THE INFLUENCE OF SOCCER-SPECIFIC FATIGUE ON THE RISK OF THIGH INJURIES IN AMATEUR BLACK AFRICAN PLAYERS

BY

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ABSTRACT

Background: Epidemiological findings indicate a higher risk of muscular thigh strain injury during the latter stages of both halves of soccer match-play, with muscular fatigue highlighted as a key etiological factor in injury causation. Anthropometric, biomechanical and physiological differences present in the Black African population may elicit unique thigh injury risk profiles, different from those of European and American players. **Objectives:** The purpose of the current research was to investigate the impact of soccer-specific fatigue on the risk of hamstring and quadricep injury in amateur Black African soccer players, in both the dominant and non-dominant legs. **Methods:** Participants were required to perform a soccer match-play simulation (SAFT^{90}), consisting of multidirectional and utility movements, as well as frequent acceleration and deceleration. Selected physical, physiological and psychophysical responses were collected at specific time intervals throughout fatigue protocol performance. **Results:** Heart rate responses were observed to increase significantly ($p<0.05$) in response to the start of both halves, and remain elevated (but showing no further significant increase) during the performance of the remainder of the fatigue protocol. Significant ($p<0.05$) changes in both concentric and eccentric isokinetic variables of the knee flexors and extensors highlight the effect of muscular fatigue on performance in soccer match-play. Eccentric hamstring peak torque was observed to decrease significantly over time (60°.s^{-1}=17.34%, 180°.s^{-1}=18.27%), with significant reductions observed during both halves. The functional H:Q ratio at 180°.s^{-1} indicated a significant decrease over time (10.04%), with a significant decrease indicated during the second half of the SAFT^{90} protocol. The passive half time interval did not result in significant changes in isokinetic variables. Isokinetic strength, work and power indicated no significant effects of leg dominance.. 'Central' and 'Local' ratings of exertion were observed to increase significantly ($p<0.05$) as a function of exercise duration. **Conclusion:** The overall reduction in both the eccentric hamstring peak torque and the functional strength ratio was illustrated to be similar to that of other soccer-specific fatigue research. As a result, the risk of thigh strain injuries is suggested to be similar regardless of playing level and race. These time dependent changes may have implications for competitive performance and increased predisposition to hamstring strain injuries during the latter stages of both halves of match-play.

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CHAPTER I

INTRODUCTION

BACKGROUND TO THE STUDY

Soccer, or football as it is officially called by the Federation International de Football Association (FIFA), is considered to be the most popular sport in the world and is played by at least 200 million licensed players (Witvrouw et al., 2003). Soccer is characterised as an intermittent, noncontinuous exercise incorporating periods of high intensity and lower intensity physical activity (Witvrouw et al., 2003; Svensson and Drust, 2005). A large percentage of the game is performed at maximum speed, and includes functional activities such as accelerations, decelerations, jumping, cutting, pivoting, turning and the kicking of the ball (Inklaar, 1994; Witvrouw et al., 2003). The demands of soccer require players to be competent in several aspects of fitness, including aerobic and anaerobic power, muscular strength, flexibility and agility (Svensson and Drust, 2005).

Because of its popularity and the characteristics of the game of soccer, a large amount of soccer related injuries are expected (Witvrouw et al., 2003). The overall risk of injury to professional soccer players is approximately 1000 times greater than for industrial occupations that are considered high risk (Hawkins et al., 2001). According to research by Ekstrand (2008), the incidence of injury at top level soccer is six to nine injuries per 1000 hours of total exposure (three to five injuries per 1000 training hours and 24-30 injuries per 1000 match hours). Similarly, Hawkins et al. (2001) established that 1.3 injuries occurred per player per season, with 68% of injuries being classified as minor to moderate, and a further 23% preventing a player from training or playing for at least four weeks. The incidence of injury in amateur players has been investigated in several studies, and varies between 12-35 injuries per 1000 hours of match exposure (Junge et al., 2004). Due to the high incidences of injury, research into the mechanisms of soccer related injury is required for both professional and amateur players.

The most common mechanisms of injury are related to the activities of running, twisting, turning, jumping, and landing (Wong and Hong, 2005). Hawkins and Fuller

(1999) and Hawkins et al. (2001) indicate that non body contact is a primary mechanism of soccer related injury, with these injuries accounting for approximately 59% of all soccer related injuries. Furthermore, Hawkins et al. (2001) found that the mechanisms of non body contact injuries consist of running (19%), twisting and turning (8%), shooting (4%), and landing (4%).

Over the last few decades injury trends in soccer have changed, the thigh and more specifically the hamstrings muscle group are now recognised as the most frequently injured anatomical structure (Ekstrand and Gillquist, 1983; Lewin, 1989; Arnason et al., 2004; Walden et al., 2005). According to Ekstrand (2008), 23% of all soccer related injuries occur to the thigh region, with the risk of sustaining a thigh injury suggested to be approximately 1.6 per 1000 hours of competitive match-play. In addition, an earlier audit of injuries in soccer by Hawkins et al. (2001) suggests that 81% of soccer related thigh injuries consist of muscular strains, of which 67% occurred to the posterior part of the thigh (hamstrings). Hamstring injuries commonly occur during the rapid extension of the knee, which requires eccentric action, decelerating the lower leg in the late swing phase of the running gait cycle (Croisier, 2004; Croisier et al., 2008). A number of possible causes of hamstring injury have been suggested, however the aetiology of injury remains unclear. A number of researchers have proposed many different factors in an attempt to understand the cause of hamstring injuries (Worrell and Perrin, 1992). However, it is now believed that in many instances the cause of hamstring injury is multifactorial in nature (Worrell and Perrin, 1992; Croisier, 2004; Pull and Ranson, 2007; Croisier et al., 2008). A combination of factors such as; inadequate or no warm-up, lack of flexibility, strength imbalances and fatigue have been reported to increase the risk of hamstring injury (Worrell, 1994). Hamstring injuries, in addition to being common, may be long standing and highly prone to recurrence (Croisier et al. 2008; Brukner et al., 2013). The high frequency of re-injury and persistent complaints following a hamstring strain result in major difficulties for the athlete to return to physical activity (Croisier, 2004).

Hawkins et al. (2001) found that the distribution of competitive match injuries with regards to time indicates that most injuries occur during the final 15 minutes of the first half and the final 30 minutes of the second half. Muscular fatigue is evident during the course of a soccer match, where players are able to continue to exercise at submaximal intensities but have a reduced ability to perform maximally (Rahnama et al., 2003). This is important as the negative role of muscular fatigue has been identified as a key factor in thigh injury causation, partially explaining the greater incidence of injury observed in the later stages of both halves of play (Hawkins et al., 2001; Rahnama et al., 2003). Fatigue is indicated by a reduction in maximal force or power associated with prolonged exercise and is reflected as a decrease in performance (Reilly, 1994; Taylor et al., 2000). The quantification of temporal changes in the peak eccentric and concentric isokinetic torque producing ability of the knee flexors (hamstrings) and extensors (quadriceps) is an accurate and reliable method of assessing the effects of soccer-specific fatigue (Greig, 2008). If the ability to produce muscular force is impaired by the onset of fatigue, then the altered mechanics of the sprinting gait cycle are suggested to increase the risk of thigh injury (Pinniger et al., 2000). Isokinetic research on soccer players exposed to soccer-specific fatigue protocols shows a gradual decline in both the eccentric and concentric torque producing abilities of the knee flexors and extensors (Rahnama et al., 2003; Greig, 2008; Greig and Siegler, 2009). However, research of this nature still remains limited. The deterioration of eccentric peak hamstring torque as a function of simulated match duration supports epidemiological data indicating an increased risk of thigh injury in the latter stages of both halves of match-play (Greig, 2008; Greig and Siegler, 2009). The susceptibility to muscular strain in fatigued muscles is likely to increase during explosive ballistic actions such as accelerating and decelerating during sprinting (Greig, 2008).

The game of soccer commonly involves one sided activities such as kicking and as a result asymmetries in muscle strength between the two legs are possible (Brady et al., 1993). These differences in the muscle strength profiles between the dominant and non-dominant legs are considered an important predictor of thigh injury in soccer players (Leatt et al. 1987; Kellis et al. 2001). According to Ergun et al. (2004), Voutselas et al. (2007), and Kong and Burns (2010), bilateral differences have been observed in male soccer players. However, bilateral differences in leg muscle strength in soccer players remains poorly understood. Hawkins et al. (2001) found that significantly more injuries occur in the dominant leg. Later, Henderson et al. (2010) concurred and contended that approximately 10 of 12 hamstring injuries sustained during match-play occur in the dominant leg. Contrastingly, other studies have found no difference between the dominant and non-dominant legs in soccer players (Rosene et al., 2001). The lack of agreement in the above findings may be due to methodological differences between studies. These differences include; the use of different isokinetic testing velocities, order effects resulting from a lack of leg randomisation, and the use of a fatigue protocol in order to exaggerate muscular strength deficits. It is therefore evident that further research is required in order to clarify the role of leg dominance in soccer related hamstring injuries.

The translation of the mental and physical demands placed on soccer players into injuries is of great concern to the governing bodies of soccer (Ekstrand, 2008). Any injuries sustained by important players competing in top level soccer competitions result in a negative impact on team morale, performance and financial well-being (Henderson et al., 2010). As injuries directly affect the performance of a player and subsequently the team, it seems clear that teams that are able to avoid major and long lasting injuries have a greater chance of success (Ekstrand, 2008). Consequently, a better understanding of the mechanisms of thigh injury and the identification of players most at risk will be of great benefit to both players and the team as a whole (Henderson et al., 2010). Due to their large numbers as well as the high injury rates, such research also has important implications for amateur players.

Soccer-specific research and more specifically research on the risk of thigh injuries in soccer players, has focussed exclusively 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 and Siegler, 2009; Lovell et al., 2011), North American (Worrell, 1994) and South American players (Silva et al., 2008). There is a distinct lack of research aimed at attempting to better understand the risk of thigh injuries within the population of professional and non-professional African soccer players, and more specifically South African Black players. The biomechanical and physiological differences between European runners and their African counterparts are well known (Larsen, 2003). Research by Larsen (2003) indicates that Black Kenyan and South African athletes, while possessing similar or lower VO_{2max} values as their Caucasian European counterparts, elicit a greater fractional VO_{2max} utilization as well as a better running economy. Such differences in running performance are attributed to differences in body shape (somatotype), where the African athlete’s long slender legs are greatly advantageous with regards to the energy cost of running (Larsen et al., 2003). These differences between European and African athletes suggests that the research conducted on thigh injury risk profiles in European, North American and South American soccer players may not apply to the population of Black African players. The anthropometric, biomechanical and physiological differences present in the Black African population may elicit unique thigh injury risk profiles, different from those of European and American players. Therefore, there is a need to explore the fatigue and injury profile within this specific population further.

STATEMENT OF THE PROBLEM

The majority of studies that have investigated the impact of the specific fatigue profiles associated with competitive soccer matches on the risk of thigh injuries have focused on both professional and non-professional European, South American, and North American players. However, few studies have focussed on the strength profiles or the risk of thigh injury within an African context, and more specifically a South African context. There are known biomechanical and physiological differences between African runners and their European counterparts. These differences may exist within the soccer context as well, rendering any research on the risk of thigh injury conducted in European regions meaningless within the population of African soccer players.

Soccer frequently involves one sided activities such as kicking and as a result asymmetries in muscle strength between the two legs are possible. These differences in strength profiles between the two legs are considered an important predictor of thigh injury in soccer players. However, the bilateral differences in leg muscle strength and its effect on the risk of thigh injuries remains poorly understood.

Therefore, the purpose of the current research was to investigate the impact of a soccer-specific protocol on the fatigue profiles of the lower extremities and the associated risk of hamstring and quadricep injury in amateur Black African soccer players.

RESEARCH HYPOTHESIS

Firstly, it was hypothesised that the mean peak isokinetic torque generated before the beginning of a simulated match (0 minutes) as well as following the passive half time interval (60 minutes) will be greater than the mean peak isokinetic torque generated at the end of the first half (45 minutes) and the end of the second half (105 minutes) respectively.

Secondly, it was hypothesised that the dominant leg will result in the greatest mean peak isokinetic torque in comparison to the non-dominant leg, regardless of the time interval (i.e. before, halftime, or after the protocol).

STATISTICAL HYPOTHESIS

Hypothesis 1: The null hypothesis proposed that there will be no difference in the physical responses at the beginning of the protocol (T0), end of the first half of the protocol (T45), end of the half time interval (T60), and the end of the second half of the protocol (T105) for both the dominant and non-dominant legs.

Ho: μ_{Res} T0 $_{\text{(D+ND)}}$ = μ_{Res} T45 $_{\text{(D+ND)}}$ = μ_{Res} T60 $_{\text{(D+ND)}}$ = μ_{Res} T105 $_{\text{(D+ND)}}$

Ha: μ_{Res} T0 $_{\text{(D+ND)}}$ ≠ μ_{Res} T45 $_{\text{(D+ND)}}$ ≠ μ_{Res} T60 $_{\text{(D+ND)}}$ ≠ μ_{Res} T105 $_{\text{(D+ND)}}$

Where: Responses= isokinetic peak torque, work done, power output, angle at peak torque, time rate of torque development, strength ratios.
T0, T45, T60, T105 = Time (minutes)
D= dominant leg; ND= non-dominant leg

Hypothesis 2: The null hypothesis proposed that there will be no difference in the physical responses between the dominant and non-dominant legs with regards to at the beginning of the protocol (T0), end of the first half of the protocol (T45), end of the half time interval (T60), and the end of the second half of the protocol (T105).

Ho: μ_{Res} Dominant leg $_{\text{(T0, T45, T60, T105)}}$ = μ_{Res} Non-dominant leg $_{\text{(T0, T45, T60, T105)}}$

Ha: μ_{Res} Dominant leg $_{\text{(T0, T45, T60, T105)}}$ ≠ μ_{Res} Non-dominant leg $_{\text{(T0, T45, T60, T105)}}$

Where: Responses= isokinetic peak torque, work done, power output, angle at peak torque, time rate of torque development, strength ratios.
T0, T45, T60, T105 = Time (minutes)

DELIMITATIONS

The present study was delimited to 20 male amateur soccer players. Participants for were recruited from the first team soccer squads at Rhodes University in

Grahamstown, South Africa, and Nelson Mandela Metropolitan University in Port Elizabeth, South Africa. The primary focus of this study was to identify changes in eccentric and concentric force production capabilities of the quadriceps and hamstring musculature, of both the dominant and non-dominant legs, during a simulated soccer-specific laboratory protocol. Participants performed a 90 minute soccer-specific aerobic field test (SAFT^{90}). The protocol was divided into two 45 minute periods interceded by a 15 minute half time interval. This soccer-specific fatigue protocol, designed to simulate the activity profile of a competitive soccer match, incorporates intermittently distributed periods of standing, walking, jogging, striding and sprinting. The SAFT^{90} protocol simulates the activity profile of defenders, midfield and attacking players. The field test incorporates utility movements, and frequent changes in speed as is inherent to match-play.

During the first session, experimental procedures and protocols were explained to the participants. Once the procedures were explained and any participant queries had been dealt with, each participant was required to sign an informed consent form. All participants were habituated to the performance SAFT^{90} protocol. Participants were also habituated to the CYBEX^{TM} 6000 isokinetic dynamometer, Polar^{TM} F11 Heart Rate monitor belts, and psychophysical measures (RPE and Body Discomfort). Demographic and anthropometric data were obtained, including; age, stature, mass, limb girths, skinfolds, bone breadths, resting heart rate, playing position, number of years experience and a full injury history of each participant. Participants with a history of thigh injury were excluded from the present study.

In the second session participants were required to perform the experimental conditions. Participants were provided with standardised instructions on how to perform the protocol, which included a warm up and a cool down routine. The simulation protocol was chosen so as to minimise inter-individual variability that match-play presents and allowed participants to perform at similar levels. Dependant variables examined included; isokinetic data (peak torque, angle of peak torque, total work, and average power), heart rate responses, ratings of perceived exertion (both central and local) and body discomfort. These data were recorded in the same manner and at the same time intervals for all participants during the performance of the match simulation.

LIMITATIONS

Despite efforts to rigorously control extraneous variables from affecting the reliability of measures, it is impossible to control all impinging influences. Therefore, when examining the implications and conclusions from the results, one must consider the following limitations.

