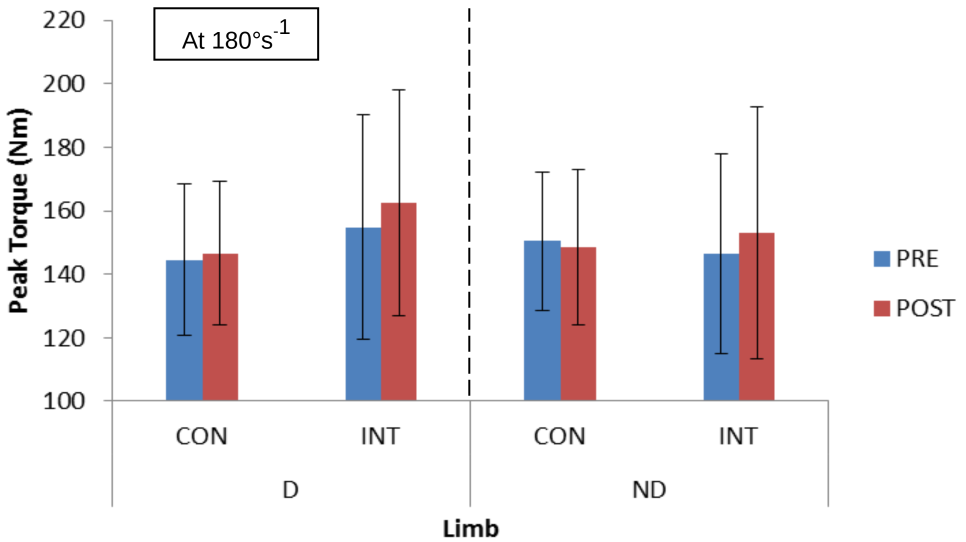


Figure 15: Peak Torque responses of concentric hamstrings in both dominant and non-dominant limbs at 60°.s^{-1} and 180°.s^{-1}

Over the course of the intervention, ANOVA evaluations indicated a time by group interaction effect (p=0.018) for peak torque of the concentric hamstrings at 60°.s^{-1}. Interestingly, statistical analysis revealed no time (p=0.171) or group (p=0.261) effects following completion of assessment. Tukey post hoc analysis was therefore employed, which revealed no significant differences across the limbs of the two groups (Appendix B). Such findings may partially be due to high inter subject variability noted within the intervention group. Changes observed were therefore not significant, with increases in of 7.5 and 7.4 Nm within the intervention group noted for the dominant and non-dominant limbs respectively. The control group experienced non-significant reductions in peak torque of 1.47% and 1.19% for the corresponding limbs.

Table XVII: Absolute and percentage changes over the intervention

		Absolute Change (Nm)		% Change	
		D	ND	D	ND
$60°s^{-1}$	Control	-2.4	-1.9	-1.47	-1.19
	Intervention	7.5	7.4	4.18	4.54
$180°s^{-1}$	Control	2.1	-1.8	1.42	-1.22
	Intervention	7.6	6.5	4.92	4.43

At the more functional speed of $180°.s^{-1}$, a time effect was noted (p=0.049), with combined increases in peak torque of 3.7 Nm. Further analysis, revealed no time by group effect (p=0.056) indicating no significant differences were observed within groups. Peak torque values of the intervention group increased by 4.92% and 4.43% for the dominant limb and non-dominant limbs, while the control group observed a 1.42% increase in the dominant limb and a 1.22% decrease within the non-dominant limb. Such changes were not significant.

Torque Related Factors - *Time to Peak Torque*

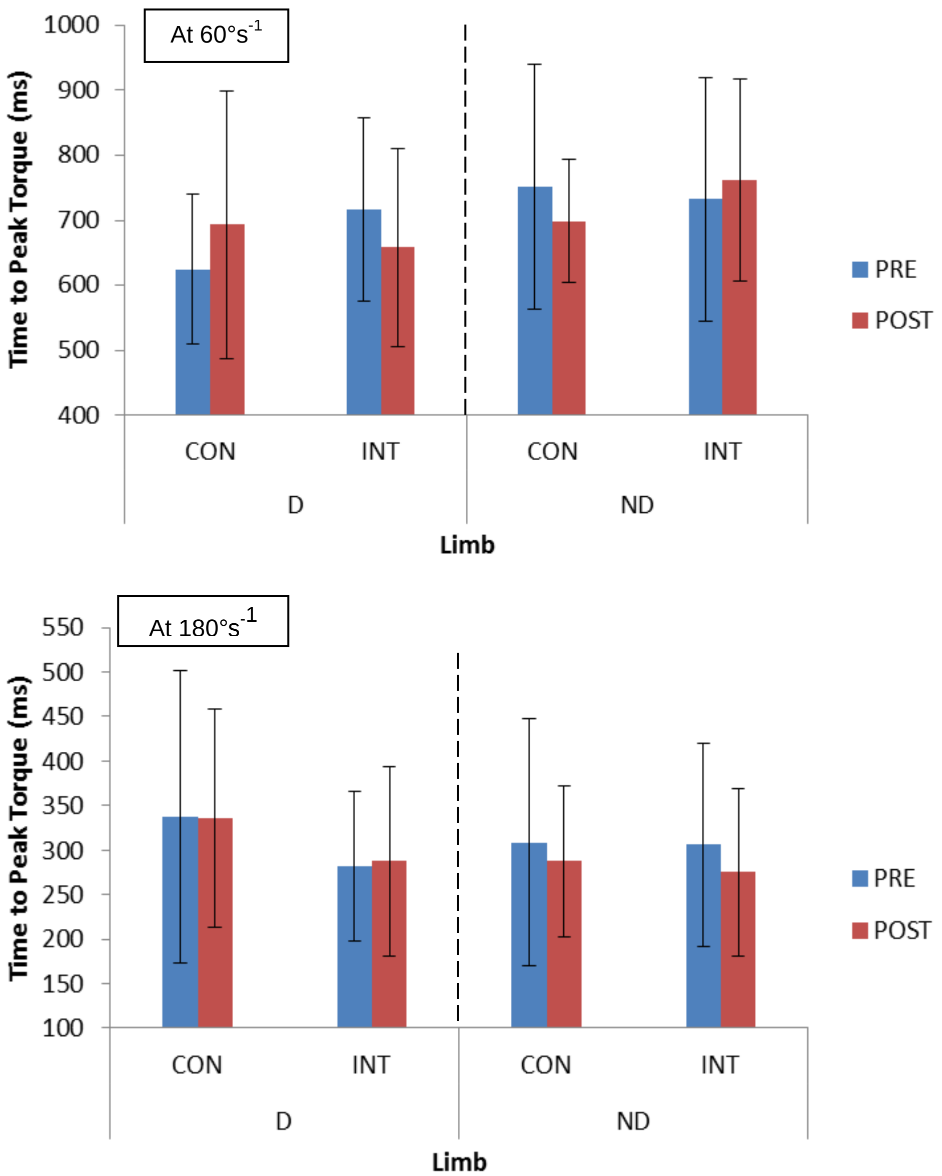


Figure 16: Time to Peak Torque responses of concentric hamstrings in both dominant and non-dominant limbs at $60°.s^{-1}$ and $180°.s^{-1}$

Statistical analysis revealed no time (p=0.924), group (p=0.569) or limb (p=0.171) effect for time to peak torque at $60°.s^{-1}$. Interestingly, a limb by time by group effect (p=0.027) was reported, however, post hoc analysis did not reveal any changes of interest (appendix B). Over the time course of the intervention, ANOVA evaluations indicated no time by group effect (p=0.726) for time to peak torque of the concentric hamstrings at the strength related speed of 60°.s^{-1}. Pre and post values were therefore not significantly different between the two groups. Non-significant increases in time to peak torque were observed in the dominant limb of the control (11.03 %) and the non-dominant of the intervention group (4.1%) while similar non-significant reductions in time to peak torque were noted in the non-dominant limb of the control (52.2 ms) and the dominant limb of the intervention group (59 ms). Such responses may have been influenced by the high variability for all responses at this speed.

Table XVIII: Absolute and percentage changes over the intervention

		Absolute Change (ms)		% Change	
		D	ND	D	ND
60°s^{-1}	Control	68.9	-52.2	11.03	-6.95
	Intervention	-59.0	30.0	-8.23	4.10
180°s^{-1}	Control	-2.2	-21.1	-0.66	-6.83
	Intervention	6.0	-31.0	2.13	-10.13

For the isokinetic speed of 180°.s^{-1}, no time by group effect was noted ($p=0.984$) following the ANOVA. Additionally, no time ($p=0.567$) or group ($p=0.467$) effects were reported, indicating that there were no significant differences between responses for both groups. Both the intervention and control groups experienced a non-significant reduction in time to peak torque for the non-dominant limb (6.83 and 10.13%). Furthermore, the dominant limb responses indicated a decrease of 0.66% within the control group and a 2.13% increase for the intervention group. Such responses were not significant.

Torque Related Factors - *Angle of Peak Torque*

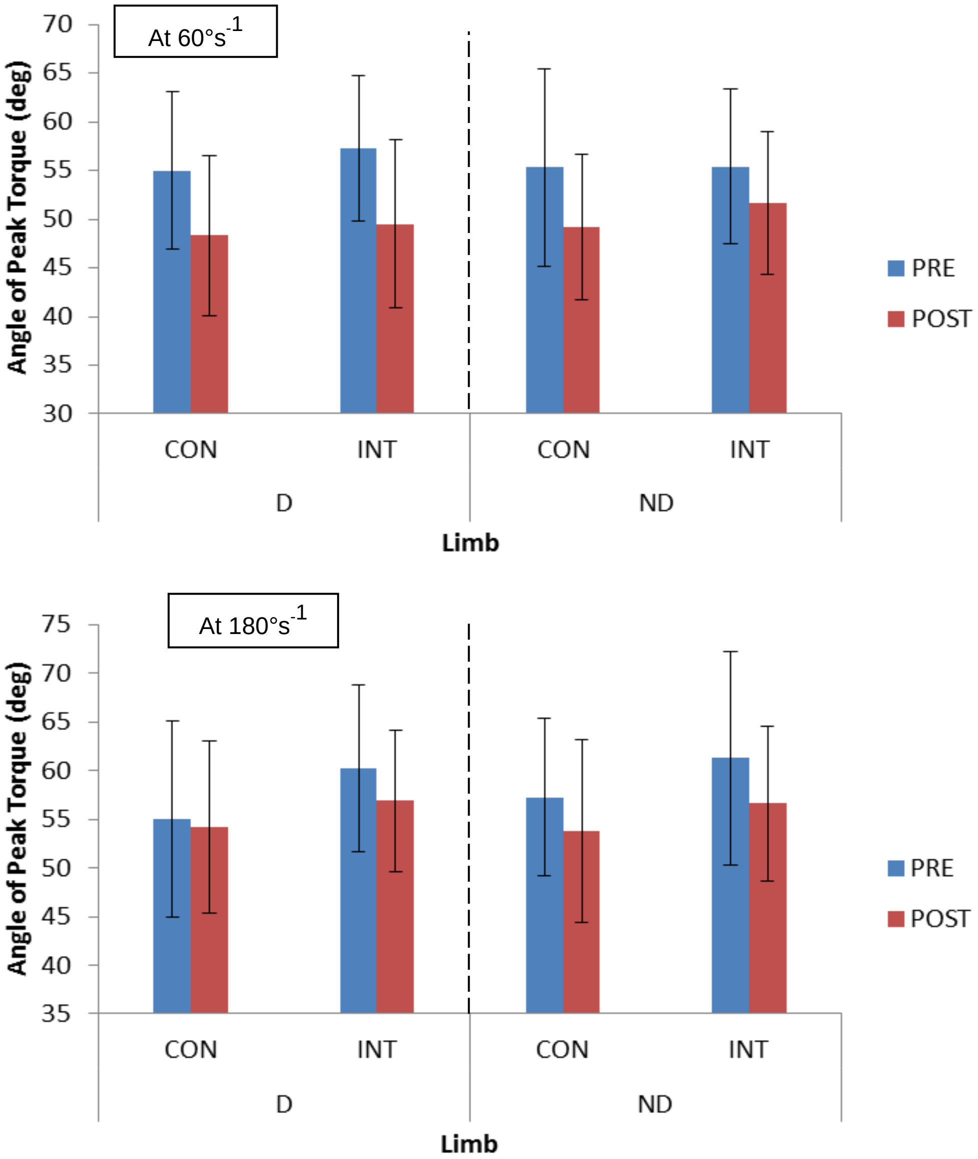


Figure 17: Angle of Peak Torque responses of concentric hamstrings in both dominant and non-dominant limbs at 60°.s^{-1} and 180°.s^{-1}

ANOVA evaluations regarding angle of peak torque noted a time effect (p=0.003) for concentric hamstrings at 60°.s^{-1}, indicating that angle of peak torque decreased from 55.78 to 49.73°. Further analysis revealed no time by group interaction effect (p=0.8568), indicating that such reductions were consistent across both groups.

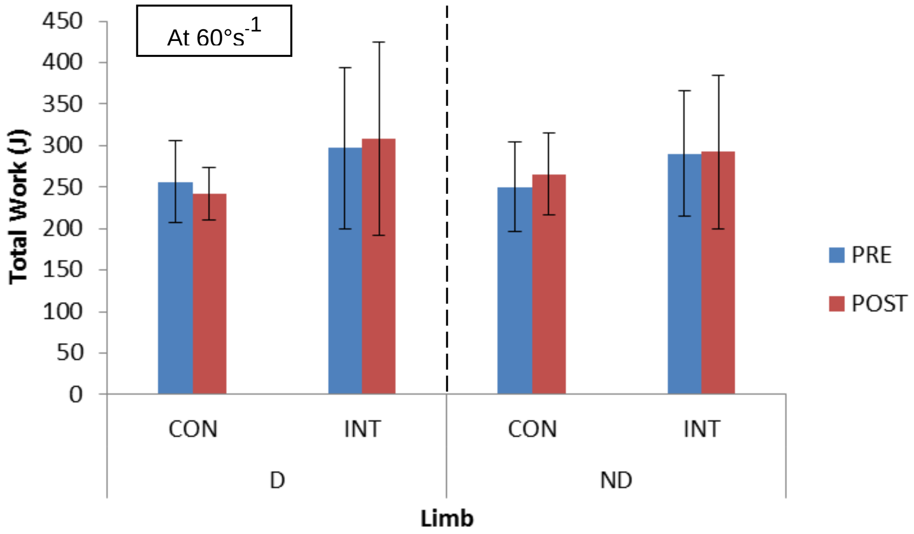
These reductions were 12.12 and 11.04 % for the control group and 13.61 and 6.68% for the intervention group.

Table XIX: Absolute and percentage changes over the intervention

		Absolute Change (°)		% Change	
		D	ND	D	ND
$60°s^{-1}$	Control	-6.7	-6.1	-12.12	-11.04
	Intervention	-7.8	-3.7	-13.61	-6.68
$180°s^{-1}$	Control	-0.8	-3.4	-1.41	-6.02
	Intervention	-3.3	-4.7	-5.48	-7.67

At the more functional speed of $180°.s^{-1}$, no time (p=0.088) or group (p=0.108) effects were noted within the ANOVA. Furthermore, no interaction between time and group was reported for angle of peak torque of the concentric hamstrings (p=0.584). Non-significant reductions were noted for both groups with a 1.41 and 6.02 % decrease within the control group for the dominant and non-dominant limbs respectively. Similarly, the intervention group experienced a 3.3 and 4.7 ° reduction for the respective limbs, which were not significant.

Total Work



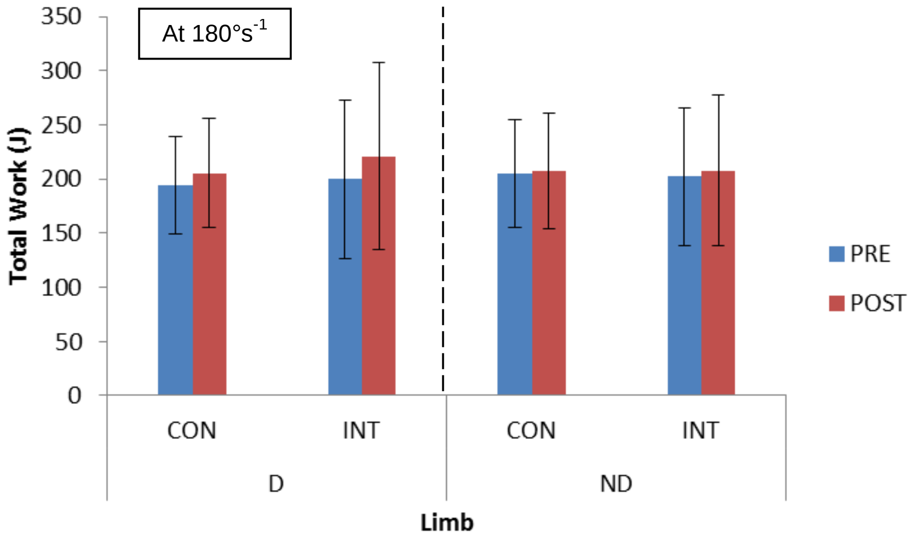


Figure 18: Total Work responses of concentric hamstrings in both dominant and non-dominant limbs at 60°.s^{-1} and 180°.s^{-1}

Analysis of variance indicated no interactional effect between time and group (p=0.635) for total work of the concentric hamstrings at the slower isokinetic speed of 60°.s^{-1}. With no effects noted for time or group, additional findings suggest that pre and post values for total work were not significantly different for the two groups, with no significant changes observed. Within the control group, a 14.6 J reduction in total work was recorded for the dominant limb; while a 6.2 J increase was observed for the non-dominant limb. The intervention group noted an overall increase in work of 3.83 % for the dominant limb and a 0.75% increase in the non-dominant limb.

Table XX: Absolute and percentage changes over the intervention

		Absolute Change (J)		% Change	
		D	ND	D	ND
$60°s^{-1}$	Control	-14.6	15.4	-5.70	6.17
	Intervention	11.4	2.2	3.83	0.75
$180°s^{-1}$	Control	11.1	2.3	5.72	1.13
	Intervention	21.5	5.7	10.74	2.83

At the power related speed of $180°.s^{-1}$, no time (p=0.075), group (p=0.86) or time by group interaction effect (p=0.53) was noted over the time course of investigation. Total work responses were therefore similar for both groups pre and post intervention, with minor increases noted for both limbs of both groups. The control group observed an increase of 5.72 % for the dominant limb, while the non-dominant limb experienced a 1.13% increase. Participants within the intervention group showed a 10.74 and 2.83 % increase in total work for the dominant and non-dominant limbs. All changes were not significantly different between the two groups.

Average Power

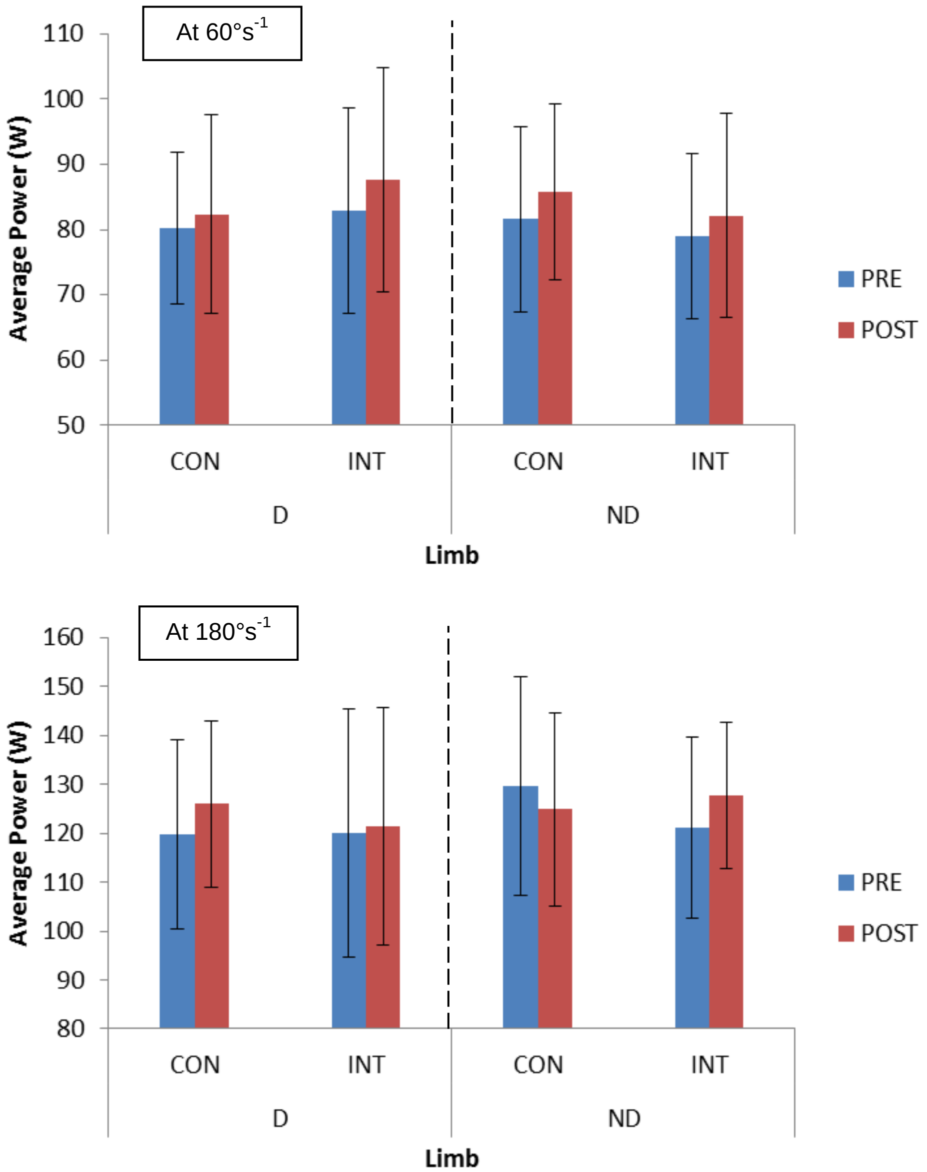


Figure 19: Average Power responses of concentric hamstrings in both dominant and non-dominant limbs at 60°.s^{-1} and 180°.s^{-1}

At the strength related speed of 60°.s^{-1}, the ANOVA indicated a time effect (p=0.002), with a combined increase in average power from 80.9 W to 84.5 W. Changes observed were not significantly different between groups, as analysis indicated no interaction between time and group (p=0.687). The intervention group experienced non-significant increases in average power of 5.71 and 3.98 % for the dominant and non-dominant limbs respectively, while the control group observed increases of 2.6 and 5.14 % which were not significant.

Table XXI: Absolute and percentage changes over the intervention

		Absolute Change (W)		% Change	
		D	ND	D	ND
$60°s^{-1}$	Control	2.1	4.2	2.60	5.14
	Intervention	4.7	3.1	5.71	3.98
$180°s^{-1}$	Control	6.3	-4.7	5.23	-3.59
	Intervention	1.2	6.5	1.02	5.36

ANOVA analysis indicated a time-limb-group effect (p=0.007) for the concentric hamstrings at $180°.s^{-1}$, with post hoc analysis indicating a significant difference between baseline values of the limbs of the control group. Further analysis at $180°.s^{-1}$, noted no time (p=0.315), group (p=0.771) or time by group interaction effect (p=0.507), indicating that pre and post values were not significantly different between the two groups for average power. Increases of 1.2 W and 6.5 W were noted in the dominant and non-dominant limbs of the intervention group, while a 4.7 W decrease was observed in the non-dominant limb and a 6.3 W increase of the dominant limb of the control group. Such changes were not significant.

Eccentric Hamstrings

Torque Related Factors - *Peak Torque*

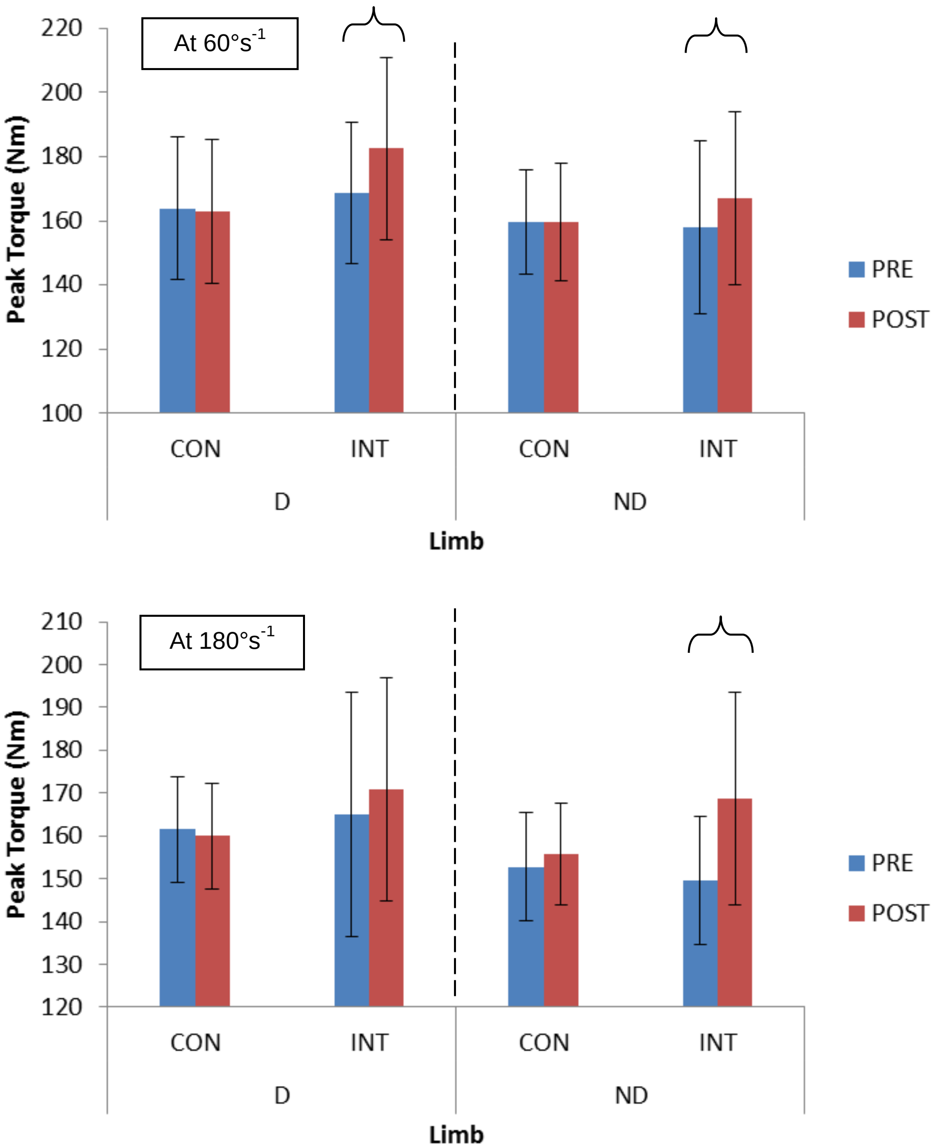


Figure 20: Peak Torque responses of eccentric hamstrings in both dominant and non-dominant limbs at 60°.s^{-1} and 180°.s^{-1} (brackets indicate significant difference between conditions)

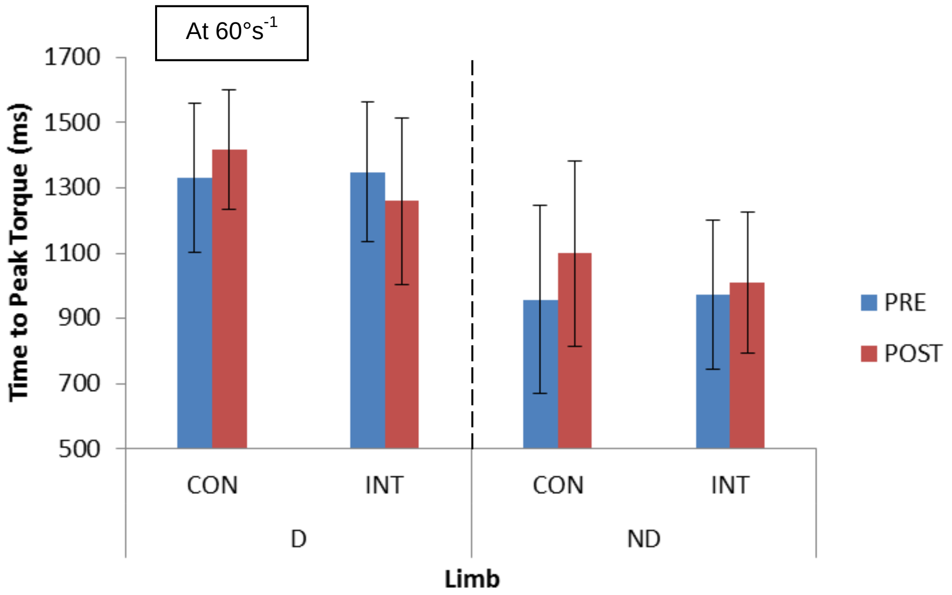
For the isokinetic speed of 60°.s^{-1}, statistical analysis revealed a significant time effect ($p<0.001$) over the duration of the intervention. Combined values for eccentric hamstring peak torque increased from 162.5 Nm to 168.4 Nm. Furthermore, ANOVA evaluations indicated a time by group interactional effect ($p<0.001$) for peak torque at the strength related speed of $60°.s^{-1}$. Post hoc analysis revealed significant increases within both limbs of intervention group when compared to the control. Increases were reported as 8.24 and 5.72 % for the dominant and non-dominant limbs respectively. The control group experienced negligible changes as indicated in the table below.

Table XXII: Absolute and percentage changes over the intervention (red values indicate significant differences)

		Absolute Change (Nm)		% Change	
		D	ND	D	ND
$60°s^{-1}$	Control	-0.9	0.1	-0.58	0.06
	Intervention	13.9	9.0	8.24	5.72
$180°s^{-1}$	Control	-1.5	3.1	-0.91	2.01
	Intervention	5.9	19.2	3.56	12.82

At the more functional speed of $180°.s^{-1}$, findings from the ANOVA indicated a time effect ($p=0.002$), with significant increases for the peak torque pooled data of both groups. Further analysis revealed a time by group interaction effect ($p=0.006$), with Tukey post hoc analysis revealing a significant increase within the non-dominant limb of the intervention (19.2 Nm). The dominant limb responses of the intervention group indicated a 5.9 Nm increase, while the control group indicated a 0.91% reduction in peak torque of the dominant limb and a 2.01% increase for the non-dominant limb. Such changes were however, not significant.

Torque Related Factors - *Time to Peak Torque*



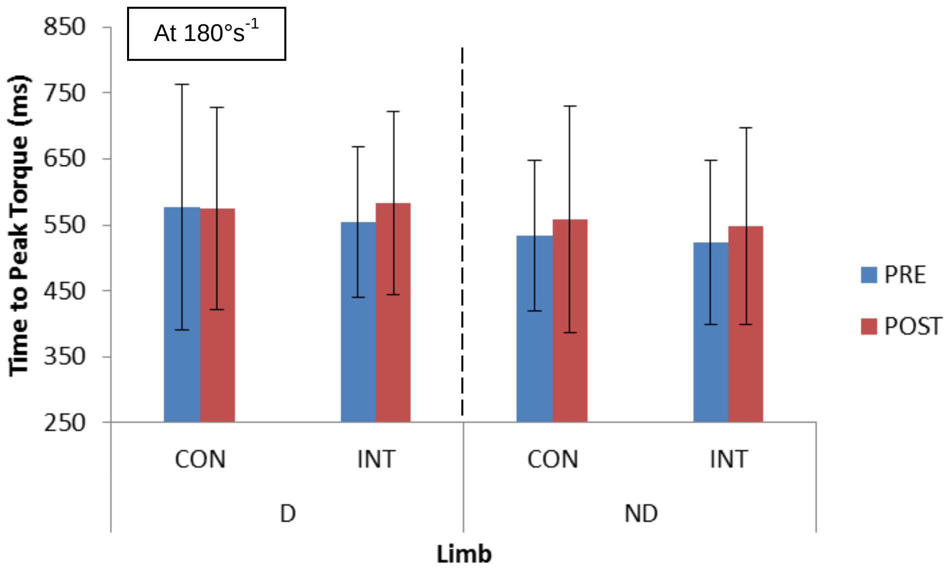


Figure 21: Time to Peak Torque responses of eccentric hamstrings in both dominant and non-dominant limbs at $60°.s^{-1}$ and $180°.s^{-1}$

ANOVA analysis reported a significant limb effect (p=0.03) indicating significantly longer time to peak torque values in the non-dominant limbs of both groups. Combined time to peak torque responses decreased from 1337.1 ms to 1008.7 ms. Further ANOVA evaluations indicated no time (p=0.423), group (p=0.495) or time by group interaction effect (p=0.218) for time to peak torque of the eccentric hamstrings at 60°.s^{-1}. Findings indicate that pre and post values were not significantly different for the two groups. Increases in time to peak torque were observed in both limbs of the control (6.6 and 14.73%), while responses in the intervention group indicated a 6.53 % reduction in the dominant limb and a 3.91% increase in the non-dominant limb. Such changes were not significant.

Table XXIII: Absolute and percentage changes over the intervention

		Absolute Change (ms)		% Change	
		D	ND	D	ND
60°s^{-1}	Control	87.8	141.1	6.60	14.73
	Intervention	-88.0	38.0	-6.53	3.91
180°s^{-1}	Control	-1.1	24.4	-0.19	4.57
	Intervention	29.0	25.0	5.23	4.78

At the functional speed of 180°.s^{-1}, no interactional effect between time and group was noted (p=0.821) following the ANOVA. Furthermore, no time or group effect was noted (p=0.569 and p=0.854), indicating that no significant changes were observed for both groups over the course of the intervention. Non-significant increases of 29 and 25 ms were observed within the intervention group of the respective limbs, while the control group reported non-significant changes of a 4.57 % increase in the non-dominant limb and a 0.19 % reduction within the dominant limb.

Torque Related Factors - *Angle of Peak Torque*

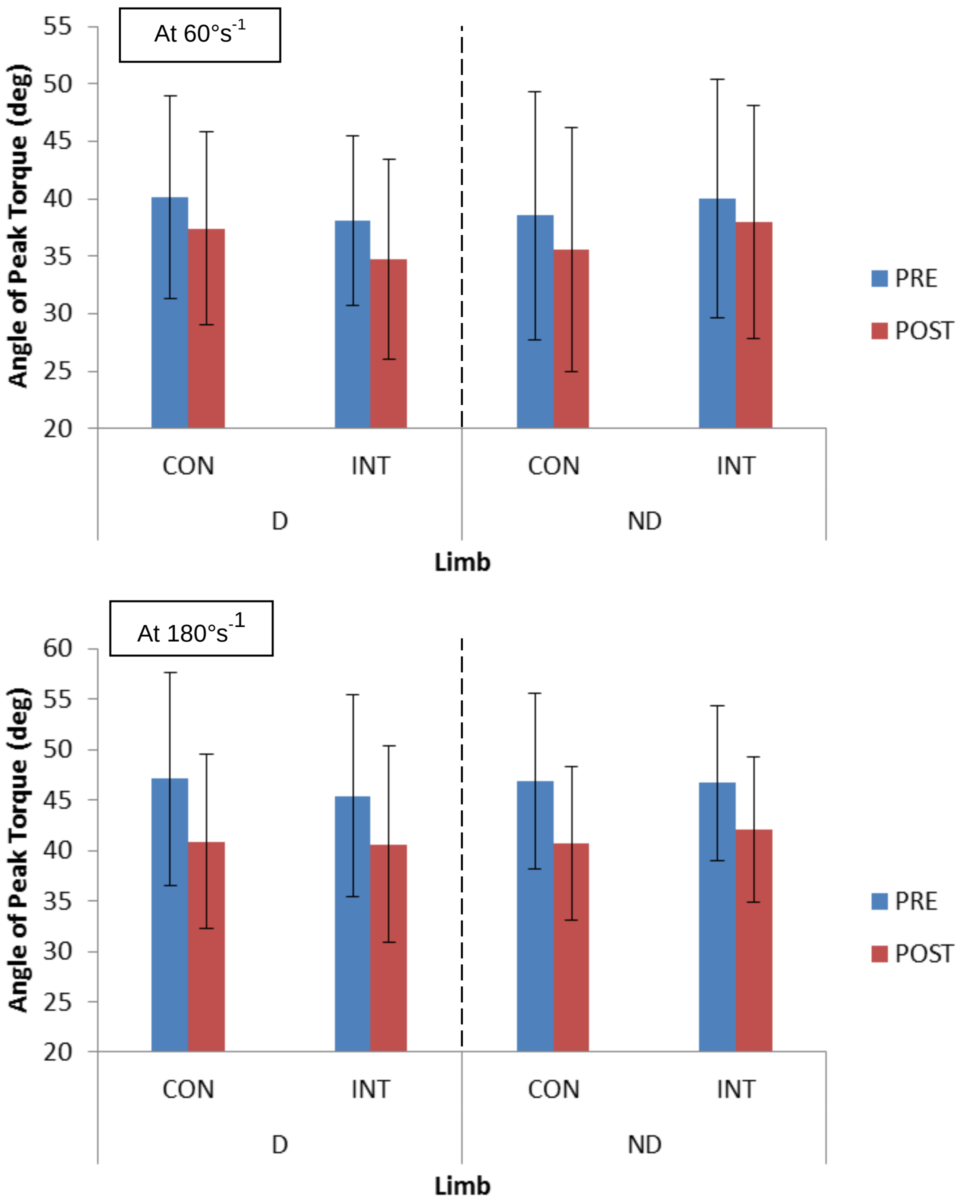


Figure 22: Angle of Peak Torque responses of eccentric hamstrings in both dominant and non-dominant limbs at 60°.s^{-1} and 180°.s^{-1}

ANOVA evaluations regarding angle of peak torque at 60°.s^{-1}, revealed no time ($p=0.169$) or time by group interaction effects ($p=0.962$) for eccentric hamstrings at the strength related speed. Reductions in angle of peak torque were observed in both limbs and both groups; however, such reductions were not significant. Decreases in angle of peak torque for the eccentric hamstrings were reported as 6.65 and 7.78 % for the dominant and non-dominant limbs of the control group, while 8.66 and 5% were indicated for the respective limbs of the intervention group. This may be partially influenced by large inter individual variability noted within responses.

Table XXIV: Absolute and percentage changes over the intervention

		Absolute Change (°)		% Change	
		D	ND	D	ND
$60°s^{-1}$	Control	-2.7	-3.0	-6.65	-7.78
	Intervention	-3.3	-2.0	-8.66	-5.00
$180°s^{-1}$	Control	-6.2	-6.2	-13.21	-13.27
	Intervention	-4.8	-4.6	-10.57	-9.85

At the more functional speed of $180°.s^{-1}$, ANOVA analysis indicated a time effect (p=0.012), with overall reductions in peak torque of 5.421°. Further analysis revealed, no interaction between time and group for angle of peak torque (p=0.7) with pre and post values for both groups not significantly different. Within the control group, a 6.22 ° reduction was noted for the dominant and non-dominant limbs respectively. The intervention group experienced a 4.8 and 4.6 ° reduction for angle of peak torque of each limb. Such changes were not significant.

Total Work

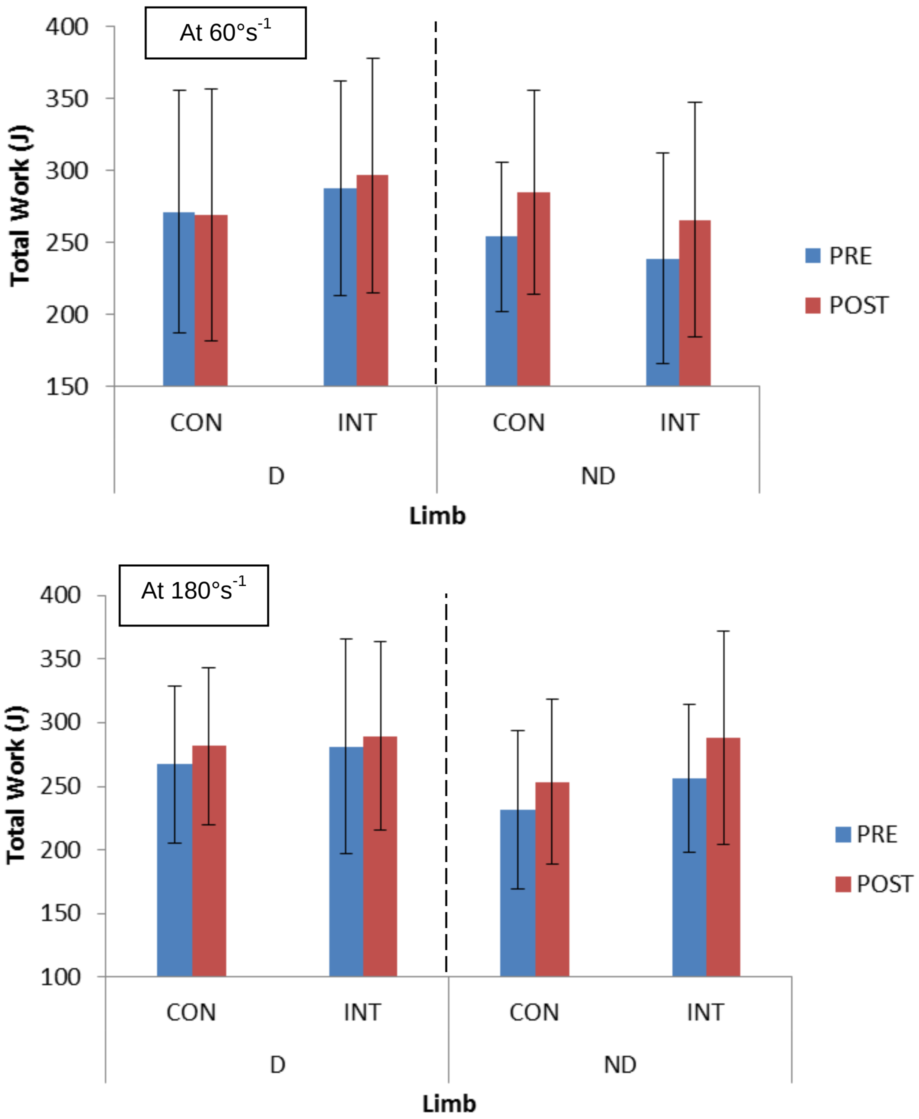


Figure 23: Total Work responses of eccentric hamstrings in both dominant and non-dominant limbs at 60°.s^{-1} and 180°.s^{-1}

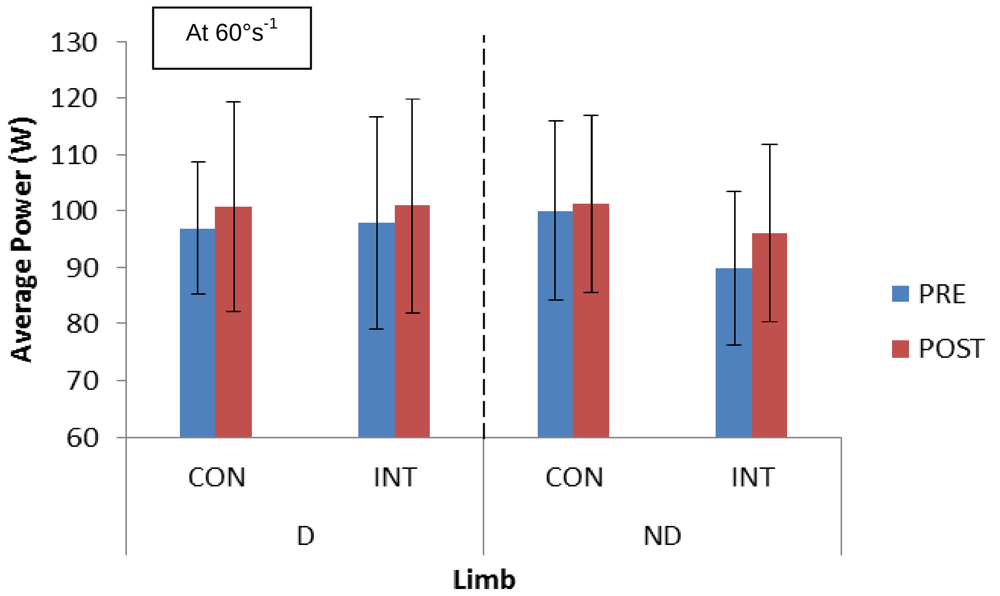
Analysis of variance regarding total work indicated a time effect (p=0.015) with a significant increase in total work for combined responses. Further analysis revealed no interaction between time and group (p=0.764) for total work of the eccentric hamstrings at the slower isokinetic speed of 60°.s^{-1}. Responses at baseline and following completion of the intervention were therefore not significantly different for the two groups. Within the control group, a 2.2 J reduction in total work was recorded for the dominant limb; while a 30.8 J increase was observed for the non-dominant limb. The intervention group noted an overall increase in work of 3.17 % for the dominant limb and an 11.27% increase in the non-dominant limb.

Table XXV: Absolute and percentage changes over the intervention

		Absolute Change (J)		% Change	
		D	ND	D	ND
$60°s^{-1}$	Control	-2.2	30.8	-0.81	12.15
	Intervention	9.1	26.9	3.17	11.27
$180°s^{-1}$	Control	14.4	21.8	5.38	9.39
	Intervention	8.1	31.9	2.88	12.47

At the more functional speed of $180°.s^{-1}$, ANOVA analysis indicated a time effect (p <0.001), indicating that combined data for both groups indicated an increase in total work from 259.6 J to 278.7 J. Interestingly, a limb effect (p=0.01) was noted, with responses for the non-dominant limb significantly lower. Further analysis indicated no time by group interactional effect (p=0.84) for total work of eccentric hamstrings. Increases in total work were not significantly different between groups. Findings from the present study noted an increase of 5.38 % for the dominant limb, while the non-dominant limb experienced a 9.39% increase within the control group. Participants within the intervention group indicated an 8.1 and 31.9 J increase in total work for the dominant and non-dominant limbs respectively. Such changes were not significant.

Average Power



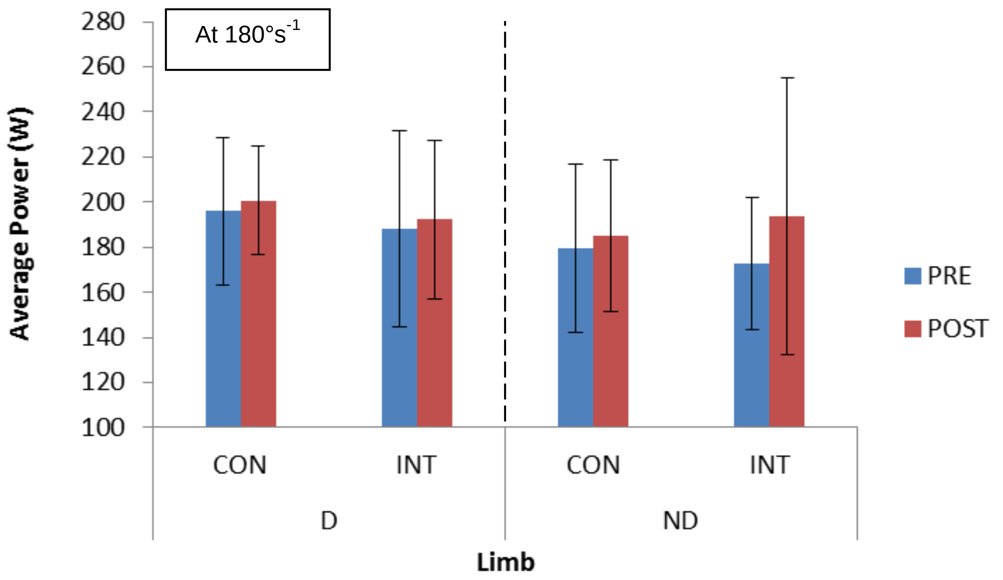


Figure 24: Average Power responses of eccentric hamstrings in both dominant and non-dominant limbs at 60°.s^{-1} and 180°.s^{-1}

At the strength related speed of 60°.s^{-1}, ANOVA analysis indicated a time effect (p=0.002), with increases in average power for combined responses of 3.6 W. Additionally, no time by group interactional effect (p=0.687) was reported over the time course of evaluation. Changes over the intervention were therefore similar for both groups. Non-significant changes were noted in both groups, with the intervention group experiencing a 3.14 and 6.79 % increase in average power capabilities for the dominant and non-dominant limbs respectively, while the control noted a 3.14 and 6.79 % increases for the relative limbs.

Table XXVI: Absolute and percentage changes over the intervention

		Absolute Change (W)		% Change	
		D	ND	D	ND
$60°s^{-1}$	Control	3.8	1.3	3.97	1.27
	Intervention	3.1	6.1	3.14	6.79
$180°s^{-1}$	Control	4.7	5.2	2.38	2.88
	Intervention	3.9	20.8	2.11	12.01

At $180°.s^{-1}$, statistical analysis revealed a limb by time by group effect (p=0.006), indicating differences in baselines values for the limbs of the control group. Further analysis indicated no interaction between time and group (p=0.507), with pre and post values not significantly different between the two groups. Non-significant increases were noted in both groups, with the intervention group noting increases of 3.9 W and 20.8 W for the dominant and non-dominant limbs while a 5.2 W increase was observed in the non-dominant limb and 4.7 in the dominant limb of the control group.

Functional Ratio

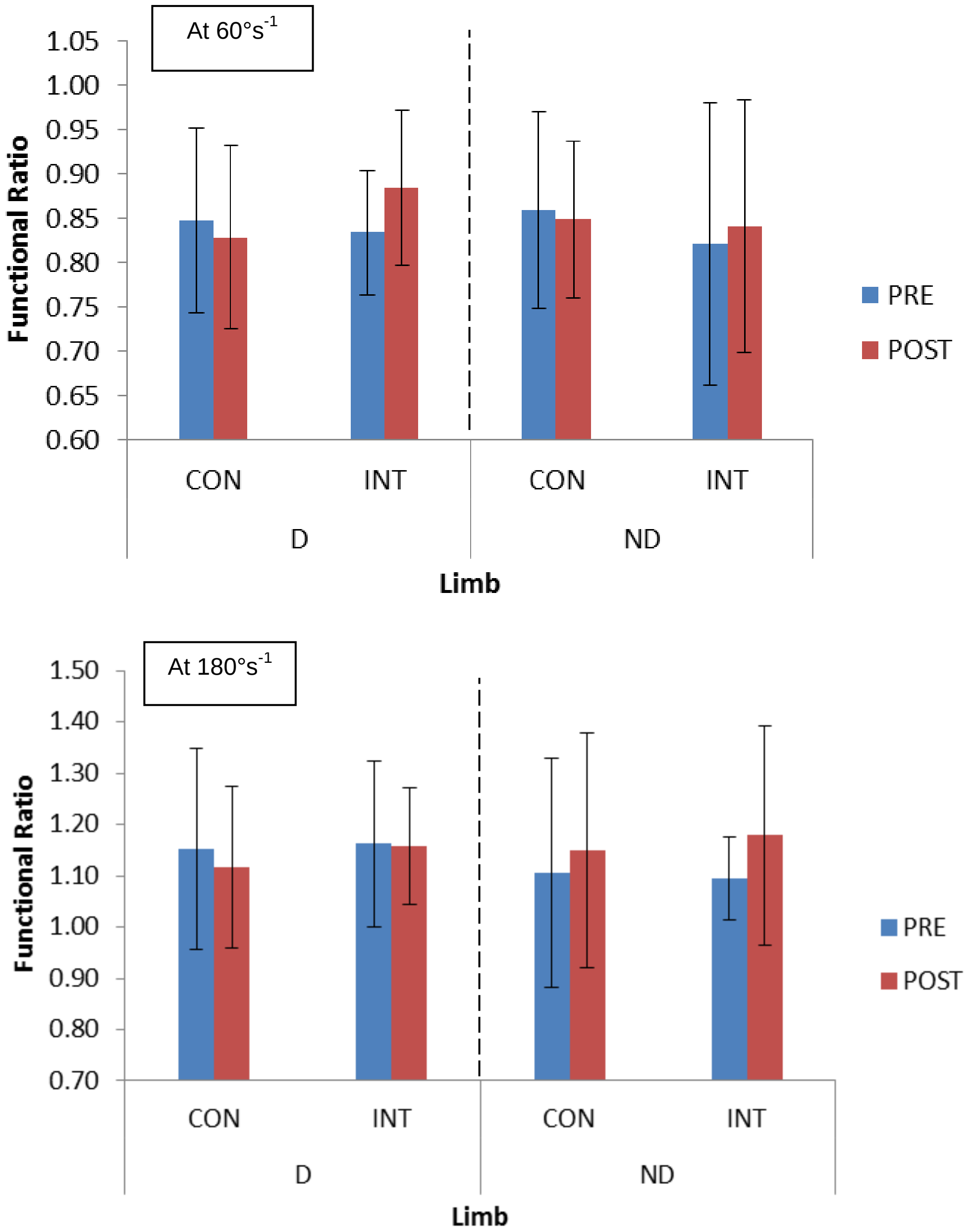


Figure 25: Functional Ratio responses of both dominant and non-dominant limbs at $60°.s^{-1}$ and $180°.s^{-1}$

Following completion of the intervention period, no time (p=0.276) or group (p=0.985) effect were indicated for the functional ratio at $60°.s^{-1}$. Further ANOVA analysis revealed a time by group interaction effect (p=0.0121). However, Tukey post hoc analysis revealed no significant changes for the respective limbs. Following the intervention period, the intervention group experienced a 6.18 and 2.48 % increase in relative strength capabilities of the upper thigh for the dominant and non-dominant limbs respectively. Within the control group, functional ratio responses decreased by 2.38 and 1.23 % for the dominant and non-dominant limbs. Such changes were however, not significant.

Table XXVII: Absolute and percentage changes over the intervention

		Absolute Change		% Change	
		D	ND	D	ND
$60°s^{-1}$	Control	-0.02	-0.01	-2.38	-1.23
	Intervention	0.05	0.02	6.18	2.48
$180°s^{-1}$	Control	-0.04	0.04	-3.05	3.87
	Intervention	0.00	0.08	0	7.66

At the functional speed of $180°.s^{-1}$, ANOVA analysis revealed no interaction between time and group (p=0.298) over the course of the intervention for the functional ratio. Further analysis revealed no time (p=0.208) or group effect (p=0.805). Changes observed were therefore similar for both groups. Within the intervention group, there was no increase for the dominant limb while a non-significant 7.66% increase was recorded for the non-dominant limb. Non-significant changes were observed within the control group, with a reduction of 3.05 % and 3.87 % noted for the respective limbs.

Performance Indicators

10m Sprint

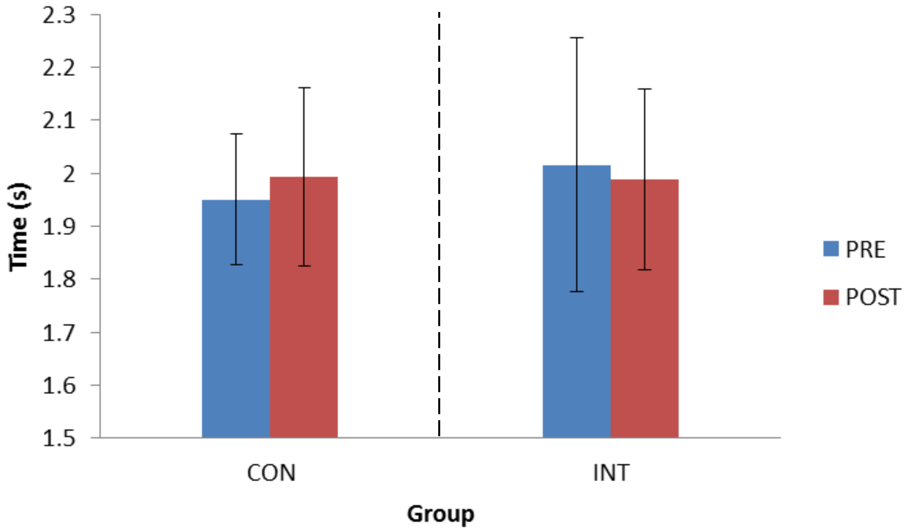


Figure 26: 10m Sprint times of the control and intervention groups

Analysis of variance following completion of the investigation indicated no time (p=0.441), group (p=0.834) or time by group interaction effects (p=0.482) for 10m sprint, indicating pre and post values were not significantly different between groups. Minimal changes were observed for both groups with a 2.22 % increase in 10m sprint time observed for the control, while the intervention group indicated a reduction in sprint time of 1.37%.

Table XXVIII: Absolute and percentage changes over the intervention

	Absolute Change (s)	% Change
Control	0.04	2.22
Intervention	-0.03	-1.37

Yo-Yo Shuttle Run

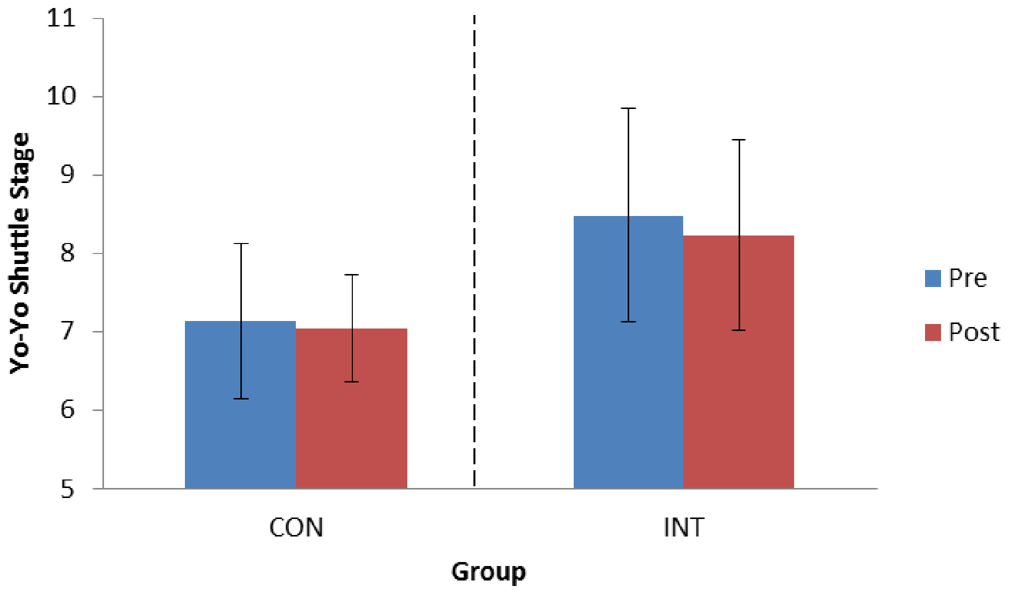


Figure 27: Yo-Yo Shuttle Test for both the control and intervention groups

Following the completion of the intervention, the ANOVA indicated no interaction between time and group (p=0.407)8 for the Yo-Yo shuttle run. Additional findings indicate that pre and post values were similar for both groups. The control group indicated a reduction in shuttle stage reached of 1.24% while the intervention group indicated a 2.91% reduction over the 10 week intervention period. The changes observed were not significant.

Table XXIX: Absolute and percentage changes over the intervention

	Absolute Change	% Change
Control	-0.1	-1.24
Intervention	-0.3	-2.91

Vertical Jump

Countermovement Jump

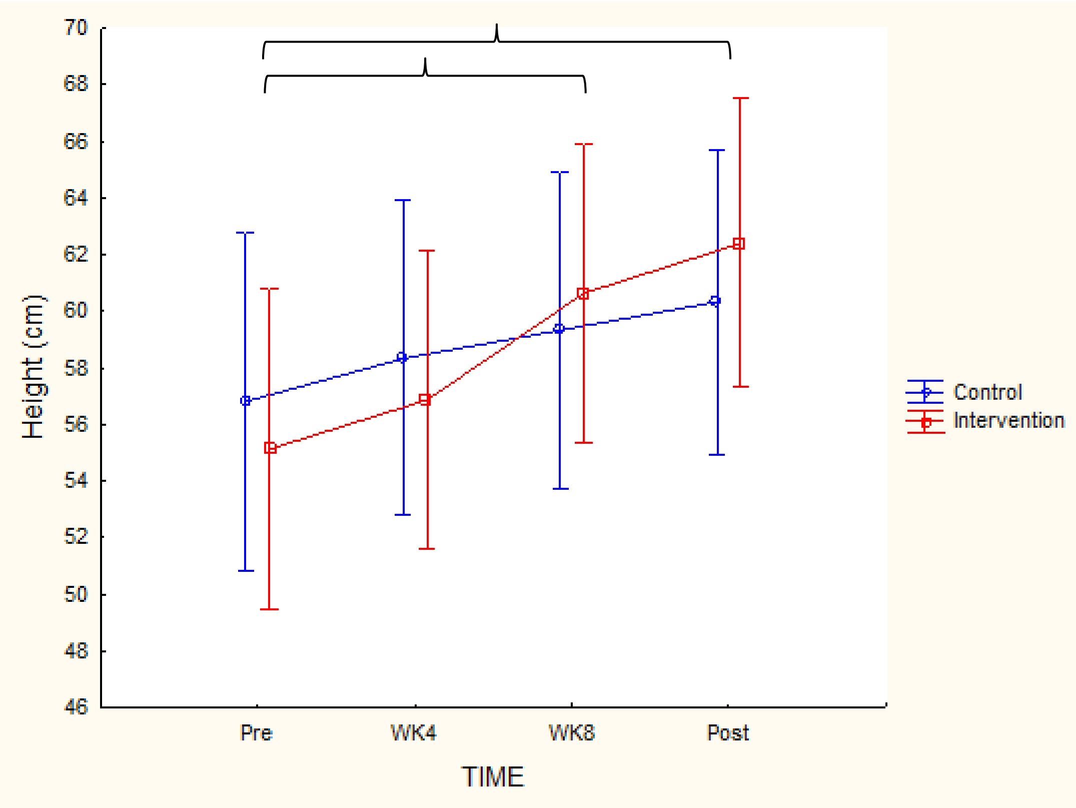


Figure 28: Countermovement jump heights of the control and intervention groups over the intervention period (brackets indicate significant difference between conditions)

ANOVA analysis indicated a time effect ($p<0.001$) over the duration of the intervention, with increases observed for both groups at week 4 and post assessment. Further analysis indicated a time by group interactional effect ($p=0.029$) for the countermovement jump. Post hoc analysis revealed significant improvements in the intervention group at week 8 (12.23%) and post intervention (15.59%). Furthermore, the control noted an overall significant improvement of 6.2 % over the time course of investigation. Significantly greater improvements were noted for the intervention group.

Table XXX: Absolute and percentage changes over the intervention (red values indicate significant differences)

	Absolute Change (cm)			% Change		
	WK4	WK8	POST	WK4	WK8	POST
Control	1.5	2.5	3.5	2.7	4.4	6.2
Intervention	3.4	6.6	8.4	6.2	12.2	15.6

Squat Jump

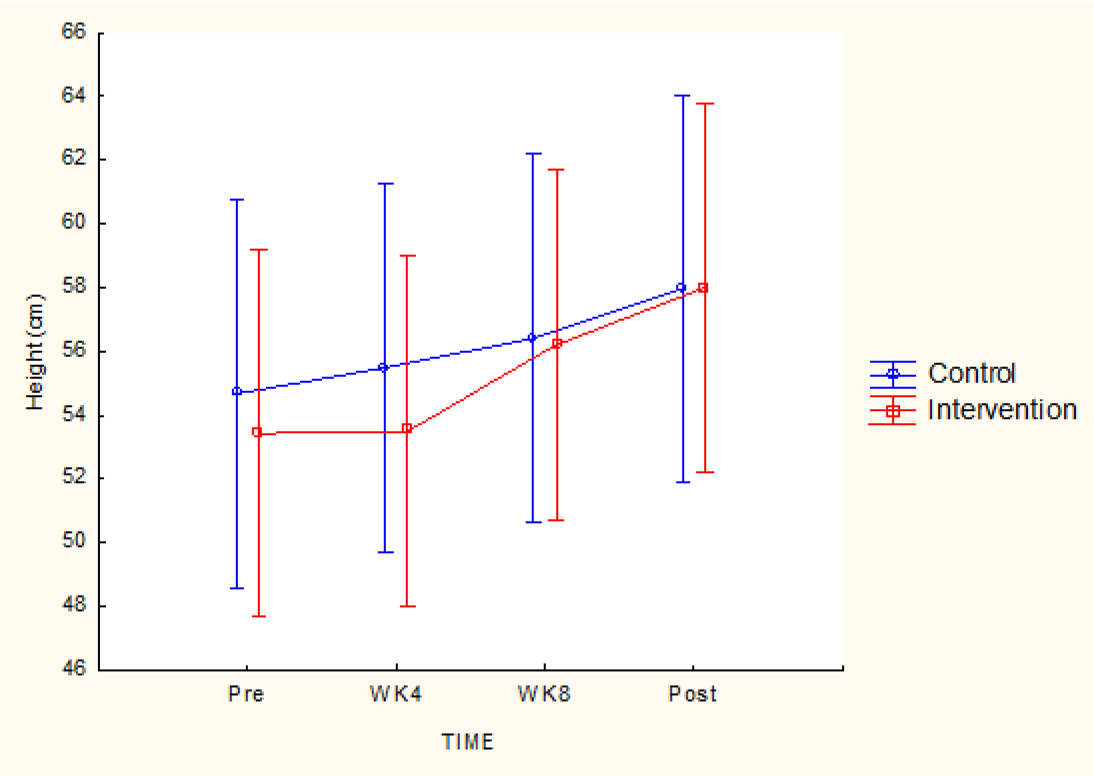


Figure 29: Squat jump heights of the control and intervention groups over the intervention period

Statistical analysis regarding the squat jump indicated a time effect (p=0.00001), with increases in squat jump height for combined responses. ANOVA analysis following completion of the intervention, indicated that there was no interaction between time group (p=0.284) for the squat jump. Tukey post hoc analysis, however, revealed significant increases in jump height for the intervention group at week 8 (6.83%) and post assessment (9.84%), while the control group recorded an overall significant increase of 6.02%. Increases observed within the intervention group were not significantly different to those within the control.

Table XXXI: Absolute and percentage changes over the intervention

	Absolute Change			% Change		
	WK4	WK8	POST	WK4	WK8	POST
Control	0.8	1.7	3.3	1.5	3.2	6.0
Intervention	1.9	3.6	5.2	3.7	6.8	9.8

Eccentric Utilization Ratio

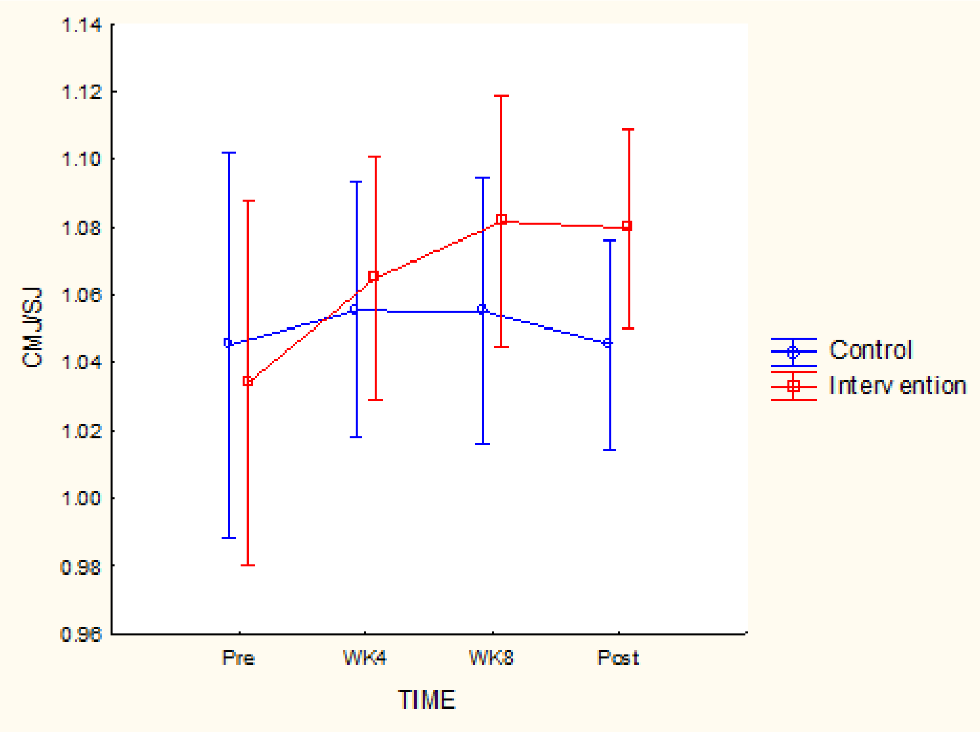


Figure 30: Eccentric utilization ratio of the control and intervention groups over the intervention period

The eccentric utilization ratio indicates the relationship between countermovement jump and the squat jump. Statistical analysis indicated no time effect (p=0.378), along with no interaction between time and group with a p-value of 0.379. Findings indicate that changes were not significantly different across the two groups. The intervention group experienced a progressive increase in the EUR with a 2.49% increase at week 4, a 6 % increase at week 8 and a 5.8 % increase overall. The control group experienced minimal changes in EUR with an overall increase in eccentric utilization of 0.65 % following completing of the intervention protocol.

Table XXXII: Absolute and percentage changes over the intervention

	Absolute Change			% Change		
	WK4	WK8	POST	WK4	WK8	POST
Control	0.01	0.01	0.01	0.98	0.96	0.65
Intervention	0.03	0.06	0.06	2.49	6	5.8

Table XXXIII: Summary of Responses from Administered Socio-Economic Questionnaire

Race	African	100%
Mass	Mean (SD)	66.35 (±9.06) kg
Stature	Mean (SD)	171.34 (±6.37) cm
Home Language	IsiXhosa	100%
Medical Aid	Yes	15.78%
	No	84.22%
Occupation	**Casual Worker/Manual Labourer**	89.47%
	Manual Materials Handling, Maintenance, Cleaning	
	Correctional Officer	5.26%
	Guard Duty and Supervision	
	Soccer Coach	5.26%
	Coaching, tactics, preparation	
Monthly Income	Mean	R1647.36
	Range	R500 - R10000
Household Numbers	Mean	4.89
	Range	2 - 0
Household Earning	Mean	R5252.63
	Range	R3000-R25000
Level of Education	Grade 10	10.50%
	Grade 11	21.05%
	Grade 12	52.63%
	Matric + Short Course	15.78%
Reasons for Discontinuation of Education	Financial Problems	63.15%
	Failed	31.57%
	Problems at Home	5.26%
Previous Injury	Ankle Injury	36.84%
	Hamstring Injury	5.27%
	Knee Injury	26.31%
	N/A	31.57%

CHAPTER V

DISCUSSION

INTRODUCTION

A number of different soccer specific studies have identified the strength and performance profile of soccer players; however, minimal studies have evaluated such characteristics within the unique population of South African Peri-urban amateur players. Furthermore, whilst interventional research regarding hamstring strengthening is well established, the efficacy of such interventions within this unique context is unknown. The two primary aims of the present study were therefore identified. This discussion will be split into two distinct sections; firstly the overall strength and performance profile of the participants will be discussed, followed by critical analysis of the efficacy of a field based eccentric hamstring strengthening intervention within the Peri-Urban environment. It is imperative that findings from the current study be viewed within the light of the context within which it was conducted. To avoid redundancy, these contextual factors affecting the two components of the present investigation, will be discussed as separate sections, following comparison to previous literature.