This study was limited as the protocol utilised was designed such that the physical demands of soccer match-play could be simulated in a laboratory setting. Therefore, the study eliminated the physical impact of contact situations within the game as well as a player's interaction with the ball during actions such as kicking, tackling, or heading. Competitive match-play involves elements of unpredictability, pressures to perform and influences from the crowd (encouragement), factors limiting the extrapolation of data collected during the performance of the laboratory protocol to real life situations. In addition, environmental conditions such as humidity, sun exposure and wind resistance, differed significantly from the dynamic conditions experienced outdoors, which may compromise this studies external validity. However, the above limitation ensures all data collected are reliable, therefore a reasonable limitation to impose on the study.

Due to the nature of the isokinetic testing involved in the current research, the fatigue imposed by the experimental testing procedures may be exaggerated. The measurement of both the concentric and eccentric muscle actions of the quadriceps and hamstring musculature, at four different intervals, may have negatively impacted the isokinetic variables collected.

All participants were recruited from amateur South African soccer leagues. Although the players possessed high levels of physical fitness, strength and skill, extrapolation to professional players is limited.

Despite all participants being part of the same teams and therefore attending the same practices, the training status of the participants could not be controlled. This is as many players partake in their own exercise programmes. Each participants exercise involvement was recorded through the use of a physical activity screening questionnaire.

Participants were instructed not to consume alcohol, refrain from exercise at least 24 hours prior to testing, and avoid food and caffeine ingestion at least three hours before testing. The researcher was unable to fully control the above. On arrival, participants were asked whether they had done any of the above mentioned activities and if they had, testing was rescheduled.

No control condition was used for this investigation. This may limit the study in terms of not having a comparative value with which the muscle fatigue from the simulation can be compared to. However, due to the multidirectional and intermittent nature of soccer, a treadmill based protocol would yield invalid comparative results. The use of a control sample consisting of White amateur soccer players may have enhanced the findings of the present study, however the use of such a control was not possible due to time constraints.

CHAPTER II

REVIEW OF RELATED LITERATURE

GENERAL CHARACTERISTICS OF SOCCER

Soccer or football is the most popular sport in the world, with more than 240 million amateur and 200 000 professional players (Junge and Dvorak, 2004). Physiologically soccer is characterised as an intermittent, high intensity, non continuous exercise (Witvrouw et al., 2003). The physical demands of competitive soccer require players to be competent in several aspects of fitness, technical ability, agility, ball skills, as well as psychological aspects (Svensson and Drust, 2005; Silva et al., 2008). These components often vary within the individual player, the positional role in the team and a team's style of play. Running is the predominant activity, yet explosive efforts such as jumps, duels and kicking are important factors for successful soccer performance (Cometti et al., 2001). According to Silva et al. (2008), on average, soccer players cover 10km at an intensity of 80-90% of maximal heart rate over the 90 minutes of a match. As seen in Table I, the midfield players typically run the greatest distance during a match, while defenders run the least distance (Tourny-Chollet et al., 2000). Variation in sprint distance and duration also depends on the playing field position. Due to the large distances covered during match-play, large distances covered while sprinting, and the constant acceleration and deceleration required, soccer players experience high levels of fatigue, placing them at a high risk of injury (Tourny-Chollet et al., 2000).

Table I: Differences in distance covered during match-play depending on position.

Positional role	Mean distance covered	SD(±)
Central defender	10627 m	893 m
External defender	11410 m	708 m
Central midfield	12027 m	625 m
External midfield	11990 m	776 m
Forward	11254 m	894 m
Average	**11393 m**	**779 m**

(Adapted from Tourny-Chollet et al., 2000)

A soccer kick is the result of coordinated segmental actions aiming to propel the ball towards a certain target (player or the goal). During a kick, the force exerted by knee extension makes the ball attain speeds between 23.5 $m.s^{-1}$, when utilising a stationary approach. and 30.8 $m.s^{-1}$ when using a five to eight stride running approach (Tourny-Chollet et al., 2000).

TYPES OF MUSCLE ACTION

According to Tortora and Derrickson (2006), muscle action can be classified as either isotonic or isometric. During isometric muscle action, the tension generated by the muscle is not sufficient to exceed the resistance of the limb, resulting in the muscle's length remaining constant. Although this form of muscular action does not result in movement, energy is still expended. Isometric contractions are important as they stabilise some joints while others are moved (Tortora and Derrickson, 2006). In contrast, isotonic muscle actions are used for body movements (Enoka, 1996). The tension generated in the muscle remains more or less constant while the muscle changes its length (Tortora and Derrickson, 2006). Furthermore, two types of isotonic muscle actions exist:

Concentric muscle action

During concentric muscle action, when the tension generated by the muscle is great enough to overcome the resistance of the limb, the muscle shortens and produces movement, reducing the angle at the joint (Tortora and Derrickson, 2006).

Eccentric muscle action

During eccentric muscle action, the tension generated by the myosin cross bridges resist the movement of the limb, allowing the muscle to lengthen in a controlled manner through the action of the muscle (Tortora and Derrickson, 2006). Where concentric muscle action initiates movement, the eccentric action of muscles slows or stops movement (Proske and Morgan, 2001a). In an eccentrically acting muscle the muscle is forcibly lengthened, pulling the myosin heads out to angles of 90 degrees or more (Noakes, 2001). The mechanisms of eccentric muscle action are not fully understood, however the loose binding theory proposed by Toshio Yanagida has become an increasingly popular hypothesis when attempting to account for the controlled lengthening of a muscle (Noakes, 2001). According Friden et al. (1984)

and Noakes (2001), eccentric muscle actions use less oxygen and ATP, and recruit fewer muscle fibers than equivalent concentric muscle actions. Eccentric muscle actions produce approximately twice as much force in each active muscle fiber, increasing the risk of both muscle and tendon injury during eccentric action (Noakes, 2001). Skeletal muscle is not designed for repeated eccentric activity and is susceptible to damage when forced to continually contract in such a manner (Noakes, 2001). For reasons that are not fully understood, repeated eccentric muscle actions produce greater muscle damage than concentric muscle actions (Tortora and Derrickson, 2006).

SOCCER INJURIES

Research has shown that soccer has a higher injury rate than other sports such as field hockey, basketball, rugby, cycling, swimming, volleyball, and cricket (Wong and Hong, 2005). As a result, the governing bodies of football, FIFA and UEFA (Union of European Football Associations) have expressed their concern about the demands placed on the modern footballer, and the subsequent translation of the physical and mental demands into injuries (Ekstrand, 2008).

Incidence of soccer injury

The incidence of soccer injury has been investigated in numerous studies and varies considerably depending on the definition of injury, the characteristics of the investigated players and the research design (Junge et al., 2002). Kibler (1993) defined injury as any condition causing a player to be removed from a game, or miss a game. While Hawkins and Fuller (1999) later defined injury as a contusion, laceration or strain received during training or competition which prevented the injured player from participating in normal training or competition for more than 48 hours. Ekstrand (2008) stated that a recordable injury is defined as an injury resulting in a player being unable to take full part in training or match-play at any time following the injury. Furthermore, injury severity is categorised by the number of days elapsed from the date of injury to the date of return (Ekstrand, 2008). These severities include; slight (1-3 days), minor (4-7 days), moderate (8-28 days), and major (more than 28 days).

In reviewing the available literature, it was found that the majority of research focused on adult male professional soccer players. According to Junge and Dvorak (2004), on average, the incidence of match injuries in both professional and amateur soccer players is four to six times greater than the incidence of injuries that occur during training. Wong and Hong (2005) suggest that the higher speed of play and increased match intensity contribute to the increased injury incidence. Due to this increased incidence of injury, the current research was undertaken in an attempt to better understand the fatigue levels and resulting risk of injury associated with competitive soccer match-play.

During match-play, professional players generally have a higher rate of injury when compared to amateur players (Junge and Dvorak, 2004; Wong and Hong, 2005). The higher competitive levels provide greater awards for success, and there is more competition for places on a team. This results in greater levels of exertion by players, leading to a greater occurrence of injury (Wong and Hong, 2005). Ekstrand (2008) proposes that the incidence of injury in elite soccer is six to nine injuries per 1000 hours of total match exposure (three to five injuries per 1000 hours of training and 24 to 30 injuries per 1000 hours of match-play). Therefore as an average, a team of approximately 25 players can expect 40 to 50 injuries per nine month season, half of them causing absence for less than a week (slight to minor), but six to nine causing players to be absent for more than a month (major). Similarly, in a two season prospective epidemiological study by Hawkins et al. (2001), it was established that 1.3 injuries occurred per player per season, with 68% of injuries being classified as minor to moderate, and a further 23% preventing a player from training or playing for at least four weeks. On average 4 matches were missed per injury, with a mean of 24.2 days lost per injury. These figures confirm previous reports of the high risk of injury in professional soccer (McPherson, 1985; Lewin, 1989; Hawkins and Fuller, 1999; Hawkins et al., 2001). With regards to amateur players, the incidence of injury has been found to vary from 12 to 35 injuries per 1000 hours of total match exposure (Junge et al., 2004). Epidemiological research focussed on soccer-related injuries within an African context remains lacking.

A correlation between match exposure versus injury and match performance has been intensively debated among soccer’s governing bodies (Ekstrand, 2008). According to various authors, the incidence of injury has been reported to vary over different periods of the playing season (Ekstrand, 1982; Lewin, 1989; Hawkins and Fuller, 1999; Hawkins et al., 2001; Ekstrand, 2008). Such literature provides support for the risk of overplaying (Ekstrand et al., 2004). Peak injury rates were found to occur following pre-season training, following the mid season break, and during match intensive periods (Hawkins et al., 2001). During these periods, players have either not reached appropriate levels of physical fitness and conditioning enabling them to withstand the stresses associated with top level soccer, or match intensive schedules increase the risk of injury due to constant stress and lack of recovery time (Hawkins et al., 2001; Ekstrand, 2008).

From Figure 1, the distribution of competitive match injuries with regards to time, it can be seen that the greatest number of injuries occurred during the final 15 minutes of the first half and the final 30 minutes of the second half. Furthermore, more injuries occurred during the second half of matches (Hawkins et al., 2001).

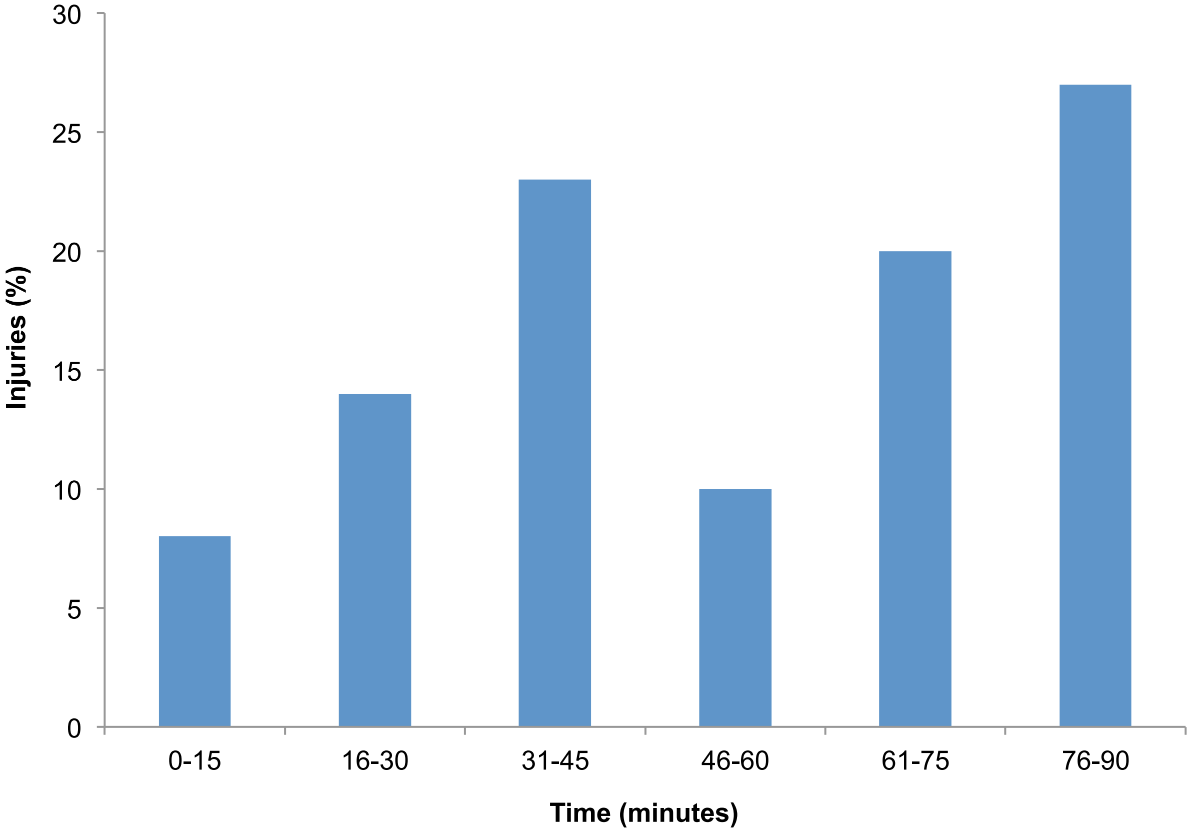


Figure 1: Time of occurrence of injuries in competitive soccer matches. (Adapted from Hawkins et al., 2001)

Also of interest is the possible negative influence of the passive half time interval. Greig (2008) and Greig and Siegler (2009) observed that there is an increased risk of injury due to reduced isokinetic torque during the early stages of the second half, following the half time interval.

Characteristics and causes of soccer injury

The most common mechanisms of injury in soccer are running, shooting, twisting, turning, jumping, landing, tackling, and being tackled (Wong and Hong, 2005). Previous studies indicate that non body contact is a primary mechanism of injury (Hawkins and Fuller, 1996; Hawkins et al., 2001; Wong and Hong, 2005; Ekstrand, 2008). Hawkins and Fuller (1999) reported that non body contact injuries accounted for 59% of all soccer related injuries. In addition, non body contact actions such as running, sprinting, shooting, turning, and jumping caused 39% of all injuries. More recently, Hawkins et al. (2001) found that 58% of all soccer injuries were non body contact related, consisting of running (19%), twisting and turning (8%), shooting (4%), and landing (4%). As non-body contact injuries are the most common injury occurring to soccer players during match-play, a better understanding of the mechanisms are important in order to attempt to avoid such injuries.

An epidemiological study of injury in football by Ekstrand (2008), consisting of 17 teams performing in the UEFA Champions League (UCL), highlighted that 80 to 90% of injuries occurred to the lower extremities, with the most common sites of injury being the thigh (23%), knee (20%), ankle (13%), and the groin/hip (12%) (Figure 2). Similarly, the lower extremities are suggested to be the most frequently injured anatomical area in amateur players (Schmikli et al., 2011). These levels of injury to the lower extremities are similar to those of numerous authors (Anglietti et al., 1994; McGregor and Rae, 1995; Hawkins and Fuller, 1999; Hawkins et al., 2001; Wong and Hong, 2005). Muscle injury to the thigh is the most common injury in top level soccer, accounting for 23% of all injuries (Ekstrand, 2008). The risk of sustaining an injury to the thigh is approximately 1.6 per 1000 hours of competitive play, meaning a team of 25 players can expect 10 thigh injuries per season (Ekstrand, 2008). Given the prevalence of muscular injuries localised to the thigh, research focussing on the etiological factors attributed to an increased risk of thigh injury is essential.