ISOKINETIC AND PERFORMANCE PROFILE OF PERI-URBAN AMATEUR SOUTH AFRICAN SOCCER PLAYERS

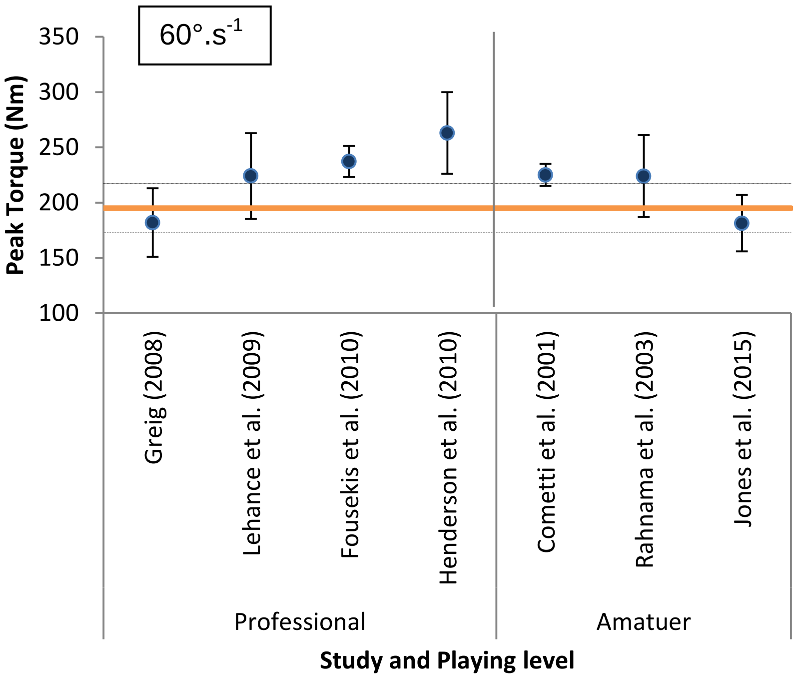
Due to a distinct lack of related research, the characteristics of the unique population of Peri-urban community based South African players are unknown. The strength and performance profile identified within the present study is therefore discussed below, to place this unique population within the context of other soccer playing populations, and to indicate inherent differences.

Concentric Isokinetic Quadriceps Strength (extensors)

Concentric quadriceps peak torque values reported for soccer players have varied significantly due to differences in playing level (Cometti *et al.,* 2001) and the inherent population of interest (Jones *et al,* 2015), making meaningful comparison difficult. Consequently, the comparisons drawn here need to be done with caution. Findings from the present study indicate that at both testing speeds the peak torque values recorded are predominantly lower than those found in other studies conducted on professional soccer players (Lehance *et al.,* 2009; Fousekis *et al.,* 2010; Henderson *et al.,* 2010). For 60°.s^{-1}, responses in the present study were found to be between 12.9 and 25.8% lower than those reported in these studies (Figure 31). Similarly at 180.s^{-1}, values observed were between 15.6 and 26.78 % lower (Fousekis *et al.,* 2010; Henderson *et al.,* 2010), for peak torque of the concentric quadriceps (Figure 31). This is an expected finding as the level of play has been shown to be an important indicator of isokinetic strength (Cometti *et al.,* 2001).

Interestingly however, current findings at 60°.s^{-1} are also 13.3% lower than those found by Rahnama *et al.* (2003) and Cometti *et al.* (2000), who observed European and French amateur players respectively. At 180°.s^{-1}, an 11.68% decrement was noted when compared to Cometti *et al.* (2000). In the only study conducted within the SA context, Jones *et al*. (2015) observed values of 182 (±25.5) Nm at the strength related speed of 60°.s^{-1} for a population of black amateur university players. Such findings are comparatively lower than that observed here. It is important to note that

Jones *et al.* (2015) was conducted by the same research group as the present study. Due to the similarity in context, comparisons will often be made to this investigation.



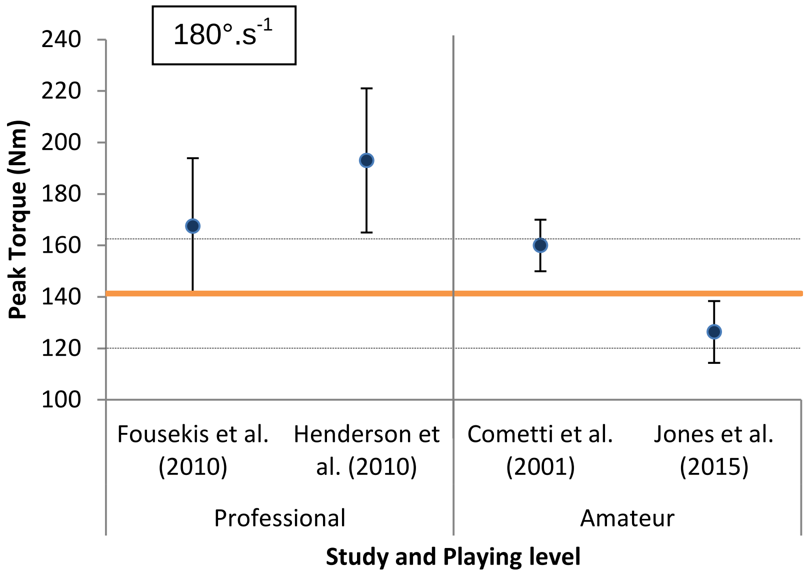


Figure 31: Concentric quadriceps peak torque responses at 60°.s^{-1} and 180.s^{-1} relative to previous literature (Y axis constants indicating mean (orange line) and standard deviation (dotted line) for the current study)

It can therefore be concluded that the amateur soccer players used in the current study demonstrated lower concentric peak torque strength for the quadriceps when compared to both amateur and professional European populations. The responses were however similar to those found by Jones *et al.* (2015) for Black South African university level soccer players. Such discrepancies may have implications for performance and injury risk, however, the relative capabilities of the hamstrings (such as the functional ratio) is of paramount importance (Croisier *et al.,* 2002), due to the fundamental antagonist relationship within the gait cycle (Mjolsnes *et al.,* 2004). This will be discussed in due course.

Unfortunately, minimal studies have reported on the angle of peak torque at the isokinetic speeds proposed in this study, with most placing focus on peak torque responses (Askling *et al.,* 2003; Mjolsnes *et al.,* 2004; Greig, 2008). However, angle of peak torque and time to peak torque have become increasingly important, as the location of peak torque within the range of motion, and time taken to generate such force, are vital indicators for injury risk (Soderman *et al.,* 2001; Small *et al.,* 2010, Timmins *et al.,* 2015). Regarding intermittent sports, a study by Brughelli *et al.* (2010) observed the angle of peak torque within a sample of Australian Rules football players at $60°.s^{-1}$. With a similar intermittent profile, comparison is therefore justified. Angles observed within the present study of 74.9 (±9.7) ° were similar to the mean angle of 70.8 (±3.5) ° observed within that of Brughelli *et al.* (2010), while Coratella *et al.* (2015) observed a pre exercise angle of 68 (±5.2) ° for the concentric quadriceps in sample of university athletes. For the current study increasing the isokinetic speed to $180°.s^{-1}$ resulted in only a small change in the angle of peak torque to 71.5°, while Coratella *et al*. (2015) noted a much bigger change with a mean angle of 62.6 °.

Within the only study conducted on a similar population, Jones (2012) reports mean angles of 65° and 58° at the strength and functional speeds respectively. These are lower than the mean angles obtained in the present study at the isokinetic speeds of $60°.s^{-1}$ and $180°.s^{-1}$. According to Small *et al.* (2010), an increased angle of peak torque is associated with longer muscle lengths for peak tension. Values observed indicate similar or higher angles of peak torque when compared to other intermittent sports. Findings suggest that peak torque production occurred later in the range of motion, indicating a greater risk of quadriceps injury within the present sample.

According to Aagaard *et al.* (2002), time to peak torque is a representation of the muscles functional ability to generate force quickly. Unfortunately, minimal studies report on time to peak torque within the context of soccer, or such assessment was conducted at differing isokinetic speeds. Findings from the present study indicate time to peak torque at 60°.s^{-1} as 534 (±126.7) ms, while 345.3 (±118.8) ms was observed for 180°.s^{-1}. Such values are similar to those observed by Jones (2012), who reported mean values of 630 ms and 320 ms at the isokinetic speeds of 60°.s^{-1} and 180°.s^{-1} respectively. Time to peak torque capabilities are therefore similar within the South African player population, although the implications for injury require more research.

With regards to the ability of the quadriceps to sustain force throughout the range of motion, total work and average power are common indicators to assess the capacity of the relevant muscle group (Ozkaya *et al.,* 1991). Reduced work and power are indicative of a reduced capacity (Beam *et al.,* 2013), while greater capabilities infer an improved ability to sustain torque and work. At 60°.s^{-1}, when compared to a sample of elite American football players (Zvijac *et al.,* 2014), total work values are 16% greater within the present study. Such differences may be attributed to the specialized nature of the elite activity selected. Furthermore, within a sample of men with varying ages (Neder *et al.,* 1999), work was indicated as 45 % greater. Such findings must be considered with caution however as according to Metter *et al.* (1997), age has significant effect on strength and so such a large age range may be misleading.

Such responses indicate that the ability to sustain torque through the range of motion is greater within the present population of Peri-urban players, which may have positive implications for performance and injury risk. Average power responses within the present study were observed as 125.4 (±8.6) W and 122.2 (±11.9) for the dominant and non-dominant limbs at 60°.s^{-1} respectively. At the functional speed of 180°.s^{-1}, a mean response of 208.9 (±22) W was noted for the average power of the concentric quadriceps. No studies have reported on average power values within the South African context. Values presented here provide for future comparison.

Findings regarding concentric quadriceps responses indicate lower peak torque capabilities and a potentially greater risk of injury with regards to angle of peak torque when compared to other amateur populations. Interestingly, total work responses indicate a greater capacity within the concentric quadriceps when compared to a sample of NFL players. Participants within the present study therefore presented with contrasting responses, suggesting that more research is needed to identify the relationship between peak torque and work with regards to injury risk. However, numerous factors have been identified which may influence this profile, which will be discussed at a further point namely socio-economic status and employment.

Eccentric Isokinetic Quadriceps Strength (extensors)

The focus of injury prevention research within a soccer context has been on the concentric quadriceps and eccentric hamstrings due to their antagonistic relationship during the gait cycle (Small *et al.,* 2010). Thus important studies such as Greig (2008) and Croisier *et al.* (2008) typically have not reported on values such as eccentric quadriceps strength. However, within the South African peri-urban community based context, there is very little literature regarding strength characteristics of the population of interest. Responses were therefore reported in order to contribute to the body of knowledge regarding players from this context.

The current research reports an average eccentric quadriceps peak torque value of 208.3 (±29.4) Nm at the isokinetic speed of $60°.s^{-1}$. This value is 22.5% lower than that of Fousekis *et al.* (2010), who observed Greek professional players. With regards to amateur populations, responses within the present study are 19.9 % lower than that of Cometti *et al.* (2000), while within a comparative study by Jones (2012), a 7.8% decrement in responses was noted. This may be indicative of reduced strength capabilities within the Peri-urban amateur Black South African soccer player. Important to note is the high variability observed within some of these studies such as Fousekis *et al.* (2010) and Jones (2012), perhaps indicating large inter subject variability (Figure 32).

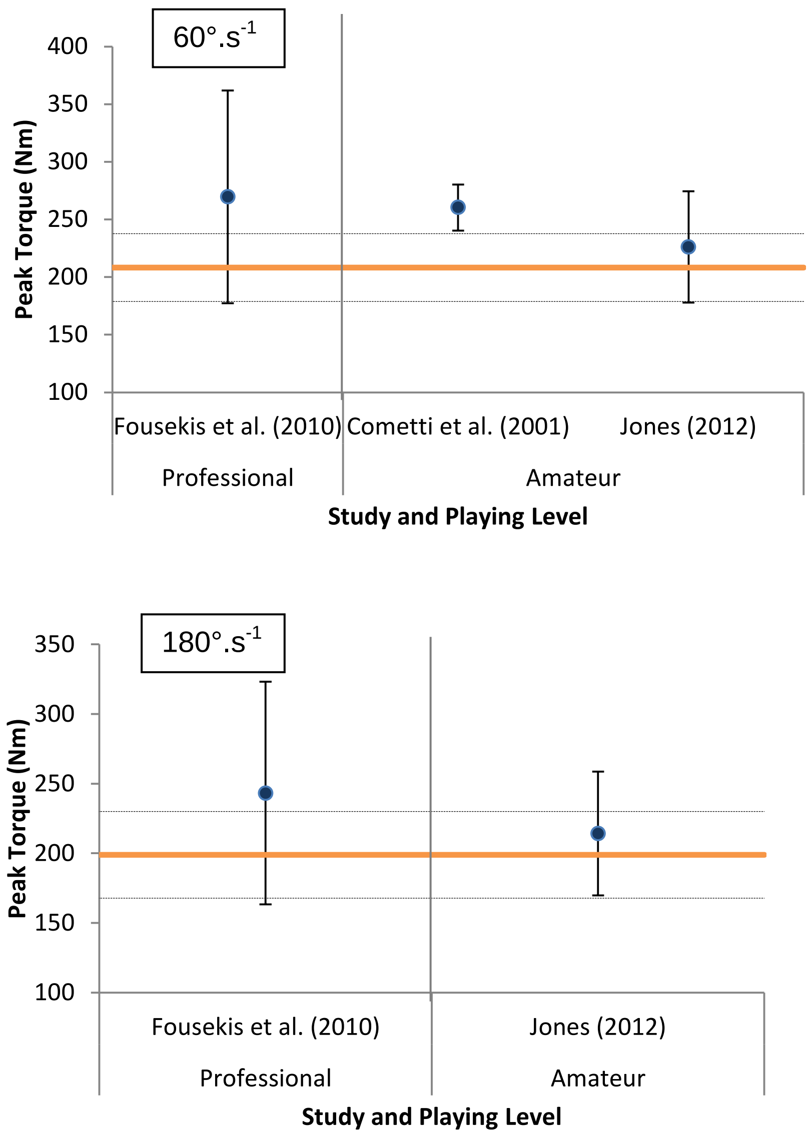


Figure 32: Eccentric quadriceps peak torque responses at 60°.s^{-1} and 180.s^{-1} relative to previous literature (Y axis constants indicating mean (orange line) and standard deviation (dotted line) for the current study)

Responses for peak torque at 180°.s^{-1} are shown in Figure 32, in comparison to previous literature. Such findings are similar to those observed at 60°.s^{-1}., with comparative studies indicating 7.47% and 12% higher peak torque responses for Jones (2012) and Fousekis *et al.* (2010) respectively. Findings at both isokinetic speeds therefore indicate that Peri-urban South African players have an eccentric quadriceps profile that is weaker than previously reported. Furthermore, in combination with concentric findings, the overall quadriceps strength profile is weaker than that of other playing populations.

Findings from the present study for angle of peak torque, indicated higher mean angle when compared to a study by Jones (2012), conducted within a similar context. Angular responses for the present study were reported as 73.1 (±8.6) ° for the dominant limb and 75.1 (±8.6) ° for the non-dominant limb, at the strength related speed of 60°.s^{-1}, while Jones (2012) reports angles of 66 (±10.5) ° and 66.7 (±11.3) ° which are comparatively lower. Similar findings were observed at the more functional speed of 180°.s^{-1}, with a mean value of 72.6 (±8.1) ° indicated within the present study substantially higher than those observed by Jones (2012). Such findings may indicate a trend towards longer muscle lengths for the eccentric quadriceps, described as a significant risk factor for injury (Small *et al.,* 2010). The present sample of Peri-urban South African players may therefore be at an increased risk of injury within the eccentric quadriceps, due to an inability to produce force earlier within the range of motion.

Mean responses for time to peak torque of 1167.9 (±299.8) ms were noted at the strength related speed of 60°.s^{-1}. Such findings are consistent with responses observed within Jones (2012), who indicated pre-exercise values of 1260 ms. Similar findings were observed at 180°.s^{-1}, with 610 ms observed by Jones (2012), comparative to the 757 (±151.9) ms observed here. The ability to generate force quickly therefore was not significantly different within the South African player population.

In comparison to the similar study conducted by Jones (2012), findings for total work and average power for the eccentric quadriceps within the present study indicated that at both speeds, capabilities were greater than those observed within the comparative study. This is surprising considering lower values observed for eccentric quadriceps peak torque. However, such findings may indicate an improved ability throughout the range of motion to generate torque, rather than singular indications of maximal torque. Therefore, there may be a greater capacity to sustain torque and work through the range of motion within the eccentric quadriceps for the unique population of Peri-urban South African players, when compared to university players within the South African context. This may have implications for the general strength profile of the population of interest, with an improved ability to sustain torque an important characteristic.

Findings regarding the eccentric capabilities of the quadriceps are similar to those observed during concentric activation. In comparison to previous studies, peak torque findings indicate a decreased capacity while angle of peak torque may demonstrate an increased injury risk, with work and power indicating an increased comparative capability. Such contradictory findings may be influenced by factors affecting efficacy, although the interaction between peak torque and work, and the relation to injury risk, requires more research.

Concentric Isokinetic Hamstring Strength (flexors)

As indicated in Figure 33 below, multiple studies have reported on concentric hamstring peak torque at $60.s^{-1}$. This Findings from the present study indicated a higher capacity for peak torque when compared to both professional and amateur populations (Figure 33). Studies regarding professionals indicated a 3-21.9% deficit compared to the present study (Askling *et al.,* 2003; Fousekis *et al.,* 2010; Henderson *et al.,* 2010; Lehance *et al.*, 2009), while amateur populations indicated greater decrements of between 7-24.9 % (Cometti *et al.,* 2000 and Rahnama *et al,* 2003). Similar findings were observed at the functional speed of $180.s^{-1}$, with 149 (±28) Nm noted for peak torque of the concentric hamstrings of the present study. Professional populations such as those observed by Fousekis *et al.* (2010) and Henderson *et al.* (2010), indicated decrements of between 18.8 and 26.8 %, while Cometti *et al.* (2001) indicated peak torque values 16.1 – 26.2 % lower, dependent on playing position.

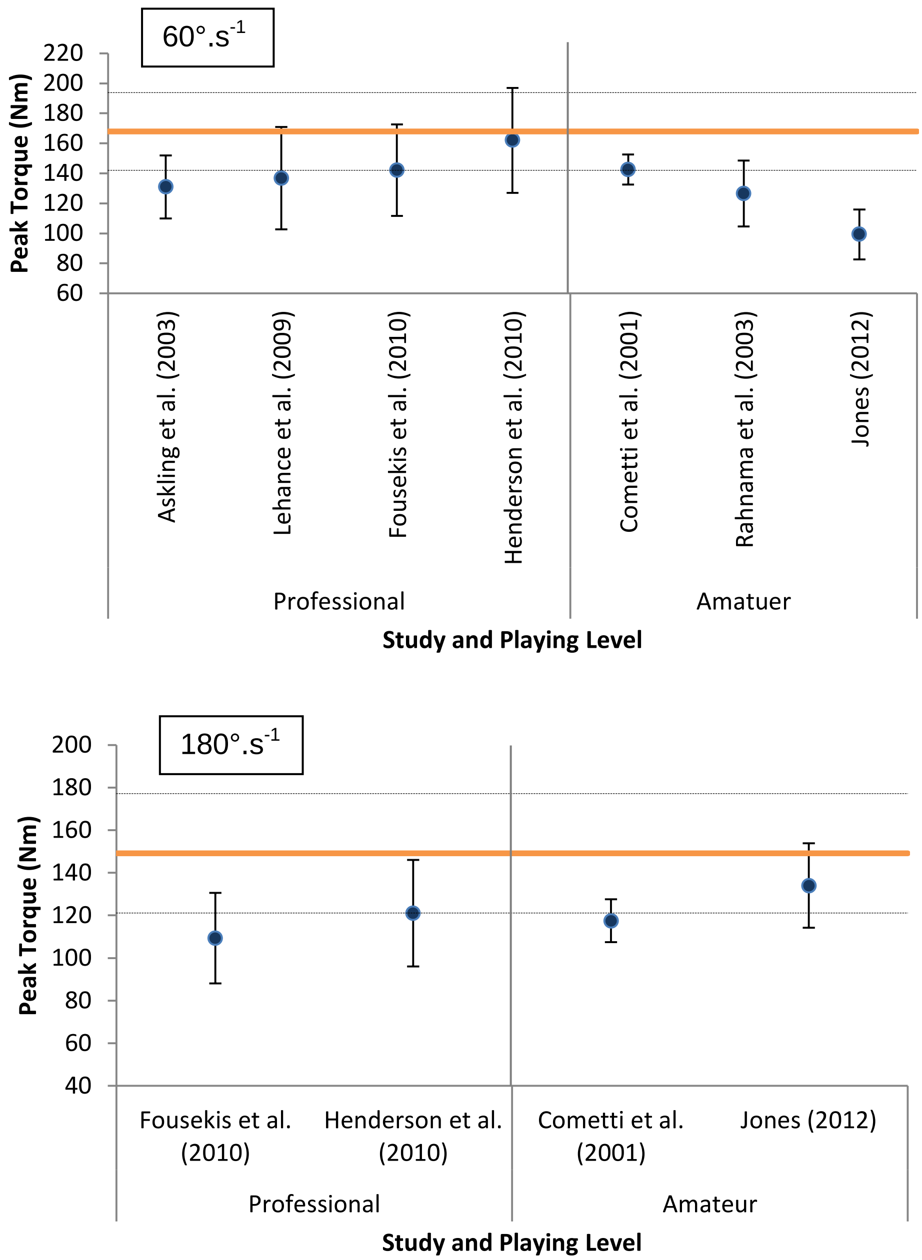


Figure 33: Concentric hamstring peak torque responses at 60°.s^{-1} and 180.s^{-1} relative to previous literature (Y axis constants indicating mean (orange line) and standard deviation (dotted line) for the current study)

Within a comparative study, Jones (2012) observed substantially lower values with a deficit of 40% at the strength related speed of 60.s^{-1} and 10% at the more functional speed of 180.s^{-1} within a sample of black university players. This is indicated in the figure above (Figure 33). Responses observed suggest that Peri-urban amateur players within the present context have greater concentric hamstring strength, at both strength and power related speeds when compared to both the amateur and professional playing populations. Such findings have positive implications for the general strength profile of the population, while also an important aspect of soccer specific performance (Cronin & Hansen, 2005). This comparatively greater strength capability may be attributed to the physically demanding nature of typical employment, although this will be expanded upon in due course. Within the context of soccer, it is important to note that capabilities relative to the quadriceps and eccentric activation are important considerations due to the intermittent demands of soccer match play.

With regards to the angle of peak torque for the concentric hamstrings, the present study observed mean angles of 56.2 (±7.6) ° and 55.3 (±8.8) ° at the strength related speed of $60.s^{-1}$ for the dominant and non-dominant limbs respectively. Findings are substantially higher than those observed within a study by Soper and Samuel (2013), with a response angle of 46.5 (±10.6) ° within a sample of female players. Additionally, angles observed within the present study are also greater than those observed in cyclists and ARF players (Brughelli *et al.,* 2010), although sport specificity may influence responses. The present study therefore, exhibits greater angle of peak torque when compared to other populations for the concentric quadriceps. However, little is known about this unique context and its impact on such responses, and so a platform is provided here for future research.

Comparisons to Jones (2012) also indicate higher values for angle of peak torque within the present study, with the author reporting an average angle of peak torque for the concentric hamstrings of 42° at $60.s^{-1}$. Furthermore, similar findings were observed at the functional speed of $180.s^{-1}$, with angle of peak torque of the present study reported as 58.6 (9.5) °, while Jones (2012) observed peak torque mean angles of 49°. Force generation may therefore be later within the range of motion, cited as a risk factor for injury. Peri-urban South African players may therefore be at a greater risk of injury with regards to the location of peak torque generation. It is important to note the multifactorial nature of injury risk (Bahr and Krosshaug, 2005). It is difficult to draw conclusions from singular responses such as angle of peak torque. Although a greater angle of peak torque is a predisposing factor for injury risk (Small *et al*., 2010), the interaction between the vast number of factors is poorly understood, and requires further research.

As reported by Aagaard *et al.* (2002), time to peak torque values are representative of the ability to generate force quickly. Responses from the present study indicate time to peak torque of the concentric hamstrings as 707.1 (±161.7) ms and 307.9 (±123.7) ms at $60.s^{-1}$ and $180.s^{-1}$ respectively. Faster times to generate peak torque indicate an improved capability, and a reduced injury risk (Soderman *et al.,* 2001).Unfortunately, minimal studies have indicated time to peak torque responses following isokinetic evaluation, and so it is difficult to identify relative capability.

The ability of the concentric hamstrings to sustain work and power is an important characteristic of muscular capacity (Kannus, 1988), particularly within the intermittent sport context. Findings from the present study at $60.s^{-1}$ indicated total work as 274.6 (±72.85) J. Values observed are significantly higher than both Neder e*t al.* (1999) who observed men of varying ages (112.7 J), and Zvijac *et al. (*2014), who observed NFL players (225.1 J). It is important to note the impact of range of motion employed within such studies. Limiting the range of motion has a direct impact on total work, and so findings must be considered with caution. At the more functional speed of $180.s^{-1}$, findings from this study indicate mean values of 197.3 (±59.6) and 203.5 (±56.1) J for the dominant and non-dominant limb respectively. Considering findings at $60.s^{-1}$, it can be tentatively stated that the ability to sustain torque through the range of motion was greater within the concentric hamstring for a sample of Peri-urban South African players. This has direct implications as greater capacity results in greater performance capability.

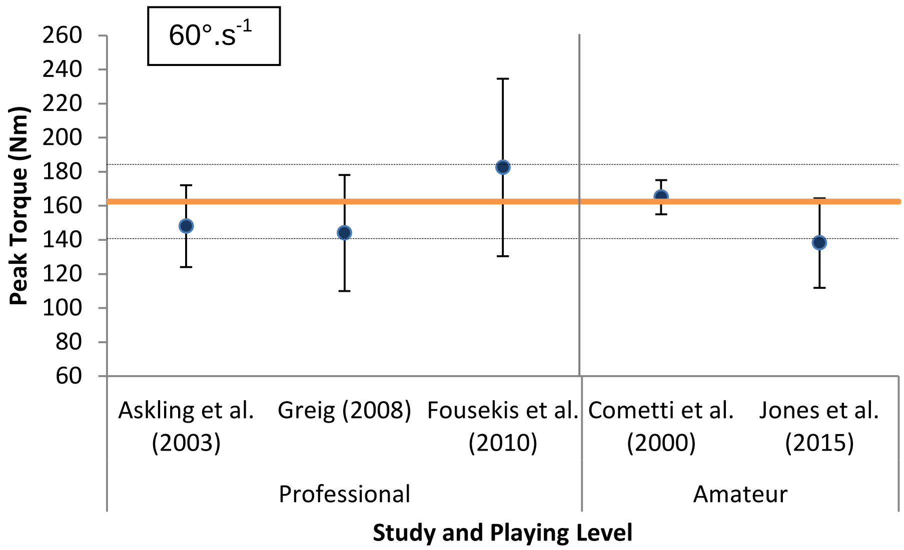
With regards to average power capacity, at both isokinetic speeds, findings compare favourably to a study by Binder *et al.* (2001), who observed female athletes. Mean average power values were reported as 80.9 W and 122.5 W for the present study; similar to 80.9 W and 125.1 W noted within the comparative study. These are surprising as the current study was conducted on males, and who on average, have a greater capacity (Hoffman *et al.,* 1979). Furthermore, such findings are unexpected considering high work values, however, the factors affecting efficacy (Page 145) may shed some light on such discrepancies.

Findings regarding the concentric hamstrings therefore indicated comparatively greater capability with regards to peak torque and total work. Such responses suggest an inherently greater capacity within the population in the present study. However, angle of peak torque indicated a comparatively higher angle, while power may be deemed lower than expected, as comparable to a female population. Contrasting results may indicate a unique strength profile amongst the Peri-urban South African playing population.

Eccentric Isokinetic Hamstring Strength (flexors)

Together with the concentric quadriceps strength, the eccentric hamstring strength values are of vital importance in understanding injury risk within a soccer context. It is therefore unsurprising that there is a large body of soccer specific knowledge. Accordingly, peak torque reported by multiple authors has varied substantially across populations (Figure 34). Eccentric hamstring capabilities, do however, have a significant relationship to injury risk (Small *et al.,* 2010), and so greater strength to counteract forward momentum of the lower limb is a crucial characteristic (Mjolsnes *et al.*, 2004). Findings from the present study compare favourably to both amateur and professional populations. Responses observed by Askling *et al.* (2003) and Greig (2008) are 8 and 11% lower than those observed here, while Fousekis *et al.* (2010) indicated responses 18% higher. Within amateurs, Cometti *et al.* (2001) observed negligible differences compared to the present study. When compared to a similar context, Jones (2012) reported lower peak torque values of 138.2 (±26.3) Nm for a sample of black South African university players. Hamstring responses were therefore similar when compared to the relevant literature.

For the functional speed of 180.s^{-1}, a study by Greig (2008) observed eccentric hamstring peak torque values similar to those observed within the present study, while another investigation conducted on professionals by Fousekis *et al.* (2010) indicated substantially greater peak torque values (18%). Similar to the strength related speed, Jones *et al.* (2015) reported responses as 14% lower than those in the present study. Eccentric hamstring peak torque related findings suggest that eccentric hamstring capacity within the present sample of Peri-urban amateur players was comparative to professionals at both speeds, and greater than a comparative study by Jones *et al.* (2015). Findings suggest adequate strength for the hamstrings during this activation mode, although the functional ratio is more representative of injury risk associated with the gait cycle.



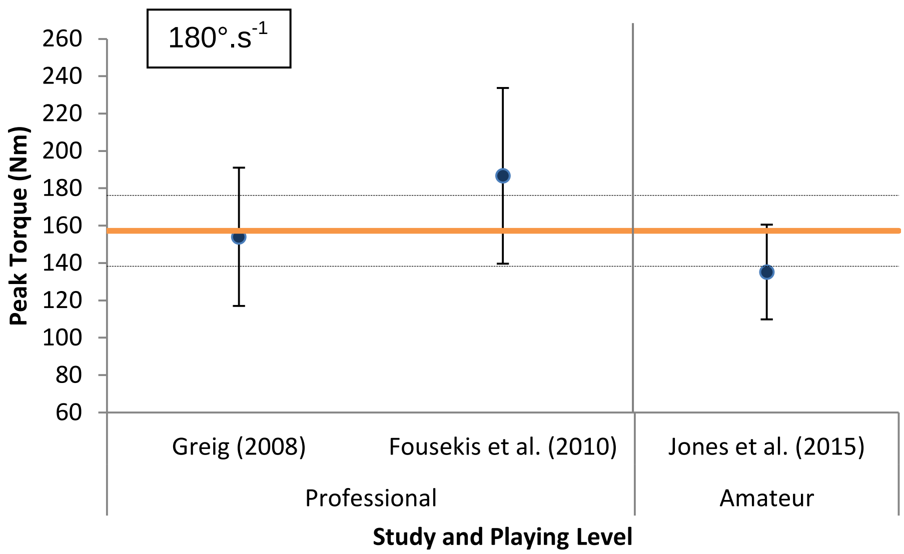


Figure 34: Eccentric hamstring peak torque responses at 60°.s^{-1} and 180°.s^{-1} relative to previous literature (Y axis constants indicating mean (orange line) and standard deviation (dotted line) for the current study)

With regards to angle of peak torque responses for the eccentric hamstrings the present study observed values of 39.2 (±9.1) ° at the isokinetic testing speed of $60°.s^{-1}$. Such values compare favourably to sample of u/18 youth players observed by Forbes *et al.* (2012) with an angle of 38.7 (±12.4) °. Interestingly within a sample of male players (Coratella *et al.,* 2015), substantially lower values of 26.8° were noted. Similar findings were observed within Jones (2012) who indicated values of 28.4 (±21.8) ° and 29.3 (±23.1) ° for the dominant and non-dominant limbs respectively. This serves as an inherent injury risk as the hamstrings are unable to tolerate the concentric force of the quadriceps earlier within the range of motion (Small *et al.,* 2010). Findings at the strength related speed of $60.s^{-1}$ therefore indicate an increased risk of injury with regards to angle of peak torque. At the functional velocity of $180.s^{-1}$, the present study observed a mean angle of 46.5 (±8.9) ° for the eccentric hamstring peak torque. Findings from Coratella *et al.* (2015) and Jones (2012) indicate substantially lower angles of 34.9 °and 34.6 ° respectively. Such discrepancies are consistent with those discussed previously regarding $60.s^{-1}$. Such findings suggest an inherent injury risk (Small *et al.,* 2010), with a preference towards longer muscle lengths indicating a reduced capacity to counteract forward momentum during the gait cycle.

Time to generate maximal force within the eccentric hamstring was observed as 1339 (±214.6) and 956 (±251.7) ms within the dominant and non-dominant limbs at $60.s^{-1}$. According to Soderman *et al.* (2001), a slower time to peak torque is indicative of greater injury risk, particularly ACL injury. Findings from the present study indicate asymmetry between the limbs with slower time to peak torque for the dominant limb, potential risk factors indicative of unbalanced training techniques. Interestingly however, at the more functional speed of $180.s^{-1}$ the present study observed time to peak torque values of 564.7 (±148.8) and 528.4 (±116.2) for the respective limbs indicating a comparable values between the limbs.

The decreased ability of the eccentric hamstrings to sustain work and power is symptomatic of a decreased capacity (Jones, 2012), which has significant implications for match-play. Observations from the present study (262.4 (±71.5) J) indicate a greater work within the Peri-urban population when compared to NFL players (Zvijac *et al.,* 2014) who noted values of 225.1 J. At the more functional speed of 180°, responses indicate mean values of 274.7 (±72.9) and 244.5 (±59.5) J for the dominant and non-dominant limb respectively. Greater work responses infer a greater capacity to sustain torque through the range of motion, with positive implications for soccer match play due to the intermittent demands. The Peri-urban population may therefore have a superior capacity when compared to other sporting codes. With regards to average power capabilities, at the strength related speed of $60.s^{-1}$, eccentric hamstring findings within this study indicate values of 97.4 (±15.4) and 94.7 (±15.2) W for the preferred and non-preferred limb. At the more functional speed of $180.s^{-1}$, 191.9 (±38.1) W was observed for the dominant limb, while 176.1 (±32.6) W was reported for the non-dominant limb.

Findings regarding eccentric hamstrings activation indicated comparable peak torque values, while angle of peak torque indicated comparatively higher angle, a factor for injury risk. Total work inferred a greater capacity through the range of motion. Such findings indicate that the ability of the hamstrings to produce torque is adequate; however, the location of peak torque may indicate an increased injury risk. This is an important consideration as the location of peak torque is paramount with regards to injury (Small *et al.,* 2010). Further research is required to identify the relationship between torque related factors and injury risk.

Functional Ratio

A significant risk factor for hamstring strain injury is the functional ratio between the peak torque values of the eccentric hamstrings and the concentric quadriceps (Woods, 2004). The ability of the hamstring to counteract the force generated by concentric quadriceps action during the swing phase of the running gait is a vital consideration (Jones *et al.,* 2015). Within the Peri-urban context functional strength data is particularly lacking and so such findings are of significant interest. The current study indicated values of 0.84 (±0.09) and 0.84 (±0.14) for functional ratio of the dominant and non-dominant limbs at $60.s^{-1}$. This is substantially greater than that observed in a study by Cometti *et al.* (2000) reporting a ratio range of 0.65 – 0.85 for

French amateur players, depending on position. When compared to professional players, a study by Croisier *et al.* (2002) indicates similar ratio values of 0.9 (±0.16). This suggests that the relative capabilities of the upper thigh within this population are sufficiently strong (Bennell et al., 1998). When compared to an ethnically similar population such as that observed by Jones (2012), values of 0.77 (±0.13) indicate greater relative eccentric hamstring capacity within the present study's population, attributed to the unique characteristics of the Peri-urban population.

At the functional velocity of $180.s^{-1}$, findings indicate ratio values of 1.16 (±0.17) and 1.1 (±0.16) for the dominant and non-dominant limbs respectively. In the comparative study by Jones (2012), values of 1.09 were observed for the functional ratio, citing substantially greater values than those observed within professional players (Greig, 2008). A greater ratio may indicate a greater tolerance of the hamstrings to decelerate the limb during the late swing phase of the running gait. This is particularly relevant at $180.s^{-1}$, which is more representative of functional action. It can therefore be tentatively suggested that South African amateur, community based players have a decreased risk of hamstring injury from the perspective of the baseline functional ratio. This is a significant finding as such injuries have significant implications within this unique context. These will be discussed shortly. However, the impact of fatigue over the course of match-play is a significant consideration regarding the H: Q ratio and injury risk (Jones et al., 2015).