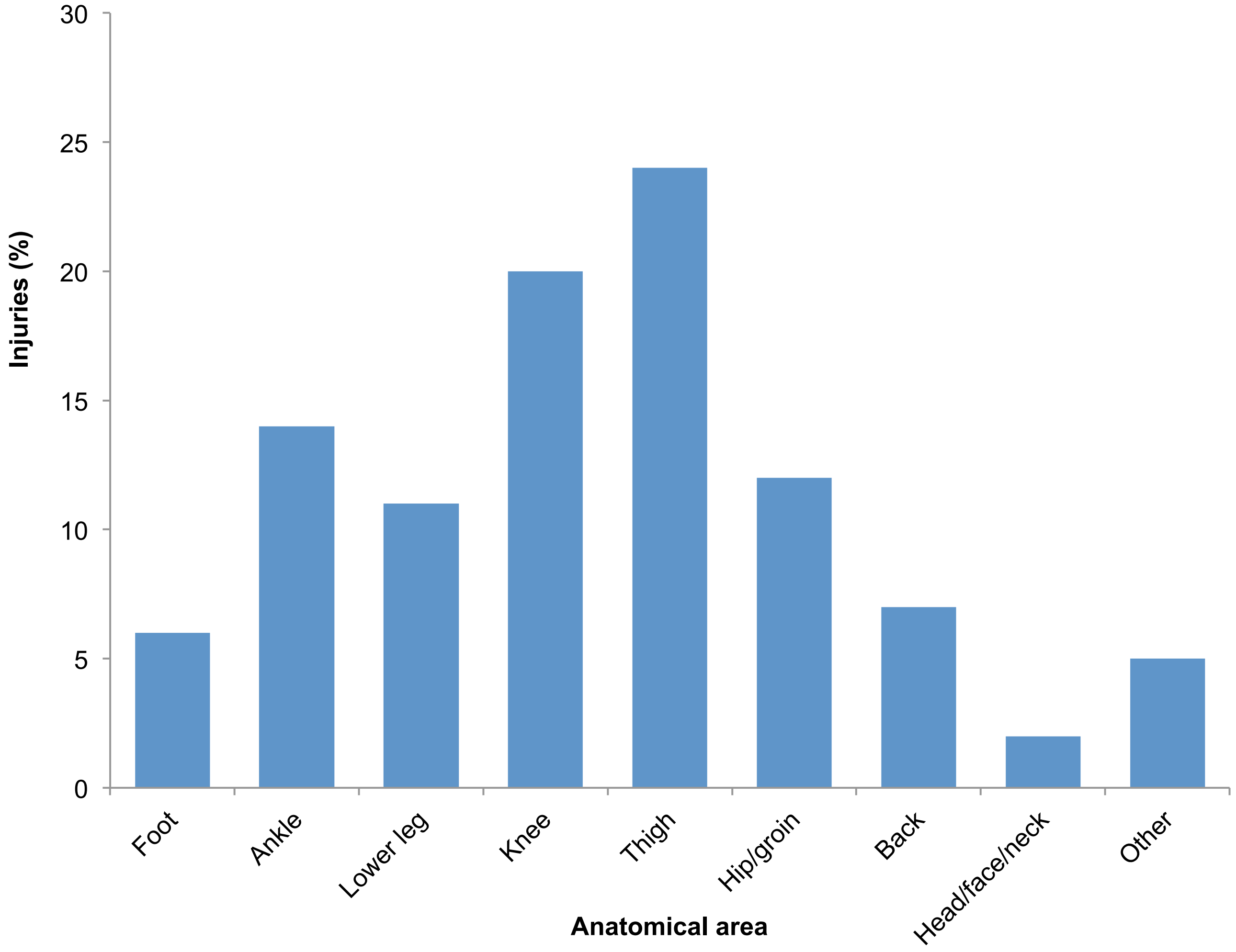


Figure 2: Localisation of injuries in male soccer.
(Adapted from Ekstrand, 2008)

Injuries classified as strains, sprains or contusions represent 69% of all injuries in professional and amateur soccer (Hawkins et al., 2001). Ekstrand (2008) suggests that overuse injuries are the most common type of injury, typically affecting the knee, groin and lower leg, while muscle- tendon injuries (strains) and ligament injuries (sprains) also commonly occur (Figure 3). An audit of injuries in soccer (Hawkins et al., 2001) revealed that 81% of soccer related thigh injuries consisted of muscular strains. Furthermore, 67% of thigh strains occurred to the posterior part of the thigh (hamstrings) rather than the anterior (quadriceps). Typically, injury to the posterior thigh muscles occur during a fast burst of speed and the frequent occurrence of these injuries reflects the speed and physically demanding nature of soccer (Ekstrand, 2008).

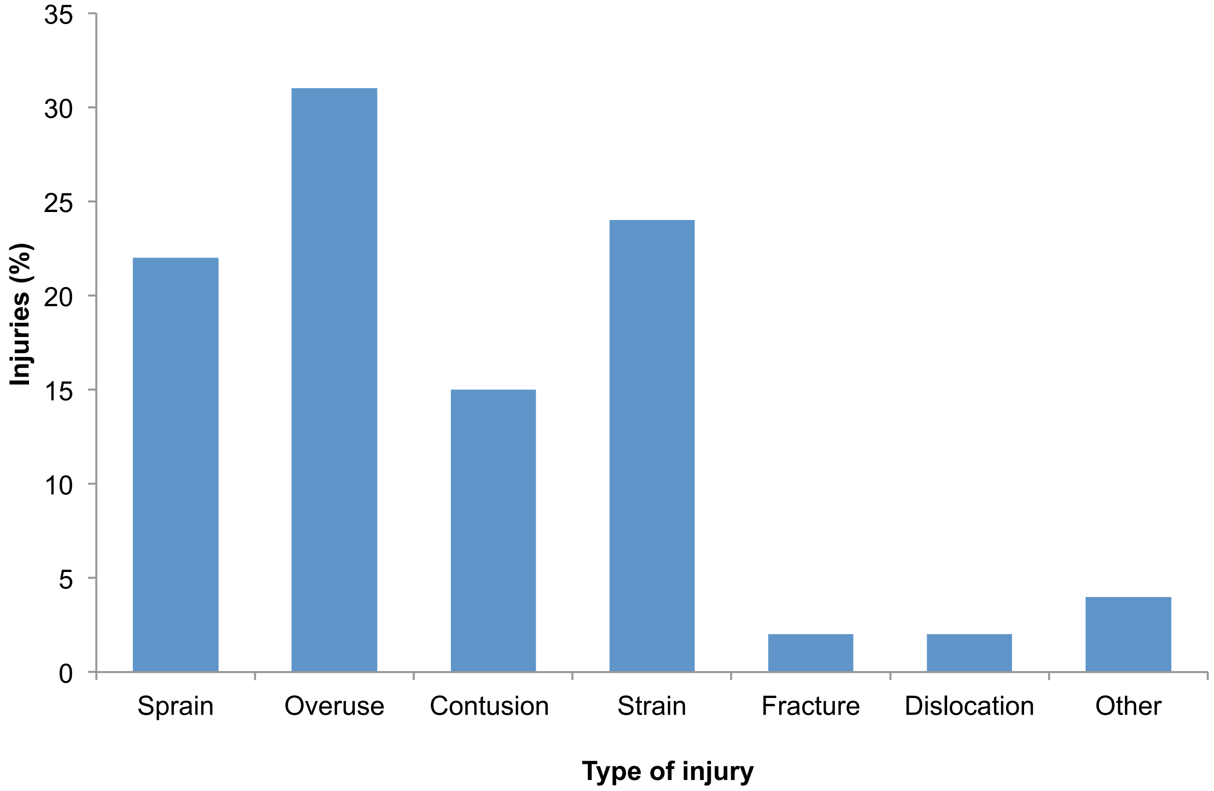


Figure 3: Distribution of injuries by type.

(Adapted from Ekstrand, 2008)

Hamstring injury

The hamstring muscle group is recognised as the most commonly injured anatomical structure, accounting for more playing time lost than other muscular groups (Arnason et al., 2004; Walden et al., 2005; Henderson et al., 2010; Brukner et al., 2013). The Football Association Audit of Injuries found that over a two season period, strains to the hamstring musculature accounted for 12% of all injury in the English Premier League (Woods et al., 2004). Muscle strains most commonly arise in biarticular muscles such as the hamstrings, occurring proximally near the muscle tendon junction (Speer et al., 1993; Garrett, 1996; Croisier, 2004; Pull and Ranson, 2007). During sporting activities that require sprinting, these biarticular muscles are required to cope with large internal forces as well as rapid changes in muscle length and mode of contraction (Pull and Ranson, 2007). Injury to the hamstring muscle group most frequently occurs during the late swing phase of the running gait cycle, when the hamstrings are required to act eccentrically in order to decelerate the lower leg (Croisier, 2004; Croisier et al., 2008). It is also suggested that the hamstring muscle group is vulnerable to strain during the rapid change between eccentric and concentric action while acting as hip extensors (Petersen and Holmich, 2005). The specific circumstance during which injury occurs corresponds to the period at which the player exceeds the mechanical limits tolerated by the muscular unit (Croisier, 2004). Strain injuries occur when muscle and tendon fibers are not able to maintain the tension placed upon them and are disrupted (Pull and Ranson, 2007). Muscle strains range in severity from minor damage with minimal loss of function, to total rupture of the muscle, marked reductions in force capability, severe bruising, swelling and severely impaired function (Coburn, 2002). Additionally, injuries to the hamstring muscles have been shown to have the highest rates of recurrence (Henderson et al., 2010). According to Junge and Dvorak (2004), approximately 20% to 25% of injuries are re-injuries of the same type and location. Many instances are reported where a player had already sustained one injury during a season, which was subsequently followed by an injury to the same anatomical area during the same season (Hawkins et al., 2001). This is an area of concern as re-injuries within the same season were found to be more severe than the previous injuries (Hawkins et al., 2001). Hamstring re-injuries appear to result from multiple causes, including; factors inherent in sporting activity, premature return to play and inadequate or inappropriate rehabilitation programs (Bennell et al., 1998; Croisier, 2004).

The relationship between the architecture of the hamstrings, its contribution to human locomotion and its propensity for injury is complex (Henderson et al., 2010). A number of possible causes of hamstring injury have been postulated; however it is widely thought that in many instances the cause of hamstring injury may be multifactorial in nature (Worrell and Perrin, 1992; Croisier, 2004; Pull and Ranson, 2007; Croisier et al., 2008; Henderson et al., 2010).

Multifactorial model of injury

Orchard (2001) distinguishes between extrinsic factors (environment related) principally inherent to sporting activity and intrinsic factors (player related) related to individual features and player profiles. Orchard (2001) suggested that intrinsic factors are more predictive of muscle strain than the extrinsic factors. The theoretical model proposed by Worrell (1994) suggests that the combination of a number of factors increases the likelihood of hamstring strain. The extrinsic and intrinsic factors include:

Warm up

The absence of a warm up, or an inadequate warm up routine represents a commonly reported causative event in the available literature (Worrell and Perrin, 1992; Worrell, 1994; Garrett, 1996; Croisier, 2004). Early studies by Dorman (1971) as well as Ekstrand et al. (1983) reported that hamstring muscle injuries were more common at the beginning of practices and match sessions in teams not utilizing warm up routines. Stretching before exercise is critical because the capacity of the musculotendinous unit to absorb energy is directly proportional to its resting length and temperature (Taylor et al., 1990; Croisier, 2004). The above authors concluded that a period of warm up prior to participation in training or competition may prevent injury to the musculotendinous unit by increasing its elasticity and force absorption capacity.

Fatigue

Muscular fatigue, a non contact mechanism of injury, has previously been highlighted as an important area for consideration if the incidence of injury in soccer is to be reduced (Hawkins and Fuller, 1999). The role of fatigue is frequently suggested in the causation of injury, as hamstring strains regularly occur late in training as well as competition (Garrett, 1996; Croisier, 2004). Furthermore, Hawkins et al. (2001) states that muscular fatigue can partially explain the greater incidence of injury observed in the second half of competitive matches, especially the final 15 minutes. Fatigue may induce physiological changes to the muscle, as well as alter coordination, technique or concentration, predisposing fatigued soccer players to injury (Devlin, 2000). More specifically, the dual intervention of the biceps femoris (hamstrings) may lead to asynchrony in the activation of separate parts of the muscle, resulting in muscle inefficiencies (Croisier, 2004). Abnormalities in running gait may be as a consequence of muscular fatigue, increasing the workload of the stabilising biarticular muscles around the pelvis. This amplifies levels of fatigue and predisposes the soccer player to subsequent injury (Croisier, 2004). If an individual’s muscular force producing ability is impaired due to fatigue, then the altered mechanics of sprinting may pose an injury risk (Greig, 2008). More specifically, if the hamstrings have insufficient strength to decelerate the lower limb during sprinting, eccentric overload could cause injury to the musculotendinous unit (Lovell et al., 2008). As fatigue has been identified as a key factor in injury causation, the present study aims to quantify muscular fatigue in response to soccer match-play.

Flexibility

A lack of muscular flexibility is one of the most commonly postulated risk factors for the development of muscular injuries (Worrell, 1994; Garrett, 1996; Gleim and McHugh, 1997; Witvrouw et al., 2003). Research by Worrell et al. (1991) and McHugh et al. (1999) provided experimental evidence of an association between muscular flexibility and injury. More recently, a prospective study by Witvrouw et al. (2003) indicated that soccer players with an increased tightness of the hamstring muscles have a statistically higher risk ($p=0.02$) of developing subsequent hamstring injury. Similarly, soccer players with quadriceps muscle injury were also found to have statistically lower flexibility ($p=0.047$) in the quadriceps muscle group (Witvrouw et al. 2003). Since the ability of connective and muscular tissue to absorb force is related to its resting length, the greater the resting length (flexibility), the greater the ability to absorb forces and avoid strain injuries (Safran et al., 1988; Worrell and Perrin, 1992; Witvrouw et al., 2003; Croisier, 2004). Therefore, the importance of muscular flexibility cannot be over emphasised as increasing flexibility leads to a decreased chance of muscular injury (Worrell and Perrin, 1992).

Strength imbalance

While unilateral movements involve the use of one limb, bilateral movements involve the use of both limbs, working together, in order to move a load (Tortora and Derrickson, 2006). Admitting to the multifactorial nature of hamstring injury, some factors may be more predictive of injury than others and it has been suggested that strength imbalances play a key role in hamstring injury (Croisier, 2004; Croisier et al., 2008). Several authors have discussed the importance of hamstring strength and the hamstring/quadriceps (H:Q) ratio in relation to hamstring injury (Paton et al., 1989; Worrell and Perrin, 1992; Croisier et al., 2008). The aforementioned authors predict that a predisposition to hamstring muscle injury exists when bilateral deficits in isometric hamstring strength or H:Q ratios exist. In spite of abundant literature, the relationship between muscle injury and strength disorders remains controversial

(Croisier et al., 2002; Proske et al., 2004). A prospective isokinetic study, by Croisier et al. (2008), determined that soccer players lacking preseason strength imbalances showed an injury frequency significantly lower ($p<0.05$) than that of players with untreated strength imbalances. Thus, it was indicated that soccer activity with untreated strength imbalances increased a player's risk of hamstring injury by four to five times, in comparison to players with normal strength profiles (Croisier et al., 2008).

Mann and Sprague (1980) and more recently Croisier et al. (2008) postulate that it is during the late swing phase of the running gait cycle that injury most commonly occurs, this is as the hamstrings are subjected to large forces during the required eccentric action of decelerating the lower leg. Consequently, since the ability of connective and muscular tissue to absorb force is directly proportional to both passive and active components, a stronger hamstring muscle group is able to absorb greater forces, decreasing the risk of hamstring injury (Safran et al., 1988; Garrett, 1996; Croisier et al., 2008).

The evaluation of knee joint function through the use of isokinetic dynamometry should comprise data on conventional and functional hamstrings to quadriceps ratios as well as data on absolute muscle strength (Aagaard et al., 1998).

HAMSTRING TO QUADRICEPS RATIO

The hamstring: quadricep ratio is used to examine the similarity between hamstring and quadriceps moment-velocity patterns to assess the functionality of the knee and muscle balance (Rosene et al., 2001).

Conventional H:Q

The H:Q ratio has conventionally been expressed as concentric hamstring strength divided by concentric quadriceps strength. This ratio is calculated at the same angular velocity and mode of contraction, and does not provide adequate information on agonistic and antagonistic muscle action of the knee (Svensson and Drust, 2005). The conventional H:Q ratio implies that concentric and eccentric muscle contractions occur for the knee flexors and extensors simultaneously. (Graham-Smith and Lees, 2002). As such, the conventional ratio has been suggested to simply indicate whether a qualitative similarity exists between the moment-velocity patterns of the hamstring and quadriceps muscle (Aagaard et al., 1998). According to Aagaard et al., (1998) and later confirmed by Kong and Burns (2010), as a percentage, a typical conventional H:Q ratio of a healthy knee ranges from 50% to 80% depending on knee angle and angular velocity.

Functional H:Q

A more functional eccentric hamstring muscle strength to concentric quadriceps muscle strength ratio has been proposed as a better descriptor of agonistic and antagonistic knee function (Aagaard et al., 1998). The functional H:Q ratio is calculated as maximal eccentric hamstring strength divided by maximal concentric quadriceps strength during extension, or vice versa during flexion. The ideal functional H:Q ratio should be 1.0, indicating that the hamstrings have significant capacity to resist the forces generated by the quadriceps. Aagaard et al. (1998) illustrated a functional H:Q ratio of 0.96 based on measurements of peak torque in competitive track and field athletes. This suggests that the “braking” action of the hamstrings is roughly equal in magnitude to the maximal quadriceps knee extension moment. There is evidence to suggest that soccer players have a lower functional H:Q ratio towards the end of matches as a result of fatigue associated with prolonged exercise (Rahnama et al., 2003).

Both the conventional and the functional H:Q ratios may be helpful in identifying the functional muscle balance and stability at the knee joint in soccer players (Svensson and Drust, 2005). Given the function of the hamstrings during overground sprinting, it is feasible that a reduction in strength, inequality of strength between the dominant and non-dominant limbs, or strength imbalances between the hamstrings and quadriceps musculature may predispose an individual to injury (Bennell et al., 1998). This predisposition may result from decreased antagonistic hamstring activation during leg extension. However, the relationship between muscle imbalance and injury is poorly illustrated by scientific research (Croisier et al., 2002). The combination of data on conventional H:Q ratios with data on functional H:Q ratios and values of absolute strength will result in a more detailed description of the muscular strength properties at the knee (Aagaard et al., 1998).

MUSCULAR FATIGUE

Muscular fatigue has been described as a time dependant process that encompasses numerous central, peripheral and psychological factors that affect muscular force production (Pincivero et al., 2000). Muscular fatigue is usually evident in the course of a soccer match, especially towards the end of play (Rahnama et al., 2003). Players are able to continue to exercise at lower intensities but have a reduced ability to perform maximally (Rahnama et al., 2003). With a higher incidence of injuries being observed during the later stages of the first and second half of competitive soccer matches, it seems fatigue plays a large role in the occurrence of hamstring injuries (Hawkins et al., 2001). According to Vollestad (1997), the two most common indicators of fatigue are a decrease in maximal force production and a reduction in power output.

In recent years there has been distinct interest in two main theories of fatigue. The theory of peripheral fatigue suggests that the metabolic and cardiovascular components of effective muscle function are the limiting factor to performance (Noakes, 2001; St Claire Gibson and Noakes, 2001). Whereas, the theory of central fatigue states that altered efferent signals from the brain and nervous system limit performance, through down regulation (Noakes, 2001; St Claire Gibson and Noakes, 2001). Factors that are highlighted to contribute to peripheral fatigue include muscle activity (excitability of muscle), excitation contraction coupling deficiencies (Na+ movement), and metabolic energy supply (muscle glycogen and phosphocreatine availability) (Girard and Millet, 2008). Central fatigue factors include factors such as reflex dysfunction and alpha motor neuron disruptions and neurotransmitter alterations (Girard and Millet, 2008). Which form of fatigue occurs first, and which form of fatigue limits performance remains controversial (Noakes, 2001).

Due to these changes in fatigued muscle it has been proposed that the dual innervations of the bicep femoris are a factor in hamstring injury due to their poor coordination during a fatigued state (Brooks et al., 2005). This results in a decrease in strength of the hamstrings and a resulting decrease in the hamstrings: quadriceps ratio, placing the hamstrings at an increased risk of injury (Devlin, 2000). Small et al. (2009) states that injury risk may be greatest with muscle weakness during eccentric contractions, as fatigued muscles are more susceptible to stretch injury whilst contracting eccentrically. Therefore, it could be hypothesised that fatigue during the latter stages of soccer match-play may cause an increased disposition to hamstring strain injury by negatively altering the biomechanics of running in relation to muscle flexibility, muscular strength, or body mechanics (Small et al., 2009).

THIGH MUSCLE GROUP FUNCTION:

In various sports, players use their muscles in a manner that leads to muscular fatigue, after which further strenuous exercise can result in muscle damage (Kawabata et al., 2000). The predominant activity leading to fatigue in soccer performance is running (Cometti et al., 2001). Players run distances of over 10 kilometres at different intensities during match-play, resulting in high levels of muscular fatigue (Di Salvo et al., 2007). Muscle activity during running has been well documented through the use of electromyography (EMG). During running, the quadriceps muscle group is active from the late swing phase to midstance in order to prepare the limb for ground contact and to absorb the shock of that impact during stance phase absorption (Novacheck, 1998). The rectus femoris muscle is active during midswing, this is essential in order to restrain the posterior movement of the tibia as the knee flexes. The hamstring musculature extends the hip in the second half of the swing phase and the first half of the stance phase. The hamstrings also decelerate the momentum of the tibia as the knee extends just prior to initial contact with the ground (Novacheck, 1998).

During overground sprinting, Yu et al. (2008) found the maximum activation of the hamstring muscles occurred during the early stance phase and the late swing phase. Results of this study also show that the hamstring muscles undergo an eccentric contraction during the late stance phase as well as the late swing phase of sprinting. Mann and Sprague (1980) and Yu et al. (2008) indicate that the hamstring muscles have a potential for strain injury during the late stance phase and the late swing phase. Due to the intermittent activity profile of soccer match-play, players are required to sprint for short distances throughout the 90 minute match. Towards the latter stages of both halves of play, when the hamstrings are fatigued, players have an increased risk of hamstring strain injury when sprinting (Pull and Ranson, 2007; Small et al., 2009; Small et al., 2010). A fatigued hamstring muscle may have insufficient strength while acting eccentrically to decelerate the lower leg during the latter swing phase of sprinting (Small et al., 2010). As fatigued muscles are more susceptible to strain injury during eccentric contractions, the late swing phase of the sprinting gait cycle may result in damage to the hamstrings muscle group (Pull and Ranson, 2007).

CHARACTERISTICS OF ECCENTRIC MUSCLE ACTION

Due to the intermittent, multidirectional and irregular activity profile of soccer match-play, large amounts of eccentric muscle actions are required throughout the duration of soccer performance. The hamstring musculature is required to contract eccentrically in order to decelerate the leg during the latter stage of the swing phase of the running gait cycle (Small et al., 2009). Repeated eccentric muscle actions are associated with impaired muscle function and more importantly, it has been suggested that eccentric muscle damage to a muscle may predispose it to strain injury (Friden et al., 1983).

The stretch-shortening cycle refers to the sequence of an active muscle lengthening before shortening (Byrne et al., 2004). This integrated muscle activity allows for performance increases when compared to isolated concentric muscle contractions. As eccentric muscle actions contribute during the stretch-shortening cycle, exercise induced muscle damage is a common occurrence following such movements (Small et al., 2009). Repeated stretch-shortening cycles may lead to fatigue which has been proposed to occur in response to muscle contractile capacity failure. This failure can be attributed to muscle damage caused during the eccentric phases of the stretch-shortening cycle (Abbiss and Laursen, 2005). The mechanisms of fatigue during eccentric muscle actions have been shown to produce immediate and prolonged loss of muscle strength caused by factors at (or distal to) the neuromuscular junction (Byrne et al., 2004). Characteristics of neuromuscular fatigue are a failure of the contractile capacity of the exercised muscles, a reduced tolerance to stretch and a delayed transfer from muscle stretch to shortening during the stretch-shortening cycle (Noakes, 2000). These changes reduce the ability of a player to effectively accelerate and decelerate during match-play.

It is hypothesised that when a muscle acts eccentrically, the actin-myosin bonds undergo a mechanical detachment (Flintney and Hirst, 1978). In addition, during eccentric muscle action large amounts of muscle strain is distributed over fewer fibers, making eccentric muscle action more efficient than concentric contractions (Linnamo et al., 2003). Despite this, eccentric muscle action is associated with increased force generation capabilities when compared to concentric muscle contractions (Faulkner, 2003). According to Enoka (1996), eccentric muscle action requires unique neural activation strategies. Eccentrically acting muscles require a reduced level of voluntary activation by the nervous system in order to generate a required level of force. Differences in neural recruitment patterns between concentric and eccentric muscle action may be related to the modulation of the relative excitability within the motor neurons innervating the muscle (Enoka, 1996).

It has been theorised that the increase in tension during eccentric muscle actions may disrupt the intermediate filaments that surround the Z-bridges, and stretch out the space between the pairs of intermediate filaments that surround the Z-lines of single sarcomeres. This results in the streaming and destruction of the Z-lines (Waterman-Storer, 1991). This may be further exacerbated by the damage to the sarcolemma or sarcoplasmic reticulum, resulting in an increased intracellular calcium concentration. This increase in intracellular calcium activated proteolytic enzymes causing further structural protein damage (Waterman-Storer, 1991). This is compounded by muscular ultrastructure changes that occur in response to repeated eccentric action, including; disruption of the sarcolemma, fragmentation of the sarcoplasmic reticulum, dilation of the T- tubule system, disruption of myofibrillar contractile proteins, disruption of the cytoskeleton, changes in extracellular myofibril matrix and swollen mitochondria (St Claire Gibson et al., 1998; Friden and Lieber, 1992; Noakes, 2000).

Increases in passive and dynamic muscle stiffness occur due to repeated eccentric muscle action (Enoka, 1996). This increase in stiffness is attributed to either an increase in crossbridge stiffness, or increased tendon stiffness (Burgess, 2009). According to Friden et al. (1983) the force per active muscle unit results in a mechanical distribution of ultra structural elements such as the Z-line and contractile proteins. Coupled with this, eccentric muscle action is associated with a reduction in muscle fiber recruitment, resulting in an increase in loading of individual muscle fibers (Armstrong, 1991).

Eccentric actions result in the overstretching of sarcomeres beyond their optimum length. This is further exacerbated by a lack of homogeneity in sarcomere length. Therefore, during eccentric actions the majority of muscle lengthening is accommodated by the weakest sarcomeres until a critical point is reached (Morgan and Allen, 1999). Following this, the sarcomeres undergo uncontrolled changes in their length resulting in no overlap between the thick and thin contractile proteins. Following the completion of exercise, only some of the stretched sarcomeres return to their resting length whilst others do not, this results in a loss of interdigitation of the myofilaments and subsequent disruption (Proske and Morgan, 2001b). Furthermore, following repeated eccentric exercise a loss of calcium homeostasis and an inflammatory response results in the characteristic pathology associated with muscle damage (Armstrong, 1991). The effects of exercise induced muscle damage on the function of the myofilaments include; streaming of Z-lines, focal disruptions of the A-band and mitochondrial disruptions (Morgan and Allen, 1999). Cytoskeletal disturbances are a major factor contributing to the changes observed in muscle ultrastructure, following eccentric exercise (Friden et al., 1983).

Functional consequences

It is no longer a matter of controversy that eccentric exercise leads to structural signs of muscle damage (Friden et al., 1981; Proske and Morgan, 2001a). Skeletal muscle function and force production are significantly impaired during, and following exercise involving eccentric muscle action (Clarkson et al., 1992; Friden and Lieber, 1992; Enoka, 1996). Changes seen after eccentric exercise include; shifts in optimum length for active muscle tension, increase in passive muscle tension, force loss, swelling and muscle soreness, and alterations in neuromuscular control (Proske and Morgan, 2001b).

Shift in optimum length

Many studies have reported a shift in optimum muscle length following eccentric exercise (Enoka, 1996; Proske and Morgan, 2001a; Clarkson and Hubal, 2003). It has been proposed that the presence of overstretched sarcomeres leads to a shift in the muscle's active length-tension relationship in the direction of the longer muscle lengths (Morgan, 1990). Increased exercise duration and intensity are associated with larger shifts in optimum length. According to Jones et al. (1997), the shift appears to be a reliable and useful measure of exercise induced muscle damage, as the magnitude of the shift appears to correlate with the extent of muscle damage. Proske and Morgan (2001b) proposed that following eccentric loading there is an increase in series compliance, due to the stretched and non-contracting sarcomeres. As a result, a longer muscle length is required to obtain the same degree of myofilament overlap and force production. This places individuals at a greater risk of muscle strain injuries as the active muscle is often lengthened beyond its capacity.

Increase in passive tension

An increase in passive tension occurs following eccentric exercise and is accompanied by a shift in optimum length and an increase in active muscle tension (Proske and Allen, 2004). This increase in passive tension occurs as a result of sarcomere disruption and membrane damage at the level of the T-Tubules or sarcoplasmic reticulum following an eccentric bout (Enoka, 1996). The subsequent release of calcium ions into the sarcoplasm results in the activation of the thick and thin filaments, leading to the development of an injury contracture (Proske and Allen, 2004). Following muscle damage, it is believed that the contracture will be maintained whilst ATP levels remain high. Due to the damage associated with eccentric muscle action, the sarcomeres within the region of damage will also shorten. This results in added stress being applied to the surrounding areas, extending the contracture and increasing passive tension and the risk of injury (Proske and Allen, 2004).

Force loss

One of the most reliable, indirect, measures of exercise induced muscle damage is the prolonged strength loss following eccentric loading (Clarkson and Hubal, 2003). Concentric muscle contractions result in immediate force decrements after exercise, and do not produce damage lasting for more than a few hours (Warren et al., 1999). However, eccentric muscle action results in force loss immediately after exercise, but the recovery period following muscle damage is far longer (up to 24 hours). According to Clarkson and Hubal (2003), the largest reduction in muscle force and the longest recovery times are associated with high force eccentric exercise. Eccentric exercise consisting of maximal or near maximal eccentric action can often generate up to a 65% loss in force generating capacity (Saxton et al., 1995). This force loss has implications for competitive soccer players as players may be exposing themselves to injury, especially during sprinting when eccentric muscle force is continually required (Small et al., 2009). Greig and Siegler (2009) highlighted the deterioration of the force produced by the hamstring musculature in response to soccer-specific fatigue. A loss in muscle force producing capabilities places fatigued soccer players at risk of both muscular strain injuries as well as impaired joint stability.

Through the use of isokinetic dynamometry, researchers are able to accurately and reliably measure the eccentric and concentric force production of the knee flexors and extensors (Rahnama et al., 2003; Greig, 2008; Small et al., 2010). Furthermore, isokinetic testing allows for the quantification of the temporal changes in isokinetic torque of the knee flexors and extensors during soccer match-play simulations (Greig, 2008). Soccer related research has focussed exclusively on players from Europe, North America and South America, with no data available regarding time dependant force losses in African players.

Neuromuscular control

Research carried out on intermittent sports containing periods of high intensity exercise, such as soccer, have resulted in significant reductions in maximal stretch shortening cycles, eccentric and concentric forces and EMG (electromyographic activity) of the lower limb musculature (Rahnama et al., 2003; Greig, 2008; Greig and Siegler, 2009). Several mechanisms have been proposed to explain the reduction in neural input and thus muscle function following exercise. The reduction in neural activity may be due to the occurrence of central fatigue, supraspinal fatigue, peripheral fatigue, and disfacilitation of the alpha motor neuron pool or the impairment of peripheral mechanisms (Burgess, 2009). Furthermore, a reduction in stretch reflex sensitivity has been associated with decreased muscle stiffness. This may occur due to the fact that reduced muscle stiffness may be related to the reduction in muscle function, leading to the impaired utilisation of elastic energy (Avela et al., 1999).

A reduction in neuromuscular efficiency of the knee extensors has also been observed following eccentric muscle action (Byrne et al., 2004). Such studies demonstrate that the force generating capacity of muscle and motor control may be affected by the performance of eccentric exercise.

Muscle swelling and soreness

The delayed onset of muscle soreness (DOMS) describes the combined sensation of muscle pain, tenderness and swelling that develops following unaccustomed exercise and is particularly evident following eccentric muscle action or repetitive stretch shortening cycles (Cleak and Eston, 1992). DOMS is generally first evident within eight to 24 hours after an exercise bout, peaks at 48 hours, and dissipates within seven to ten days (Proske and Morgan, 2001b).

The mechanisms responsible for the effects associated with DOMS remain controversial, although discomfort and muscle disturbance depends on the intensity and duration of the exercise performed (McArdle et al., 2007). Smith (1991) suggests that the soreness may result from swelling and pressure in the muscle. This swelling and pressure has been attributed to connective tissue and muscle damage, and may relate to the inflammatory response induced by eccentric muscle actions (Armstrong, 1984). Symptoms associated with DOMS include; reduced range of motion, reduced force production capabilities, increases in limb volume, swelling, stiffness and leakage of myofibrillar proteins into the blood stream (Smith, 1991; Clarkson et al., 1992; McArdle et al., 2007). Despite the symptoms associated with DOMS being induced by eccentric muscle action or repetitive stretch shortening cycles, DOMS shares a poor temporal relationship with histological evidence of muscle damage (Byrne et al., 2004). Therefore, DOMS is not a direct indicator of muscle damage (McIntyre et al., 1995).