Performance

Vertical Jump

Jump capabilities are an important characteristic of soccer match-play, both as a functional representation of upper thigh strength, and performance requirements within the game (Cochrane et al., 2004). Responses from the present study indicate a mean jump height of 54 (±8.4) cm for the squat jump at baseline. An important factor to consider is the differing techniques used to complete the jump type. Technique is often dependent on the system of measurement available. These predominantly focus on the involvement of the arms. The present study included a 1 arm jump, due to the nature of the self-made measurement jump meter (See page 68). Responses indicated by multiple studies (Arnason *et al.,* 2004; Casajus, 2001; Henderson *et al.,* 2010; Cometti *et al.,* 2000) reported a range of values for the no arm squat jump (37.6 – 41.8 cm). However, with arms, jump responses were indicated in a study conducted by Casajus (2001), reporting a mean squat jump height of 47.8 (2.9) cm. Squat jump heights indicated in the present study are therefore substantially greater than those observed previously, indicating greater concentric strength within the present population. Such findings are in conflict to those observed regarding concentric quadriceps. However, the vertical jump (while more functionally representative) does not allow for the same extent of control as isokinetic dynamometry (such as the coefficient of variation). and so other factors such as motivation may have influenced responses observed.

With regards to the countermovement jump, technique must be considered once more. Interestingly, countermovement jump height is typically greater than the squat jump due to the inclusion of the eccentric component (Cochrane *et al.,* 2004). Values obtained within the present study for a one arm countermovement jump indicate a jump height of 55.9 (±8.3) cm. Comparatively speaking; multiple studies (Cometti *et al.,* 2000 & Henderson *et al.,* 2010) indicate a range of 39.2 – 46.9 cm across multiple population groups and jump techniques. The mean jump height observed within the present study is substantially greater than those presented in similar studies observing soccer players, suggesting a comparatively greater strength capability within the present population. This is an important component of the present study. Although numerous factors such as nutrition and nature of employment may have a negative impact on performance, the current population elicited a greater than average vertical jump. This demonstrates the athletic potential within this population of Peri-urban black South African players.

An important consideration regarding the vertical jump is the ratio between squat and countermovement ability. This is known as the eccentric utilization ratio (EUR) and according to McGuigan *et al.* (2006); a value of 1 or greater is indicative of a well-balanced strength profile of the upper thigh musculature. Findings within the present study indicate a EUR of 1.04 (±0.08). Minimal research has indicated the EUR within soccer players, and so comparison is difficult. It can however, be tentatively suggested that the EUR is in agreement with the previous findings of the functional ratio: that the present population at baseline is at a decreased risk of hamstring injury.

10m Sprint

As reported by Bangsbo (1994), an important performance characteristic of soccer match-play is sprint ability. In order to identify the sprint ability of the present population, a 10m sprint was employed. Mean sprint time over 10m was found to be 1.99 (±0.18) s for the present population of Peri-urban community based South African players. This compares favourably to Lehance *et al.* (2009) who observed Belgian 1^{st} division players and noted an average sprint time of 1.96s. However, a study conducted by Ozcakar *et al.* (2003) noted a mean sprint time of 1.69s, within a population of Turkish elite players. Findings from the present study therefore indicate a typical ability over a 10 m sprint. However, there are limitations within this study as timings were taken using a stop watch. Other studies incorporate the use of timing gates which are more accurate (Waldron *et al.,* 2011). However, due to the applicability to the amateur South African context, the more practical and accessible measurement device of a stopwatch was used. The efficacy of the data obtained may therefore be reduced.

Yo-Yo Intermittent Fatigue Shuttle Run

Average Yo-Yo fatigue shuttle ability was recorded as stage 7.8 (±1.4) of the protocol. Unfortunately, minimal studies have employed this specific shuttle test on soccer players, and so comparison is difficult. An important consideration when investigating shuttle runs is the contribution of motivation. Participants within this study are amateur players, and use soccer as a social outlet as opposed to a means to be a professional athlete. It was noted by the researcher that participants often dropped out before exhaustion. This is a vital aspect of any research as it is imperative that participant motivation remains consistent across all testing. It is acknowledged that this is difficult, but it must be considered when assessing the amateur soccer playing population.

SUMMARY

Both vertical jump and isokinetic responses from the present study indicated a comparable capacity when compared to both amateur and professional soccer playing populations in a rested condition. Furthermore, the functional ratio and eccentric utilization ratios at rest for the present population indicated a greater hamstring capacity and thus, decreased injury risk (Croisier *et al.,* 2002). However, as reported by Calligeris *et al.* (2015) injury during match play is still prevalent within the South African context. It would appear that the Black South African population may not be at increased risk at rest but are during performance. This is a limitation of the present study, as the effects of fatigue on such responses within this unique context were not identified. It is possible that the population of interest may fatigue eccentrically more quickly, due to differences in muscle fibre type (Hunter, 1996), resulting in an increased injury risk. This is speculative however, and future research should endeavour to identify the effect of soccer specific fatigue on such responses, to identify the unique factors and interactions that induce injury.

FACTORS AFFECTING BASELINE RESPONSES

Findings from baseline isokinetic and performance evaluation indicate certain similarities, and differences, when compared to previous literature. To avoid redundancies, the factors that may influence such responses are outlined below.

Complex Nature of Human Performance

As previously discussed (page 24), there are a vast number of both modifiable and non-modifiable factors that influence performance and injury risk. Quantification of the effects within a soccer context is, however, particularly difficult due to the unique interaction between such aspects. In order to illuminate these factors, Bahr and Holme (2003) formulated an effective table to indicate the complex nature of injury risk within a sporting context (Figure 35). The unique physical profile of the athlete plays a significant role with aspects such as physical fitness, previous injury, anthropometrical characteristics, age, sex, all influencing capacity. Furthermore, external factors such as the nature of the sport exposed, level of training, environmental conditions and equipment, are further influencing the inherent capability of the athlete, and thus, injury risk. It becomes evident that the nature of human performance is multifactorial and distinctly complex. This is further supported by research regarding African athletes such as Hamilton (2000) and Larsen (2003), when identifying performance characteristics.

Internal Factors	External Factors
Physical defect/dysfunction	Sport Factors
Physical Fitness	• Type
• Aerobic endurance (M)	• Exposure (M)
• Strength (M)	• Nature (e.g. collision)
• Speed (M)	• Action of opposition (NM)
• Skill (M)	• Action of team mate/s (NM)
• Co-ordination (M)	• Action/Non action of officials
• Flexibility (M)	Venue
Previous injury (NM)	• Lighting (M)
Psychological Factors	Weather conditions
Physical Build	• Temperature
Age (NM)	Equipment (M)
Sex (NM)	

Figure 35: Examples of both modifiable (M) and non-modifiable (NM) injury risk factors (Taken from Bahr *et al.,* 2005)

With regards to the unique soccer context, an effective framework is indicated by

With regards to the soccer specific factors that influence injury risk, Fousekis *et al.* (2010) provides an effective analysis, as indicated in the diagram below. Inherent strength capabilities are influenced by a number of soccer specific aspects such as playing position, leg dominance, training age and strength asymmetries. Vast differences are therefore evident across populations, across playing levels and even between players, as levels of exposure to such factors vary significantly. A holistic approach is therefore vital in order to appreciate the numerous factors that influence capacity, and their unique interaction. This complex interaction of factors is a vital consideration within the unique context of the South African Peri-urban player.

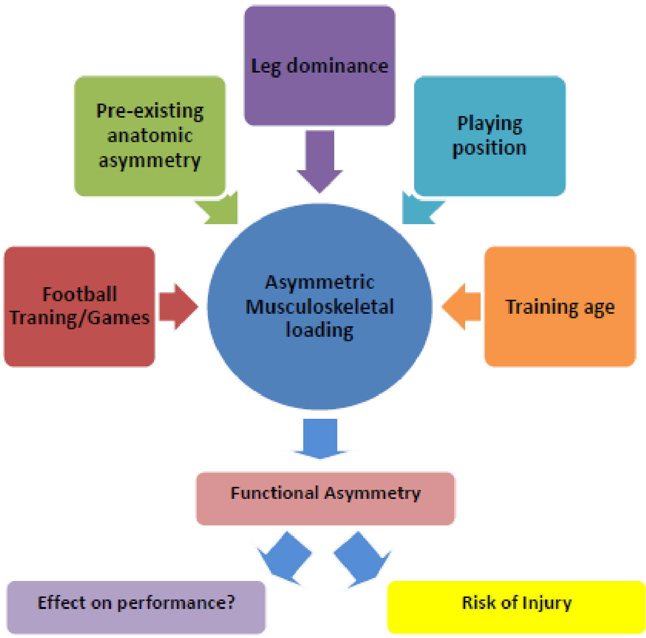


Figure 36: Theoretical model of the interaction factors affecting performance and injury risk in soccer (Fousekis et al., 2010)

Ethnicity

A fundamental aim of the present study was to identify the unique characteristics of the Peri-urban community based South African soccer player. Furthermore, as indicated in numerous papers, the African athlete profile is influenced by a vast number of factors (Wilber *et al.,* 2012) and has a unique physical profile. It is also imperative to note vast diversity within certain ethnic groups, due to environmental and socio-economic factors (Tucker *et al.,* 2013).Therefore; the population included within this investigation have a unique physical profile.

Typically, African athletes are distinguished by certain anthropometrical traits, such as lower stature and mass. Such aspects are due to historical influences such as environmental factors (Weston *et al*., 2000). Participants included within the present study are no different, with a stature of 171.34 (±6.37) cm and a mass of 66.35 (±9.06) kg, comparatively lower than other soccer playing populations (Rahnama *et al.,* 2003; Greig, 2008, Small *et al.,* 2010). As body mass has been implicated as a significant factor for strength (Bennell *et al*., 1991), decreased strength responses may be due to such anthropometrical discrepancies. This may have been the case for the quadriceps which reported comparatively lower strength responses. Additionally, the BMI responses indicated values of 22.6 (±2.97). Findings indicate a normal and healthy population; however such observations may be simplistic. As indicated on page 124, socio economic factors within the present sample indicate a vast number of pressures placed on the athlete. These include and are not limited to income, household dynamics and poor education. According to Mayosi *et al.* (2009), such socio-economic factors have a significant impact on performance, and are of vital consideration.

Socio-Economic Status

The context of the Peri-urban South African player is particularly distinct due to a number of factors. According to Bradshaw *et al.* (2003), South Africa is uniquely affected by a quadruple burden of disease: pre-transitional disease, chronic diseases, injuries and HIV/AIDS. Illustrated in Figure 37, is the contribution of each to relative mortality, compared to established first world nations. It is evident that comparisons between such countries are futile due to the vastly different environmental factors to which these populations are exposed. It is important to note that a vital characteristic of the players included within the present study is low income and low socio-economic classification. According to Mayosi *et al.* (2009), low income groups are at a significantly higher risk to burdens of disease. This burden of disease is therefore a crucial consideration when investigating the Peri-urban community based South African playing population.

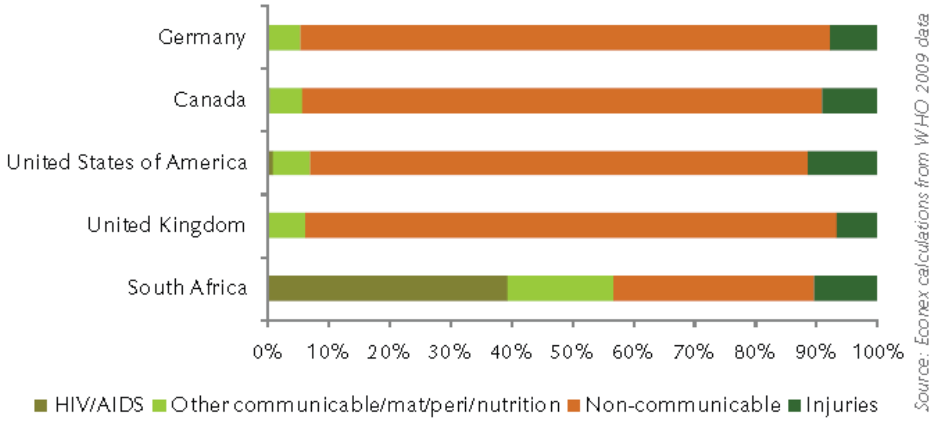


Figure 37: Disability adjusted life years for developed countries for 2004 (WHO, 2009)

As discussed, players included within the present study are classified as low income. Furthermore, following administration of the socio-economic questionnaire, participants intimated that due to financial constraints, and a relative low level of education, players from this Peri-urban context are forced into manual labour related tasks to generate income (Christie, 2001). As a result, players do not have access to quality nutrition and effective housing. Furthermore, as indicated in Figure 38 below, such factors lead to a general poor health, lower capacity and overall lower productivity.   The unique context of the Peri-urban South African player may therefore have a detrimental effect on soccer related performance. Due to socio-economic factors, responses indicated at baseline such as decreased isokinetic quadriceps strength may have been affected by this burden of disease.

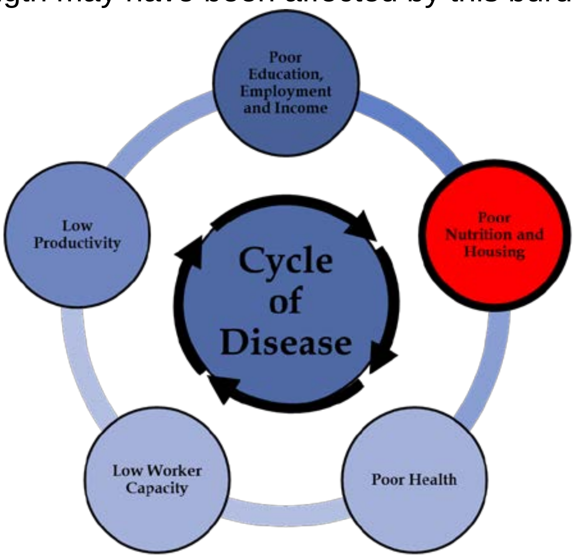


Figure 38: Cycle of Disease associated with low income populations

A further vital characteristic of a low income classification is poor nutrition (Mayosi *et al.,* 2009). Participants within the present study indicated that their average earning per month is around R1500. Furthermore, most players are members of households of 5 or more, that they must support. The ability to control nutritional intake is therefore influenced by necessity. It is well understood that nutrition plays a fundamental role in performance (Jeukendrup *et al*., 2010). Poor nutrition or a lack of balanced nutrition may therefore have influenced responses observed within the present study of Peri-urban community based players. However, players included within the present study indicated an overall comparative profile to both amateur and professional European based populations. An interesting consideration is therefore how such responses may be affected by proper nutrition within this context.

Type of Work

The majority of participants included within the present study perform manual labour to generate income. Such work is often associated with manual materials handling (MMH), which is accompanied, by a unique set of risk factors (Waters *et al.,* 1996). Furthermore, Marras (2012) indicates that such work is associated with a number of different influences that affect capacity, and furthermore, requires high levels of related fitness. Such contributing factors to overall force generation and performance are indicated in the figure below.

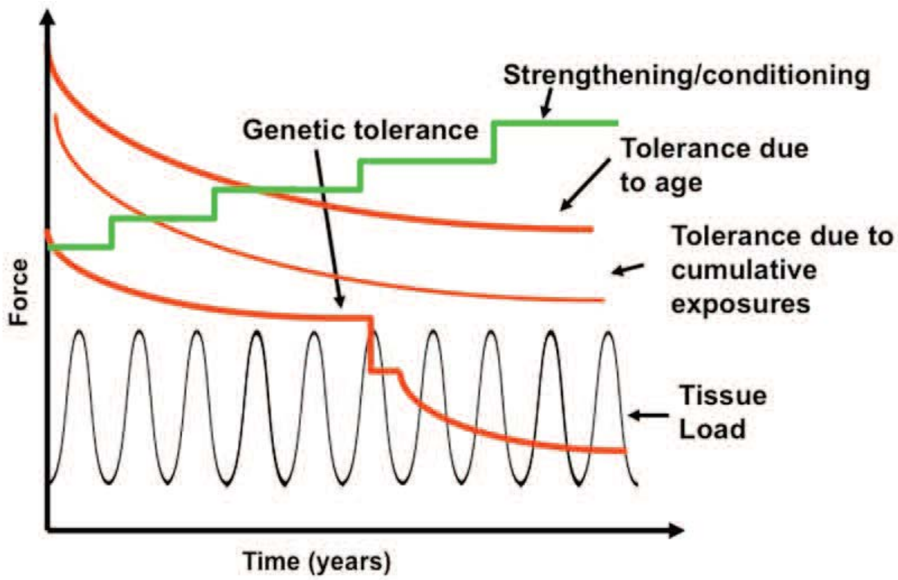


Figure 39: A graphic representation of the conceptual relationship between factors that influence material tolerance (Marras, 2012)

This is an important consideration when evaluating participants within the present context. Peri-urban players are often involved in manual labour tasks throughout the day, and then attend practice sessions and occasionally match-play. The variability of such work, the related demands, the difference in job requirements across participants, will therefore have a significant impact on the capacity of the player to produce force. Furthermore, each player will be exposed to differing tissue loads, and different genetic factors, which impact capability.

Results from the present study may therefore have been influenced by the nature of work associated with low income Peri-urban community based players. As assessment occurred following completion of the work day, maximal capacity would be heavily influenced by exposure levels that day. Differing strength and performance responses may therefore be attributed to players performing at a different percentage of their capacity, due to the exposure over the day. This is a significant limitation of field based research, as researchers cannot control factors such as those described.

Habituation

Due to a lack of investment and infrastructure, players within this context were not exposed to equipment such as the Biodex isokinetic dynamometer prior to testing. Additionally, all participants were Bantu descendants with isiXhosa as their mother tongue. To reduce the impact of language, all letters of consent were translated into isiXhosa and administered accompanied by a fluent research assistant.

Although habituation was intensive and strength evaluations were rejected if a coefficient of variation greater than 20 was produced, an inability to maintain maximal force through the range of motion may have been present. This was particularly evident for eccentric action, which participants reported as extremely difficult. Furthermore, transitions between activation modes were not always fluid, and so total work and average power may have been influenced by such discrepancies.

Player Classification

Player classification does not have a direct influence on capacity; however, it is a crucial consideration with regards to comparing and contrasting relative literature. Vast differences are often indicated between playing levels, such as increased levels of strength for professionals when compared to amateurs (Cometti *et al.,* 2001). However, findings presented from this study indicate that there are often discrepancies within classifications. For instance, the only study from a similar context is that of Jones *et al.* (2015), conducted on university players. Although both samples are black amateur players, strength responses are often greater within the present study. It is therefore crucial that classification of playing level is not generalized. Not all amateur players are comparable, due to a vast number of modifiable and non-modifiable factors already discussed. Each population must be observed within their own unique context, with acknowledgment of the unique factors that such players are exposed to.

SUMMARY

Findings from the current study indicate a strength profile comparative to other amateur populations. Greater peak torque responses indicate greater strength capabilities which may be attributed to the nature of employment associated with the present population. Functional ratio findings indicated a low risk of hamstring injury. However, the impacts of angle of peak torque and time to peak torque are crucial considerations when evaluating injury risk, as the context of torque production capability relative to antagonist muscles is vital. The performance profile indicated greater strength capabilities within vertical jump parameters, in agreement with observation from isokinetic assessment. Performance parameters indicated average to low performance, although such responses may have been influenced by motivation. It can therefore be concluded that the Peri-urban community based South African player has a unique profile that is comparable to other amateur population. This is the case even though there are significant factors affecting performance. It is therefore possible that the present population are capable of greater performance characteristics, if barriers relating to socio economic status are negated. Further research is therefore required to examine the true capabilities of Peri-urban players of this context.

EFFICACY OF AN ECCENTRIC HAMSTRING INTERVENTION IN SOUTH AFRICA

A primary aim of the present study was to evaluate the efficacy of interventional research within the unique context of the South African Peri-urban amateur player. An eccentric hamstring strengthening exercise intervention was employed, as according to Ekstrand *et al*. (2011) the most prominent soccer related injury occurs within the hamstring muscle group. Both isokinetic evaluation and selected performance measures were assessed, to identify the efficacy within this unique context.

Isokinetic Assessment

Hamstring strengthening related literature has cited two methods for identifying the effect of a hamstring intervention on injury risk. The analysis of injury frequency over following seasons (Peterson *et al.,* 2011); or relative strength improvements within the hamstring muscle group, following completion of the intervention (Mjolsnes *et al.,* 2004). Due to a number of limitations such as time constraints and squad availability, the focus of the present study was to identify isokinetic strength improvements following administration of a Nordic hamstring lower eccentric strengthening intervention.

<u>Peak Torque</u>

Concentric Quadriceps

Statistical analysis regarding concentric quadriceps peak torque capabilities indicated no significant differences ($p=0.395$) between the groups at $60°.s^{-1}$, over the course of the intervention. The Nordic hamstring strengthening exercise therefore did not result in strength changes over time for either group. Such findings are to be expected within the intervention group as earlier investigations such as Tomberlin *et al.* (1991) and Seger *et al.* (1998) indicate that both eccentric and concentric strength training are mode and muscle specific. Furthermore, an initial study conducted by Mjolsnes *et al.* (2004), observed minimal concentric peak torque improvements of 2 Nm within the intervention group following a similar Nordic eccentric strengthening program. The responses observed indicate that the concentric quadriceps peak torque capabilities were not influenced by the intervention or the relative training load over the course of the intervention at this speed.

Interestingly, at 180°.s^{-1}, statistical analysis revealed a time group interaction effect (p=0.035) for peak torque of the concentric quadriceps. Post hoc analysis revealed however, that such differences were attributed to variables of non-interest such as differences between post dominant limb and pre non-dominant limb values. There was therefore no meaningful differences in the change over time within groups for concentric quadriceps peak torque at either speed, indicating that Nordic hamstring lower did not result in changes to the concentric quadriceps for peak torque. This is an important finding as a vital aspect of soccer specific injury risk is the functional ratio between the concentric quadriceps and eccentric hamstrings (Small *et al.,* 2010). Increases in concentric peak torque would reduce the impact of eccentric strengthening, as the hamstrings must tolerate greater force during the swing phase of the gait cycle. Considering that strengthening exercises are muscle and mode specific (Tomberlin *et al*., 1991), this is an expected but important finding nonetheless.

The focus of the present investigation was to assess the efficacy of an eccentric hamstring intervention. As the quadriceps are not a frequently injured anatomical structure during eccentric activation and were not the focus of the present investigation, such responses were excluded from analysis.

Concentric Hamstrings

The ability of the concentric hamstrings to produce torque indicated an interaction effect between group and time (p=0.018) at the isokinetic speed of 60°.s^{-1}, however, post hoc analysis revealed no relevant significant differences with regards to the effects of the intervention (See appendix B). Therefore no significant changes were observed for either group over the course of experimentation for concentric hamstring peak torque capabilities at the strength related speed. This is to be expected as concentric hamstrings were not the focus of the strengthening intervention. At the speed of 180°.s^{-1}, concentric hamstring peak torque capabilities experienced no significant differences between pre and post assessment (p=0.056) for both groups. Interestingly, statistical analysis revealed a time effect (p=0.049), indicating changes within both groups regarding concentric hamstring capabilities. Such improvements may indicate an improved performance capacity, with direct implications for match play. As such changes occurred within both groups, such improvements may be attributed to the normal training regimen. It is interesting to note that the p values obtained here are remarkably similar. It is therefore imperative that statistical findings are interpreted with caution, due to the absolute nature of statistical significance. Findings for concentric hamstrings therefore indicate no significant differences between the control and intervention group pre and post intervention. The Nordic hamstring exercise therefore did not impact the ability of the hamstring to perform concentrically.

Eccentric Hamstrings

As highlighted previously, the eccentric capabilities of the hamstring play a pivotal role in hamstring injury epidemiology. According to Orchard (2001), this is due to a lack of strength to counteract the forward motion of the leg during the swing phase of the running gait. Eccentric interventions have therefore placed focus on improving the eccentric strength capabilities of the hamstrings (Mjolsnes *et al.,* 2004), to reduce injury risk. Improvements in eccentric hamstring peak torque may therefore indicate a reduced injury risk within a sample of Peri-urban community based players.

Following completion of the intervention period, the present study indicated significant strength improvements at both isokinetic speeds ($p<0.001$ and $p=0.006$), for the intervention group. At $60°.s^{-1}$, an 8.24 % and 5.72% increase was noted for the dominant and non-dominant limbs respectively, while a significant increase of 12.82 % was indicated for the non-dominant limb and a non-significant 3.56 % for the dominant limb at $180°.s^{-1}$. The control group did not experience any statistical changes over the 10 weeks for both speeds, and were similar for pre and post measures. The Nordic hamstring lower intervention therefore resulted in significant increases in eccentric hamstring peak torque of the intervention group when compared to the control. Such changes present within the intervention group are comparable to Mjolsnes *et al.* (2004) who observed an 11% increase for eccentric hamstring peak torque at $60°.s^{-1}$. Furthermore, responses at the faster speed indicate the potential benefit of the eccentric intervention, particularly within the gait cycle, although this was confined to the non-dominant limb. The confinement of findings to the non-dominant limb may perhaps be attributed to the small sample size within the present study. A greater number of participants may have induced significant results across both limbs. This is a significant finding for the present study.

It can therefore be concluded that the Nordic hamstring exercise is effective in improving eccentric strength of the hamstrings in Peri-urban amateur community based South African soccer players. This has important implications for the introduction of such exercises into the warm up strategies of teams of this nature. This is imperative as even with lower economic status and higher physical demands associated with their work environments, such intervention techniques are still effective within this unique context. Additionally, experimentation was conducted in season, potentially impacting results due to cumulative fatigue. It is important to note that although significant improvements in eccentric hamstrings strength have been identified as a crucial characteristic (Mjolsnes *et al.,* 2004), the relationship to concentric capabilities is paramount within the gait cycle. The functional ratio may therefore have greater implications.

Functional Ratio

The functional ratio is regarded as a significant indicator for hamstring injury risk (Aagaard *et al.,* 1998). Furthermore, improvements in the functional ratio are indicative of an increased capacity within the hamstrings to counteract the force of the lower limb, generated by concentric quadriceps action (Greig, 2008). Improvements in the functional ratio within the present study may therefore indicate an improved capacity within the hamstring of Peri-urban South African players when compared to the quadriceps.

Responses at the strength related speed of $60°.s^{-1}$ indicated a time group interaction effect ($p=0.012$) for the functional ratio, suggesting relative strength improvements within the intervention group. Interestingly, however, Tukey post hoc analysis revealed no significant changes when compared to the control. The functional ratio therefore improved within the intervention group; however, such changes were not significantly different to those of the control. At this strength related speed of $60°.s^{-1}$, the ratio improved from 0.83 to 0.88 in the dominant limb and from 0.82 to 0.84 in the non-dominant limb.

At the isokinetic speed of $180°.s^{-1}$, the present study observed no significant differences (p=0.298) in the functional ratio between the two groups for pre and post measures. The intervention group experienced no change for the dominant limb, while a non-significant 7.66 % increase was noted within the non-preferred leg. Minimal strength improvements were therefore noted at this faster speed, although the increase observed within the non-dominant limb may indicate that the potential of such an intervention is hampered by additional socio economic factors. The Nordic hamstring intervention therefore induced improvements in the relative capabilities of the hamstring, resulting in minor non-significant improvements to the functional ratio. Findings suggest that within the Peri-urban community based South Africa context a strengthening intervention was partially successful in reducing inherent injury risk, with relative improvements in the functional ratio. However, the lack of significant findings may be due to a number of factors, as there were substantial barriers to implementation within the present study. For further discussion, see page 164.

Angle of Peak Torque

With regards to angle of peak torque responses, concentric quadriceps and concentric hamstrings indicated no significant differences in responses between the two groups at either testing speed (See Figure 10). This is to be expected as interventions are mode and muscle specific (Tomberlin *et al*., 1991), and thus minimal changes are expected for these strength measures. The Nordic hamstring eccentric strengthening intervention therefore did not impact the location of peak torque for the concentric activation of the quadriceps and hamstrings.

As with concentric quadriceps and concentric hamstrings, angle of peak torque of the eccentric hamstrings was not significantly different (p=0.962 and p=0.699) for pre and post measures between the two groups, at either speed. Non-significant reductions were noted for both groups with a 6.65 % and 8.66 % decrease for the dominant limb of the control and intervention groups respectively, at $60°.s^{-1}$. Similar findings were indicated at $180°.s^{-1}$, with both groups experiencing an average reduction of 11.72%. Additionally, a time effect (p=0.011) was indicated at 180°.s^{-1}. As reductions were noted in both groups, a learning effect may therefore have been present. Reductions in eccentric hamstring angle of peak torque indicate an improved ability of the hamstrings to counteract the force generated during the gait cycle of the concentric quadriceps (Small *et al.,* 2010). However, the present study did not indicate significant differences between the intervention and control groups. Therefore the Nordic hamstring lower did not significantly influence the angular peak torque characteristics of the eccentric hamstrings, and thus, did not influence inherent strength and thus injury risk characteristics.

Time to Peak Torque

Time to peak torque is indicative of the capabilities of the relevant muscle group to produce force quickly (Aagaard *et al.,* (2002). A faster time to peak torque therefore represents improved muscular capability within the relevant muscle group. Findings from the present study indicated no significant changes (p=0.68 and p=0.726) for time to peak torque of the concentric quadriceps and concentric hamstrings at the strength related speed of 60°.s^{-1}. Similarly at 180°.s^{-1}, no significant differences were observed between the two groups for either activation mode (p=0.49 and p=0.98). As previously discussed, this is an expected finding as interventions such as the Nordic hamstring lowers are eccentric focused and muscle specific.

Findings for the eccentric hamstrings indicated no significant differences within groups for pre and post values (p=0.218) at the strength related speed of 60°.s^{-1}. Additionally, responses for the eccentric hamstrings at 180°.s^{-1}, indicated similar findings with no significant differences between the two groups (p=0.82) following completion of the intervention. Minimal changes were observed for both groups. The eccentric strengthening program therefore did not impact the ability of the hamstrings to generate force quickly when acting eccentrically, and thus did not improve the capability to counteract the momentum generated by the quadriceps during the late swing phase of the running gait. Additionally, few studies have identified the factors that affect torque production within this unique sample of players. The lack of significant finds with regards to time to peak torque is perhaps due to the large number of factors affecting efficacy of interventional research within this context.

Work

Improvements in work done can be seen as an increase in the capacity to sustain torque over time (Baltzopoulos *et al.,* 1983), and thus an improvement in relative muscular performance. Findings from the present study observed limb by time by group interaction effects (p=0.0128 and p=0.0137) for concentric work of the quadriceps at the isokinetic speeds of 60°.s^{-1} and 180°.s^{-1}. Further analysis revealed significant increases (13.49% and 16.09%) in work of the dominant leg of the intervention group at both speeds. Such findings are surprising and may indicate an improved ability to sustain torque through the range of motion for the concentric quadriceps within the intervention. This has negative implications as a greater capacity is required by the eccentric hamstrings to decelerate the limb during the gait cycle. This may increase the rate of hamstring fatigue, increasing the risk of injury. However, such limb discrepancies may be due to a number of factors such as asymmetrical training loads and motivation. With regards to the concentric hamstrings, total work noted no significant differences in pre and post values for both groups at either speed (p=0.635 and p=0.53), with minimal changes observed for both groups. Findings for the concentric hamstrings are expected due to the eccentric hamstring focus of the Nordic hamstring lower.

Increases in total work of the eccentric hamstrings may indicate an increased ability to tolerate force generated by the quadriceps through the range of motion, particularly within the running gait. Following completion of the intervention, no significant differences (p=0.764) were observed for total work of the eccentric hamstrings at the isokinetic speed of 60°.s^{-1}. Considering that eccentric hamstring peak torque experienced a significant increase within the intervention group, this is an unexpected finding. However, the eccentric focused exercise may purely improve peak torque capabilities, rather than the ability to sustain work through the range of motion. However, this is speculative and more research is required to better understand this relationship. Responses for total work of the eccentric hamstrings at the more isokinetic speed of 180°.s^{-1}, indicated that total work responses were not significantly different (p=0.84) within groups pre and post intervention. The Nordic hamstring lower eccentric strengthening exercise therefore did not impact the ability of the eccentric hamstrings to sustain torque through the range of motion at either isokinetic speed.

Power

Average power is an indicator of work sustained over time. Improvements in work may therefore indicate a greater capacity to perform work through the range of motion. Interestingly, at the strength related speed of 60°.s^{-1}, a significant time by group interaction effect (p=0.024) was noted for concentric quadriceps, however, post hoc analysis revealed no significant differences between the control, and intervention groups (Appendix B). At 180°.s^{-1}, no significant differences were noted between pre and post values for both groups (p=0.114). Similar findings were observed with regards to the concentric hamstrings at both 60°.s^{-1} and 180°.s^{-1}, with no significant differences noted for average power (p=0.218 and p=0.507). Such findings are important as they demonstrate no improvements in the concentric quadriceps rate of work development.

Average power of the eccentric hamstrings did not observe any significant changes within the intervention group (p=0.687) at the strength related speed of 60°.s^{-1}, when compared to the control group. Additionally, the present study observed no significant comparative improvements in average power capabilities within the intervention group (p=0.507) at the faster isokinetic speed of 180°.s^{-1}. Interestingly, a substantial increase of 12.01% was noted within the non-dominant limb at this speed. This may indicate that the Nordic hamstring intervention resulted in improvements in power capabilities, however, such increases may be hampered by factors affecting efficacy. It can therefore be concluded that average power of the eccentric hamstrings was not influenced by an eccentric strengthening exercise intervention within the Peri-urban South African context.

Performance

Although strength improvements and their relation to injury risk is a vital consideration, performance related factors are crucial to improvements on the pitch. The present study therefore identified the impact of an eccentric strengthening program on certain relevant performance variables. For justification of performance measures, please see page 62.

Vertical Jump

According to McGuigan *et al*. (2006) the vertical jump is an effective measure of lower extremity strength. Furthermore, within the context of soccer match-play, vertical jump capabilities are an important performance characteristic (Bangsbo, 1994). Additionally, simple vertical jump measures (such as the self-made device employed within the present study (page 68)), are cost effective, and a vital characteristic for interventional research within the peri-urban community based South African player. This may have implications for future research conducted in a similar context.

Vertical jump measures were performed pre and post intervention, as well as at 4 and 8 weeks. As the squat jump is an indication of the concentric capabilities of the lower limb (Cochrane *et al.,* 2004), it could be anticipated that the Nordic intervention would have no impact on the responses observed. The results of the current study support such a notion as one armed squat jump responses indicated no significant differences in responses for either group ($p=0.284$) over the course of the intervention. The Nordic hamstring intervention therefore did not influence the squat jump capabilities of the Peri-urban South African community based player.

According to Cochrane et al. (2004), the countermovement jump incorporates the eccentric component (stretch shortening cycle) of the vertical jump, a crucial indicator of the effectiveness of an eccentric intervention. Increases in jump height may therefore indicate a positive impact of the eccentric strengthening intervention. Following the completion of the intervention period, a time by group interaction effect was noted ($p=0.029$) for the countermovement jump, with post hoc analysis revealing significant improvements for the intervention group at week 8 and post intervention, when compared to the control group. Additionally, an overall significant improvement of 15.59% was observed within the intervention group. Such increases indicate an improved ability within the lower extremities to produce force, when incorporating the stretch shortening cycle. This may indicate a reduced injury risk, consistent with isokinetic findings regarding eccentric hamstring peak torque. Importantly, however, the isolation of the eccentric component may illuminate the influence of such an intervention on eccentric capability.

Eccentric Utilization Ratio

In order to isolate the eccentric component of the countermovement jump, a ratio between the countermovement jump and the squat jump was employed. This is known as the eccentric utilization ratio (McGuigan et al., 2006). Improvements may indicate an increased eccentric capacity within the hamstrings, which may in turn reduce hamstring injury risk. Over the course of the intervention, no significant changes were noted for the eccentric ratio (p=0.379), with the intervention group experiencing a greater increase of 5.3% compared to that of the control group (0.65%). Such findings indicate that the Nordic hamstring intervention did not have a significant impact on eccentric capability, as represented through vertical jump. However, there may be practical significance as substantially greater increases were observed within the intervention group. A limitation of the present study was a small sample size, and findings suggest that Nordic hamstring intervention may induce positive changes within the eccentric utilization ratio. Further research is needed within this unique context to assess its true impact. The findings presented here are in agreement with those observed for the isokinetic functional ratio.

10m Sprint

A crucial aspect of soccer related performance is sprint ability (Bangsbo, 1994). Furthermore the eccentric capabilities of the hamstrings are a crucial component of the running gait. Therefore, to assess the effect of an eccentric hamstring intervention, a 10m sprint was employed. Following completion of the intervention period, no time by group interaction effect (p=0.482) was indicated between the control and intervention groups. Both groups experienced minimal changes over the time course of investigation. An eccentric strengthening program therefore did not impact sprint capabilities within the intervention group. This is a positive finding. Responses observed for the eccentric hamstrings and vertical jump indicate that the Nordic hamstring lowers had a positive effect on strength and thus injury risk. Findings from the 10m sprint suggest that the Nordic hamstring intervention did not have a detrimental effect on performance within the unique context of the peri-urban South African player. It can therefore be concluded that an eccentric strengthening intervention, while improving strength characteristics, does not impact soccer specific performance factors.

Yo-Yo Intermittent Fatigue Shuttle Run

Although sprint times are important, the ability to resist fatigue is a crucial factor associated with soccer match-play. To identify the effect of an eccentric training regimen on intermittent endurance performance, the Yo-Yo fatigue shuttle run was employed to identify any improvements in intermittent performance. Statistical analysis indicated no difference in stage completion between the two groups ($p=0.408$) for the shuttle run, with a decrease in stage reached noted for both groups. This reduction may be due to a lack of motivation within the present population. This is a vital consideration within this context, as participants have a number of external pressures which may impact performance and motivation. Such factors will be elaborated upon in due course. The Nordic hamstring lower eccentric strengthening intervention therefore did not have a detrimental impact on performance, indicating that such intervention strategies are effective at increasing strength capabilities, while not impacting performance on the pitch.

FACTORS AFFECTING EFFICACY

A main outcome of the present research was to assess the efficacy of interventional research within the context of the amateur South African player. Although interventions such as the Nordic hamstring lowers have been proven to be successful in studies such as Mjolsnes *et al.* (2004) and Petersen *et al.* (2011), compliance has been sighted as a vital factor of an intervention of this nature (Goode *et al.,* 2014).

Compliance

Findings from the present study such as improvements in eccentric hamstring peak torque and vertical jump capabilities, indicate the potential effectiveness of such an intervention, but also indicate that there are factors that affect efficacy within this context. Furthermore, compliance from the present study was reported as 67.58 (±6.4) %. For more details see appendix B. This is substantially lower than that observed by Petersen *et al.* (2011) and Askling *et al*. (2008) with a compliance of 91% and 100% respectively. Compliance therefore may have impacted the findings from the present study. These fundamental factors affecting efficacy have been identified, and are outlined below.

Employment Characteristics

A difficulty faced by players within the peri-urban South African context is their socio-economic status and consequently the need to provide financially for their families from a young age. Due to these financial constraints, players within the present study indicated that they are often forced out of school before completion in order to begin earning (Table XXXIII). Additionally, Christie (2001) reports that black South African males (the sample used within the present study) are often employed to carry out heavy manual materials handling. This is consistent with findings from the socio-economic questionnaire (Table XXXIII), which indicated 89.47% of the included sample is employed within this industry. Furthermore, the physical demands placed on workers of this nature are substantial (Ayoub, 1989). With practices often following the work day, fatigue is therefore a significant factor, synonymous with a decrease in capacity and motivation (Rampinini *et al.,* 2009).

Figure 40: Typical housing from the Peri-urban South African environment

The effect of this fatigue on the muscular adaptation as a result of exercise is well established. According to Marras (2012), over the course of an intervention an adequate training load normally results in an increase in capacity. This is indicated as line B in Figure 41 below. However, insufficient time to recover (A) prevents adaptation and reduces the overall effects of any training program.

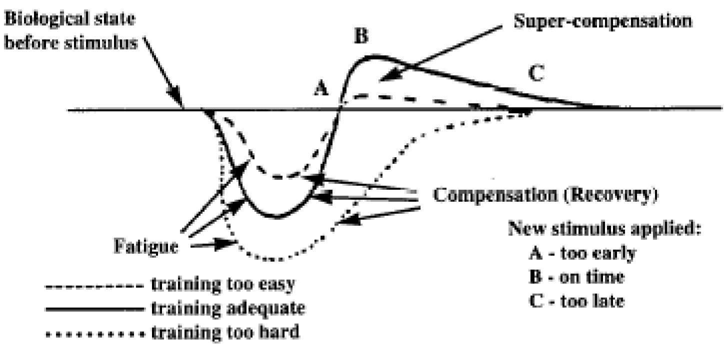


Figure 41: General workout/recovery Cycle

Employment characteristics and poor health characteristics may have resulted in greater levels of fatigue, and thus insufficient recovery was afforded to the participants. This may have resulted in a decreased capability as indicated in Figure 41. A further consideration is that the intervention was conducted within season. Cumulative fatigue may therefore have further reduced inherent capacity within the population of peri-urban South African players. It is imperative that interventions and measurement batteries consider work characteristics when designing interventional research.

Motivation

It is important to note that players included within the study do not see soccer as a professional opportunity, but rather as escapism and an outlet to remain physically active (Table XXXIII). The influence of motivation is therefore a significant factor; particularly if evaluation requires maximal effort, such as isokinetic assessment or performance related measures (McNair, 1996). As previously discussed, peri-urban players are associated with low income and low socio-economic status. Such circumstances have a significant impact on home dynamics (Lillard & Panis, 1998), influencing motivation for maximal effort within a soccer specific context. Such factors may have influenced responses noted within the sample of Peri-urban South African players. Additionally, participants within the present study were not blinded. This may play a significant role as control group members may be demotivated by changes observed within the intervention group. Additionally, the intervention group itself had greater motivation to increase performance due to the sensation of being exposed to the intervention, otherwise known as the placebo effect (Brown, 1998). As a result, the intervention group may have greater motivation during training due to the association with intervention, inducing greater strength improvements over the intervention period.

Leg Dominance

Responses within the present study observed significant differences in strength capabilities between the dominant and non-dominant limbs for concentric quadriceps total work and eccentric hamstring peak torque. According to Zakas (2006), limb asymmetries have a significant impact on injury risk particularly within the weaker limb. Additionally, according to Capranica *et al.* (1992), soccer training should increase the force generating capacity of both legs, regardless of lateral dominance. This suggests that conditioning within the present study did not adequately train independent of limb dominance. Furthermore, practices within the peri-urban context are often unstructured, with a large focus on tactical play rather than symmetrical training and conditioning. Asymmetrical development may have resulted from unbalance practice, and therefore impacted the responses observed within the present study such as greater concentric quadriceps work within the dominant limb.

Health

As previously described (page 28), the South African context is unique due to the quadruple burden of disease (Bradshaw *et al.,* 2003), particularly within populations associated with a low socio economic status (Christie, 2001). Additionally, the prevalence of non-communicable disease, communicable disease and HIV have a direct impact on physical capacity (Bradshaw *et al.,* 2003), and thus, soccer specific performance. While the peri-urban South African players included within the present study may not be affected by this burden directly, it is an important consideration for all community based research within this context. Furthermore, the peri-urban context is associated with poor nutrition, poor health and poor housing (Christie, 2001). Such factors may have affected the responses observed within the present study. This is interesting as the intervention still yielded some positive results such as increased eccentric hamstring peak torque. If the players included within the present study were provided access to improved health care and nutrition, the inherent capabilities assessed may be further improved.

Isokinetic Assessment

\An important consideration is the impact of isokinetic assessment. Although every effort was made to adequately habituate participants, responses indicated over the course of the intervention period, may show an improved ability to perform isokinetic assessment. This is indicated by a time effect for angle of peak torque of the eccentric hamstring. Participants included within the present study have a low socio economic background, and so intimidating technology such as the isokinetic dynamometer may have influenced responses over the course of the intervention. This is an important consideration with regards to future research within this context.

It is important to note that while Isokinetic assessment is the undisputed gold standard for lower extremity assessment, its applicability to the South African context is limited. The average cost of such equipment can be in excess of R1 million, whilst consultancy fees are potentially more expensive due to the constant need for renewal. Only a minute portion of the population will therefore have the financial means to access such elite equipment. Furthermore, such equipment is particularly rare within the context of Africa, due to a lack of facilities and infrastructure. Whilst isokinetics is an effective measurement technique, in order to actively engage with the context of the South African player, a more economically viable solution is needed.

CRITICAL REFLECTION

Categorization of the Amateur Player

A vital aspect identified within the present study is the categorization of the amateur player. Petersen *et al.* (2011) conducted a study of a similar nature, with a sample size of 942 players including both amateur and professional players. Participants were allocated to a control or intervention group with medical staff recording injury frequency over the following season. Here is a fundamental difference. Amateur peri-urban teams in South Africa do not have access to medical staff or even support staff. Teams are often run by a coach with minimal support. This places greater pressure on the team, as injuries etc. cannot be adequately rehabilitated by proper personnel. Players are therefore often left to 'fend for themselves', which is difficult considering a lack of access to medical aid. Furthermore, the employment characteristics of the population at play are a crucial consideration. A soccer specific injury impacts the ability to perform manual labour work. With no insurance (page 124), such players will therefore not receive income or compensation, impacting household and social dynamics.

A significant purpose of the present study was therefore to provide support for the hundreds of thousands of soccer players in South Africa that play at a grass roots level. The application of intervention strategies such as the Nordic hamstring lower, has significant implications for the peri-urban player. As highlighted within the present study, this unique South African context presents with unique limitations and challenges. It is imperative that we broaden the category of amateur to adequately represent the inherent differences between amateur players around the world. Unique solutions that are effective within this unique context can then be developed, resulting in the improvement of standards across the board.

Infrastructure

A further soccer specific issue facing the amateur player within this context is the lack of infrastructure at a grass roots level. Players that participated in the present study conduct practices and matches on municipal fields which are shared between a number of different entities and for a number of different uses. A particular example occurred when practices were cancelled due to the field being used by a travelling circus. The quality of the field is therefore substandard with uneven ground; improper drainage and inconsistent grass cover a few such issues. Effective practice is therefore difficult *in situ*, and is a severe limiting factor on interventional research of this nature. Furthermore such fields often do not have adequate facilities such as goal posts, field lines and even lighting and so practice is often dependent on a number of random factors, such as the weather.

Researcher and Player Relationship

Observations from this study indicate that the researcher plays a vital role in investigations and interventions such as the present study. Due to the lack of resources and infrastructure, ensuring compliance requires constant monitoring by related researchers. This is not sustainable, as few players can be monitored at any one time. In order to perform effective investigation, players and coaches alike must 'buy-in' to the research itself. Quantitative measures to indicate improvements are crucial to maintain motivation. Competition is also a useful mechanism to encourage all members of the squad.

A significant issue within South Africa is cultural, language and educational differences. Such discrepancies create distinct barriers between population groups due to differences in learned experience, a result of social inequality. These social issues lead to barriers to exercise intervention implementation. It is vital to engage with the unique context and history of the population at play, embrace the language and culture in order to fully engage and empathize with players. This will assist in generating sustainable solutions with community buy-in. It was observed by the researcher that this relationship between the player and the researcher is paramount. If there is no rapport, it is unlikely that retention and compliance will be high. It is vital that researchers engage with their context, develop unique solutions and instil passion and drive to enrich Peri-urban community based players.

SUMMARY

Findings from the present study indicated significant improvements within the intervention group when compared to the control for eccentric hamstrings peak torque and the countermovement jump. Such responses show that the Nordic hamstring eccentric strengthening exercise had a positive effect on strength characteristics within the Peri-urban community based South African context. Additionally, no decrements in performance measures indicate that the eccentric strength interventions did not negatively impact performance. However, responses regarding the functional ratio and the eccentric utilization ratio indicated that while comparative improvements were noted in the intervention group, such changes were not significant. Findings therefore suggest that the present study was a partial success, with improvements in eccentric strength characteristics indicating a potential reduction in injury risk although such affects may have been hampered by extraneous factors. This is an important finding of the present study as while there were improvements in eccentric hamstring strength, such improvements were not consistent at the faster isokinetic speed. This is important within the Peri-urban context as soccer specific injuries have significant implications for players due to the physical demands associated with typical employment. Additionally, it was noted that such research is not sustainable due to the reliance on the researcher to ensure completion of the exercise regimen. Future research must therefore develop comprehensive soccer specific training programs that focus on the education of coaches, to ensure sustainability of interventional practice within this unique context.

CHAPTER VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

Soccer is the most popular sport around the world. Furthermore, due to this popularity and the high profile nature of elite soccer, related research has grown substantially over the last 20 years (Carling, 2005; Olsen, 2004). Predominantly, research has focused on European (Greig *et al*., 2006 & Rahnama *et al,* 2002) and American populations (Rienzi *et al.,* 2000), with minimal research being established on African and specifically Southern African populations. As a result, South African conditioning and training practices have been adopted from investigations on differing player populations. This has significant implications as numerous studies concerning African running dominance indicate significant anthropometrical, biomechanical and physiological differences between populations, which have a significant impact on performance, and thus, injury risk (Hamilton, 2000; Larsen, 2003). These may in turn be applicable to the context of soccer. Furthermore, the majority of the South African playing population are amateurs, residing within Peri-urban environments (Lehohla, 2006). Such environments are associated with unique factors such as low socio-economic status, low income and overall poor nutrition (Simon, 2008 & Harris *et al.,* 2011). According to Mayosi *et al.* (2009), such influences have a significant impact on physical capacity. It is therefore vital to engage with the unique characteristics of the Peri-urban Black population in order to develop context specific strategies that optimize player performance and reduce injury. The first aim of this study was therefore identified. To establish the unique soccer specific strength and performance profile of the Peri-urban community based South African population.

Additionally, hamstring injury is the most frequent in soccer due to the demands of match-play, as reported in an epidemiological study by Ekstrand *et al.* (2011). Furthermore, eccentric overload has been established as the predominant cause of such injury, as the capacity of the hamstrings to produce force eccentrically is reduced over the duration of match play (Rahnama *et al.,* 2002). This time dependent effect is in agreement with findings from Ekstrand *et al.* (2011) indicating that most injuries occur during the later stages of both halves. Due to the risk of hamstring injury, preventative interventional research has been employed, establishing the effect of eccentric exercises on relative hamstring strength (Mjolsnes *et al.,* 2004; Petersen *et al.,* 2011), which has been effectively correlated to injury risk (Rahnama *et al.,* 2002). However, the efficacy of such hamstring intervention programs within the Peri-urban South African context is limited, due to a lack of research and a poor understanding of the unique factors affecting this population. Due to these aspects, the secondary aim of this thesis was to establish the efficacy of an eccentric hamstring strengthening programme on amateur low income black Southern African players.

SUMMARY OF PROCEDURES

Participants within the present study were required to be present for all four stages of investigation. The purpose of the initial testing session was to collect basic anthropometric and demographic data, as well as an injury history for each participant. Additionally, participants were habituated to the experimental procedures, including: isokinetic dynamometry, vertical jump, 10 m sprint and the Yo-Yo shuttle test. Participants were then presented with a consent form which they were required to sign, and a list of pre-test instructions.

During the second phase, participants were required to perform the test battery. Participants presented themselves for testing in groups of four. Following a 5 minute cycle ergometer warm up and 5 minutes of self-selected stretching, participants completed isokinetic thigh muscle function tests on both the dominant and non-dominant limbs at the selected testing speeds of $60°.s^{-1}$ and $180°.s^{-1}$, in both eccentric and concentric activation modes. Each set consisted of 3 repetitions for each modality and testing speed, with a 30 second rest interval between each aspect. Participants then completed the associated performance measures, namely, three countermovement jumps, three squat jumps, three 10 m sprints and the Yo-Yo shuttle test. Each test was separated by a recovery interval.

The following dependant variables were therefore selected:

Isokinetic parameters: Peak Torque, functional strength ratio, Angle of peak torque, time to peak torque, total work and average power.

Performance Parameters: 10m sprint time, Countermovement jump height, squat jump height, eccentric utilization ratio and Yo-Yo shuttle run stage completion.

The third phase involved the completion of the intervention program. Participants were randomly assigned to the control or intervention groups. The intervention group participants were then habituated to the Nordic hamstring eccentric strengthening exercise. Over the following 12 weeks, the intervention group followed the incremental program design as proposed by Mjolsnes *et al*. (2004). The exercise was completed during regular training, following completion of the warm up. Over the time course of investigation, vertical jump measures were taken for both groups at week 4 and week 8.

Following completion of the intervention program, participants were required to present themselves for the fourth session, namely, post assessment. Procedures were identical to those performed during the second session, with the addition of the administration of the socio-economic questionnaire. 32 participants were initially recruited for the present study. 4 were removed due to previous injury prior to assessment. Over the course of the intervention period, 9 participants were excluded due to factors such as non-compliance, injury or inability to complete isokinetic assessment. Therefore, 10 participants formed the intervention group, while 9 were allocated to control.

SUMMARY OF RESULTS

The cohort of Peri-urban community based South African players, recruited for participation within the present study, and indicated the following mean demographic characteristics: age of 23.53 (±5.23) years, stature of 171.34 (±6.37) cm, body mass of 66.35 (±9.07) kg, and a BMI of 22.61 (±2.67) $kg.m^{-2}$.

Strength and Performance Profile

With regards to isokinetic assessment, concentric quadriceps responses elicited peak torque values of 195 (±22) Nm and 141 (±21) Nm at $60°.s^{-1}$ and $180°.s^{-1}$ respectively. Mean angles of 74.9 (±9.6) ° and 71.8 (±8.5) ° were recorded for angle of peak torque at the relative speeds, while time to peak torque values were indicated as 534 (±126) ms and 345 (±118) ms for the concentric quadriceps at $60°.s^{-1}$ and $180°.s^{-1}$ respectively. Total work values were reported as 333 (±74) J and 230 (±50) J at the isokinetic testing speeds, whilst average power values of 123 (±10) W and 208 (±22) W were observed for $60°.s^{-1}$ and $180°.s^{-1}$.

Concentric hamstring peak torque responses were recorded as 167 (±25) Nm and 149 (±28) Nm for the isokinetic speeds selected, while angle of peak torque indicated mean angle of 55.8 (±8.2) ° at $60°.s^{-1}$ and 58.6 (±9.5) ° at $180°.s^{-1}$.Time to peak torque responses were 707 (±161) ms and 307 (±123) ms for the relevant isokinetic speeds. Total work values of the present study were reported as 274 (±72) J and 200 (±57) J at $60°.s^{-1}$ and $180°.s^{-1}$. Average power responses were observed as 80 (±13) W and 122 (±21) W for the concentric quadriceps at $60°.s^{-1}$ and $180°.s^{-1}$ respectively.

Particularly relevant values of 162 (±21) Nm were observed for peak torque of the eccentric hamstrings at $60°.s^{-1}$, which showed only a small decrease to 157 (±18) Nm at $180°.s^{-1}$. With regards to Angle of peak torque, responses were indicated as 39.2 (±9.1) ° and 46.5 (±8.9) ° at the selected isokinetic testing speeds. Additionally, responses of 1152 (±298) ms and 546 (±132) ms were reported for time to peak torque of the eccentric hamstrings at both isokinetic speeds. Total work for the present study indicated values of 262 (±71) J and 259 (±67) J at $60°.s^{-1}$ and $180°.s^{-1}$ for the eccentric hamstrings while average power responses were recorded as 96 (±15) W and 184 (±35) W for these speeds.

Mean functional ratio responses for the present study at the isokinetic speed of $60°.s^{-1}$ were reported as 0.83 (±0.11). At the faster isokinetic speed of $180°.s^{-1}$, 1.12 (±0.16) was indicated for the functional ratio within the population of Peri-urban community based South African players.

Performance indicators from the present study indicated mean responses of 55.9 (±8.3) cm for the countermovement jump, whilst 54 (±8.4) cm was observed for the squat jump. Eccentric utilization ratio responses were recorded as 1.04 (±0.08). 10 m sprint times from the present study indicated a mean value of 1.98 (±0.18) seconds, while the average stage completed during the Yo-yo shuttle run was 7.85 (±1.35).

Nordic Hamstring Intervention

The majority of isokinetic variables recorded for the concentric quadriceps and concentric hamstrings indicated no changes over the time course of the intervention. The only exception was concentric quadriceps total work which experienced a significant improvement within the dominant limb of the intervention group at both isokinetic speeds ($p<0.05$). With regards to eccentric hamstring capabilities, peak torque values experienced significant increases ($p<0.05$) in both limbs at the isokinetic speed of $60°.s^{-1}$, and significant improvements in the non-dominant limb of the intervention group at $180°.s^{-1}$ ($p<0.05$). Angle of peak torque, time to peak torque, total work and average power indicated no significant changes over the time course of the investigation for the intervention group when compared to the control. Additionally, following completion of the assessment period, functional ratio responses indicated no significant changes for the intervention group when compared to the control. This was reported at both isokinetic speeds.

Vertical jump responses indicated a significant improvement for the countermovement jump height of the intervention group at week 8 ($p<0.05$) and following completion of the intervention ($p<0.05$). The squat jump and eccentric utilization ratio both observed no significant differences between groups pre and post intervention. With regards to 10m sprint and Yo-yo shuttle run capability, no significant changes were noted between the two groups following completion of the intervention period.

STATISTICAL HYPOTHESIS

Hypothesis 1: The first null hypothesis proposed is that there will be no differences in physical responses between pre and post assessment for both control and intervention group

With regards to the first statistical hypothesis, the significant changes over time for the following variables force the rejection of the null hypothesis:

Concentric Quadriceps

- At 60°.s^{-1}, peak torque and total work
- At 180°.s^{-1}, peak torque, angle of peak torque, total work and average power

Concentric Hamstrings

- At 60°.s^{-1}, angle of peak torque and average power
- At 180°.s^{-1}, peak torque

Eccentric hamstrings

- At 60°.s^{-1}, peak torque and total work
- At 180°.s^{-1}, peak torque, angle of peak torque and total work

Performance

- Countermovement Jump and Squat Jump

Conversely, a lack of significant differences between pre and post measures leads the null hypothesis to be accepted for the following variables;

Concentric Quadriceps

- At 60°.s^{-1}, angle of peak torque, time to peak torque, average power
- At 180°.s^{-1}, angle of peak torque

Concentric Hamstrings

- At 60°.s^{-1}, Peak torque, time to peak torque, total work
- At 180°.s^{-1}, angle of peak torque, time to peak torque, total work, average power

Eccentric hamstrings

- At 60°.s^{-1}, angle of peak torque, time to peak torque, average power
- At 180°.s^{-1}, time to peak torque, average power

Functional Ratio – At 60°.s^{-1} and 180°.s^{-1}

Performance – 10m Sprint, Yo-Yo Shuttle run and Eccentric Utilization Ratio

Hypothesis 2: The second null hypothesis proposed is that there will be no differences in physical responses between the Control and Intervention groups, pre and post the 10 week Nordic intervention.

With regards to the second statistical hypothesis, no significant differences were noted between the control and intervention groups for all physical responses, pre and post the 10 week Nordic intervention. Accordingly, the null hypothesis is accepted for all variables.

However in order to investigate the true efficacy of the intervention it was necessary to look at the interaction effects between time and group:

Hypothesis 3: The third null hypothesis proposed is that there will be no interaction between time and group for physical responses, pre and post the 10 week Nordic intervention.

With regards to the third statistical hypothesis, the significant changes over time for the following variables within the intervention group force the rejection of the null hypothesis:

- Eccentric Hamstring Peak Torque and Countermovement Jump

Conversely, a lack of significant differences between groups for pre and post measures leads the null hypothesis to be accepted for the following variables:

- Concentric quadriceps; Concentric hamstrings; Eccentric hamstring angle of peak, time to peak torque, total work, average power; functional ratio; squat jump; eccentric utilization ratio; 10m sprint; Yo-Yo shuttle run

CONCLUSION

Profile of the Peri-urban community based South African player

Findings from the present study indicated lower quadriceps capabilities when compared to both South African tertiary amateur players and French professional players (Cometti *et al.,* 2001; Jones *et al.,* 2015). Interestingly, hamstring strength responses indicated an overall greater capacity when compared to these populations (Greig 2008; Jones *et al.,* 2015). As a result, the pre-exercise functional ratio of the Peri-urban community based player is greater when compared to amateur players (Cometti *et al.,* 2001) and greater than those of professionals (Greig, 2008). This is significant as the functional ratio has been identified as a significant contributor to hamstring injury risk (Small *et al.,* 2010). The Peri-urban South African player, according to the pre exercise functional ratio, therefore has a decreased hamstring injury risk due to a greater capacity to counteract the forward momentum of the lower extremity generated by the concentric quadriceps during the gait cycle (Small *et al.,* 2010).

Furthermore, vertical jump responses indicated substantially better lower extremity strength when compared to multiple populations (Cometti *et al.,* 2000; Henderson *et al.,* 2010). As a result, the eccentric utilization ratio reported similar findings to that of the functional ratio, with improved capabilities noted within the unique South African Peri-urban player. Findings from the present study therefore indicate a decreased injury risk with regards to the relative ratios, prior to exercise. However, there is still a high frequency of hamstring injury associated with the South African context (Calligeris *et al*., 2015). The impact of fatigue on the H: Q ratio over the duration of match-play may therefore have a substantial impact on injury risk.

It is important to note the unique characteristics of the population utilized in the current study (Table XXXIII). South African Peri-urban players are associated with low socio-economic status and poor education, resulting in employment within the manual labour sector (Christie, 2001). Such work carries high physical demands, which may in turn impact soccer related performance due to fatigue and an insufficient time to recover. Furthermore, low income results in difficulty accessing balanced nutrition, further influencing strength characteristics (James *et al.,* 1997. This unique context and such accompanying factors are therefore a vital consideration when investigating the Peri-urban South African player and their inherent responses.

Efficacy of the Nordic hamstring lower in Peri-urban South African players

Over the course of the intervention period, no significant changes were observed within the concentric hamstrings and quadriceps of the intervention group when compared to the control. This is an expected finding as interventions are muscle and mode specific (Tomberlin *et al.,* 1991). However, this is a positive finding as increased quadriceps strength would result in a greater capacity needed within the hamstrings to decelerate the limb during the late swing phase of the running gait (Small *et al.,* 2010).

For the targeted eccentric hamstrings, peak torque responses indicated a significant improvement in both limbs at $60°.s^{-1}$ and the non-dominant limb at $180°.s^{-1}$ within the intervention group. The Nordic hamstring eccentric strengthening intervention therefore resulted in increases in eccentric peak torque within Peri-urban South African players. According to Small *et al.* (2010) insufficient strength is a significant risk factor for injury and so such findings indicate the success of the intervention within this context. However, their capacity relative to the quadriceps is of the utmost importance, due to their antagonist relationship within the gait cycle (Croisier *et al.,* 2008).

Over the time course of investigation, the functional ratio indicated no significant differences in changes between groups at both isokinetic speeds. However, there may be practical value as the functional ratio within the intervention group indicated increases of 6.18 and 7.66 % at the selected isokinetic speeds, while the control group observed reductions of 2.38 and 3.05 %. The intervention may therefore be deemed partially successful. However, factors affecting the efficacy of the intervention such as employment characteristics, efficacy of isokinetic assessment, socio economic status etc., may play a significant role regarding the efficacy of interventions within this unique context.

Similar findings were noted for the vertical jump with the countermovement jump indicating a significant increase in jump height when compared to the control, while the squat jump indicated no significant changes following completion of the intervention. The eccentric utilization ratio therefore followed a similar trend to isokinetic findings, with no significant change within the ratio, although a non-significant increase was noted within the intervention group while the control reported no change. Additionally, performance responses for the 10m sprint and Yo-Yo shuttle run indicated no change over the time course of the intervention, indicating that the Nordic hamstring lowers did not have a detrimental effect on performance.

It can therefore be concluded that the Nordic hamstring eccentric strengthening program was partially successful within the unique Peri-urban South African context, as there were significant improvements in eccentric peak torque and countermovement jump. This is despite the fact that these individuals are involved in heavy physical work, are typically poorly nourished and are of poor health. Furthermore, the two ratio responses indicated that while no significant changes occurred, improvements were noted within the intervention group. Such findings suggest that the Nordic hamstring intervention resulted in a reduction in injury risk regarding the hamstring muscle group. This has substantial implications as Peri-urban players are often employed within the manual labour industry, with soccer specific injuries having large repercussions for income and social dynamics within this context.

Interventional strategies such as the Nordic hamstring lower, therefore have the potential to be successful within the unique Peri-urban South African context as indicated by the findings of the present study. However, there are numerous factors that affect the efficacy of such interventions within this context. It is imperative that researchers engage with the unique context of the population at play in order to generate sustainable interventions.

RECOMMENDATIONS

The majority of the soccer playing population within South Africa competes at an amateur level, often living within the Peri-urban environment. This environment is characterised by low socio-economic status, poor housing and poor health. Unfortunately, there is a distinct lack of soccer-specific research within this context. Future research should therefore engage with this reality in order to generate strategies to improve the playing standards at a grass roots level. Furthermore, injuries to players of this nature have significant ramifications as such players are often employed within the manual labour industry and are forced out of work with no-compensation. Research should therefore aim to prevent such injuries through a proactive approach rather than rehabilitation strategies. Additionally, such research will result in an improved understanding of how factors such as ethnicity, socio economic status and playing level influence injury risk.

Furthermore, future research is advised to be conducted *in situ* in order to accurately assess physical, physiological and psychophysical responses within this unique Peri-urban South Africa context.

The present study identified the profile of South African black amateur players, indicating a reduced hamstring injury risk with regards to the functional ratio. However, the impact of fatigue over the course of match play is a vital characteristic as there is still a high prevalence of hamstring injury within this unique context. Future research should therefore investigate match related responses, to better understand the contributors to injury risk.

A limitation of the present study was the small sample size. Future soccer specific community based South African research should recruit larger samples in order to generate greater statistical power and generality of findings. Furthermore, such samples should be recruited from other Peri-urban contexts in order to ascertain the extrapolation potential across amateur South African players.

A constraint of the current study was the lack of blinding with regards to the experimental design of intervention and control groups. The impact of motivation may have a crucial impact on performance within this context. Studies should ensure the blinding of the control group to develop effective inference regarding interventional research within this context.

A vital aspect identified by the present study is the unique context within which players included within the present study reside. Factors such as socio-economic status, income, employment characteristics have a substantial impact on performance. Furthermore, lack of infrastructure and investment at this level, results in a lack of technical and medical support, unlike that associated with other amateur populations such as European amateur players. It is therefore imperative that the category of amateur player be broadened in order to represent the vast differences between these amateur populations.

Interventional research such as that employed within the unique South African Peri-urban context can be successful; however, more sustainable strategies are needed. The development of holistic programs to educate coaches is therefore recommended. This will lead to improve the education regarding injury, and generate appropriate intervention and coaching methods. This has a significant impact at this level, as soccer can act as a motivator and provide a platform for social cohesion. Soccer is the future of South African transformation through sport.

LIMITATIONS

Despite efforts to control extraneous variables, it was impossible to control all such factors. When examining the implications and conclusions from the results of the present study, one must consider the following limitations.

The present study was limited by its sample size. 32 players were initially recruited, however, over the time course of investigation, participant numbers decreased to 19 due to factors such as injury, non-compliance and inability to complete isokinetic procedures. Performance measures were all performed *in situ* and so environmental factors such as humidity, sun exposure and wind resistance may have influenced individual responses. Although every effort was made to adequately habituate participants to isokinetic procedures, difficulties were observed during maximal eccentric activation. Although responses with a coefficient of variation greater than 20 were excluded, the foreign nature of isokinetic assessment within this unique context may have influenced responses.

Participants were recruited from the local Grahamstown amateur South African soccer teams. Although the players possessed high levels of physical fitness, strength and skill, extrapolation to professional players is limited. Participants were recruited from 2 similar teams. However, individual training status could not be controlled. Many players take part in their own physical training, as well as unique demands associated with employment. Identification of such factors was included within the administered socio economic questionnaire.

Participants were instructed not to consume alcohol 24 hours before testing, and avoid food and caffeine ingestion 2 hours prior to testing. Participants were asked whether they had adhered to these instructions, and if not, a new session was scheduled. The researcher could not control such factors.

The present study employed a randomly controlled trial, with control group participants not included within the intervention program. Assignments were randomized within squads to ensure balanced training effects. However, participants were not blinded to the intervention. Control group participants may have adopted the Nordic hamstring in their own time, or have lost motivation due to perceived improvements in the intervention group.

Participants performed the test battery in groups of four. This was due to time constraints and to limit the effects of de-adaptation following the intervention period. Motivational factors may have varied within these sub groups. Furthermore, fatigue over the course of the testing battery may have influenced responses obtained.

Although pre exercise indications of injury risk such as the functional ratio were identified, the impact of fatigue over the course of match-play on such responses was not assessed by the present study. Future research should identify the effects of match-specific fatigue on injury risk factor within the unique population of Peri-urban South African players.

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APPENDIX A: GENERAL INFORMATION

Letter of Information

Letter of Information (isiXhosa)

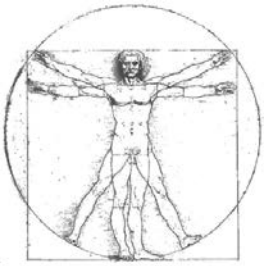
Participant Consent Form

Pre-Testing Procedure

Equiptment Checklist

Socio-Economic Questionnaire

Order of Procedure



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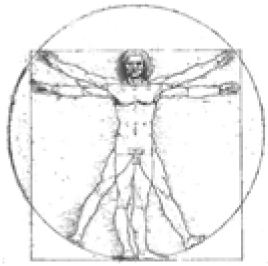


THE DEPARTMENT OF HUMAN KINETICS AND ERGONOMICS

Cell: 0732121311 Email: g08r5157@campus.ru.ac.za

Dear Participant

Thank you for showing interest in my project entitled 'The Efficacy of a Community based Eccentric Hamstring Strengthening Program in Peri-Urban Black South African Players.' This letter will explain the aims, procedures, and feedback related to this project.

<u>Aims</u>

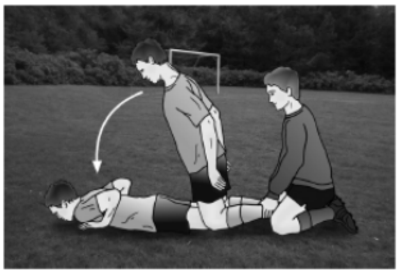
The aim of this research is to see whether a hamstring strengthening exercise improves hamstring strength and certain performance characteristics. Hamstring injury is the most common injury when playing soccer. If the player gets such an injury, they may have to spend time away from the pitch, pay to see a medical professional, or risk re-injury. In order to reduce how often hamstring injuries occur, programs and exercises that strengthen the hamstrings have been used. The most common exercise is called the Nordic Hamstring Lower. This is a partner based exercise that requires no equipment. This means it is ideal for the South African context. This exercise has been used in other countries but no one has seen how much it helps locally based players. The purpose of this project is therefore to establish the effects of a 12 week hamstring strengthening program on Eastern Cape Players, on hamstring strength and performance measures.

Procedure

The testing for this research will take place over 14 weeks. Firstly, a habituation session will be conducted. During this first session, you will be presented with the exact focus and purpose of the study. Everything will be explained in detail. This will then be followed by an introduction session. This session will take place in the HKE department at Rhodes during practice time. I will take 6 people per session. This will take at least 2hr. to show you exactly how each test will work and give time to perform these tests. Firstly I will measure your basic characteristics. I will measure your weight with a scale and your height with a measuring tape. I will then measure your heart rate using a sensor strap around your chest. This is to see how fit you are. Then we will move onto the hamstring tests.