A number of theories have been proposed in an attempt to explain the pain experienced during DOMS, these include; muscle damage, lactic acid, muscle spasm, connective tissue damage, inflammation, and enzyme efflux (Cheung et al., 2003). It has been suggested that the initial events following exercise induced muscle damage may relate to either mechanical or metabolic mechanisms. The metabolic theory involved alterations in calcium concentrations, pH, muscle temperature, insufficient mitochondrial respiration and oxygen free radical production (Kendall and Eston, 2002). The mechanical theory includes adaptations at the levels of the whole muscle and muscle fiber, specifically the cytoskeleton (Kendall and Eston, 2002).

Exercise induced muscle damage, as a result of eccentric muscle action, frequently occurs in athletes. The greatest concern for performing athletes is the reduction of muscle function that accompanies muscle damage. This is as a reduction in muscle function results in a decrease in performance, the inability to perform at required levels, and an increased risk of injury (Byrne et al., 2004). Thompson et al. (1999) highlighted that muscle soreness was the greatest in the hamstring musculature following shuttle running, and persisted for the longest period of time. In competitive soccer, which requires large amounts of eccentric and concentric muscle action, the likelihood of reductions in muscle function and predisposition to injury is high.

Mechanisms for altered muscle function following eccentric muscle action

The reduction in force producing capabilities following eccentric exercise may be associated with alterations in peripheral mechanisms. These mechanisms include; disorganisation of the contractile elements, disruption of calcium regulation, excitation contraction coupling failure, muscle fiber damage and the redistribution of sarcomere lengths (Morgan and Allen, 1999; Proske and Morgan, 2001b). Nevertheless, the role of central fatigue and alterations in neuromuscular control should also be considered with regards to the reduction in muscle function following an eccentric bout (Morgan and Allen, 1999).

The structural changes associated with eccentric exercise may be accompanied by alterations in neuromuscular performance (Sergeant and Dolan, 1986). This has been demonstrated in the knee extensors as a reduction in the neuromuscular efficiency following eccentric exercise (Byrne et al., 2004). In order to compensate for changes in contractile function, alterations in the firing patterns of the damaged muscles may occur. Alterations in firing patterns include the recruitment of additional motor units and increased motor neuron firing frequencies (Ebbing and Clarkson, 1989).

AFRICAN ATHLETES VERSUS EUROPEAN AND AMERICAN COUNTERPARTS

Research on the risk of thigh injuries in soccer players has focussed exclusively on European, North American and South American top level, semi-professional and amateur players (Cometti et al., 2001; Rahnama et al., 2003; Witvrouw et al., 2003; Croisier, 2004; Zakas et al., 2006; Croisier et al., 2008; Silva et al., 2008; Lovell et al., 2011). There are known biomechanical and physiological differences between European runners and their African counterparts (Larsen, 2003). During the past two decades, Black African Athletes have dominated middle and long distance running (Larsen, 2003). Research indicates that Black African athletes, while possessing similar VO_{2max} values as their Caucasian counterparts, are able to perform at a higher fractional VO_{2max} utilization when performing endurance running (Bosch et al., 1990; Weston et al., 1999; Larsen, 2003). In addition, Black African athletes elicit a better running economy than Caucasian European and American athletes, with Kenyan runners' oxygen cost of running, at a given running velocity, lower than Caucasian athletes (Bosch et al., 1990; Weston et al., 2000; Larsen, 2003). Such differences in running performance are attributed to differences in body mass index (BMI) and body shape, where the African athlete's long slender legs are greatly advantageous with regards to the energy cost of running (Larsen et al., 2003). VO_{2max}, running economy and VO_{2max} utilization during running are crucial factors for running success (Larsen, 2003). Investigations of these factors indicate that Black African runners' superiority in distance running is to a large extent due to a unique combination of these factors (Weston et al., 2000; Larsen, 2003).

Running forms the primary component of soccer performance, with players run distances averaging over 10 kilometres during match-play. This results in high levels of muscular fatigue (Di Salvo et al., 2007). Coetzer et al. (1993) indicated a greater resistance to fatigue in Black South African compared to Caucasian South African runners during repeated isometric contractions of the quadriceps. However, this form of fatigue test was suggested not to be representative of fatigue during running (Weston et al., 1999). Utilizing a 10 kilometre treadmill run, (Weston et al., 1999) showed a pronounced difference in fatigue resistance between African and Caucasian runners. Although the direct mechanisms of fatigue are complex and not completely understood, Black African athletes have a superior fatigue resistance during sustained running tasks (Weston et al., 1999).

These differences between Caucasian and Black African athletes suggests that research conducted on thigh injury risk profiles in European, North American and South American soccer players may not be applicable to the population of Black

African players. As African runners show fatigue rates lower than those of Caucasian runners, research is required in order to establish if the African athlete's increased resistance to fatigue persists within intermittent activities such as soccer performance. The anthropometric, biomechanical and physiological differences present in the Black African population may elicit unique thigh injury risk profiles, different from those of European and American players.

Somatotype

Some sports events are suitable to individuals that have a specific physique and certain anthropometric profiles or physical characteristics that determine whether an individual is suitable to compete at a high level in a particular sport (Mohr et al., 2003). In order to compete effectively, soccer players are expected to possess morphological and physiological characteristics that are applicable both for the sport of soccer and specifically to their playing position (Hazir, 2010). Somatotype is the basic classification of physical characteristics and body type. The ideal somatotype for an athlete differs according to the requirements of the particular sport and includes physical characteristics such as; relative fatness (endomorph), musculoskeletal component (mesomorph), and linearity (ectomorph) (Fry et al., 1991). Variations in somatotype were determined between different playing positions on the field (Table II), as well as in the different competitive soccer leagues around the world (Table III) (Gualdi-Russo and Zaccagni, 2001). Previous studies have indicated that the somatotype of elite soccer players was dominated by a balanced mesomorph category (Rahmawati et al., 2007; Hazir, 2010).

Table II: Somatotype ratings according to position of play.

Study	Level/Country	Defence	Midfield	Attack
Hazir (2010)	1st Division/Turkey	2.4 - 4.8 - 2.3 (0.66-0.89-0.72)	2.6 - 4.9 - 2.2 (0.78-0.92-0.64)	2.4 - 5.0 - 2.1 (0.66-1.10-0.78)
Rogan et al. (2011)	Amateur/Germany	3.2 - 5.0 - 2.3 (1.0-0.9-0.9)	3.1 - 4.7 - 2.6 (1.2-1.1-1.1)	3.2 - 5.3 - 2.1 (0.7-0.9-0.9)

A number of studies indicate that the physical characteristics of soccer players are heterogeneous with regards to playing levels and playing positions (Casajus, 2001; Gualdi-Russo and Zaccagni, 2001; Rahmawati et al., 2007; Hazir, 2010). However, the somatotypes of soccer players in general show a balanced mesomorphic characteristic (Hazir, 2010).

Table III: Somatotype of soccer players according to geographical location.

Area/League	Year	Somatotype
Europe	2001	2.4 - 4.8 - 2.3
•*English First Division*	1988	2.6 - 4.2 - 2.8
•*Spanish First Division*	2001	2.4 - 4.8 - 2.3
•*Turkish First Division*	2010	2.5 - 4.8 - 2.3
•*German Amateur Division*	2011	3.2 – 5.0 - 2.4
South America	2000	2.2 - 5.4 - 2.2
Asia-Pacific	2007	2.7 - 4.9 - 2.9
Africa (Nigeria)	**1985**	**2.2 - 5.4 - 2.9**

Morphological data such as the somatotype ratings of African Black players remains poorly documented. Research by Mathur et al. (1985) on Nigerian soccer players identified a mean somatotype rating of 2.2 - 5.4 - 2.9. However, no data are available pertaining to modern soccer players performing in competitive African soccer leagues. The possible differences in endomorphy, mesomorphy and ectomorphy present in the Black African population may result in unique thigh injury risk profiles. Therefore, further research carried out focussing on the measurement of somatotype is required in order to better understand the impact of differences in somatotype ratings on thigh muscle function.

PERFORMANCE TESTING IN SOCCER

According to Svensson and Drust (2005), performance in sports is the result of a blend of several factors, including genetics, training and the health status of the individual athlete. Through performance testing, sports scientists can analyse these factors and use the information to provide individual profiles of strengths and weaknesses in athletes (Viru and Viru, 2001). These data can be used for the development of optimal training strategies, while further testing can be used to evaluate the impact of interventions on players.

Influence of fatigue on isokinetic strength

With half of all hamstring injuries during competitive soccer matches occurring within the last 15 minutes of each half, muscular fatigue is a predisposing factor to hamstring injury (Small et al., 2010). By using an appropriate soccer-specific fatigue protocol, used to simulate the running conditions of a competitive soccer match, researchers are able to investigate the effects of fatigue on the torque producing capabilities of both the knee flexors and extensors, while acting both concentrically and eccentrically.

A number of researchers have utilised soccer-specific fatigue protocols in order to investigate the temporal changes in knee flexor and extensor torque production as a result of muscular fatigue. Small et al. (2010) utilised a 90 minute soccer-specific aerobic field test (SAFT^{90}), while performing isokinetic tests at a speed of $120^{\circ}.s^{-1}$ on semi-professional soccer players. It was found that concentric quadriceps (conQ) peak torque (PT) and concentric hamstring (conH) PT did not significantly decrease ($P>0.05$). These findings are supported by Greig (2008) in professional soccer players, when utilising an intermittent treadmill protocol. Contradicting these findings however, Rahnama et al. (2003) observed significant reductions in both conH and conQ peak torque values in amateur players during an intermittent treadmill protocol. Although there was a lack of agreement with regards to the concentric responses, the above studies all found similar responses for eccentric hamstring torque development. Significant decreases in eccentric hamstring (eccH) PT during soccer-specific fatigue protocols have been indicated by Rahnama et al. (2003), Greig (2008) and Small et al. (2010).

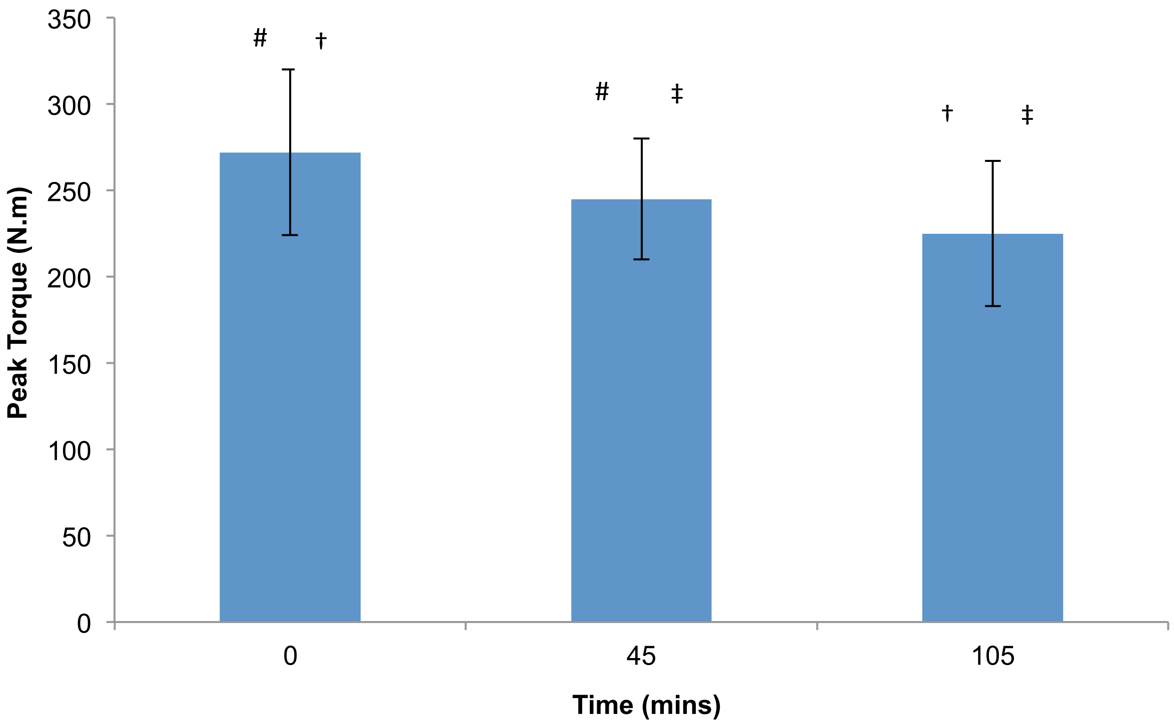


Figure 4: Eccentric hamstring peak torque (120º.s^{-1}) during SAFT^{90}.

(# Significant difference between T0 and T45; † significant difference between T0 and T105; ‡ significant difference between T45 and T105)

(Adapted from Small et al., 2010)

Both Rahnama et al. (2003), in amateur players, and Small et al. (2010), in semi-professional players, observed a 16.8% reduction in eccentric hamstring peak torque over the course of the 90 simulation (Figure 4), while Greig (2008) observed an 18.8% reduction.

According to Small et al. (2010), the traditional conH:conQ ratio revealed no significant changes as a function of time at an isokinetic testing speed of 120º.s^{-1}. Similarly, Greig (2008) revealed no significant main effect for time for the traditional strength ratio at isokinetic testing speeds of 60, 180 and 300º.s^{-1}. However, significant changes (P>0.05) in the functional eccH:conQ ratio was observed by Rahnama et al. (2003) at isokinetic testing speeds of 120º.s^{-1} and 300º.s^{-1}. These significant changes in the functional H:Q ratio were later confirmed by Greig (2008) and Small et al. (2010). As seen in Figure 5, Small *et al.* (2010) observed a decrease in eccH:conQ between the start of the match and half time, as well as between half time and the end of the second half. However, the decrease between the end of half time and full time was not statistically significant (P>0.02).

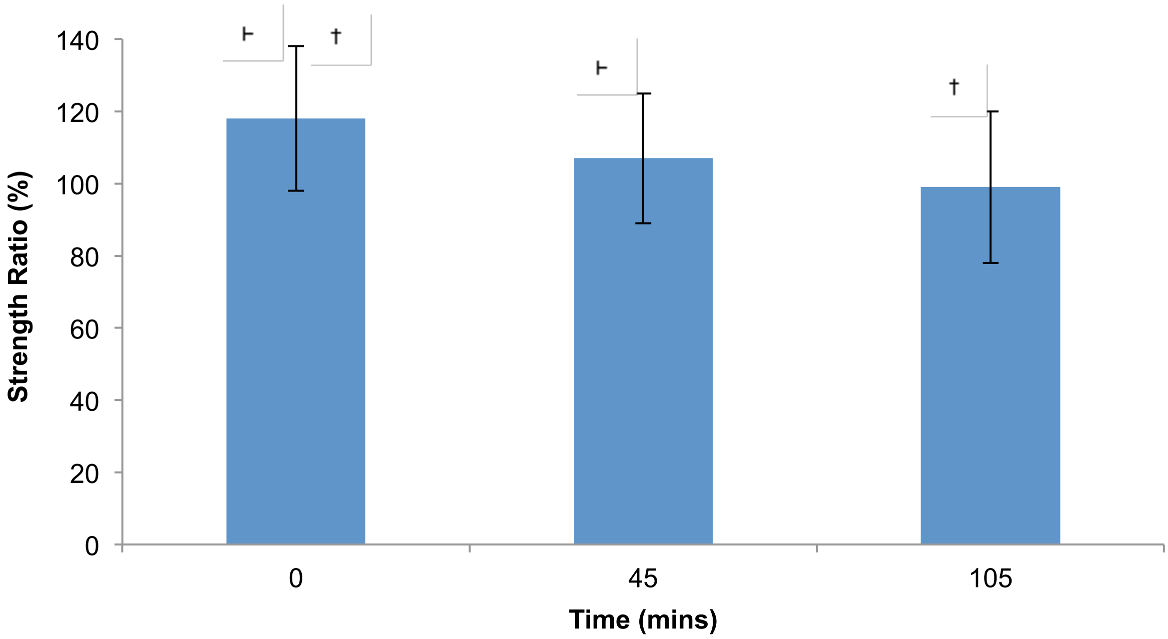


Figure 5: Eccentric hamstring:concentric quadriceps ratio (120^{o}.s^{-1}) during SAFT^{90}.