The tests include vertical jump, Isokinetics, and performance measures. Vertical jump is used to measure how strong your legs are. There are 2 different types of jumps which show different types of strength. You will perform 3 of each jump. Isokinetics is another method of measuring how strong your legs are. It is the most accurate method. It involves a complex machine which is at the HKE Department at Rhodes; however, it is completely safe as the machine only pushes back as hard as you push. There are 3 different leg tests I will be using. These will be done on both legs as well as at two different speeds. I also want to see how this exercise helps your performance. You will perform a 10 m sprint to see how fast you are, then perform a shuttle test to assess your physical capacity as a soccer player. Your times for these tests will be taken.

I will then split your team into 2 groups. Both groups will continue training as usual, every Monday to Thursday. The only difference is that one group will perform the Nordic hamstring exercise at each practice. This will take 10 minutes to complete. It is really important that if you are in the group that doesn't do the exercise, that you don't do the exercise. I need to see how the exercise helps, and in order to do this I need to compare to players who haven't done it. This may sound unfair, but it is important to make sure the program is correct and effective. After we have completed the testing, every player will be able to perform the exercise.



If you are in the group that does the exercise, you will perform the exercise more and more over the weeks of the study. My assistants and I will always be there to help and make sure everything is running smoothly. To see the progress of both groups, at the end of each week, you will perform the 6 vertical jumps again. You will also complete the Isokinetics, 10m sprint and shuttle tests again at the end of the 12 weeks.

Risks and benefits:

This study carries some risks which must be acknowledged. Isokinetics, vertical jump and the related performance tests have all been evaluated as effective and have been designed to minimise risk. These are appropriate for soccer players. However, if performed incorrectly, they may carry additional risks. To avoid this, I will oversee all tests, but it is important you are fully dedicated to performing all measures and exercises correctly. If at any point you feel any pain, you MUST report it to me and I will stop the tests. Furthermore, the hamstring exercise has been designed to avoid injury. If you do not keep to the program however, you may be at risk of injury. Additionally, if you have a previous injury, or get injured at work or home, are intoxicated and or taking medicines you must tell the researcher. This is to make sure you are safe at all times.

What is great about this research is that it carries benefits to you. All players will get information about their soccer fitness and especially hamstring ability. I can compare it to players from the Premier League so you can see how you compare to the best players. I will also give individual advice to help you train better. You will also receive relevant hamstring strengthening, during and following the study. If you don’t perform the exercise now, I will ensure you get the benefits after the study. Finally, if successful, this intervention can be applied all over South Africa, which will reduce the extent of hamstring injuries throughout the country at amateur level. You will have been a part of helping soccer players all over the country.

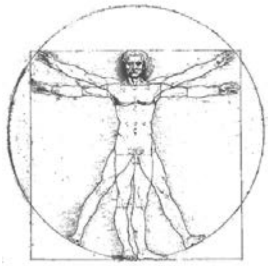
Attached is what you need to do before each testing day

Anonymity and Feedback

All the information will be anonymous and at no time will your name be used. The data collected will be used for statistical purposes and kept in the HKE department. It may be used to teach other students. You are allowed to withdraw from the study at any time during experimentation. Following the testing, you will receive a breakdown of your personal results as well as comparisons to the group and general soccer playing population. Thank you for agreeing to participate in my project. If you have any questions feel free to contact me.

Yours Sincerely,

Ben Ryan



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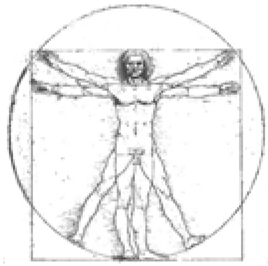


i-DEPARTMENT OF HUMAN KINETIC AND ERGONOMICS

Inombolo: 0732121311 Imeyile: g08r5157@campus.ru.ac.za

Mthathi nxaxheba

Enkosi ngobonisa umdla ekuthatheni inxaxheba kuphando nzulu lwam olubizwa, 'The Efficacy of a Community based Eccentric Hamstring Strengthening Program in Peri-Urban Black South African Players'. Lencwadi yeyokwazisa nokucacisa kakuhle iinjongo zoluphando nzulu.

<u>Iinjongo</u>

Injongo yoluphando kukubona umehluko emva kokuba uthathile inxaxheba koluphando malunga ne-Hamstrings (amadla asemlenzeni) zakho ungumdlali webhola ekhatywayo. Sifuna ukubona ukuba kulula okanye kunzima kangakanani na ukonzakala kwe-Hamstrings zakho xa udlala lomdlalo, ngoba yeyona ndawo emzimbeni le abadlali bebhola ekhantywayo bonzakala kuyo. Ukuba umdlali angonzakala kulendawo emzimbeni, lonto ingabangela ukuba angadlali ixesha elide, kufuneke abone ugqirha okanye aphinde onzakale kwakhona ethubeni apho aphinde wadlala khona. Abantu abaninzi bafumene ukuba xa uzilolonga, unciphisa ukonzakala kwakho kulendawo emzimbeni. Okona kuzilolonga okuxhaphakileyo kubizwa i-Nordic Hamstring Lower. Akukho zixhobho zifunekayo xa uzilolonga ngoluhlobo, kwaye lonto inceda kakhulu. Lendlela yokuzilolonga isetyenziswa kwezinye iindawo elizweni, kodwa ayikasetyenziswa apha eMzantsi Afrika, apho kujongwe ukuba iyasebenza okanye ayisebenzi. Injongo yoluphando kukubona iimpawu emva kweeveki ezi-12 ezivela kolulolongwa komzimba oluthile lwe-Hamstrings kwabantu abahlala eMpuma Koloni.

Inqubo

Oluphando luzokuqhubekeka kwiiveki ezi-14. Kuzoqalwa ngokwaziswa kwenqubela yophando lulonke. Ngemini yokuqala, iinkcukaca zoluphando zizokwaziswa, emva koko kwaziswe ukuba uphando luqalwa njani. Yonke lento izokwenziwa e-HKE Department yase-Rhodes, ngexesha lesiqhelo lokudlala. Kuzothathwa abantu aba-6 qho ngexesha lwesiqhelo lokudlala. Ukuzilolonga kuzothatha ixesha eli ngangeeyure ezi-2, apho umdlali ngamye uzoboniswa kakuhle ukuba kumele enze ntoni na. Kuzoqalwa ngomlinganiso womzimba ngabadlali, kwaye kubonwe ba umntu ngamnye mde kangakanani na. Kuzolinganiswa umsebenzi owenziwa yintliziyo yakho, kusetyenziswa ibanti elizobekwa esifubeni. Emva koko, kuzokulolongwa ii-Hamstrings.

Ii-Hamstrings zizololongwa nge-vertical jump, Isokinetics kunye nezinye idlela zokulolonga umzimba ezizokuboniswa ngumphandi. I-vertical jumps (ukutsiba) zezobona ukuba imilenze yomdlali yomelele kangakanani na. Zimbini iindlela zotsiba apho zibonisa iindlela ezahlukileyo zokumelela kwemilenze. Umdlali ngamnye uzokutsiba kathathu. I-Isokinetics yenye indlela yokubona ukomelela kwemilenze yomdlali, apho kusetyenziswa isixhobo esithile esikhuselekileyo. Zintathu kwakhona iindlela zokulolonga imilenze ngesisixhobo, apho umphandi azojonga ngeendlela ezimbini ukomelela kwemilenze leyo. Umphandi ufuna ukubona ukuba emveni kokuba uzilolonga, kuzonceda na ekudlaleni kwakho ibhola ekhatywayo, kengoku umdlali ngamnye uzokubaleka i-10 m ngokukhawuleza kuze sizokubona ukomelela kwakho ungumdlali webhola ekhatywayo. Amaxesha obaleka azokuthathwa ngomdlali ngamnye.

Iqela lilonke lizokwahlulwa kubekho amaqela amancinane amabini. Omabini lamaqela azokuqhubekeka nje ngesiqhelo, qho ngooMvulo kuyokutsho ngooLwezine. Umehluko ozobakhona kukuba iqela elinye kulamaqela mabini luzokuzilolonga nge-Nordic hamstring qho emveni kugqityiwe ukudlala. Lonto izothatha imizuzu eyi-10 qah. Kubalulekile ukuba uhlale kwiqela elinye maxesha onke kwaye ukuba kuthiwa musa ukuzilolonga, kubalulekile wenze nje ngokuba umphandi esitsho. Lento izobonakalisa ukuba ulolongo olu longeziweyo luyasebenza na, kuzobonakala ukuba ukhona na umehluko phakathi kwalamaqela. Ibalulekile kakhulu into yokubona ukuba kukho umehluko okanye akekho. Emva kokuba sigqibile, iqela lonke lingakwazi ukulolonga ngokufanayo.

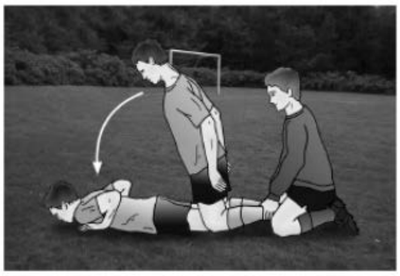


Figure 2. The Nordic hamstring exercise.

Ukuba ukwiqela eli lilolongayo, kuzofuneka uqhubekeke uzilolonga qho ngeeveki zophando kude lugqitywe uphando. Abancedisi kunye nam, umphandi, sizobesikhona qho sincedisa apho kufuneka uncedo. Ukubona inqubela yamaqela omabini, qho xa iphela iveki, abadlali bazokwenza i-vertical jumps (utsiba) kayi-6. Abadlali bazophinda benze ne-Isokinetics, babaleke i-10 m kunye nelinye uhlobo lokulolonga kwakhona emva kweveki ezi-12.

Imingeni neenzuzo

Oluphando lunemingeni ethile azochazwa. I-Isokinetics, i-vertical jump kunye nezinye iintlobo zololonga zihloliwe kwafumaniseka ukuba zilungile kwaye aziyongozi ingaphaya. Kufunyeniswe ukuba ezindlela zololongo zilungile ukwenziwa ngabadlali bebhola ekhatywayo, kodwa ukuba azenziwanga ngendlela efanelekileyo, ingabayingozi kumdlali lowo. Ukuqiniseka ukuba akukho ngozi kwabadlali, ndingumphandi ndizokuqinisekisa ukuba umdlali ngamnye uzilolonga ngendlela. Ukuba uva kabuhlungu xa uzilolonga ngezindlela, uyacelwa ukuba wazise abancedi okanye mna uqobo sizokwazi ukuba sithini kwaye siyeke. Oluhlobo lokulolonga lweziwe ukuba abadlali bangazondzakalisi. Ukuba wakhe wonzakala phambili okanye uyewonzakala ekhaya nasemsebenzini, okanye enxilile okanye uthatha/usela amayeza, uyacelwa wazise umphandi kuze ungonzakali.

Into emnandi ngoluphando yeyokuba ineenzuzo ezizokunceda wena ungumdlali webhola ekhatywayo. Wonke umdlali uzokufumana iinkcukaca malunga nenqubelo yakhe yoluphando. Ndingumphandi ndizokwazi ukubona umehluko phakathi kweliqela nalawe-Premier league, sizokwazi ukubona ngabaphi abadlali abaphambili. Ndingakwazi nokucebisa abadlali ukuba bazilolonge njani xa befuna ukuba kwizinga eliphezulu ekudlaleni. Umziba wakho emveni kwaye naxa uthatha inxaxheba koluphando luzokuba kwizinga eliphucukileyo. Ukuba oluphando luhambe ngedlela eyiyo, ezindlela zokulolonga zingaqalwa ukusetyenziswa kwilizwe lonke apha eMzantsi Afrika, lincede nabadlali abaninzi abadlala ibhola ekhatywayo. Wena ungumthathi nxaxheba koluphando uzokube uluncedo kwabadlali bonke boMzantsi Afrika bebhola ekhatywayo.

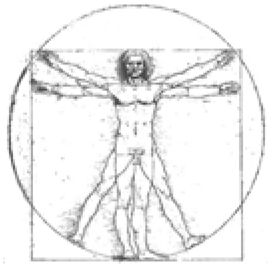
Kulencwadi kudityaniswe iinkcukaca ezizofuneka ezenzile phambi kokuba uqale uphando qoh, mini nganye.

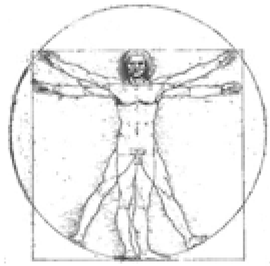
Ukufihleka kweenkcukaca zomthathi nxaxheba

Iinkcukaca zonke zabadlali zizokugcinywa zifihlakele kwaye amagama enu awazokufuneka. Inqubela yakho yoluphando izokugcinwa ngumphandi akwazi ukuthelekisa inqubela yakho kwiiveki ezizayo kwaye incede nakwengcebiso kwabanye abantu abenza oluphando. Ezonkcukaca zizogcinwa e-HKE Department. Umntu uyakwazi ukurhoxisa naninina xa efuna koluphando. Emveni kogqiba uphando, umdlali ngamnye uzokufumana iinkcukaca ezithexhaxha ngenqubela yakhe, apho azokwazi ukubona umehluko phakathi kokuqala kwakhe naxa esegqibile noluphando. Ndiyabulela ngongazenzisiyo ngokuthatha inxaxheba koluphando lwam. Ukuba unemibuzo, ndiyacela undazise nanini na.

Ozithobileyo,

Ben Ryan





THE DEPARTMENT OF HUMAN KINETICS AND ERGONOMICS

Cell: 0732121311 Email: g08r5157@campus.ru.ac.za

'The Efficacy of a Community Based 10 week Hamstring Strengthening Program in Peri-urban Black South African Players'

I, ________________________________ having been fully informed of the research project entitled; 'The Efficacy of a Community Based 10 week Hamstring Strengthening Program in Peri-urban Black South African Players' and hereby give my consent to act as a participant in the above-mentioned research.

I am fully aware of the research procedures involved with this study, as well as any potential risk and benefits that may be associated with my participation. This has been explained extensively, both verbally and in writing. I understand that I am required to report any previous injury, or any medicine that is currently prescribed to me. This information will be accessed anecdotally and if necessary, through my medical practitioner. In agreeing to participate in this study, I wave any legal recourse against the researchers from the HKE Department of Rhodes University, from any claims resulting from personal injury whilst participating in the above research project.

I am fully aware that the HKE Department is not responsible for any injuries due to personal negligence and non-compliance. I am also aware that the HKE Department does have a responsibility to act in the small chance of a protocol-induced injury. I realize it is necessary for me to report any signs or symptoms indicating any abnormality or distress to the researchers promptly during any of the experimental sessions. I am aware that I may withdraw my consent and from participation in the study at any time without negative repercussions. I am aware that my anonymity will be protected at all times by the researcher, and agree that all the information collection during this research project may be used and published for statistical or scientific purposes.

I have read the letter of information accompanying this form in its entirety and understand its components completely. Any questions which I may have had, have been answered entirety and to my satisfaction.

I therefore consent to participate voluntarily in this research project.

Participant Providing Consent:

____________________	__________________	___________________
(Print Name)	(Signed)	(Date)

Witness:

(Print Name)	(Signed)	(Date)

Researcher Administering Informed Consent:

(Print Name)	(Signed)	(Date)

PRE-TESTING PROCEDURE

Please inform the researcher of any factors that you think may influence the results on the day of testing (medication, illness, and asthma). In order to establish reliable results, please follow certain pre-testing instructions before completing the testing for Isokinetics, vertical jump and the performance measures:

24 Hours Prior to testing

- Do not consume alcohol or coffee before the exercise session
- Do not participate in exercise that makes you feel tired and affects your ability to perform
- Do not take any medication unless prescribed (If so, please inform the researcher)

On the day of testing

- Eat a solid balanced meal 2 hours before the testing session.

Please comply with these rules as it will assist me greatly in collecting accurate and beneficial data. Your co-operation is greatly appreciated.

EQUIPTMENT CHECKLIST

1. Biodex turned on and working
2. Warm up Cycle Ergometer
3. Toledo® Scale
4. Harpenden Stadiometer
5. Cones
6. Whistle
7. Speakers Turned on and Working
8. Yo-Yo Instructions – Bleep Test iPhone app
9. Stop Watch
10. Vertical Jump Measuring Device
11. Chalk
12. Camera (iPhone)
13. Data Collection Sheets

Socio-Economic Questionnaire

General

Name: ____

Age: __________________

Stature: ___________________

Mass: _____________________

Race: _________________________

Home Language: __________________

Home Town: ____________________

Do you have medical aid or are involved in a medical assistance program?

____

Work

What is your Occupation?

____

What tasks do you complete at work?

____

____

____

What is your monthly income?

____

What transport do you use to get to work?

____

The Household

Who do you live with?

____

____

____

Who supports the family financially? Is it more than one person?

____

____

____

How much does the family earn per month?

____

____

____

Education

Have you attended school? To what level did you study?

____

____

____

____

What is the reason you stopped studying?

____

____

____

Soccer

What teams have you competed for?

____

____

Describe the soccer training you have received?

How important is soccer to you?

Have you experienced a soccer related injury?

What access to rehabilitation etc. do you have?

ORDER OF PROCEDURE

Introductory Session

1) Welcome Participant
2) Introduction
3) Give participants letter of information
4) Complete informed consent form
5) Habituate to vertical jump, 10m sprint, shuttle test and intervention overview
6) Habituate to Isokinetic procedures (60/180 + H/Q + Ecc/Con)
7) Explanation of testing protocol and equipment
8) Describe pre-test instructions
9) Answer queries

Baseline Assessment

1) Welcome participants
2) Assignment of Participant
3) Perform warm-up (5 minute cycle and 5 minute self-selected stretches)
4) Re-familiarization with isokinetic procedures
5) Queries addressed
6) Selection of limb to be tested 1st (Randomized)
7) Quadriceps eccentric and concentric for both speeds completed
8) Hamstring eccentric and concentric for both speeds completed
9) Assessment of other limb
10) Recovery Period
11) 10m Sprint performance
12) Break
13) Shuttle test performance
14) Break
15) Vertical Jump Completion – 6 jumps (3 x CMJ, 3 x SJ)
16) Short cool down

Intervention

1) Intervention Group habituated to Nordic hamstrings lower

2) Normal training
3) Following warm up, performance of Nordic hamstring regime according to the incremental design
4) Week 4 and Week 8, performance of vertical jump

Post Assessment

1) Identical to baseline assessment
2) Administration of Socio Economic Questionnaire

APPENDIX B: SUMMARY REPORTS

Compliance

Isokinetic Assessment Summary

Statistical Analyses

Week 1	Week 2		Week 3			Week 4			Week 5			Week 6			Week 7		
X	X	X	X	X	X	X	Easter	Easter	Easter	Easter	X	X	Mid Week Game		X	X	X
X	X	X	Family	Family	X	Family	Easter	Easter	Academic	Easter	X	X	Mid Week Game	X	Family	Family	X
X	X	X	Work	X	X	X	X	X	Easter	Easter	Work	X	Rain	Rain	X	Midweek Game	X
X	X	X	X	X	X	X	X	X	Easter	Easter	X	X	Rain	Rain	X	Midweek Game	X
X	X	X	X	X	X	X	X	Work	Easter	Easter	Work	X	Rain	Rain	X	Midweek Game	X
X	X	X	X	X	X	X	X	X	Easter	Easter	X	X	Rain	Rain	X	Midweek Game	X
X	X	X	X	X	X	X	Easter	Easter	Easter	Rain	X	X	Mid Week Game	X	X	X	X
X	X	X	X	X	X	X	X	X	Easter	Easter	X	X	Rain	Rain	X	Midweek Game	X
X	X	X	X	X	X	X	X	Rest	Easter	Easter	X	X	Rain	Rain	X	Midweek Game	X
X	X	X	X	X	X	Work	X	X	Easter	Easter	X	X	Rain	Rain	X	Midweek Game	X

Week 8			Week 9			Week 10			Week 11			Week 12			Sessions Completed	% Compliance
X	X	X	X	X	X	X	X	X	X	X	X	X	Sick	Sick	25	75.76
Academic	X	X	Academic	X	X	Academic	X	X	Sick	X	X	X	X	Work	18	54.55
X	X	X	X	Break	Break	Work	Work	X	X	X	X	Enforced Break	X	Work	20	60.61
X	X	X	X	Break	Break	X	X	Family	X	X	X	Enforced Break	X	X	24	72.73
X	X	X	X	Break	Break	Work	X	X	X	X	X	Enforced Break	X	Work	21	63.64
X	X	X	X	Break	Break	X	Academic	X	X	X	X	Enforced Break	X	Work	23	69.70
X	X	X	Work	Work	X	Sick	Sick	Sick	X	X	X	X	Work	X	22	66.67
X	X	X	X	Break	Break	X	Academic	X	X	X	X	Enforced Break	X	X	24	72.73
X	X	X	X	Break	Break	X	X	X	X	X	X	Enforced Break	X	Work	23	69.70
X	X	X	X	Break	Break	Work	X	X	X	X	X	Enforced Break	X	X	23	69.70

Mean 67.58
SD 6.40

Table XXXIV: Summary tables of Isokinetic Responses at $60°.s^{-1}$ and $180°.s^{-1}$, and performance measures for both the control and intervention groups

At 60 °	Control						Intervention					
	Dominant			Non-Dominant			Dominant			Non-Dominant		
	PRE	POST	Change (Abs/%)	PRE	POST	Change (Abs/%)	PRE	POST	Change (Abs/%)	PRE	POST	Change (Abs/%)
Concentric Quadriceps												
Peak Torque (Nm)	193.76 (18.1)	197.17 (17.72)	3.41 (1.76)	187.37 (20.58)	189.01 (20.06)	1.64 (0.88)	202.41 (19.25)	205.99 (20.61)	3.58 (1.77)	195.68 (29.71)	201.28 (29.64)	5.6 (2.86)
Time to Peak Torque (ms)	535.56 (138.48)	518.89 (136.79)	16.67 (3.11)	566.67 (136.84)	542.22 (131.89)	24 (4.31)	512 (105.07)	542 (142.74)	30 (5.86)	527 (139.85)	520 (101.43)	7 (1.33)
Angle of Peak Torque (°)	76.67 (9.55)	72.44 (8.32)	4.22 (5.51)	76.11 (9.6)	73.78 (11.23)	2.33 (3.07)	75.30 (11.41)	73.60 (9.57)	1.7 (2.26)	72.1 (8.76)	72.5 (9.2)	0.4 (0.55)
Total Work (J)	360.52 (75.31)	350.70 (77.58)	9.82 (2.72)	312.01 (73.15)	323.24 (84.07)	11.23 (3.6)	329.51 (79.27)	373.97 (86.2)	44.46 (13.49)	331.59 (73.16)	355.15 (60.6)	23.56 (7.11)
Average Power (W)	126.86 (9.4)	123.73 (7.56)	3.12 (2.46)	121.71 (9.24)	118.46 (11.91)	3.26 (2.67)	124.06 (8.01)	131.56 (14.1)	7.5 (6.05)	122.6 (14.45)	128.09 (18.03)	5.49 (4.48)
Eccentric Quadriceps												
Peak Torque (Nm)	201.27 (20.78)	208.54 (17.95)	7.27 (3.61)	191.11 (22)	201.96 (17.39)	10.85 (5.67)	225.4 (25.61)	243.03 (31.1)	17.63 (7.82)	212.83 (37.37)	225.34 (32.54)	12.51 (5.87)
Time to Peak Torque (ms)	1136.67 (198.56)	1166.67 (190.92)	30 (2.64)	1062.23 (318.15)	1012.22 (333.38)	50.01 (4.7)	1192 (219.64)	1272 (318.53)	80 (6.71)	1267 (415.4)	1240 (353.63)	27 (2.13)
Angle of Peak Torque (°)	74.89 (8.74)	72 (8.03)	2.89 (3.86)	75.44 (8)	72.11 (8.62)	3.33 (4.41)	71.50 (8.67)	67.7 (8.6)	3.8 (5.31)	74.8 (9.44)	72.2 (8.32)	2.6 (3.47)
Total Work (J)	274.03 (43.8)	295.53 (50.03)	21.5 (7.85)	248.57 (46.86)	267.5 (44.31)	18.93 (7.61)	268.37 (71.27)	298.28 (86.54)	29.91 (11.14)	274.88 (53.75)	280.13 (53.64)	5.25 (1.9)
Average Power (W)	107.62 (12.31)	116.26 (12.64)	8.64 (8.02)	99.23 (10.45)	106.54 (11.62)	7.31 (7.36)	119.16 (18.53)	124.34 (19.68)	5.81 (4.34)	105.7 (13.3)	114.76 (15.05)	9.06 (8.57)
Concentric Hamstrings												
Peak Torque (Nm)	164.98 (17.88)	162.54 (22.74)	2.43 (1.47)	162.87 (23.72)	160.92 (21.5)	1.94 (1.19)	179.11 (37.39)	186.6 (34.13)	7.49 (4.18)	163.97 (19.68)	171.41 (26.07)	7.44 (4.54)
Time to Peak Torque (ms)	624.44 (114.79)	693.33 (206.16)	68.89 (11.03)	751.11 (187.65)	698.89 (94)	52.22 (6.95)	717 (140.4)	658 (152.67)	59 (8.23)	732 (187.66)	762 (155.26)	30 (4.1)
Angle of Peak Torque (°)	55 (8.09)	49.33 (8.23)	6.67 (12.12)	55.33 (10.15)	49.22 (7.48)	6.11 (11.04)	57.3 (7.47)	49.5 (8.63)	7.8 (13.61)	55.4 (7.97)	51.7 (7.32)	3.7 (6.68)
Total Work (J)	256.68 (49.07)	242.04 (32.12)	14.63 (5.7)	250.16 (54.33)	265.58 (49.48)	15.42 (6.17)	296.83 (97.68)	308.19 (116.13)	11.36 (3.83)	290.4 (75.96)	292.59 (92.31)	2.19 (0.75)
Average Power (W)	80.27 (11.57)	82.36 (15.19)	2.09 (2.6)	81.56 (14.1)	85.74 (13.52)	4.19 (5.14)	82.89 (15.77)	87.62 (17.25)	4.73 (5.71)	78.99 (12.68)	82.13 (15.59)	3.14 (3.98)
Eccentric Hamstrings												
Peak Torque (Nm)	163.81 (22.14)	162.86 (22.48)	0.96 (0.58)	159.57 (16.15)	159.67 (18.37)	0.1 (0.06)	168.6 (22.02)	182.5 (28.29)	13.9 (8.24)	157.97 (26.89)	167.01 (26.87)	9.04 (5.72)
Time to Peak Torque (ms)	1330 (228.64)	1417.78 (183.9)	87.78 (6.6)	957.78 (288.78)	1098.89 (828.69)	141.11 (14.73)	1348 (213.27)	1260 (254.99)	88 (6.53)	972 (229.14)	1010 (217.26)	.38 (3.91)
Angle of Peak Torque (°)	40.11 (8.82)	37.44 (8.34)	2.67 (6.65)	38.56 (10.81)	35.56 (10.6)	3 (7.78)	38.1 (7.34)	34.8 (8.7)	3.3 (8.66)	40 (10.35)	38 (10.15)	2 (5)
Total Work (J)	270.82 (84.19)	268.62 (87.91)	2.2 (0.81)	253.74 (51.84)	284.57 (70.86)	30.82 (12.15)	286.86 (74.42)	295.95 (81.58)	9.09 (3.17)	238.33 (73.06)	265.19 (81.72)	26.86 (11.27)
Average Power (W)	96.9 (11.72)	100.74 (18.58)	3.84 (3.97)	99.97 (15.81)	101.23 (15.78)	1.27 (1.27)	97.92 (18.76)	100.99 (18.93)	3.07 (3.14)	89.94 (13.64)	96.05 (15.61)	6.11 (6.79)
Functional Ratio	0.85 (0.1)	0.83 (0.1)	0.02 (2.38)	0.86 (0.11)	0.85 (0.09)	0.01 (1.23)	0.83 (0.07)	0.88 (0.09)	0.05 (6.18)	0.82 (0.16)	0.84 (0.14)	0.02 (2.48)

At 180 °

	Control						Intervention					
	Dominant			Non-Dominant			Dominant			Non-Dominant		
	PRE	POST	Change (Abs/%)	PRE	POST	Change (Abs/%)	PRE	POST	Change (Abs/%)	PRE	POST	Change (Abs/%)
Concentric Quadriceps												
Peak Torque (Nm)	143.46 (24.19)	145.79 (23.44)	2.33 (1.63)	142.38 (26.92)	139.81 (27.74)	2.57 (1.8)	142.08 (16.18)	147.42 (15.46)	5.34 (3.76)	137.66 (20.11)	145.16 (21.9)	7.5 (5.45)
Time to Peak Torque (ms)	374.44 (125.01)	396.67 (87.32)	22.22 (5.93)	390 (161.4)	326.67 (61.85)	63.33 (16.24)	311 (80.75)	327 (141.43)	16 (5.14)	313 (95.46)	317 (108.33)	4 (1.28)
Angle of Peak Torque (°)	71.89 (8.95)	66.22 (9.9)	5.67 (7.88)	70.56 (9.18)	65.67 (8.11)	4.89 (6.93)	73 (8.83)	66 (8.89)	7 (9.59)	71.8 (8.19)	67.9 (8.88)	3.9 (5.43)
Total Work (J)	242.18 (36.79)	242.84 (35.23)	0.67 (0.28)	218.1 (39.72)	228.53 (42.63)	10.43 (4.78)	228.15 (58.09)	264.85 (46.22)	36.7 (16.09)	235.12 (64.47)	259.06 (61.32)	23.94 (10.18)
Average Power (W)	212.63 (18.4)	213.67 (26.98)	1.03 (0.49)	195.42 (21.08)	207.02 (23.38)	11.6 (5.94)	217.62 (19.61)	230.01 (21.96)	12.39 (5.69)	208.93 (25.23)	223.5 (32.83)	14.57 (6.97)
Eccentric Quadriceps												
Peak Torque (Nm)	201.46 (17.14)	201.46 (13.97)	0 (0)	192.74 (23.6)	192.28 (31.65)	0.46 (0.23)	203.69 (42.31)	205.76 (38.81)	2.07 (1.02)	197.45 (36.95)	204.68 (33.27)	7.23 (3.66)
Time to Peak Torque (ms)	706.67 (157.56)	742.22 (126.07)	35.55 (5.03)	797.78 (98.33)	766.67 (101.98)	31.11 (3.89)	747 (195.96)	776 (118.62)	29 (3.88)	779 (144.95)	732 (129.43)	47 (6.03)
Angle of Peak Torque (°)	72.89 (8.15)	68.22 (7)	4.67 (6.4)	71.11 (9.23)	67.22 (8.86)	3.89 (5.47)	72.3 (8.41)	68.6 (10.3)	3.7 (5.11)	73.9 (7.82)	68.9 (9.72)	5 (6.76)
Total Work (J)	266.82 (76.56)	285.06 (90.14)	18.24 (6.83)	284.13 (86.61)	298.57 (92.3)	14.44 (5.08)	253.26 (73.37)	263.27 (88.34)	10.01 (3.95)	251.81 (57.78)	263.74 (53.19)	11.93 (4.73)
Average Power (W)	190.21 (21.29)	194.63 (18.35)	4.42 (2.32)	182.12 (19.31)	185.36 (25.11)	3.24 (1.78)	194.88 (30.24)	196.73 (30.87)	1.85 (0.95)	190.95 (36.01)	199.59 (36.53)	8.64 (4.52)
Concentric Hamstrings												
Peak Torque (Nm)	144.58 (23.69)	146.63 (22.68)	2.06 (1.47)	150.4 (21.74)	148.57 (24.54)	1.94 (1.19)	154.78 (35.37)	162.39 (35.55)	7.61 (4.92)	146.45 (31.53)	152.94 (39.75)	6.49 (4.43)
Time to Peak Torque (ms)	337.78 (164.15)	335.56 (122.38)	2.22 (0.66)	308.89 (139.32)	287.78 (84.52)	21.11 (6.83)	282 (83.51)	288 (106.33)	6 (2.13)	306 (114.23)	275 (93.48)	31 (10.13)
Angle of Peak Torque (°)	55 (10.11)	54.22 (8.87)	0.78 (1.41)	57.22 (8.09)	53.78 (9.4)	3.44 (6.02)	60.2 (8.53)	56.9 (7.28)	3.3 (5.48)	61.3 (10.97)	56.6 (7.93)	4.7 (7.67)
Total Work (J)	194.5 (44.87)	205.63 (50.23)	11.13 (5.72)	204.76 (50)	207.07 (53.16)	2.31 (1.13)	199.73 (72.86)	221.19 (86.84)	21.46 (10.74)	202.28 (63.85)	208.01 (69.2)	5.73 (2.83)
Average Power (W)	119.71 (19.33)	125.98 (16.96)	6.27 (5.23)	129.52 (22.3)	124.87 (19.66)	4.66 (3.59)	120.08 (25.36)	121.3 (24.23)	1.22 (1.02)	121.19 (18.53)	127.69 (14.9)	6.5 (5.36)
Eccentric Hamstrings												
Peak Torque (Nm)	161.49 (12.46)	160.02 (12.3)	1.47 (0.58)	152.83 (12.53)	155.9 (11.86)	3.07 (2.01)	165.02 (28.49)	170.89 (25.95)	5.87 (3.56)	149.62 (14.68)	168.8 (24.8)	19.18 (12.82)
Time to Peak Torque (ms)	576.67 (186.41)	575.56 (153.31)	1.11 (0.19)	534.44 (114.03)	558.89 (171.57)	24.44 (4.57)	554 (114.52)	583 (138.09)	29 (5.23)	523 (123.92)	548 (149.06)	25 (4.78)
Angle of Peak Torque (°)	47.11 (10.54)	40.89 (8.59)	6.22 (13.21)	46.89 (8.68)	40.67 (7.63)	6.22 (13.27)	45.4 (9.97)	40.6 (9.71)	4.8 (10.57)	46.7 (7.69)	42.1 (7.19)	4.6 (9.850
Total Work (J)	267.3 (61.82)	281.68 (61.69)	14.38 (5.38)	231.68 (61.97)	253.43 (65.03)	21.76 (9.39)	281.37 (84.49)	289.47 (73.81)	8.1 (2.88)	256.02 (57.91)	287.95 (83.47)	31.93 (12.47)
Average Power (W)	195.99 (32.9)	200.64 (23.95)	4.66 (2.38)	179.66 (37.28)	184.82 (33.61)	5.17 (2.88)	188.29 (43.64)	192.26 (35.32)	3.97 (2.11)	287.95 (83.47)	193.72 (61.15)	20.77 (12.01)
Functional Ratio	1.15 (0.2)	1.12 (0.16)	0.04 (3.05)	1.11 (0.22)	1.15 (0.23)	0.04 (3.87)	1.16 (0.16)	1.16 (0.11)	0 (0)	1.09 (0.08)	1.18 (0.21)	0.08 (7.66)

	Control							Intervention						
	PRE	Week 4	Change (Abs/%)	Week 8	Change (Abs/%)	POST	Change (Abs/%)	Change (Abs/%)	Week 4	Change (Abs/%)	Week 8	Change (Abs/%)	POST	Change (Abs/%)
Vertical Jump														
Countermovement Jump	56.81 (8.4)	58.33 (7.74)	1.52 (2.67)	59.33 (7.1)	2.52 (4.43)	60.33 (7.23)	1.35 (2.37)	53.96 (9.14)	56.59 (8.48)	3.36 (6.23)	60.56 (9.11)	6.6 (12.23)	62.37 (8.47)	8.41 (15.59)
Squat Jump	54.67 (8.59)	55.48 (8.47)	0.81 (1.49)	56.41 (7.64)	1.74 (3.18)	57.96 (8.5)	0.85 (1.56)	53.04 (9.52)	53.81 (8.38)	1.98 (3.74)	56.67 (9.08)	3.62 (6.83)	58.26 (9.3)	5.22 (9.84)
Eccentric Utilization Ratio	1.05 (0.1)	1.06 (0.05)	0.01 (0.98)	1.06 (0.06)	0.01 (0.96)	1.05 (0.05)	0.006 (0.65)	1.02 (0.06)	1.05 (0.04)	0.02 (2.49)	1.07 (0.04)	0.05 (4.95)	1.07 (0.04)	0.05 (5.33)

	Control			Intervention		
	PRE	POST	Change (Abs/%)	PRE	POST	Change (Abs/%)
10m Sprint	1.95 (0.122)	1.99 (0.168)	0.04 (2.22)	2.015 (0.239)	1.988 (0.17)	0.03 (1.37)
Yo-Yo Shuttle	7.14 (0.98)	7.05 (0.68)	0.09 (1.24)	8.47 (1.36)	8.23 (1.214)	0.25 (2.91)

Statistical Analysis

Concentric Quadriceps

Peak Torque - 60°.s^{-1}

Effect	Repeated Measures Analysis of Variance (Isokinetics in Results - New F Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 42.81558 SS	Degr. of Freedom	MS	F	p
Intercept	2928860	1	2928860	1597.698	0.000000
Group (1=CON, 2=INT)	1715	1	1715	0.936	0.346933
Error	31164	17	1833		
LIMB	800	1	800	4.864	0.041476
LIMB*Group (1=CON, 2=INT)	11	1	11	0.069	0.795337
Error	2795	17	164		
TIME	240	1	240	9.066	0.007868
TIME*Group (1=CON, 2=INT)	20	1	20	0.761	0.395161
Error	450	17	26		
LIMB*TIME	0	1	0	0.004	0.952040
LIMB*TIME*Group (1=CON, 2=INT)	17	1	17	0.832	0.374333
Error	347	17	20		

Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 926.79, df = 17.378

Cell No.	Group (1=CON, 2=INT)	LIMB	TIME	{1} 193.76	{2} 197.17	{3} 187.37	{4} 189.01	{5} 202.41	{6} 205.99	{7} 195.68	{8} 201.28
1	1	1	1		0.743234	0.112203	0.383217	0.998106	0.984784	1.000000	0.999231
2	1	1	2	0.743234		0.004978	0.023160	0.999929	0.997863	1.000000	0.999986
3	1	2	1	0.112203	0.004978		0.992539	0.953902	0.874791	0.998530	0.969235
4	1	2	2	0.383217	0.023160	0.992539		0.974846	0.917083	0.999649	0.984542
5	2	1	1	0.998106	0.999929	0.953902	0.974846		0.644790	0.060977	0.999004
6	2	1	2	0.984784	0.997863	0.874791	0.917083	0.644790		0.001896	0.332215
7	2	2	1	1.000000	1.000000	0.998530	0.999649	0.060977	0.001896		0.166906
8	2	2	2	0.999231	0.999986	0.969235	0.984542	0.999004	0.332215	0.166906	

Peak Torque - 180°.s^{-1}

Effect	Repeated Measures Analysis of Variance (Isokinetics in Resu Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 4: SS	Degr. of Freedom	MS	F	p
Intercept	1549151	1	1549151	893.6326	0.000000
Group (1=CON, 2=INT)	1	1	1	0.0005	0.981781
Error	29470	17	1734		
LIMB	223	1	223	1.4037	0.252404
LIMB*Group (1=CON, 2=INT)	0	1	0	0.0010	0.974535
Error	2706	17	159		
TIME	188	1	188	4.8722	0.041326
TIME*Group (1=CON, 2=INT)	202	1	202	5.2396	0.035148
Error	657	17	39		
LIMB*TIME	9	1	9	0.2298	0.637807
LIMB*TIME*Group (1=CON, 2=INT)	59	1	59	1.5254	0.233599

Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 886.12, df = 17.759

Cell No.	Group (1=CON, 2=INT)	LIMB	TIME	{1} 143.46	{2} 145.79	{3} 142.38	{4} 139.81	{5} 142.08	{6} 147.42	{7} 137.66	{8} 145.16
1	1	1	1		0.991116	0.999937	0.907366	1.000000	0.999988	0.999840	1.000000
2	1	1	2	0.991116		0.931947	0.487071	0.999992	1.000000	0.998540	1.000000
3	1	2	1	0.999937	0.931947		0.984644	1.000000	0.999937	0.999960	0.999999
4	1	2	2	0.907366	0.487071	0.984644		1.000000	0.999054	1.000000	0.999906
5	2	1	1	1.000000	0.999992	1.000000	1.000000		0.556815	0.750562	0.946504
6	2	1	2	0.999988	1.000000	0.999937	0.999054	0.556815		0.043504	0.989977
7	2	2	1	0.999840	0.998540	0.999960	1.000000	0.750562	0.043504		0.189594
8	2	2	2	1.000000	1.000000	0.999999	0.999906	0.946504	0.989977	0.189594	

Angle of Peak Torque - 60°.s^{-1}

Repeated Measures Analysis of Variance (Isokinetics in Results - Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 11.77(

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	415724.5	1	415724.5	2997.642	0.000000
Group (1=CON, 2=INT)	35.8	1	35.8	0.258	0.617820
Error	2357.6	17	138.7		
LIMB	14.7	1	14.7	0.118	0.735925
LIMB*Group (1=CON, 2=INT)	30.5	1	30.5	0.244	0.627459
Error	2124.9	17	125.0		
TIME	73.1	1	73.1	1.503	0.236929
TIME*Group (1=CON, 2=INT)	32.7	1	32.7	0.673	0.423459
Error	826.6	17	48.6		
LIMB*TIME	18.8	1	18.8	0.273	0.607783
LIMB*TIME*Group (1=CON, 2=INT)	0.1	1	0.1	0.001	0.978244
Error	1171.4	17	68.9		

Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 103.80, df = 30.549

Cell No.	Group (1=CON, 2=INT)	LIMB	TIME	{1} 76.667	{2} 72.444	{3} 76.111	{4} 73.778	{5} 75.300	{6} 73.600	{7} 72.100	{8} 72.500
1	1	1	1		0.952970	1.000000	0.994300	0.999989	0.997652	0.974666	0.984845
2	1	1	2	0.952970		0.977584	0.999962	0.998512	0.999997	1.000000	1.000000
3	1	2	1	1.000000	0.977584		0.998488	1.000000	0.999363	0.987847	0.993489
4	1	2	2	0.994300	0.999962	0.998488		0.999977	1.000000	0.999956	0.999993
5	2	1	1	0.999989	0.998512	1.000000	0.999977		0.999728	0.985919	0.993524
6	2	1	2	0.997652	0.999997	0.999363	1.000000	0.999728		0.999881	0.999985
7	2	2	1	0.974666	1.000000	0.987847	0.999956	0.985919	0.999881		1.000000
8	2	2	2	0.984845	1.000000	0.993489	0.999993	0.993524	0.999985	1.000000	

Angle of Peak Torque - 180°.s^{-1}

Effect	Repeated Measures Analysis of Variance (Isokinetics in Results - N Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 10.5538 SS	Degr. of Freedom	MS	F	p
Intercept	362185.9	1	362185.9	3251.692	0.000000
Group (1=CON, 2=INT)	22.6	1	22.6	0.203	0.658219
Error	1893.5	17	111.4		
LIMB	1.7	1	1.7	0.017	0.896428
LIMB*Group (1=CON, 2=INT)	7.9	1	7.9	0.083	0.777028
Error	1629.7	17	95.9		
TIME	545.1	1	545.1	11.551	0.003417
TIME*Group (1=CON, 2=INT)	0.1	1	0.1	0.003	0.957123
Error	802.3	17	47.2		
LIMB*TIME	17.8	1	17.8	0.295	0.593985
LIMB*TIME*Group (1=CON, 2=INT)	6.4	1	6.4	0.106	0.748886
Error	1025.6	17	60.3		

Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 85.857, df = 31.239

Cell No.	Group (1=CON, 2=INT)	LIMB	TIME	{1} 71.889	{2} 66.222	{3} 70.556	{4} 65.667	{5} 73.000	{6} 66.000	{7} 71.800	{8} 67.900
1	1	1	1		0.772810	0.999941	0.687877	0.999995	0.857982	1.000000	0.979808
2	1	1	2	0.772810		0.926145	1.000000	0.751352	1.000000	0.888195	0.999918
3	1	2	1	0.999941	0.926145		0.873024	0.999006	0.958462	0.999989	0.998285
4	1	2	2	0.687877	1.000000	0.873024		0.673343	1.000000	0.831457	0.999452
5	2	1	1	0.999995	0.751352	0.999006	0.673343		0.500550	0.999959	0.813367
6	2	1	2	0.857982	1.000000	0.958462	1.000000	0.500550		0.705047	0.999138
7	2	2	1	1.000000	0.888195	0.999989	0.831457	0.999959	0.705047		0.942691
8	2	2	2	0.979808	0.999918	0.998285	0.999452	0.813367	0.999138	0.942691	

Time to Peak Torque - 60°.s^{-1}

Effect	Repeated Measures Analysis of Variance (Isokinetics in Results Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 166.4 SS	Degr. of Freedom	MS	F	p
Intercept	21534322	1	21534322	777.3752	0.000000
Group (1=CON, 2=INT)	4601	1	4601	0.1661	0.688688
Error	470923	17	27701		
LIMB	2666	1	2666	0.1350	0.717832
LIMB*Group (1=CON, 2=INT)	4471	1	4471	0.2264	0.640237
Error	335658	17	19745		
TIME	388	1	388	0.0384	0.846992
TIME*Group (1=CON, 2=INT)	4867	1	4867	0.4810	0.497333
Error	172025	17	10119		
LIMB*TIME	2374	1	2374	0.2449	0.626993
LIMB*TIME*Group (1=CON, 2=INT)	1011	1	1011	0.1043	0.750644
Error	164791	17	9694		

Cell No.	Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format) Approximate Probabilities for Post Hoc Tests Error: Between; Within; Pooled MSE = 18697., df = 27.600 Group (1=CON, 2=INT)	LIMB	TIME	{1} 535.56	{2} 518.89	{3} 566.67	{4} 542.22	{5} 512.00	{6} 542.00	{7} 527.00	{8} 520.00
1	1	1	1		0.999946	0.996854	1.000000	0.999939	1.000000	1.000000	0.999996
2	1	1	2	0.999946		0.963029	0.999500	1.000000	0.999947	1.000000	1.000000
3	1	2	1	0.996854	0.963029		0.999324	0.986495	0.999917	0.998098	0.994722
4	1	2	2	1.000000	0.999500	0.999324		0.999679	1.000000	0.999997	0.999959
5	2	1	1	0.999939	1.000000	0.986495	0.999679		0.996510	0.999962	0.999999
6	2	1	2	1.000000	0.999947	0.999917	1.000000	0.996510		0.999962	0.999519
7	2	2	1	1.000000	1.000000	0.998098	0.999997	0.999962	0.999962		1.000000
8	2	2	2	0.999996	1.000000	0.994722	0.999959	0.999999	0.999519	1.000000	

Time to Peak Torque - 180°.s^{-1}

Effect	Repeated Measures Analysis of Variance (Isokinetics in Results - New Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 169.0159				
	SS	Degr. of Freedom	MS	F	p
Intercept	8993263	1	8993263	314.8196	0.000000
Group (1=CON, 2=INT)	57200	1	57200	2.0024	0.175112
Error	485629	17	28566		
LIMB	4618	1	4618	0.6923	0.416932
LIMB*Group (1=CON, 2=INT)	2554	1	2554	0.3830	0.544229
Error	113396	17	6670		
TIME	528	1	528	0.0608	0.808159
TIME*Group (1=CON, 2=INT)	4423	1	4423	0.5096	0.484983
Error	147522	17	8678		
LIMB*TIME	11270	1	11270	1.8283	0.194048
LIMB*TIME*Group (1=CON, 2=INT)	6407	1	6407	1.0394	0.322261
Error	104796	17	6164		

Cell No.	Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format) Approximate Probabilities for Post Hoc Tests Error: Between; Within; Pooled MSE = 17365., df = 24.011										
	Group (1=CON, 2=INT)	LIMB	TIME	{1} 374.44	{2} 396.67	{3} 390.00	{4} 326.67	{5} 311.00	{6} 327.00	{7} 313.00	{8} 317.00
1	1	1	1		0.998421	0.999846	0.890270	0.961590	0.992514	0.967581	0.977496
2	1	1	2	0.998421		1.000000	0.573683	0.841766	0.938174	0.856641	0.884044
3	1	2	1	0.999846	1.000000		0.680979	0.888297	0.962979	0.900517	0.922440
4	1	2	2	0.890270	0.573683	0.680979		0.999995	1.000000	0.999998	1.000000
5	2	1	1	0.961590	0.841766	0.888297	0.999995		0.999737	1.000000	1.000000
6	2	1	2	0.992514	0.938174	0.962979	1.000000	0.999737		0.999892	0.999989
7	2	2	1	0.967581	0.856641	0.900517	0.999998	1.000000	0.999892		1.000000
8	2	2	2	0.977496	0.884044	0.922440	1.000000	1.000000	0.999989	1.000000	

Total Work - 60°.s^{-1}

Effect	Repeated Measures Analysis of Variance (Isokinetics in Results - New Format) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 134.0961 SS	Degr. of Freedom	MS	F	p
Intercept	8869162	1	8869162	493.2304	0.000000
Group (1=CON, 2=INT)	2266	1	2266	0.1260	0.726973
Error	305690	17	17982		
LIMB	10178	1	10178	2.5266	0.130365
LIMB*Group (1=CON, 2=INT)	4154	1	4154	1.0312	0.324110
Error	68480	17	4028		
TIME	5709	1	5709	5.1743	0.036164
TIME*Group (1=CON, 2=INT)	5254	1	5254	4.7622	0.043413
Error	18756	17	1103		
LIMB*TIME	0	1	0	0.0001	0.991901
LIMB*TIME*Group (1=CON, 2=INT)	2085	1	2085	7.7189	0.012880
Error	4591	17	270		

Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 9125.9, df = 17.511

Cell No.	Group (1=CON, 2=INT)	LIMB	TIME	{1} 360.52	{2} 350.70	{3} 312.01	{4} 323.24	{5} 329.51	{6} 373.97	{7} 331.59	{8} 355.15
1	1	1	1		0.898647	0.000331	0.003310	0.995675	0.999982	0.997189	1.000000
2	1	1	2	0.898647		0.002341	0.040601	0.999620	0.999302	0.999808	1.000000
3	1	2	1	0.000331	0.002341		0.822160	0.999893	0.840438	0.999774	0.971174
4	1	2	2	0.003310	0.040601	0.822160		1.000000	0.934319	0.999999	0.994858
5	2	1	1	0.995675	0.999620	0.999893	1.000000		0.000417	0.999989	0.045187
6	2	1	2	0.999982	0.999302	0.840438	0.934319	0.000417		0.000609	0.235706
7	2	2	1	0.997189	0.999808	0.999774	0.999999	0.999989	0.000609		0.077225
8	2	2	2	1.000000	1.000000	0.971174	0.994858	0.045187	0.235706	0.077225	

Total Work - 180°.s-1

Effect	Repeated Measures Analysis of Variance (Isokinetics in Results - New Format) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 88.77836 SS	Degr. of Freedom	MS	F	p
Intercept	4360180	1	4360180	553.2102	0.000000
Group (1=CON, 2=INT)	3651	1	3651	0.4632	0.505290
Error	133987	17	7882		
LIMB	1640	1	1640	1.2532	0.278503
LIMB*Group (1=CON, 2=INT)	1854	1	1854	1.4173	0.250214
Error	22240	17	1308		
TIME	6095	1	6095	15.8125	0.000976
TIME*Group (1=CON, 2=INT)	2906	1	2906	7.5403	0.013784
Error	6552	17	385		
LIMB*TIME	11	1	11	0.0302	0.864028
LIMB*TIME*Group (1=CON, 2=INT)	601	1	601	1.7119	0.208149
Error	5967	17	351		

Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 4116.3, df = 18.511

Cell No.	Group (1=CON, 2=INT)	LIMB	TIME	{1} 242.18	{2} 242.84	{3} 218.10	{4} 228.53	{5} 228.15	{6} 264.85	{7} 235.12	{8} 259.06
1	1	1	1		1.000000	0.180362	0.774267	0.999661	0.992885	0.999997	0.998877
2	1	1	2	1.000000		0.158866	0.733090	0.999541	0.994049	0.999994	0.999132
3	1	2	1	0.180362	0.158866		0.926784	0.999963	0.752610	0.998818	0.850923
4	1	2	2	0.774267	0.733090	0.926784		1.000000	0.911850	0.999998	0.962422
5	2	1	1	0.999661	0.999541	0.999963	1.000000		0.007744	0.988509	0.030599
6	2	1	2	0.992885	0.994049	0.752610	0.911850	0.007744		0.040281	0.996196
7	2	2	1	0.999997	0.999994	0.998818	0.999998	0.988509	0.040281		0.144384
8	2	2	2	0.998877	0.999132	0.850923	0.962422	0.030599	0.996196	0.144384	

Average Power - 60°.s^{-1}

Effect	Repeated Measures Analysis of Variance (Isokinetics in Results - New Format) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 19.90313				
	SS	Degr. of Freedom	MS	F	p
Intercept	1177271	1	1177271	2971.894	0.000000
Group (1=CON, 2=INT)	287	1	287	0.723	0.406896
Error	6734	17	396		
LIMB	279	1	279	3.025	0.100065
LIMB*Group (1=CON, 2=INT)	36	1	36	0.387	0.542060
Error	1569	17	92		
TIME	52	1	52	0.713	0.410233
TIME*Group (1=CON, 2=INT)	444	1	444	6.116	0.024250
Error	1235	17	73		
LIMB*TIME	5	1	5	0.150	0.703348
LIMB*TIME*Group (1=CON, 2=INT)	4	1	4	0.115	0.738685

Cell No.	Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format) Approximate Probabilities for Post Hoc Tests Error: Between; Within; Pooled MSE = 216.20, df = 20.087										
	Group (1=CON, 2=INT)	LIMB	TIME	{1} 126.86	{2} 123.73	{3} 121.71	{4} 118.46	{5} 124.06	{6} 131.56	{7} 122.60	{8} 128.09
1	1	1	1		0.948252	0.621116	0.120889	0.999870	0.996192	0.997966	1.000000
2	1	1	2	0.948252		0.995418	0.592984	1.000000	0.934723	1.000000	0.997645
3	1	2	1	0.621116	0.995418		0.936473	0.999960	0.819905	1.000000	0.977391
4	1	2	2	0.120889	0.592984	0.936473		0.989133	0.541931	0.998285	0.835056
5	2	1	1	0.999870	1.000000	0.999960	0.989133		0.163503	0.999186	0.799396
6	2	1	2	0.996192	0.934723	0.819905	0.541931	0.163503		0.061576	0.891198
7	2	2	1	0.997966	1.000000	1.000000	0.998285	0.999186	0.061576		0.487161
8	2	2	2	1.000000	0.997645	0.977391	0.835056	0.799396	0.891198	0.487161	

Average Power - 180°.s^{-1}

Effect	Repeated Measures Analysis of Variance (Isokinetics in Results - New Fo Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 41.93330 SS	Degr. of Freedom	MS	F	p
Intercept	3457910	1	3457910	1966.507	0.000000
Group (1=CON, 2=INT)	3118	1	3118	1.773	0.200542
Error	29893	17	1758		
LIMB	1806	1	1806	4.147	0.057606
LIMB*Group (1=CON, 2=INT)	89	1	89	0.204	0.657483
Error	7405	17	436		
TIME	1856	1	1856	21.168	0.000255
TIME*Group (1=CON, 2=INT)	243	1	243	2.772	0.114275
Error	1491	17	88		
LIMB*TIME	192	1	192	3.613	0.074438
LIMB*TIME*Group (1=CON, 2=INT)	83	1	83	1.564	0.228039
Error	905	17	53		

Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 905.83, df = 18.029

Cell No.	Group (1=CON, 2=INT)	LIMB	TIME	{1} 212.63	{2} 213.67	{3} 195.42	{4} 207.02	{5} 217.62	{6} 230.01	{7} 208.93	{8} 223.50
1	1	1	1		0.999984	0.002299	0.727118	0.999946	0.903250	0.999993	0.991869
2	1	1	2	0.999984		0.001311	0.549806	0.999989	0.927180	0.999962	0.995541
3	1	2	1	0.002299	0.001311		0.056522	0.741781	0.255456	0.972262	0.490258
4	1	2	2	0.727118	0.549806	0.056522		0.992986	0.709369	1.000000	0.924299
5	2	1	1	0.999946	0.999989	0.741781	0.992986		0.024782	0.200270	0.627378
6	2	1	2	0.903250	0.927180	0.255456	0.709369	0.024782		0.000279	0.512515
7	2	2	1	0.999993	0.999962	0.972262	1.000000	0.200270	0.000279		0.006552
8	2	2	2	0.991869	0.995541	0.490258	0.924299	0.627378	0.512515	0.006552	

Concentric Hamstrings

Peak Torque - 60°.s^{-1}

Effect	Repeated Measures Analysis of Variance (Isokinetics in Results - I Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 46.654				
	SS	Degr. of Freedom	MS	F	p
Intercept	2165908	1	2165908	995.0785	0.000000
Group (1=CON, 2=INT)	2934	1	2934	1.3481	0.261647
Error	37003	17	2177		
LIMB	1374	1	1374	2.8936	0.107148
LIMB*Group (1=CON, 2=INT)	838	1	838	1.7641	0.201671
Error	8073	17	475		
TIME	132	1	132	2.0380	0.171518
TIME*Group (1=CON, 2=INT)	441	1	441	6.8233	0.018217
Error	1100	17	65		
LIMB*TIME	0	1	0	0.0028	0.958492
LIMB*TIME*Group (1=CON, 2=INT)	0	1	0	0.0042	0.949047
Error	1390	17	82		

Cell No.	Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format) Approximate Probabilities for Post Hoc Tests Error: Between; Within; Pooled MSE = 1129.2, df = 18.275										
	Group (1=CON, 2=INT)	LIMB	TIME	{1} 164.98	{2} 162.54	{3} 162.87	{4} 160.92	{5} 179.11	{6} 186.60	{7} 163.97	{8} 171.41
1	1	1	1		0.998867	0.999546	0.975640	0.980588	0.845915	1.000000	0.999859
2	1	1	2	0.998867		1.000000	0.999921	0.954822	0.767706	1.000000	0.998853
3	1	2	1	0.999546	1.000000		0.999735	0.959138	0.778837	1.000000	0.999095
4	1	2	2	0.975640	0.999921	0.999735		0.928427	0.708943	0.999999	0.996650
5	2	1	1	0.980588	0.954822	0.959138	0.928427		0.597071	0.027468	0.566002
6	2	1	2	0.845915	0.767706	0.778837	0.708943	0.597071		0.000797	0.026807
7	2	2	1	1.000000	1.000000	1.000000	0.999999	0.027468	0.000797		0.604481
8	2	2	2	0.999859	0.998853	0.999095	0.996650	0.566002	0.026807	0.604481	

Peak Torque - 180°.s^{-1}

Effect	SS	Degr. of Freedom	MS	F	p
	Repeated Measures Analysis of Variance (Isokinetics in Results - New Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 58.90736				
Intercept	1724466	1	1724466	496.9533	0.000000
Group (1=CON, 2=INT)	824	1	824	0.2375	0.632223
Error	58991	17	3470		
LIMB	119	1	119	0.9147	0.352278
LIMB*Group (1=CON, 2=INT)	772	1	772	5.9353	0.026134
Error	2212	17	130		
TIME	243	1	243	4.4937	0.049038
TIME*Group (1=CON, 2=INT)	228	1	228	4.2191	0.055680
Error	919	17	54		
LIMB*TIME	30	1	30	0.5711	0.460169
LIMB*TIME*Group (1=CON, 2=INT)	9	1	9	0.1745	0.681358
Error	884	17	52		

Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 1761.1, df = 17.510

Cell No.	Group (1=CON, 2=INT)	LIMB	TIME	{1} 144.58	{2} 146.63	{3} 150.40	{4} 148.57	{5} 154.78	{6} 162.39	{7} 146.45	{8} 152.94
1	1	1	1		0.998351	0.680285	0.929145	0.999311	0.979390	1.000000	0.999812
2	1	1	2	0.998351		0.946351	0.998895	0.999842	0.989708	1.000000	0.999972
3	1	2	1	0.680285	0.946351		0.999213	0.999998	0.998051	0.999999	1.000000
4	1	2	2	0.929145	0.998895	0.999213		0.999974	0.995269	1.000000	0.999998
5	2	1	1	0.999311	0.999842	0.999998	0.999974		0.319484	0.227806	0.998872
6	2	1	2	0.979390	0.989708	0.998051	0.995269	0.319484		0.002584	0.127268
7	2	2	1	1.000000	1.000000	0.999999	1.000000	0.227806	0.002584		0.502402
8	2	2	2	0.999812	0.999972	1.000000	0.999998	0.998872	0.127268	0.502402	

Angle of Peak Torque - 60°.s^{-1}

Effect	Repeated Measures Analysis of Variance (Isokinetics in Results - N Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 9.15374 SS	Degr. of Freedom	MS	F	p
Intercept	210678.0	1	210678.0	2514.327	0.000000
Group (1=CON, 2=INT)	42.8	1	42.8	0.511	0.484547
Error	1424.4	17	83.8		
LIMB	2.7	1	2.7	0.039	0.845267
LIMB*Group (1=CON, 2=INT)	1.0	1	1.0	0.014	0.905847
Error	1187.9	17	69.9		
TIME	698.0	1	698.0	12.114	0.002862
TIME*Group (1=CON, 2=INT)	1.9	1	1.9	0.034	0.856820
Error	979.5	17	57.6		
LIMB*TIME	25.7	1	25.7	0.449	0.512022
LIMB*TIME*Group (1=CON, 2=INT)	14.9	1	14.9	0.260	0.616682
Error	972.8	17	57.2		

Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 70.507, df = 32.834

Cell No.	Group (1=CON, 2=INT)	LIMB	TIME	{1} 55.000	{2} 48.333	{3} 55.333	{4} 49.222	{5} 57.300	{6} 49.500	{7} 55.400	{8} 51.700
1	1	1	1		0.586699	1.000000	0.733147	0.998735	0.838947	1.000000	0.988100
2	1	1	2	0.586699		0.531071	0.999996	0.311537	0.999987	0.604312	0.986620
3	1	2	1	1.000000	0.531071		0.679474	0.999551	0.795648	1.000000	0.979355
4	1	2	2	0.733147	0.999996	0.679474		0.439617	1.000000	0.746202	0.997957
5	2	1	1	0.998735	0.311537	0.999551	0.439617		0.344712	0.998979	0.713290
6	2	1	2	0.838947	0.999987	0.795648	1.000000	0.344712		0.661637	0.997390
7	2	2	1	1.000000	0.604312	1.000000	0.746202	0.998979	0.661637		0.949655
8	2	2	2	0.988100	0.986620	0.979355	0.997957	0.713290	0.997390	0.949655	

Angle of Peak Torque - 180°.s^{-1}

Effect	Repeated Measures Analysis of Variance (Isokinetics in Results - New Format) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 9.488038				
	SS	Degr. of Freedom	MS	F	p
Intercept	245400.7	1	245400.7	2725.982	0.000000
Group (1=CON, 2=INT)	258.6	1	258.6	2.873	0.108330
Error	1530.4	17	90.0		
LIMB	7.9	1	7.9	0.089	0.768487
LIMB*Group (1=CON, 2=INT)	1.1	1	1.1	0.013	0.911000
Error	1495.3	17	88.0		
TIME	176.9	1	176.9	3.262	0.088634
TIME*Group (1=CON, 2=INT)	16.9	1	16.9	0.312	0.583946
Error	921.9	17	54.2		
LIMB*TIME	19.6	1	19.6	0.220	0.644866
LIMB*TIME*Group (1=CON, 2=INT)	1.9	1	1.9	0.021	0.885519
Error	1512.1	17	88.9		

Cell No.	Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format) Approximate Probabilities for Post Hoc Tests Error: Between; Within; Pooled MSE = 89.485, df = 33.999										
	Group (1=CON, 2=INT)	LIMB	TIME	{1} 55.000	{2} 54.222	{3} 57.222	{4} 53.778	{5} 60.200	{6} 56.900	{7} 61.300	{8} 56.600
1	1	1	1		1.000000	0.999518	0.999991	0.927483	0.999839	0.827667	0.999949
2	1	1	2	1.000000		0.996723	1.000000	0.861980	0.998441	0.730441	0.999294
3	1	2	1	0.999518	0.996723		0.992403	0.996925	1.000000	0.979876	1.000000
4	1	2	2	0.999991	1.000000	0.992403		0.813652	0.995862	0.668162	0.997826
5	2	1	1	0.927483	0.861980	0.996925	0.813652		0.991951	0.999994	0.986683
6	2	1	2	0.999839	0.998441	1.000000	0.995862	0.991951		0.960382	1.000000
7	2	2	1	0.827667	0.730441	0.979876	0.668162	0.999994	0.960382		0.944770
8	2	2	2	0.999949	0.999294	1.000000	0.997826	0.986683	1.000000	0.944770	

Time to Peak Torque – 60°.s^{-1}

Repeated Measures Analysis of Variance (Isokinetics in Results - New Format)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 189.8469

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	37626233	1	37626233	1043.960	0.000000
Group (1=CON, 2=INT)	12133	1	12133	0.337	0.569383
Error	612711	17	36042		
LIMB	74739	1	74739	2.043	0.171029
LIMB*Group (1=CON, 2=INT)	207	1	207	0.006	0.940912
Error	621911	17	36583		
TIME	180	1	180	0.009	0.924558
TIME*Group (1=CON, 2=INT)	2470	1	2470	0.127	0.726322
Error	331523	17	19501		
LIMB*TIME	1221	1	1221	0.136	0.716941
LIMB*TIME*Group (1=CON, 2=INT)	52279	1	52279	5.818	0.027443
Error	152745	17	8985		

Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 22513., df = 24.980

Cell No.	Group (1=CON, 2=INT)	LIMB	TIME	{1} 624.44	{2} 693.33	{3} 751.11	{4} 698.89	{5} 717.00	{6} 658.00	{7} 732.00	{8} 762.00
1	1	1	1		0.775952	0.150082	0.707179	0.873648	0.999644	0.768288	0.504403
2	1	1	2	0.775952		0.889465	1.000000	0.999965	0.999500	0.999104	0.970846
3	1	2	1	0.150082	0.889465		0.930416	0.999603	0.870318	0.999992	1.000000
4	1	2	2	0.707179	1.000000	0.930416		0.999994	0.998696	0.999674	0.981670
5	2	1	1	0.873648	0.999965	0.999603	0.999994		0.849027	0.999951	0.956692
6	2	1	2	0.999644	0.999500	0.870318	0.998696	0.849027		0.660677	0.278069
7	2	2	1	0.768288	0.999104	0.999992	0.999674	0.999951	0.660677		0.995594
8	2	2	2	0.504403	0.970846	1.000000	0.981670	0.956692	0.278069	0.995594	

Time to Peak Torque - 180°.s^{-1}

Effect	Repeated Measures Analysis of Variance (Isokinetics in Results - Ne Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 174.3091				
	SS	Degr. of Freedom	MS	F	p
Intercept	6940943	1	6940943	228.4432	0.000000
Group (1=CON, 2=INT)	16770	1	16770	0.5519	0.467674
Error	516523	17	30384		
LIMB	5106	1	5106	0.4163	0.527398
LIMB*Group (1=CON, 2=INT)	9101	1	9101	0.7420	0.401013
Error	208522	17	12266		
TIME	2766	1	2766	0.3404	0.567263
TIME*Group (1=CON, 2=INT)	3	1	3	0.0004	0.984183
Error	138163	17	8127		
LIMB*TIME	3699	1	3699	1.3904	0.254571
LIMB*TIME*Group (1=CON, 2=INT)	388	1	388	0.1460	0.707110
Error	45225	17	2660		

Cell No.	Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format) Approximate Probabilities for Post Hoc Tests Error: Between; Within; Pooled MSE = 16522., df = 19.954										
	Group (1=CON, 2=INT)	LIMB	TIME	{1} 337.78	{2} 335.56	{3} 308.89	{4} 287.78	{5} 282.00	{6} 288.00	{7} 306.00	{8} 275.00
1	1	1	1		1.000000	0.924760	0.476847	0.977330	0.988063	0.999266	0.957507
2	1	1	2	1.000000		0.948952	0.529878	0.981897	0.990848	0.999541	0.964771
3	1	2	1	0.924760	0.948952		0.985330	0.999753	0.999954	1.000000	0.998891
4	1	2	2	0.476847	0.529878	0.985330		1.000000	1.000000	0.999982	0.999998
5	2	1	1	0.977330	0.981897	0.999753	1.000000		0.999994	0.960918	0.999983
6	2	1	2	0.988063	0.990848	0.999954	1.000000	0.999994		0.992074	0.998956
7	2	2	1	0.999266	0.999541	1.000000	0.999982	0.960918	0.992074		0.869458
8	2	2	2	0.957507	0.964771	0.998891	0.999998	0.999983	0.998956	0.869458	

Total Work - 60°.s^{-1}

Effect	Repeated Measures Analysis of Variance (Isokinetics in Results - New Forr Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 142.2478 SS	Degr. of Freedom	MS	F	p
Intercept	5744433	1	5744433	283.8938	0.000000
Group (1=CON, 2=INT)	35670	1	35670	1.7628	0.201826
Error	343986	17	20234		
LIMB	30	1	30	0.0163	0.899910
LIMB*Group (1=CON, 2=INT)	1805	1	1805	0.9863	0.334583
Error	31112	17	1830		
TIME	243	1	243	0.2948	0.594186
TIME*Group (1=CON, 2=INT)	193	1	193	0.2335	0.635090
Error	14039	17	826		
LIMB*TIME	517	1	517	0.5029	0.487829
LIMB*TIME*Group (1=CON, 2=INT)	1822	1	1822	1.7740	0.200471
Error	17461	17	1027		

Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 10631., df = 18.721

Cell No.	Group (1=CON, 2=INT)	LIMB	TIME	{1} 256.68	{2} 242.04	{3} 250.16	{4} 265.58	{5} 296.83	{6} 308.19	{7} 290.40	{8} 292.59
1	1	1	1		0.973177	0.999816	0.998608	0.987494	0.951837	0.995552	0.993490
2	1	1	2	0.973177		0.999235	0.767447	0.934692	0.848023	0.965227	0.956254
3	1	2	1	0.999816	0.999235		0.964605	0.971162	0.914220	0.987329	0.982880
4	1	2	2	0.998608	0.767447	0.964605		0.997231	0.982476	0.999368	0.998912
5	2	1	1	0.987494	0.934692	0.971162	0.997231		0.991317	0.999763	0.999986
6	2	1	2	0.951837	0.848023	0.914220	0.982476	0.991317		0.907905	0.950857
7	2	2	1	0.995552	0.965227	0.987329	0.999368	0.999763	0.907905		1.000000
8	2	2	2	0.993490	0.956254	0.982880	0.998912	0.999986	0.950857	1.000000	

Total Work - 180°.s^{-1}

Effect	Repeated Measures Analysis of Variance (Isokinetics in Results - New Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 119.5066 SS	Degr. of Freedom	MS	F	p
Intercept	3197360	1	3197360	223.8760	0.000000
Group (1=CON, 2=INT)	439	1	439	0.0307	0.862893
Error	242791	17	14282		
LIMB	1	1	1	0.0013	0.971266
LIMB*Group (1=CON, 2=INT)	590	1	590	0.5936	0.451588
Error	16893	17	994		
TIME	1955	1	1955	3.5848	0.075459
TIME*Group (1=CON, 2=INT)	224	1	224	0.4102	0.530403
Error	9273	17	545		
LIMB*TIME	714	1	714	2.2595	0.151145
LIMB*TIME*Group (1=CON, 2=INT)	57	1	57	0.1789	0.677657
Error	5371	17	316		