(꜔Significant difference between T0 and T45; † significant difference between T0 and T105)

(Adapted from Small et al., 2010)

Comparisons between Greig (2008) and Small et al. (2010) should be treated with caution as different isokinetic speeds were utilised during both studies. Greig (2008) utilised a range of isokinetic testing velocities (60, 180, 300°.s^{-1}), where as Small et al. (2010) only used a testing speed of 120^{o}.s^{-1}. Differences in findings may also be attributed to differences in the exercise protocols utilised in the above studies. The protocols used by both Rahnama et al. (2003) and Greig (2008) were performed on a programmable treadmill and lack the utility movements present in the protocol utilised by Small et al. (2010). The greater amount of time spent performing high intensity activities such as sprinting may have created a greater physiological cost, and lack the additional muscular requirement to match the load imposed by the multidirectional and more frequently intermittent SAFT^{90} protocol (Small et al., 2010). Therefore, Small et al. (2010) speculate that their results are more representative of the response associated with actual soccer match-play. Soccer-specific research utilising a range of isokinetic testing speeds as well as an appropriate, multidirectional soccer match simulation remains lacking.

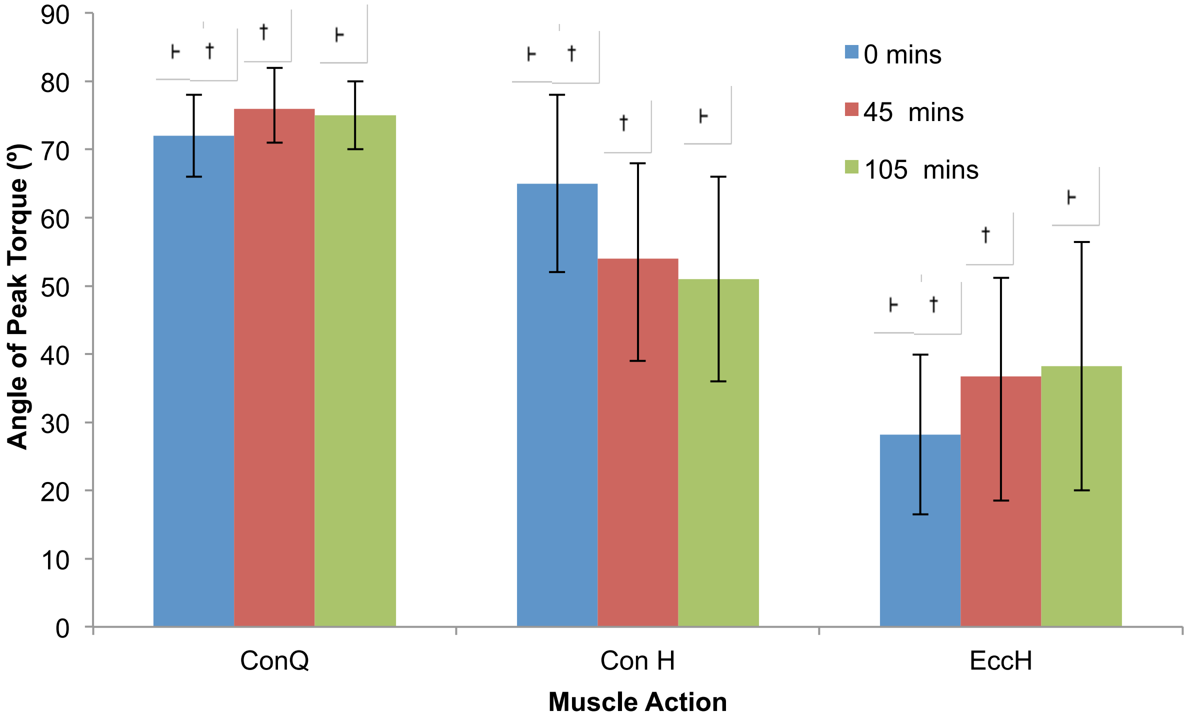


Figure 6: Angle of peak torque for concentric quadriceps, concentric hamstring and eccentric hamstring muscle actions during SAFT^{90}.

(ꜰ Significant difference between 0 and T45; † significant difference between T0 and T105)

(Adapted from Small et al., 2010)

In addition to the measurement of knee flexor and extensor peak torque, Small et al., 2010 measured the angle of peak torque (APT) of the quadriceps while acting concentrically as well as the hamstrings while acting both eccentrically and concentrically (Figure 6). While the quadriceps and hamstrings are acting concentrically, a potential consequence of shifts in optimum muscle lengths may be a loss of relative force occurring at shorter muscle lengths (Small et al., 2010). Therefore, longer muscle lengths are required in order to generate the required muscular force. It has been suggested that changes in optimal muscle lengths may result in increased susceptibility to damage. ConQ and eccH isokinetic tests revealed a shift in the optimum length for peak muscle tension in the direction of longer muscle lengths (Small et al., 2010). While acting eccentrically, hamstring angle of peak torque is thought to shift towards shorter muscle lengths as a result of fatigue (Small et al., 2010). These authors proposed that peak torque generation at a shorter optimal muscle length increases a players risk of hamstring muscle strain injury as muscles are prone to strains when operating in more lengthened positions. Contrastingly, LaStayo et al. (2003) argues that an increase in optimum muscle length increases force production before failure and therefore may prevent muscle strain injuries. Changes in optimum muscle lengths, as well as the concurrent reduction in peak eccentric hamstring torque may explain the increased hamstring injury rates during the latter stages of match-play (Small et al., 2010). However, the effect of changes in the optimum length for peak tension generation on injury risk remains poorly understood.

The soccer-specific exercise protocol, designed to replicate the physiological and mechanical demands of soccer match-play, was shown to induce a diminished capacity of the knee flexor muscles to generate eccentric force (Rahnama et al., 2003; Greig, 2008; Small et al., 2010). The observed decline in eccentric hamstring strength with fatigue is commonly associated with hamstring strain injury risk, this is as fatigued muscles are vulnerable during powerful eccentric contractions (Garrett, 1996). Sprinting is the most common mechanism of hamstring injury, whereby the hamstrings are required to act eccentrically in order to decelerate the forward motion of the thigh in preparation for foot contact (Stanton and Purdam, 1989). The reduced peak eccentric hamstring torque with fatigue observed in the above studies may help explain the increased predisposition to hamstring strain injury during the latter stages of competitive match-play (Woods et al., 2004). The reduction in the functional eccH:conQ strength ratio may indicate that the hamstring musculature have insufficient strength to decelerate the forward moving hip and knee from the acceleration caused by the quadriceps (Small et al., 2010).

Research focussing on the effect of soccer-specific fatigue on the force producing capabilities of the thigh musculature has utilised a range of isokinetic testing speeds and contraction modalities. Due to this range of methodological differences, comparisons between the available studies remain difficult. Therefore, further research utilising comparable isokinetic speeds and measures is required in order to better understand the impact of fatigue on thigh muscle function, particularly in the understudied African soccer playing population.

Influence of leg dominance on isokinetic strength

As a game of soccer commonly involves one sided activities such as kicking, asymmetries in muscle strength between the two legs are possible (Brady et al., 1993). These differences in muscle strength between the dominant and non-dominant legs are considered an important predictor of thigh injury in soccer players (Leatt et al., 1987; Kellis et al., 2001).

When leg dominance is taken into consideration, bilateral differences in both the hamstrings and quadriceps muscle strength have been observed in amateur and professional soccer players (Gur et al., 1999; Tourny-Chollet et al., 2000; Kellis et al., 2001; Voutselas et al., 2007; Kong and Burns, 2010). However, other studies have found no difference between the dominant and non-dominant legs in collegiate athletes (Rosene et al., 2001; Rahnama et al., 2003). Since the game of soccer frequently involves one sided activities such as kicking, asymmetries in muscle strength between the two legs are possible (Brady et al., 1993). Differences in the H:Q ratios between the two legs have been considered as an important predictor of injury in competitive soccer players (Leatt et al., 1987). Furthermore, bilateral differences in muscle strength profiles are useful in the identification of muscle weakness (Kellis et al., 2001).

Research by Kong and Burns (2010) observed bilateral differences in the conventional H:Q ratio of healthy males. Such differences were attributed to stronger hamstring musculature in the dominant limb while quadriceps strength was similar between both legs. While multiple studies show higher H:Q ratios in the dominant leg, other similar studies have found no such difference in strength profiles (Ergun et al., 2004; Voutselas et al., 2007; Kong and Burns, 2010). However, these studies utilised participants who had no involvement in soccer, and as such may not reflect strength values representative of competitive soccer players. Possible asymmetries in hamstring muscle strength in the non-dominant leg, and as a result a reduction in the H:Q ratios, may result in an increased susceptibility to hamstring muscle strain injuries.

A study by Kellis et al. (2001) compared the hamstring and quadriceps strength of the dominant and non-dominant legs of amateur soccer players, at a number of isokinetic velocities. The findings of this study show the isokinetic moment of the dominant leg was significantly greater during both flexion and extension (regardless of modality), when compared to the non-dominant leg. These results are in agreement with earlier findings of Leatt et al. (1987) who examined the knee extension and flexion strength in adolescent soccer players and reported a 7% difference of isokinetic moments between the dominant and non-dominant legs. Similarly, Tourny-Chollet et al. (2000) observed higher concentric hamstring strength for the dominant leg compared to those of the non-dominant leg, with no other significant differences in bilateral muscle strength observed. However, dominant leg strength was always equal to or greater than those of the non-dominant leg. These results are in agreement with research by Capranica et al. (1992) and Gur et al. (1999). Contrastingly, research by Rahnama et al. (2003) observed no significant bilateral differences in the functional H:Q ratio in response to fatigue.

Rahnama et al. *(*2003) measured the decline in knee flexor and extensor peak torque in both the dominant and non-dominant limbs in response to a treadmill soccer-specific fatigue protocol (Figure 7). These authors suggest that the decline in strength of the non-dominant leg, as a result of fatigue, was similar to that of the dominant leg. This observation is to be expected as the soccer-specific fatigue protocol utilised placed equal demands on both legs. It is possible that under competitive match conditions, bilateral asymmetry may develop as a result of asymmetric demands placed on one of the limbs (Rahnama et al., 2003).

However, this study is limiting as it did not measure the peak torque of the non-dominant limb at half time. The use of a multidirectional soccer-specific match simulation, requiring utility movements from participants, may elicit fatigue rates in both the dominant and non-dominant legs which are more representative of competitive soccer match-play.

As the presence of bilateral differences in leg strength profiles of professional soccer players remains controversial and poorly understood, further research is required in order to accurately assess the effect of soccer-specific fatigue on the hamstring and quadriceps strength profiles of both the dominant and non-dominant limbs.

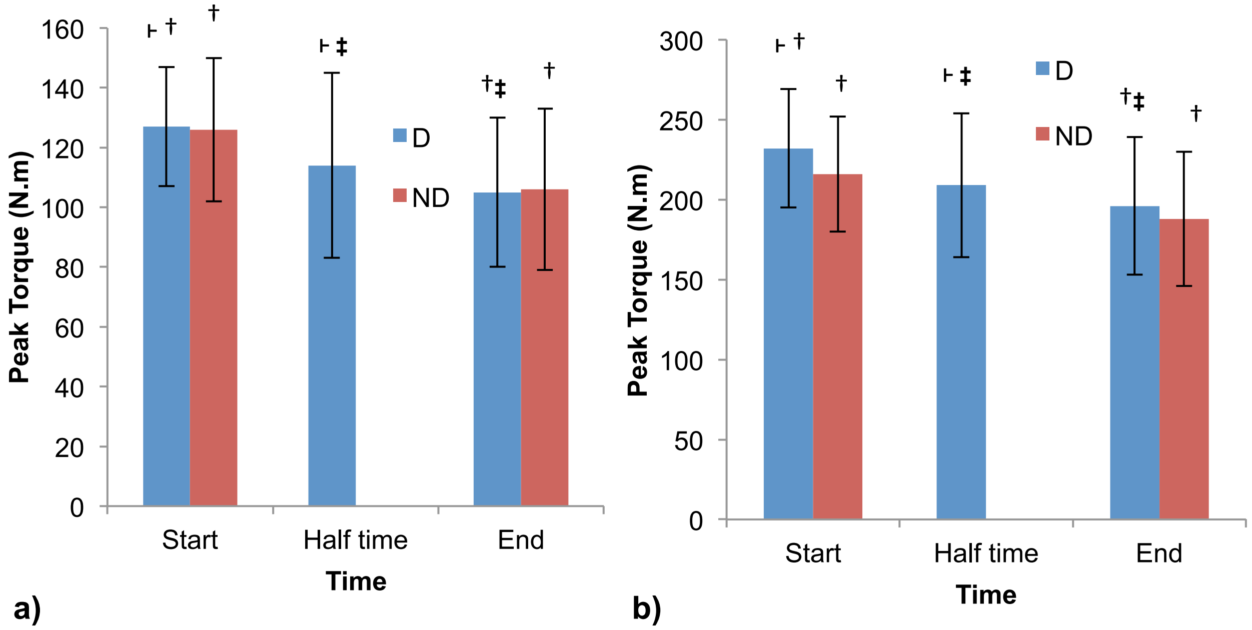


Figure 7: Comparison of the a) hamstring and b) quadricep peak torque (60^{o}.s^{-1}) for the dominant (D) and non-dominant (ND) leg.

(⊦ Significant difference between pre-exercise and half time; † significant difference between pre- and post-exercise; ‡ significant difference between half time and post-exercise)

(Adapted from Rahnama et al., 2003)

Influence of technical ability on isokinetic strength

Soccer requires intermittent physical activity in which sequences of actions requiring a variety of skills of varying intensities are strung together (Cometti et al., 2001). However, information about the influence of different practice levels on physical characteristics of soccer players is lacking.

Oberg et al. (1986) reported differences in concentric isokinetic peak torque of the quadriceps and hamstring muscles between the highest and lowest Swedish soccer divisions. It was concluded that high level soccer players had greater strength because training intensity increased with increasing playing category (Oberg et al., 1986). However, little data exists on the functional H:Q ratio with regards to different levels of practice. Research by Cometti et al. (2001) on elite, sub elite and amateur soccer players showed significant differences in the strength profiles among the three groups. Elite players' hamstring strength was significantly greater than those of amateur players, with this difference being greater during eccentric muscle action. The functional H:Q ratio was higher for professional players when compared to amateurs, with significant differences at angular velocities of 60, 120, 180 and

240°.s^{-1}, for both the hamstrings and quadriceps muscle groups (Cometti et al., 2001). Further research is required, utilising appropriate testing protocols and isokinetic testing velocities, in order to better understand the relationship between playing level and the risk of thigh injuries.

Influence of playing position

Understanding the physiological and biomechanical load imposed on players according to their positional role during competitive matches is necessary as position of play may affect activity profile, distance covered and intensity (Di Salvo et al., 2007). Research by Tourny-Chollet et al. (2000) assessed the effects of the position of the soccer player on isokinetic strength of the knee musculature. In this research, forwards showed higher eccH strength than midfield players. Forward players were found to present differences between 3% and 10% in favour of the dominant leg regardless of modality, while midfield players showed quadriceps strength differences between 4% and 9.5% in favour of the non-dominant leg. The importance of the non-dominant quadriceps strength in midfield players could be attributed to the major role of the stance leg (non-dominant) in sudden braking during running. Braking requires eccentric action from the quadriceps of the non-dominant leg, while the dominant leg is used to control the ball (Tourny-Chollet et al., 2000). Similarly, defenders demonstrated differences in quadriceps strength favouring the dominant leg. Hamstring strength of the midfield players showed very little difference between the dominant and non-dominant legs. At an isokinetic speed of 120°.s^{-1} the dominant leg hamstring strength of midfield players was significantly lower when compared to defensive and attacking players (Tourny-Chollet et al., 2000).

Through time-motion analysis of elite soccer players, Di Salvo et al. (2007) observed that midfield players cover significantly more distance than defenders and forwards. The distance covered by defenders was significantly shorter than any other position of play. Midfield players covered the greatest distance at intensities of 19.1 km.h^{-1} to 23 km.h^{-1}, while no differences in distance covered were observed between midfielders and forwards at intensities greater than 23 km.h^{-1}. Time-motion analysis revealed that midfield players and forwards performed significantly more bursts of high intensity activity than defenders (Di Salvo et al., 2007). These results are comparable to (Rampinini et al., 2004), who reported similar distances covered by midfield players during competitive English Premier League games.

Influence of the half time interval

According to Lovell et al. (2011), there is a growing body of literature reporting a decrement in the physical performance of competitive soccer players during the first 15 minutes of the second half of play. The reason for this reduction in physical performance after the half time interval have been suggested to be a consequence of a lack of preparation for the second half (Mohr et al., 2004; Lovell et al., 2007). Players routinely perform a pre-match warm up before the game, but do not before the beginning of the second half (Lovell et al., 2011). Furthermore, this initial period of play in the second half has been associated with an increased incidence of muscular injuries (Hawkins and Fuller, 1996). Utilising a soccer-specific fatigue protocol, Lovell et al. (2011) was able to assess the effects of a passive half time interval on biomechanical and physiological responses. The findings of this study support previous research (Mohr et al., 2004; Lovell et al., 2007), demonstrating the negative influence of a sedentary half time break. There is clear evidence that players are sub-optimally prepared for explosive activities within a soccer match following half time (Stolen et al., 2005). In addition, Lovell et al. (2011) observed that the half time interval reduced eccentric hamstring strength, which may leave players susceptible to hamstring strain injury. The current research aims to determine if the reduction in physical performance after the passive half time interval is present within an amateur African soccer playing population.

Heart rate responses to soccer match-play

Invasive field games, such as soccer result in more complex physiological demands than more continuous exercise. The methods that can be used in soccer competition to determine the physiological stress associated with match-play are limited (Drust et al., 2000). As a consequence, few researchers have attempted to devise soccer-specific lab protocols that replicate the activity profile of competitive soccer matches.

Through the use of a soccer-specific intermittent treadmill protocol, Drust et al. (2000) attempted to analyse heart rate responses to a simulated single half of a soccer match. A mean heart rate of 168 ±10 bt.min^{-1} was observed following the 45 minute protocol Similarly, Lovell et al. (2008) compared the mean heart rate responses of participants performing the SAFT^{90} protocol to mean heart rate data collected from various leagues around Europe. The mean heart rate values elicited were found to be similar to those elicited during competitive match-play (Table IV).

Table IV: Comparison of heart rate responses to match-play data.

Study	Level/Country	HR (b.min^{-1})
Bangsbo (1994)	League/Denmark	159
Edwards and Clark (2006)	Semi-professional/England	156
Mohr et al. (2004)	Amateur/Denmark	162
Reilly and Brooks (1986)	League/England	157
Van Gool et al. (1988)	Amateur/Belgium	167
Drust et al. (2000)	Amateur/England	168
SAFT^{90}	**Semi-professional/England**	**162**

Where: HR=Heart rate

(Adapted from Lovell et al., 2008)

CONCLUSION

It is evident that repeated eccentric demands are highly prevalent in intermittent sports such as soccer. Sports that require rapid accelerations and decelerations have shown an increased incidence of musculoskeletal injuries to the lower limbs, more specifically the hamstrings musculature. The negative role of muscular fatigue has been identified as a key factor in thigh injury causation, partially explaining the greater incidence of injury observed in the later stages of both halves of play (Hawkins et al., 2001; Rahnama et al., 2003). The majority of studies that have investigated the impact of soccer-specific fatigue on the risk of thigh injuries have focused on European, South American, and North American players. In addition, the bilateral differences in leg muscle strength and its effect on the risk of thigh injuries remains poorly understood. Therefore, the current study is aimed at quantifying the temporal changes in torque production of the knee flexors and extensors, in both the dominant and non-dominant limbs, of African Black amateur players during a simulated soccer laboratory protocol.

CHAPTER III

METHODOLOGY

INTRODUCTION

A large amount of research has been carried out focussing on the biomechanical, physiological and psychophysical demands placed on the body during steady-state activities such as endurance sports (Boobis et al., 1983; Coggan and Coyle, 1988). However, it was not until more recently that researchers have attempted to investigate the effects of intermittent sports such as soccer, rugby, field hockey and tennis on the demands placed on athletes (Drust et al., 2000). There are a number of methodological difficulties associated with research regarding intermittent sports and more specifically soccer (Svensson and Drust, 2005). The nature of intermittent sporting activities presents researchers with difficulties in data collection, as procedures aimed at obtaining accurate and reliable data tend to interfere with intermittent sports during match-play (Reilly, 1997). Match-play is unpredictable and is susceptible to human variability and changing environmental conditions, therefore a match simulation can be more effective at eliciting consistent levels of play from each participant. In addition, fitness components such as muscular strength, endurance, flexibility and agility often vary with the individual player, the positional role in the team and the team's style of play (Svensson and Drust, 2005). Consequently, researchers have developed laboratory based protocols that are now frequently used in research, attempting to replicate the activity profiles of intermittent sporting activities (Drust et al., 2000).

PILOT TEST PROTOCOL

In order to determine the feasibility and logistical working of the proposed research, pre-pilot and pilot investigations were performed in the Department of Human Kinetics and Ergonomics, Rhodes University, Grahamstown. These preliminary simulations serve to refine the testing protocols, establish the suitability of equipment, and to gain a basic overview of the expected research outcomes. The pilot testing further allowed for familiarisation with the utilised equipment.

As the current investigation involved a large amount of isokinetic testing, it was important to ensure that the isokinetic procedures did not significantly influence the fatigue of each participant. Through pilot testing, it was deduced that the isokinetic procedures necessary for research of this nature did not notably add to fatigue.

EXPERIMENTAL DESIGN

Selection of independent variables

With half of all hamstring injuries during competitive soccer matches occurring within the last 15 minutes of each half, muscular fatigue has been identified as a predisposing factor to hamstring injury (Small et al., 2010). Muscular fatigue is evident during the course of a soccer match, where players are required to exercise at submaximal intensities, but have a reduced ability to perform maximally (Rahnama et al., 2003). Muscular fatigue is indicated by a reduction in maximal force and is reflected as a decrease in performance (Reilly, 1994; Taylor et al., 2000). The reduced ability to produce muscular force towards the end of both halves, as a result of fatigue, is suggested to increase the risk of thigh injury when sprinting (Pinniger et al., 2000). Through the use of muscle strength testing at different points in a simulated soccer match, researchers are able to assess the effect of time on muscular strength (Svensson and Drust, 2005). Reductions in muscle strength, due to long durations of high intensity exercise, are considered important indicators of increased thigh injury risk (Small et al., 2010). The quantification of temporal changes in the eccentric and concentric force producing ability of the lower extremities in soccer players is an effective and reliable method of assessing the effects of fatigue on soccer performance (Greig, 2008). Such testing is of great importance in order to better understand the fatigue responses associated with soccer-specific activity, and how the reduction in muscular force production capability may increase the risk of injury.

Researchers have utilised a range of isokinetic testing times to allow for time dependant changes in force production to be assessed. Greig (2008), Greig and Siegler (2009) and Lovell et al. (2011) performed isokinetic testing every 15 minutes during a simulated soccer match. Whereas Rahnama et al. (2003), Small et al. (2009) and Small et al. (2010) performed isokinetic testing before the beginning of a simulation protocol, following the first half and following the completion of the protocol. In addition, researchers have performed isokinetic assessments after half time in order to attempt to highlight the potential negative influence of the passive half time interval (Lovell et al., 2011). Therefore, in order to accurately and effectively research the influence of time on muscular fatigue through reductions in force producing capability, isokinetic testing was performed; before the beginning of the simulation, following the first half of protocol performance, before the second half of protocol performance, and finally following the completion of the 90 minute match simulation (Table V).

Table V: Structure of isokinetic testing.

Warm up	Isokinetic test	1st half	Isokinetic test	Half time	Isokinetic test	2nd half	Isokinetic test
15 mins	T0	45 mins	T45	15 mins	T60	45 mins	T105

Where: T0= before the start of the protocol, T45= at the end of the first half, T60= the end of half time, T105= the end of the protocol.

Due to the nature of soccer, one sided activities such as kicking are frequently required (Kong and Burns, 2010). Leg dominance and possible asymmetries in muscle strength between the two legs may affect the time dependant changes in muscle strength as a result of fatigue (Rahnama et al., 2003). These differences in strength profiles between the two legs are considered an important predictor of thigh injury in soccer players (Kellis et al., 2001). Therefore, a second independent variable of interest in the current study was leg dominance, with both the dominant and non-dominant legs being assessed in order to better understand the role of dominance on muscle fatigue. Therefore, the current study was composed of a 4 by 2 experimental design (Table VI).

Table VI: Research design matrix.

Time	0 mins	45 mins	60 mins	90 mins
Dominant				
Non-Dominant				

Independent variables of no interest such as participant age and level of experience were controlled. As all participants were players competing in amateur South African soccer Leagues, they were required to be experienced in amateur match-play and between the ages of 18 and 30 years old. In order to reduce the risk of slip, trip and fall accidents occurring during the performance of the simulation protocol a non-slip, level surface was used. Wooden floorboards were utilised as they provided an ideal non-slip surface for the present study. Participants were also required to perform the protocol wearing athletic trainers rather than soccer boots to ensure maximum grip on the surface.

Selection of protocol

In order to effectively assess soccer match-play in a controlled environment, a soccer-specific match simulation protocol is required. A simulation protocol was chosen over match-play as intensity levels in match simulations are more easily controlled. Furthermore, during match-play there are likely to be large environmental fluctuations that negatively affect the accuracy of data collected and thus the study's reliability. Simulation protocols have been shown to be an effective method of assessing performance in soccer players (Rahnama et al., 2003; Greig, 2008; Lovell et al., 2008; Greig and Siegler, 2009; Small et al., 2009; Small et al., 2010; Lovell et al., 2011).

SAFT^{90}

There have been a number of attempts to simulate the activity profile and physiological responses observed during competitive soccer match-play (Lovell et al., 2008; Small et al., 2010). These simulations have predominantly attempted to replicate the physiological costs of match-play, and for this reason the activity profile does not represent the true multidirectional and intermittent nature of competitive soccer (Lovell et al., 2008). Consequently, the 90 minute soccer-specific aerobic field test (SAFT^{90}) was developed to replicate the physiological and mechanical demands of soccer match-play. The SAFT^{90} protocol, developed by Lovell et al. (2008), is based on contemporary time-motion analysis data obtained from the 2007 English Championship Level match-play and has been shown to induce both the typical activity profile and physiological demands, and to replicate the fatigue responses of male soccer match-play (Lovell et al., 2008). This free running protocol was designed to include multidirectional and utility movements that are inherent to match-play. The protocol incorporates acceleration, deceleration, cutting, side-stepping, and backwards and forwards running in a randomised and intermittent fashion (Lovell et al., 2011). The activity profile incorporates 1269 changes in speed and

1350 changes in direction over the 90 minutes. These changes in speed and direction, as inherent in match-play, are important as they require eccentric action from the lower limb musculature. No contact actions such as kicking or tackling are performed. The protocol was validated by Lovell et al. (2008) to accurately replicate the fatigue response of soccer match-play. Table VII illustrates the similarities in the distances covered and time spent in each of the aforementioned activities between the SAFT^{90} protocol and English Championship (ProZone®) match-play data, the second tier of professional English football.

Table VII: Distance covered and time spent in each activity during SAFT^{90} and English Championship match-play (ProZone®).

	Distance covered (m)		Distance covered (%)		Total time (%)	
	ProZone®	**SAFT^{90}**	ProZone®	**SAFT^{90}**	ProZone®	**SAFT^{90}**
Standing (0 km.hr^{-1})	-	-	-	-	4.8	4.3
Walking (4 km.hr^{-1})	3600	3360	32.94	31.82	56.4	52.8
Jogging (10.3 km.hr^{-1})	5810	5580	49.35	52.84	33.4	35.7
Striding (15 km.hr^{-1})	1460	1500	15.85	14.2	4.8	6.4
Sprinting (20.4 km.hr^{-1})	270	240	1.7	1.14	0.6	0.8
Total	11.14km	10.68km	-	-	-	-

(Adapted from Lovell et al., 2008)

Similarly, Lovell et al. (2008) compared the mean heart rate responses of participants performing the SAFT^{90} protocol to mean heart rate data collected from various leagues around Europe. The mean heart rate values elicited during SAFT^{90} were found to be similar to those elicited during competitive match-play. Therefore, the SAFT^{90} protocol was deemed to be an appropriate protocol to use in the current study.

Participants performing the current study each performed the SAFT^{90} protocol. The protocol was divided into two 45 minute periods interceded by a 15 minute half time interval. The design of the course was based around a 20 meter shuttle run, with the incorporation of four positioned poles for the participants to navigate through using utility movements (Small et al., 2010). The course was performed with each participant performing either side striding or backwards running around the first field pole, followed by forwards running through the remainder of the course (Figure 8). The movement intensity and activity performed by each participant whilst completing the SAFT^{90} course was maintained using verbal signals on an audio CD.

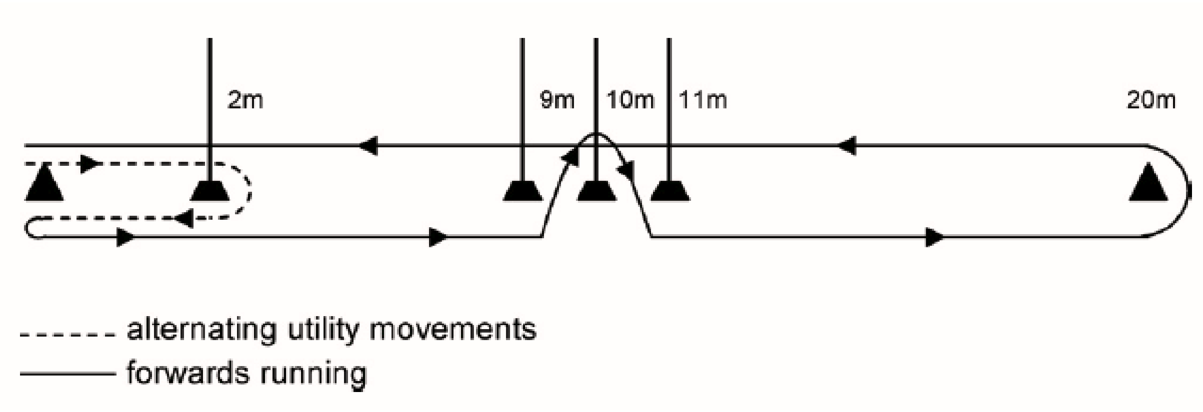


Figure 8: A diagrammatic representation of SAFT^{90}.

Selection of participants

As the present research focuses on the risk of thigh injuries in an African Black population of amateur soccer players, only Black African participants were selected for inclusion. Soccer related research has utilized solely European, South American and North American participants (Cometti et al., 2001; Rahnama et al., 2003; Witvrouw et al., 2003; Croisier, 2004; Zakas et al., 2006; Croisier et al., 2008; Silva et al., 2008; Lovell et al., 2011). Due to this dearth in data relating to Black African players, the current research aims to allow comparisons to be made between African Black players and their Caucasian counterparts from other continents.

Participants for the present study were recruited from the first team soccer squads at Rhodes University in Grahamstown, and Nelson Mandela Metropolitan University in Port Elizabeth. Players recruited from the above teams compete in the same Amateur and University leagues in the Eastern Cape, South Africa. Participants selected had experienced match-play during the 2011-2012 season. Soccer-specific research suggests players between the ages of 18 and 35 are most 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; Small et al., 2010; Lovell et al., 2011), therefore players between the above ages were utilised for the present study. During match-play, professional players generally have a higher rate of injury when compared to amateur players (Wong and Hong, 2005). Higher competitive levels as well as more competition for places on a team result in greater levels of exertion by players, leading to a greater occurrence of injury. However, amateur players are also exposed to a significant risk of injury during soccer match-play (Wong and Hong, 2005).

SAFT^{90} represents an activity profile of competitive soccer players regardless of position of play. Although midfield players cover the greatest distance during a competitive soccer match, defensive and attacking players also cover large distances (Di Salvo et al., 2007). Defensive, midfield, and attacking players require high levels of physical fitness in order to perform effectively. As a result, all outfield players experience similar levels of fatigue and are susceptible to injury (Tourny-Chollet et al., 2000). Therefore, outfield players performing various positional roles (defence, midfield, attack) were selected for participation in the present study.

Selection of dependant variables

As 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 and Fuller, 1999; Hawkins et al., 2001; Wong and Hong, 2005; Ekstrand, 2008), the knee flexors and extensors of the leg were chosen as the muscles to measure rather than other, less frequently injured areas. Isokinetic strength analyses were employed in order to accurately and reliably assess concentric and eccentric torque production. As a large percentage of the game is performed at maximum speed and players are required to perform functional activities such as; accelerations, decelerations, jumping, cutting, pivoting, and turning (Witvrouw et al., 2003), they are exposed to large amounts of eccentric and concentric muscle actions. Repeated eccentric muscle action is associated with impaired muscle function and more importantly it has been suggested that eccentric muscle fatigue may result in an increased risk of muscular strain injury (Friden et al., 1981; Friden et al., 1983). Therefore, both eccentric and concentric muscle actions were assessed through the use of isokinetics in an attempt to quantify the fatigue profiles of the hamstrings and the quadriceps muscle groups in response to soccer-specific fatigue.