Cell No.	Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format) Approximate Probabilities for Post Hoc Tests Error: Between; Within; Pooled MSE = 7298.9, df = 17.752 Group (1=CON, 2=INT)	LIMB	TIME	{1} 194.50	{2} 205.63	{3} 204.76	{4} 207.07	{5} 199.73	{6} 221.19	{7} 202.28	{8} 208.01
1	1	1	1		0.875633	0.913620	0.797637	1.000000	0.996601	0.999999	0.999960
2	1	1	2	0.875633		1.000000	1.000000	1.000000	0.999898	1.000000	1.000000
3	1	2	1	0.913620	1.000000		0.999991	1.000000	0.999852	1.000000	1.000000
4	1	2	2	0.797637	1.000000	0.999991		0.999999	0.999947	1.000000	1.000000
5	2	1	1	1.000000	1.000000	1.000000	0.999999		0.188441	0.999975	0.960688
6	2	1	2	0.996601	0.999898	0.999852	0.999947	0.188441		0.310516	0.711735
7	2	2	1	0.999999	1.000000	1.000000	1.000000	0.999975	0.310516		0.995069
8	2	2	2	0.999960	1.000000	1.000000	1.000000	0.960688	0.711735	0.995069	

Average Power - 60°.s^{-1}

Effect	Repeated Measures Analysis of Variance (Isokinetics in Results - New Format) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 27.54219 SS	Degr. of Freedom	MS	F	p
Intercept	518271.3	1	518271.3	683.2192	0.000000
Group (1=CON, 2=INT)	3.5	1	3.5	0.0046	0.946990
Error	12895.7	17	758.6		
LIMB	26.3	1	26.3	0.4319	0.519878
LIMB*Group (1=CON, 2=INT)	234.4	1	234.4	3.8489	0.066364
Error	1035.1	17	60.9		
TIME	237.0	1	237.0	13.2248	0.002040
TIME*Group (1=CON, 2=INT)	3.0	1	3.0	0.1675	0.687451
Error	304.7	17	17.9		
LIMB*TIME	0.3	1	0.3	0.0184	0.893738
LIMB*TIME*Group (1=CON, 2=INT)	16.1	1	16.1	0.9624	0.340334
Error	284.8	17	16.8		

Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 387.66, df = 17.751

Cell No.	Group (1=CON, 2=INT)	LIMB	TIME	{1} 80.267	{2} 82.356	{3} 81.556	{4} 85.744	{5} 82.890	{6} 87.620	{7} 78.990	{8} 82.130
1	1	1	1		0.952167	0.996920	0.149005	0.999988	0.990056	1.000000	0.999999
2	1	1	2	0.952167		0.999859	0.654352	1.000000	0.998739	0.999933	1.000000
3	1	2	1	0.996920	0.999859		0.413355	1.000000	0.996894	0.999989	1.000000
4	1	2	2	0.149005	0.654352	0.413355		0.999978	0.999999	0.993975	0.999892
5	2	1	1	0.999988	1.000000	1.000000	0.999978		0.227248	0.435238	0.999858
6	2	1	2	0.990056	0.998739	0.996894	0.999999	0.227248		0.003999	0.112525
7	2	2	1	1.000000	0.999933	0.999989	0.993975	0.435238	0.003999		0.678519
8	2	2	2	0.999999	1.000000	1.000000	0.999892	0.999858	0.112525	0.678519	

Average Power - 180°.s^{-1}

Effect	Repeated Measures Analysis of Variance (Isokinetics in Results - New Fc Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 36.24661 SS	Degr. of Freedom	MS	F	p
Intercept	1161437	1	1161437	884.0170	0.000000
Group (1=CON, 2=INT)	114	1	114	0.0869	0.771751
Error	22335	17	1314		
LIMB	311	1	311	1.3257	0.265503
LIMB*Group (1=CON, 2=INT)	2	1	2	0.0073	0.933028
Error	3985	17	234		
TIME	103	1	103	1.0699	0.315461
TIME*Group (1=CON, 2=INT)	44	1	44	0.4586	0.507408
Error	1638	17	96		
LIMB*TIME	38	1	38	1.1455	0.299458
LIMB*TIME*Group (1=CON, 2=INT)	311	1	311	9.4457	0.006886

Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 673.36, df = 17.851

Cell No.	Group (1=CON, 2=INT)	LIMB	TIME	{1} 119.71	{2} 125.98	{3} 129.52	{4} 124.87	{5} 120.08	{6} 121.30	{7} 121.19	{8} 127.69
1	1	1	1		0.339155	0.034489	0.564665	1.000000	1.000000	1.000000	0.996932
2	1	1	2	0.339155		0.882756	0.999868	0.999558	0.999905	0.999888	1.000000
3	1	2	1	0.034489	0.882756		0.674918	0.991468	0.996297	0.995983	1.000000
4	1	2	2	0.564665	0.999868	0.674918		0.999889	0.999985	0.999981	0.999997
5	2	1	1	1.000000	0.999558	0.991468	0.999889		0.999652	0.999813	0.119319
6	2	1	2	1.000000	0.999905	0.996297	0.999985	0.999652		1.000000	0.262777
7	2	2	1	1.000000	0.999888	0.995983	0.999981	0.999813	1.000000		0.245973
8	2	2	2	0.996932	1.000000	1.000000	0.999997	0.119319	0.262777	0.245973	

Eccentric Hamstrings

Peak Torque - 60°.s^{-1}

Repeated Measures Analysis of Variance (Isokinetics in Results - New Format)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 41.33002

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	2069563	1	2069563	1211.567	0.000000
Group (1=CON, 2=INT)	1079	1	1079	0.631	0.437779
Error	29039	17	1708		
LIMB	1333	1	1333	3.164	0.093158
LIMB*Group (1=CON, 2=INT)	414	1	414	0.981	0.335743
Error	7163	17	421		
TIME	578	1	578	17.575	0.000612
TIME*Group (1=CON, 2=INT)	671	1	671	20.404	0.000304
Error	559	17	33		
LIMB*TIME	17	1	17	0.521	0.480031
LIMB*TIME*Group (1=CON, 2=INT)	41	1	41	1.261	0.277112
Error	559	17	33		

Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 870.52, df = 17.654

Cell No.	Group (1=CON, 2=INT)	LIMB	TIME	{1} 163.81	{2} 162.86	{3} 159.57	{4} 159.67	{5} 168.60	{6} 182.50	{7} 157.97	{8} 167.01
1	1	1	1		0.999952	0.760561	0.780264	0.999953	0.855210	0.999821	0.999997
2	1	1	2	0.999952		0.915883	0.927187	0.999840	0.822986	0.999946	0.999982
3	1	2	1	0.760561	0.915883		1.000000	0.997002	0.692319	1.000000	0.999128
4	1	2	2	0.780264	0.927187	1.000000		0.997201	0.696615	1.000000	0.999201
5	2	1	1	0.999953	0.999840	0.997002	0.997201		0.001066	0.012375	0.998065
6	2	1	2	0.855210	0.822986	0.692319	0.696615	0.001066		0.000167	0.000421
7	2	2	1	0.999821	0.999946	1.000000	1.000000	0.012375	0.000167		0.042065
8	2	2	2	0.999997	0.999982	0.999128	0.999201	0.998065	0.000421	0.042065	

Peak Torque - 180°.s^{-1}

Effect	Repeated Measures Analysis of Variance (Isokinetics in Results - N Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 33.3138				
	SS	Degr. of Freedom	MS	F	p
Intercept	1954103	1	1954103	1760.747	0.000000
Group (1=CON, 2=INT)	687	1	687	0.619	0.442249
Error	18867	17	1110		
LIMB	1085	1	1085	4.310	0.053374
LIMB*Group (1=CON, 2=INT)	26	1	26	0.104	0.750481
Error	4279	17	252		
TIME	841	1	841	12.834	0.002294
TIME*Group (1=CON, 2=INT)	651	1	651	9.937	0.005814
Error	1114	17	66		
LIMB*TIME	377	1	377	4.392	0.051390
LIMB*TIME*Group (1=CON, 2=INT)	91	1	91	1.063	0.317079
Error	1459	17	86		

Cell No.	Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format) Approximate Probabilities for Post Hoc Tests Error: Between; Within; Pooled MSE = 597.83, df = 19.614										
	Group (1=CON, 2=INT)	LIMB	TIME	{1} 161.49	{2} 160.02	{3} 152.83	{4} 155.90	{5} 165.02	{6} 170.89	{7} 149.62	{8} 168.80
1	1	1	1		0.999966	0.520098	0.894446	0.999979	0.988502	0.958712	0.997490
2	1	1	2	0.999966		0.718689	0.976684	0.999787	0.974087	0.979600	0.992301
3	1	2	1	0.520098	0.718689		0.995807	0.952743	0.740959	0.999989	0.837086
4	1	2	2	0.894446	0.976684	0.995807		0.990364	0.874852	0.999057	0.937289
5	2	1	1	0.999979	0.999787	0.952743	0.990364		0.837844	0.028996	0.980652
6	2	1	2	0.988502	0.974087	0.740959	0.874852	0.837844		0.001791	0.999489
7	2	2	1	0.958712	0.979600	0.999989	0.999057	0.028996	0.001791		0.004731
8	2	2	2	0.997490	0.992301	0.837086	0.937289	0.980652	0.999489	0.004731	

Angle of Peak Torque - 60°.s^{-1}

Effect	Repeated Measures Analysis of Variance (Isokinetics in Results - New F Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 10.41132 SS	Degr. of Freedom	MS	F	p
Intercept	108410.4	1	108410.4	1000.137	0.000000
Group (1=CON, 2=INT)	0.7	1	0.7	0.006	0.937067
Error	1842.7	17	108.4		
LIMB	3.2	1	3.2	0.033	0.858343
LIMB*Group (1=CON, 2=INT)	86.5	1	86.5	0.875	0.362751
Error	1680.3	17	98.8		
TIME	142.4	1	142.4	2.054	0.169901
TIME*Group (1=CON, 2=INT)	0.2	1	0.2	0.002	0.962336
Error	1178.5	17	69.3		
LIMB*TIME	1.1	1	1.1	0.014	0.908041
LIMB*TIME*Group (1=CON, 2=INT)	3.2	1	3.2	0.039	0.845315
Error	1368.5	17	80.5		

Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 94.449, df = 33.274

Cell No.	Group (1=CON, 2=INT)	LIMB	TIME	{1} 40.111	{2} 37.444	{3} 38.556	{4} 35.556	{5} 38.100	{6} 34.800	{7} 40.000	{8} 38.000
1	1	1	1		0.997854	0.999937	0.953385	0.999802	0.929416	1.000000	0.999727
2	1	1	2	0.997854		0.999994	0.999770	1.000000	0.998791	0.999040	1.000000
3	1	2	1	0.999937	0.999994		0.995534	1.000000	0.989242	0.999979	1.000000
4	1	2	2	0.953385	0.999770	0.995534		0.999066	1.000000	0.972009	0.999287
5	2	1	1	0.999802	1.000000	1.000000	0.999066		0.989241	0.999662	1.000000
6	2	1	2	0.929416	0.998791	0.989242	1.000000	0.989241		0.888370	0.990999
7	2	2	1	1.000000	0.999040	0.999979	0.972009	0.999662	0.888370		0.999527
8	2	2	2	0.999727	1.000000	1.000000	0.999287	1.000000	0.990999	0.999527	

Angle of Peak Torque - 180°.s^{-1}

Effect	Repeated Measures Analysis of Variance (Isokinetics in Results Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 10.0 SS	Degr. of Freedom	MS	F	p
Intercept	145360.7	1	145360.7	1444.721	0.000000
Group (1=CON, 2=INT)	0.7	1	0.7	0.007	0.935629
Error	1710.5	17	100.6		
LIMB	6.6	1	6.6	0.073	0.789954
LIMB*Group (1=CON, 2=INT)	12.5	1	12.5	0.139	0.713965
Error	1525.5	17	89.7		
TIME	565.1	1	565.1	7.912	0.011978
TIME*Group (1=CON, 2=INT)	11.0	1	11.0	0.154	0.699913
Error	1214.2	17	71.4		
LIMB*TIME	0.0	1	0.0	0.001	0.975637
LIMB*TIME*Group (1=CON, 2=INT)	0.0	1	0.0	0.001	0.975637
Error	838.4	17	49.3		

Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 74.966, df = 30.437

Cell No.	Group (1=CON, 2=INT)	LIMB	TIME	{1} 47.111	{2} 40.889	{3} 46.889	{4} 40.667	{5} 45.400	{6} 40.600	{7} 46.700	{8} 42.100
1	1	1	1		0.580709	1.000000	0.540725	0.999851	0.725315	1.000000	0.906506
2	1	1	2	0.580709		0.620914	1.000000	0.943896	1.000000	0.821464	0.999986
3	1	2	1	1.000000	0.620914		0.580709	0.999942	0.757607	1.000000	0.924631
4	1	2	2	0.540725	1.000000	0.580709		0.928785	1.000000	0.792814	0.999955
5	2	1	1	0.999851	0.943896	0.999942	0.928785		0.782947	0.999861	0.958893
6	2	1	2	0.725315	1.000000	0.757607	1.000000	0.782947		0.543317	0.999642
7	2	2	1	1.000000	0.821464	1.000000	0.792814	0.999861	0.543317		0.815103
8	2	2	2	0.906506	0.999986	0.924631	0.999955	0.958893	0.999642	0.815103	

Time to Peak Torque - 60°.s^{-1}

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	104513194	1	104513194	931.3898	0.000000
Group (1=CON, 2=INT)	54458	1	54458	0.4853	0.495443
Error	1907606	17	112212		
LIMB	2054347	1	2054347	44.3066	0.000004
LIMB*Group (1=CON, 2=INT)	5020	1	5020	0.1083	0.746134
Error	788232	17	46367		
TIME	37896	1	37896	0.6745	0.422842
TIME*Group (1=CON, 2=INT)	92107	1	92107	1.6395	0.217593
Error	955072	17	56181		
LIMB*TIME	38085	1	38085	2.7410	0.116148
LIMB*TIME*Group (1=CON, 2=INT)	6253	1	6253	0.4500	0.511329
Error	236210	17	13895		

Repeated Measures Analysis of Variance (Isokinetics in Results - New Format)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 334.9807

Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 63053., df = 21.146

Cell No.	Group (1=CON, 2=INT)	LIMB	TIME	{1} 1330.0	{2} 1417.8	{3} 957.78	{4} 1098.9	{5} 1348.0	{6} 1260.0	{7} 972.00	{8} 1010.0
1	1	1	1		0.755580	0.000239	0.012055	1.000000	0.998424	0.082925	0.154928
2	1	1	2	0.755580		0.000169	0.000635	0.998455	0.861740	0.016739	0.034137
3	1	2	1	0.000239	0.000169		0.243713	0.047047	0.203200	1.000000	0.999767
4	1	2	2	0.012055	0.000635	0.243713		0.412423	0.849082	0.949871	0.993041
5	2	1	1	1.000000	0.998455	0.047047	0.412423		0.705273	0.000191	0.000290
6	2	1	2	0.998424	0.861740	0.203200	0.849082	0.705273		0.000993	0.003787
7	2	2	1	0.082925	0.016739	1.000000	0.949871	0.000191	0.000993		0.995069
8	2	2	2	0.154928	0.034137	0.999767	0.993041	0.000290	0.003787	0.995069	

Time to Peak Torque - 180°.s^{-1}

Effect	Repeated Measures Analysis of Variance (Isokinetics in Results - I Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 219.71 SS	Degr. of Freedom	MS	F	p
Intercept	23487818	1	23487818	486.5595	0.000000
Group (1=CON, 2=INT)	1670	1	1670	0.0346	0.854639
Error	820646	17	48273		
LIMB	18470	1	18470	2.1104	0.164506
LIMB*Group (1=CON, 2=INT)	60	1	60	0.0068	0.935042
Error	148782	17	8752		
TIME	7082	1	7082	0.3366	0.569397
TIME*Group (1=CON, 2=INT)	1114	1	1114	0.0529	0.820779
Error	357660	17	21039		
LIMB*TIME	550	1	550	0.0880	0.770298
LIMB*TIME*Group (1=CON, 2=INT)	1034	1	1034	0.1655	0.689230
Error	106266	17	6251		

Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 27262., df = 21.330

Cell No.	Group (1=CON, 2=INT)	LIMB	TIME	{1} 576.67	{2} 575.56	{3} 534.44	{4} 558.89	{5} 554.00	{6} 583.00	{7} 523.00	{8} 548.00
1	1	1	1		1.000000	0.940115	0.999645	0.999986	1.000000	0.995861	0.999930
2	1	1	2	1.000000		0.947482	0.999768	0.999990	1.000000	0.996370	0.999947
3	1	2	1	0.940115	0.947482		0.997249	0.999995	0.997790	1.000000	1.000000
4	1	2	2	0.999645	0.999768	0.997249		1.000000	0.999978	0.999690	1.000000
5	2	1	1	0.999986	0.999990	0.999995	1.000000		0.989409	0.984499	1.000000
6	2	1	2	1.000000	1.000000	0.997790	0.999978	0.989409		0.689289	0.969886
7	2	2	1	0.995861	0.996370	1.000000	0.999690	0.984499	0.689289		0.995618
8	2	2	2	0.999930	0.999947	1.000000	1.000000	1.000000	0.969886	0.995618	

Total Work - 60°.s^{-1}

Effect	SS	Degr. of Freedom	MS	F	p
	Repeated Measures Analysis of Variance (Isokinetics in Results - New Format) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 130.3662				
Intercept	5545973	1	5545973	326.3228	0.000000
Group (1=CON, 2=INT)	87	1	87	0.0051	0.943776
Error	288921	17	16995		
LIMB	7659	1	7659	1.5510	0.229888
LIMB*Group (1=CON, 2=INT)	7234	1	7234	1.4648	0.242734
Error	83955	17	4939		
TIME	4938	1	4938	7.2056	0.015680
TIME*Group (1=CON, 2=INT)	64	1	64	0.0928	0.764352
Error	11649	17	685		
LIMB*TIME	3055	1	3055	3.8269	0.067070
LIMB*TIME*Group (1=CON, 2=INT)	275	1	275	0.3451	0.564632
Error	13571	17	798		

Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 8896.8, df = 18.594

Cell No.	Group (1=CON, 2=INT)	LIMB	TIME	{1} 270.82	{2} 268.62	{3} 253.74	{4} 284.57	{5} 286.86	{6} 295.95	{7} 238.33	{8} 265.19
1	1	1	1		1.000000	0.893485	0.962560	0.999937	0.998788	0.993900	1.000000
2	1	1	2	1.000000		0.944114	0.922068	0.999850	0.997913	0.996018	1.000000
3	1	2	1	0.893485	0.944114		0.340654	0.993162	0.972869	0.999951	0.999994
4	1	2	2	0.962560	0.922068	0.340654		1.000000	0.999994	0.956223	0.999776
5	2	1	1	0.999937	0.999850	0.993162	1.000000		0.995129	0.022699	0.678746
6	2	1	2	0.998788	0.997913	0.972869	0.999994	0.995129		0.005419	0.286090
7	2	2	1	0.993900	0.996018	0.999951	0.956223	0.022699	0.005419		0.437892
8	2	2	2	1.000000	1.000000	0.999994	0.999776	0.678746	0.286090	0.437892	

Total Work - 180°.s^{-1}

Repeated Measures Analysis of Variance (Isokinetics in Results - New Forn
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 130.8923

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	5468408	1	5468408	319.1777	0.000000
Group (1=CON, 2=INT)	7716	1	7716	0.4504	0.511173
Error	291258	17	17133		
LIMB	9750	1	9750	8.3974	0.010009
LIMB*Group (1=CON, 2=INT)	1621	1	1621	1.3961	0.253650
Error	19738	17	1161		
TIME	6869	1	6869	15.9846	0.000931
TIME*Group (1=CON, 2=INT)	18	1	18	0.0418	0.840353
Error	7306	17	430		
LIMB*TIME	1153	1	1153	1.4596	0.243527
LIMB*TIME*Group (1=CON, 2=INT)	321	1	321	0.4057	0.532662
Error	13433	17	790		

Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 8961.5, df = 18.565

Cell No.	Group (1=CON, 2=INT)	LIMB	TIME	{1} 267.30	{2} 281.68	{3} 231.68	{4} 253.43	{5} 281.37	{6} 289.47	{7} 256.02	{8} 287.95
1	1	1	1		0.951622	0.192025	0.959744	0.999974	0.999470	0.999994	0.999667
2	1	1	2	0.951622		0.025928	0.434718	1.000000	1.000000	0.998628	1.000000
3	1	2	1	0.192025	0.025928		0.721003	0.938372	0.876564	0.999032	0.890115
4	1	2	2	0.959744	0.434718	0.721003		0.997649	0.989014	1.000000	0.991450
5	2	1	1	0.999974	1.000000	0.938372	0.997649		0.997535	0.499764	0.999350
6	2	1	2	0.999470	1.000000	0.876564	0.989014	0.997535		0.200821	1.000000
7	2	2	1	0.999994	0.998628	0.999032	1.000000	0.499764	0.200821		0.243522
8	2	2	2	0.999667	1.000000	0.890115	0.991450	0.999350	1.000000	0.243522	

Average Power - 60°.s^{-1}

Effect	Repeated Measures Analysis of Variance (Isokinetics in Results - New Forma Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 27.54219 SS	Degr. of Freedom	MS	F	p
Intercept	518271.3	1	518271.3	683.2192	0.000000
Group (1=CON, 2=INT)	3.5	1	3.5	0.0046	0.946990
Error	12895.7	17	758.6		
LIMB	26.3	1	26.3	0.4319	0.519878
LIMB*Group (1=CON, 2=INT)	234.4	1	234.4	3.8489	0.066364
Error	1035.1	17	60.9		
TIME	237.0	1	237.0	13.2248	0.002040
TIME*Group (1=CON, 2=INT)	3.0	1	3.0	0.1675	0.687451
Error	304.7	17	17.9		
LIMB*TIME	0.3	1	0.3	0.0184	0.893738
LIMB*TIME*Group (1=CON, 2=INT)	16.1	1	16.1	0.9624	0.340334
Error	284.8	17	16.8		

Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 387.66, df = 17.751

Cell No.	Group (1=CON, 2=INT)	LIMB	TIME	{1} 80.267	{2} 82.356	{3} 81.556	{4} 85.744	{5} 82.890	{6} 87.620	{7} 78.990	{8} 82.130
1	1	1	1		0.952167	0.996920	0.149005	0.999988	0.990056	1.000000	0.999999
2	1	1	2	0.952167		0.999859	0.654352	1.000000	0.998739	0.999933	1.000000
3	1	2	1	0.996920	0.999859		0.413355	1.000000	0.996894	0.999989	1.000000
4	1	2	2	0.149005	0.654352	0.413355		0.999978	0.999999	0.993975	0.999892
5	2	1	1	0.999988	1.000000	1.000000	0.999978		0.227248	0.435238	0.999858
6	2	1	2	0.990056	0.998739	0.996894	0.999999	0.227248		0.003999	0.112525
7	2	2	1	1.000000	0.999933	0.999989	0.993975	0.435238	0.003999		0.678519
8	2	2	2	0.999999	1.000000	1.000000	0.999892	0.999858	0.112525	0.678519	

Average Power - 180°.s^{-1}

Effect	SS	Degr. of Freedom	MS	F	p
	Repeated Measures Analysis of Variance (Isokinetics in Results - New Form Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 36.24661				
Intercept	1161437	1	1161437	884.0170	0.000000
Group (1=CON, 2=INT)	114	1	114	0.0869	0.771751
Error	22335	17	1314		
LIMB	311	1	311	1.3257	0.265503
LIMB*Group (1=CON, 2=INT)	2	1	2	0.0073	0.933028
Error	3985	17	234		
TIME	103	1	103	1.0699	0.315461
TIME*Group (1=CON, 2=INT)	44	1	44	0.4586	0.507408
Error	1638	17	96		
LIMB*TIME	38	1	38	1.1455	0.299458
LIMB*TIME*Group (1=CON, 2=INT)	311	1	311	9.4457	0.006886
Error	559	17	33		

Cell No.	Group (1=CON, 2=INT)	LIMB	TIME	{1} 119.71	{2} 125.98	{3} 129.52	{4} 124.87	{5} 120.08	{6} 121.30	{7} 121.19	{8} 127.69
	Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format) Approximate Probabilities for Post Hoc Tests Error: Between; Within; Pooled MSE = 673.36, df = 17.851										
1	1	1	1		0.339155	0.034489	0.564665	1.000000	1.000000	1.000000	0.996932
2	1	1	2	0.339155		0.882756	0.999868	0.999558	0.999905	0.999888	1.000000
3	1	2	1	0.034489	0.882756		0.674918	0.991468	0.996297	0.995983	1.000000
4	1	2	2	0.564665	0.999868	0.674918		0.999889	0.999985	0.999981	0.999997
5	2	1	1	1.000000	0.999558	0.991468	0.999889		0.999652	0.999813	0.119319
6	2	1	2	1.000000	0.999905	0.996297	0.999985	0.999652		1.000000	0.262777
7	2	2	1	1.000000	0.999888	0.995983	0.999981	0.999813	1.000000		0.245973
8	2	2	2	0.996932	1.000000	1.000000	0.999997	0.119319	0.262777	0.245973	

Functional Ratio - 60°.s^{-1}

Effect	Repeated Measures Analysis of Variance (Isokinetics in Results - N Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: .18114 SS	Degr. of Freedom	MS	F	p
Intercept	54.10994	1	54.10994	1649.021	0.000000
Group (1=CON, 2=INT)	0.00001	1	0.00001	0.000	0.985204
Error	0.55783	17	0.03281		
LIMB	0.00070	1	0.00070	0.048	0.829892
LIMB*Group (1=CON, 2=INT)	0.00913	1	0.00913	0.617	0.443074
Error	0.25159	17	0.01480		
TIME	0.00200	1	0.00200	1.266	0.276190
TIME*Group (1=CON, 2=INT)	0.01244	1	0.01244	7.864	0.012196
Error	0.02689	17	0.00158		
LIMB*TIME	0.00055	1	0.00055	0.468	0.503280
LIMB*TIME*Group (1=CON, 2=INT)	0.00197	1	0.00197	1.674	0.213092
Error	0.01999	17	0.00118		

Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = .01699, df = 18.217

Cell No.	Group (1=CON, 2=INT)	LIMB	TIME	{1} .84750	{2} .82735	{3} .85854	{4} .84800	{5} .83285	{6} .88433	{7} .82038	{8} .84070
1	1	1	1		0.906186	0.996444	1.000000	0.999996	0.998206	0.999755	1.000000
2	1	1	2	0.906186		0.550762	0.895099	1.000000	0.976008	1.000000	0.999998
3	1	2	1	0.996444	0.550762		0.997349	0.999828	0.999824	0.997751	0.999985
4	1	2	2	1.000000	0.895099	0.997349		0.999995	0.998356	0.999723	1.000000
5	2	1	1	0.999996	1.000000	0.999828	0.999995		0.058153	0.989930	0.999435
6	2	1	2	0.998206	0.976008	0.999824	0.998356	0.058153		0.011782	0.147519
7	2	2	1	0.999755	1.000000	0.997751	0.999723	0.989930	0.011782		0.876984
8	2	2	2	1.000000	0.999998	0.999985	1.000000	0.999435	0.147519	0.876984	

Functional Ratio - 180°.s^{-1}

Effect	Repeated Measures Analysis of Variance (Isokinetics in Results - Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: .2953				
	SS	Degr. of Freedom	MS	F	p
Intercept	98.45641	1	98.45641	1128.810	0.000000
Group (1=CON, 2=INT)	0.00543	1	0.00543	0.062	0.805977
Error	1.48276	17	0.08722		
LIMB	0.00428	1	0.00428	0.180	0.676786
LIMB*Group (1=CON, 2=INT)	0.00122	1	0.00122	0.051	0.823456
Error	0.40483	17	0.02381		
TIME	0.00898	1	0.00898	1.710	0.208364
TIME*Group (1=CON, 2=INT)	0.00606	1	0.00606	1.154	0.297691
Error	0.08926	17	0.00525		
LIMB*TIME	0.03279	1	0.03279	3.419	0.081935
LIMB*TIME*Group (1=CON, 2=INT)	0.00013	1	0.00013	0.014	0.908458
Error	0.16307	17	0.00959		

Cell No.	Tukey HSD test; variable DV_1 (Isokinetics in Results - New Format) Approximate Probabilities for Post Hoc Tests Error: Between; Within; Pooled MSE = .04841, df = 20.695										
	Group (1=CON, 2=INT)	LIMB	TIME	{1} 1.1524	{2} 1.1173	{3} 1.1064	{4} 1.1492	{5} 1.1621	{6} 1.1575	{7} 1.0948	{8} 1.1786
1	1	1	1		0.993218	0.968908	1.000000	1.000000	1.000000	0.998953	0.999994
2	1	1	2	0.993218		0.999997	0.996144	0.999797	0.999901	0.999998	0.998407
3	1	2	1	0.968908	0.999997		0.978691	0.999157	0.999516	1.000000	0.995555
4	1	2	2	1.000000	0.996144	0.978691		1.000000	1.000000	0.999267	0.999988
5	2	1	1	1.000000	0.999797	0.999157	1.000000		1.000000	0.778721	0.999923
6	2	1	2	1.000000	0.999901	0.999516	1.000000	1.000000		0.830707	0.999614
7	2	2	1	0.998953	0.999998	1.000000	0.999267	0.778721	0.830707		0.559470
8	2	2	2	0.999994	0.998407	0.995555	0.999988	0.999923	0.999614	0.559470	

Countermovement Jump

Effect	Repeated Measures Analysis of Variance (Vertical Jump in Results - New Format) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 15.48524				
	SS	Degr. of Freedom	MS	F	p
Intercept	261423.1	1	261423.1	1090.205	0.000000
Group (1=CON, 2=INT)	0.1	1	0.1	0.000	0.987927
Error	4076.5	17	239.8		
TIME	329.6	3	109.9	20.707	0.000000
TIME*Group (1=CON, 2=INT)	51.8	3	17.3	3.252	0.029120
Error	270.6	51	5.3		

Cell No.	Tukey HSD test; variable DV_1 (Vertical Jump in Results - New Format) Approximate Probabilities for Post Hoc Tests Error: Between; Within; Pooled MSE = 63.927, df = 19.303									
	Group (1=CON, 2=INT)	TIME	{1} 56.815	{2} 58.333	{3} 59.333	{4} 60.333	{5} 55.133	{6} 56.867	{7} 60.633	{8} 62.400
1	1	CMJ-Pre		0.853781	0.303516	0.040785	0.999742	1.000000	0.961951	0.788046
2	1	CMJ-WK4	0.853781		0.982652	0.595515	0.985475	0.999896	0.998027	0.947546
3	1	CMJ-WK8	0.303516	0.982652		0.982652	0.938481	0.996939	0.999954	0.988623
4	1	CMJ-Post	0.040785	0.595515	0.982652		0.839599	0.977290	1.000000	0.999012
5	2	CMJ-Pre	0.999742	0.985475	0.938481	0.839599		0.698045	0.000182	0.000131
6	2	CMJ-WK4	1.000000	0.999896	0.996939	0.977290	0.698045		0.013135	0.000177
7	2	CMJ-WK8	0.961951	0.998027	0.999954	1.000000	0.000182	0.013135		0.677709
8	2	CMJ-Post	0.788046	0.947546	0.988623	0.999012	0.000131	0.000177	0.677709	

Squat Jump

Effect	Repeated Measures Analysis of Variance (Vertical Jump in Results - New Format) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 16.57458				
	SS	Degr. of Freedom	MS	F	p
Intercept	235190.8	1	235190.8	856.1213	0.000000
Group (1=CON, 2=INT)	13.6	1	13.6	0.0494	0.826762
Error	4670.2	17	274.7		
TIME	184.8	3	61.6	19.3148	0.000000
TIME*Group (1=CON, 2=INT)	12.4	3	4.1	1.3004	0.284405
Error	162.7	51	3.2		

Cell No.	Tukey HSD test; variable DV_1 (Vertical Jump in Results - New Format) Approximate Probabilities for Post Hoc Tests Error: Between; Within; Pooled MSE = 71.071, df = 18.198 Group (1=CON, 2=INT)	TIME	{1} 54.667	{2} 55.481	{3} 56.407	{4} 57.963	{5} 53.433	{6} 53.500	{7} 56.200	{8} 58.000
1	1	SJ-Pre		0.977014	0.448975	0.006185	0.999977	0.999984	0.999899	0.986273
2	1	SJ-WK4	0.977014		0.953993	0.084065	0.999323	0.999454	0.999999	0.997448
3	1	SJ-WK8	0.448975	0.953993		0.591735	0.992925	0.993823	1.000000	0.999870
4	1	SJ-Post	0.006185	0.084065	0.591735		0.930847	0.935608	0.999746	1.000000
5	2	SJ-Pre	0.999977	0.999323	0.992925	0.930847		1.000000	0.022511	0.000147
6	2	SJ-WK4	0.999984	0.999454	0.993823	0.935608	1.000000		0.028208	0.000151
7	2	SJ-WK8	0.999899	0.999999	1.000000	0.999746	0.022511	0.028208		0.338712
8	2	SJ-Post	0.986273	0.997448	0.999870	1.000000	0.000147	0.000151	0.338712	

Eccentric Utilization Ratio

Effect	Repeated Measures Analysis of Variance (Vertical Jump in Results - New Format) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: .0949037 SS	Degr. of Freedom	MS	F	p
Intercept	84.79335	1	84.79335	9414.444	0.000000
Group (1=CON, 2=INT)	0.00413	1	0.00413	0.459	0.507404
Error	0.15311	17	0.00901		
TIME	0.00893	3	0.00298	1.637	0.192265
TIME*Group (1=CON, 2=INT)	0.00572	3	0.00191	1.049	0.378799
Error	0.09267	51	0.00182		

Cell No.	Tukey HSD test; variable DV_1 (Vertical Jump in Results - New Format) Approximate Probabilities for Post Hoc Tests Error: Between; Within; Pooled MSE = .00361, df = 39.038 Group (1=CON, 2=INT)	TIME	{1} 1.0452	{2} 1.0555	{3} 1.0553	{4} 1.0455	{5} 1.0342	{6} 1.0649	{7} 1.0816	{8} 1.0797
1	1	EUR-Pre		0.999583	0.999621	1.000000	0.999916	0.996106	0.885735	0.910952
2	1	EUR-WK4	0.999583		1.000000	0.999652	0.993783	0.999970	0.978973	0.986331
3	1	EUR-WK8	0.999621	1.000000		0.999684	0.994041	0.999967	0.978298	0.985843
4	1	EUR-Post	1.000000	0.999652	0.999684		0.999900	0.996450	0.889643	0.914312
5	2	EUR-Pre	0.999916	0.993783	0.994041	0.999900		0.740943	0.222933	0.268091
6	2	EUR-WK4	0.996106	0.999970	0.999967	0.996450	0.740943		0.986800	0.993596
7	2	EUR-WK8	0.885735	0.978973	0.978298	0.889643	0.222933	0.986800		1.000000
8	2	EUR-Post	0.910952	0.986331	0.985843	0.914312	0.268091	0.993596	1.000000	

10m Sprint

Effect	Repeated Measures Analysis of Variance (Performance in Results - New Format) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: .2224224 SS	Degr. of Freedom	MS	F	p
Intercept	148.4625	1	148.4625	3000.954	0.000000
Group (1=CON, 2=INT)	0.0022	1	0.0022	0.045	0.834485
Error	0.8410	17	0.0495		
TIME	0.0049	1	0.0049	0.620	0.441753
TIME*Group (1=CON, 2=INT)	0.0040	1	0.0040	0.516	0.482425
Error	0.1334	17	0.0078		

Cell No.	Tukey HSD test; variable DV_1 (Performance in Results - New Format) Approximate Probabilities for Post Hoc Tests Error: Between; Within; Pooled MSE = .02866, df = 22.260 Group (1=CON, 2=INT)	TIME	{1} 1.9500	{2} 1.9933	{3} 1.9860	{4} 1.9880
1	1	10mSp-Pre		0.730268	0.966423	0.960907
2	1	10mSp-Post	0.730268		0.999721	0.999892
3	2	10mSp-Pre	0.966423	0.999721		0.999956
4	2	10mSp-Post	0.960907	0.999892	0.999956	