The current investigation focused on the time dependant changes in peak hamstring and quadriceps torque, quadriceps to hamstrings 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, during the course of a competitive soccer match. In addition, psychophysical responses were collected from each participant throughout the performance of the simulation protocol in order to assess each participant's perceptual responses to the protocol. This allowed for an indication of the effects muscle fatigue has on skeletal muscle function and may offer insight into possible mechanisms of non-contact injury.

Previous studies focussing on the isokinetic assessment of the lower limbs in soccer players have utilised a large range of isokinetic speeds for both eccentric and concentric modalities. Greig (2008) and Greig and Siegler (2009) utilised isokinetic speeds of $60^{\circ}.s^{-1}$, $180^{\circ}.s^{-1}$ and $300^{\circ}.s^{-1}$, while a large number of studies utilised isokinetic speeds of $60^{\circ}.s^{-1}$ and $120^{\circ}.s^{-1}$ (Tourny-Chollet et al., 2000; Kellis et al., 2001; Croisier et al., 2008; Small et al., 2009; Small et al., 2010; Lovell et al., 2011). For the present study isokinetic testing speeds of $60^{\circ}.s^{-1}$ and $180^{\circ}.s^{-1}$ were utilised in order to accurately and safely assess the decrements in muscle forces as a result of soccer-specific fatigue. These isokinetic testing speeds were chosen as they represent the most appropriate testing speeds to test both strength ($60^{\circ}.s^{-1}$) and power ($180^{\circ}.s^{-1}$) (Perrin, 1993). The limb to be tested first, either dominant or non-dominant, was randomly assigned. However, the modality and speed of testing followed a controlled order of progression. The order of isokinetic testing can be seen in Table VIII.

Table VIII: Order of isokinetic testing.

		Testing modality			
		Con (quads)	Con (hams)	Ecc (quads)	Ecc (hams)
Isokinetic speed	60 °.s-1	1	2	5	6
	180 °.s-1	3	4	7	8

Where: Ecc=eccentric modality, Con= concentric modality, quads= quadriceps, hams= hamstrings, 1-8=testing order

In order to determine the physiological stress associated with soccer match-play, heart rate data were collected throughout the 90 minute soccer simulation. Heart rate was measured as the analysis of heart rate data during physical exercise has been shown to be an effective way to evaluate an athlete's efficiency and performance (Saunders et al., 2004; Lin et al., 2009). The collection of heart rate data allows for the comparison of the heart rate responses elicited during the present study with data collected during previously conducted research.

The methodological parameters of the current study aimed to simulate the conditions associated with competitive soccer match-play as accurately as possible. The employment of a strict laboratory based methodology to evaluate the respective responses enabled the rigorous standardisation of procedures and the exclusion of extraneous variables. In effect, adopting this approach allowed for a more stringent control of experimentation, enhancing the accuracy of measures by isolating the variables of interest, thus improving the study's reliability.

MEASUREMENT AND EQUIPMENT

During experimental testing sessions, it was vitally important that accurate and reliable data were continually collected from each participant. In order to ensure that each participant's elicited responses were representative, all equipment utilised during experimentation was correctly set up, calibrated, fitted to the participant and correctly operated. The following equipment was required in order to collect anthropometric, biomechanical, physiological and psychophysical responses:

Anthropometrical measurements

Somatotype

The ideal somatotype for an athlete differs according to the requirements of the particular sport (Fry et al., 1991). Previous studies have indicated that the somatotype of soccer players was dominated by a balanced mesomorph category, however, the somatotype scores were not homogeneous (Hazir, 2010). To present, there remains a dearth in somatotype ratings for the population of amateur Black African soccer players. Possible differences in body type of the Black African population may result in unique fatigue profiles, different from those of their Caucasian European and American counterparts.

To describe the somatotype of a soccer player, stature and body weight, four skinfolds (triceps, subscapular, supraspinale, medial calf), two bone breadths (biepicondylar humerus and femur), and two limb girths (arm flexed and tensed calf) measurements were used. All measurements were taken from the right side of the body by the same tester. The three somatotype components, endomorphy, mesomorphy, and ectomorphy, were calculated according to the Heath and Carter anthropometric somatotyping method using the following equations (Heath and Carter, 1990):

Endomorphy$= -0.7182 + 0.1451 (X) - 0.00068 (X^2) + 0.0000014 (X^3)$. (Where X=sum of supraspinale, subscapular and triceps skinfolds and corrected for stature by multiplying the sum of skinfolds by 170.18/body height in cm)

Mesomorphy= (0.858Humerus width) + (0.601Femur width) + (0.188Corrected arm girth) + (0.161Corrected calf girth) + (0.131Body height) + 4.5. (Where corrected arm girth= arm girth-bicep skinfold, corrected calf girth= calf girth-calf skinfold)

Three different equations were used to calculate ectomorphy, depending on the height-weight ratio (HWR): If HWR is ≥ 40.75 *then Ectomorphy=* $0.732HWR-28.58$
If HWR is $38.25<HWR<40.75$ *then Ectomorphy=* $0.463HWR-17.63$
If HWR ≤ 38.25 *then Ectomorphy= 0.1*
[Where HWR= (body height in cm/$3\sqrt{}$weight in kg)]

Skinfolds: Skinfold callipers

Skinfold measurements were taken using Harpenden Skinfold callipers (Quinton Instrument, Seattle, Washington, USA). Four skinfold sites were recorded, namely; triceps, subscapular, supraspinale, and medial calf. All measures were taken on the right hand side of the body with the skinfold callipers placed 10mm away from the thumb and finger, perpendicular to the skinfold, and halfway between the crest and the base of the anatomical site. Duplicate measures were taken and a retest was performed if the duplicate measures were not within a 3% error margin.

Bone breadth: Bicondylar callipers

Biepicondylar humerus and femur breadth were measured to the nearest 0.1 cm using a bicondylar calliper (Holtain Ltd, Crymych, UK). The callipers were held in a pistol grip position while the branches were gripped by the thumb and index fingers.

The middle finder was used to locate the desired anatomical landmark and firm pressure was applied to the branches. The distance between the lateral and medial epicondyles of the humerus and the femur were measured while in a flexed 90º position. Duplicate measures were taken and a retest was performed if the duplicate measures were not within a 3% error margin.

Limb girth: Tape measure

Differences in running performance of European runners and their African counterparts are attributed to differences in body mass index (BMI) and body shape (Larsen, 2003). African athlete's long slender legs are greatly advantageous with regards to the energy cost of running (Larsen et al., 2003). The anthropometric differences present in the Black African population may elicit unique thigh injury risk profiles. Therefore, the thigh girth of each participant was measured and recorded using a conventional tape measure. Thigh girth was measured mid way between the middle of the patella and the ASIS (anterior superior iliac spine). Flexed arm and tensed calf girth was also measured to the nearest 0.1 cm using the non-elastic tape measure. Duplicate measures were taken and a retest was performed if the duplicate measures were not within a 3% error margin.

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: CYBEX^{TM} 6000 Isokinetic Dynamometer

Isokinetic assessment provides a controlled environment in which the neuromuscular performance of a joint system can be safely stressed (Svensson and Drust, 2005). When used to assess the balance of strength between the hamstrings and the quadriceps, isokinetic testing provides useful data on the physical fitness of athletes, as well as highlights the potential for injury.

Isokinetic dynamometry involves the process of measuring the dynamic muscular force of action when the velocity of movement is controlled (Perrin et al., 1989). Muscle function was measured using a CYBEX^{TM} 6000 Isokinetic Dynamometer. The isokinetic dynamometer was set up to suit each participant, following the guidelines provided by the manufacturers, with each participant's set up maintained throughout the experimental testing protocol (CYBEX, Division of Lumex, Inc., Rononcoma, NY 11779). The cuff of the dynamometer's lever arm was correctly secured around the participant's ankle, proximal to the lateral and medial malleoli. Restraints were applied across the participant's chest and across the thigh, proximal to the knee joint, ensuring motion was in no way restricted. The range of motion assessed was individualised for each participant as a set range of motion would have been invalid to use, as the range of motion of the knee is known to vary (Perrin, 1993). The individualised range of motion for each participant was kept constant for all isokinetic tests performed during the experimental conditions. In the case of knee extension and flexion testing, correction for gravity was an important consideration as the weight of the leg being tested has an influence of the quadriceps to hamstrings (Q:H) ratio (Li et al., 1996). CYBEX^{TM} 6000 measures the mass of the limb through voluntary relaxation of the leg in the extended knee position (Svensson and Drust, 2005). One gravity correction for each limb was recorded and utilised for the duration of the testing procedures. In order to ensure an accurate measurement of limb mass, the researcher emphasised the importance of the participant relaxing the limb during measurement.

Isokinetic tests were carried out before the beginning of the first half (T0), at the end of the first half of play (T45), at the end of the half time interval (T60), and finally at the end of the second half of play (T105). 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. Determination of the dominant lower extremity was based on kicking preference. Participants were required to rest for 30 seconds between each set of isokinetic repetitions. Participants were instructed that each repetition should be a maximal contraction throughout the entire range of motion. In order to ensure that the data collected are reliable and valid (true representations of maximal effort), 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. No visual feedback was provided with regards to performance, but verbal encouragement was provided by the researcher. The verbal encouragement provided was consistent across all conditions and participants.

Physiological parameters

Heart Rate: Polar^{TM} F11 Heart Rate monitor

Each participant's heart rate was measured as an accurate indicator of cardiovascular exertion (Saunders et al., 2004). Heart rate was measured in beats per minute ($bt.min^{-1}$) using a Polar^{TM} F11 Heart Rate monitor, which was fitted around the participant's chest with an elastic strap and aligned with the sternum at the level of the inferior border of the pectoralis muscles.

Before experimentation took place, a reliable resting heart rate value was obtained as a 'reference' heart rate. Heart rate responses are, however, affected by anticipation, nervousness, movement, changes in breathing patterns, speech and many other factors making the recording of a resting heart rate difficult (Chen et al., 2008). Therefore, three reference heart rate measures were recorded.

Psychophysical parameters

Psychophysical responses were collected from each participant during experimental conditions testing through the use of RPE scales and a body discomfort map and scales. Psychophysical measurements were obtained and recorded every 15 minutes during the performance of the soccer-specific fatigue protocol.

Ratings of Perceived Exertion (RPE): Borg scale

Each participant's subjective feelings of fatigue were measured using an RPE scale developed by Borg (1970). The scale ranges from a value of 6 (minimal exertion) to a value of 20 (maximal exertion). A detailed explanation of the nature and use of the RPE scale was given to each participant (Appendix B).

Participants were required to focus on cardiovascular sensations or 'Central RPE', as well as 'Local RPE', an indication of perceived effort of the lower limb musculature. It was vital that each participant understood the scale's conceptual basis thoroughly in order for accurate ratings to be obtained.

Ratings of perceived discomfort: Body discomfort Scale and Map

The Body Discomfort Scale and Map developed by Corlett and Bishop (1976) divides the body into 28 regions, distinguishing between the anterior and posterior sides of the body (Appendix B). This allows discomfort to be accurately assigned to a specific region or body part. Areas experiencing discomfort are ranked using a Likert scale of one to ten, with a value of one representing no discomfort and a value of ten representing extreme discomfort. It should be noted that although this method provides quantitative data, it is a subjective rating of discomfort and could vary between participants.

EXPERIMENTAL PROCEDURES

Experimentation was divided into two main phases. The first phase involved the introduction and habituation of participants to procedures and the simulation protocol, baseline and anthropometric data collection, as well as an introduction to isokinetics. The second phase involved the performance of the SAFT^{90} protocol, with all relevant isokinetic and physiological measured taken at the appropriate aforementioned times. Experimentation on the Rhodes University soccer players was conducted in the Human Kinetics and Ergonomics (HKE) department at Rhodes University, Grahamstown, South Africa. Experimentation on the Nelson Mandela Metropolitan University soccer players was carried out in the Department of Human Movement Science (HMS) at Nelson Mandela Metropolitan University, Port Elizabeth, South Africa.

Session I: Introduction, habituation and basic data collection

Participants were required to attend an introductory session at either the HKE or HMS department depending on the player's team location. This session involved explaining the procedures to the participants verbally and in writing (Appendix A). This session also served to familiarise the participants with the RPE and Body Discomfort Scale and Map (Appendix B), and address any queries that the participant may have had. Once queries had been addressed, participants were required to sign an informed consent form before any data were collected. A physical activity screening questionnaire was completed to ensure no players were at risk of incurring injury during testing (Appendix A). Basic demographic and anthropometric data were obtained, including; age, stature, mass, limb girths, skinfolds, bone breadths, playing position, number of years experience and a full injury history of each participant. Reference heart rate data were also collected from each participant while at rest. Participants were included in the present study if they were not injured or rehabilitating from an injury at the time of testing, and did not have a history of thigh injury within three months prior to testing.

Players were then habituated to the CYBEX^{TM} 6000 isokinetic dynamometer, ensuring participants were familiar with the procedure and equipment. Players were first habituated to the slower 60^{o}.s^{-1} speed before the faster 180^{o}.s^{-1} to allow for an easier learning experience. Participants were instructed to exert a maximal force throughout the entire range of motion. Participants were then familiarised with the Polar^{TM} F11 Heart Rate monitor belts and their function.

Players were then habituated to the SAFT^{90} protocol. The protocol was explained to the participants and a short video demonstration of the protocol performance was shown for habituation purposes. Participants were permitted to perform a brief practice of the protocol if required.

Instructions were given to participants so as to maintain the validity of results. Players were instructed not to engage in strenuous activity within 24 hours of being tested, not to have consumed alcohol or caffeine within the past 24 hours, to have eaten sufficiently but not within three hours of being tested (Appendix A). Before testing commenced, participants were asked if they had followed the instructions. If not, testing was rescheduled.

Session II: Experimental protocol

Participants were required to perform the experimental conditions one at a time. Upon arrival, Polar^{TM} F11 Heart Rate monitor belts were fitted to the participants. Prior to testing, participants performed a standardised warm up procedure which included; five minutes on a cycle ergometer at 60 Watts, and five minutes of static and dynamic stretches for the major lower limb muscle groups (Lovell et al., 2008; Small et al., 2009; Small et al., 2010; Greig, 2008; Lovell et al., 2011). Players were then re-familiarised with the SAFT^{90} exercise protocol and any queries were addressed.

Following the warm up, participants performed the first set of isokinetic muscle function tests (T0) on both the dominant and non-dominant legs, at the prescribed isokinetic speeds with a 30 second rest interval between each set of three repetitions. The first leg to be tested was randomised for each player in order to prevent any order effects. Once selected, the leg to be tested first was standardised for each participant. Participants then performed the first half of the SAFT^{90} protocol, with the movement intensity and activity performed by each participant maintained using verbal signals on an audio CD. After the completion of the first 45 minute half, participants were immediately required to perform a second set of isokinetic muscle function tests (T45). Following the completion of the isokinetic tests, participants were given a 15 minute half time interval, and were required to sit at rest for the entire duration. Participants were permitted to drink water during this period. After the 15 minute half time interval, participants were then required to perform a third set of isokinetic muscle function tests (T60) and then immediately perform the second 45 minutes of the SAFT^{90} protocol. Finally, following the second 45 minutes of the SAFT^{90} protocol, participants were immediately required to perform a fourth set of isokinetic muscle function tests (T105). Participants were then instructed to perform a short cool down and a set of self selected stretches.

The same tester and assistant were present throughout experimentation and performed the same roles for each habituation session and both experimental condition testing sessions. This ensured the standardisation of the testing procedures.

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 exclude themselves from participating at any point should they choose to. 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.

SUBJECT CHARACTERISTICS

A total of 20 male soccer players were recruited for participation in the present study. The sample group included all outfield positions of a soccer team, therefore no goalkeepers were recruited for participation. All participants, whose basic demographic data can be seen in Table IX, represented Rhodes University or Nelson Mandela Metropolitan University in the same local amateur soccer leagues.

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 IX: Basic demographic data.

	Mean		SD		CV	
Age (years)	21.80		2.31		10.59	
Stature (cm)	172.12		6.20		3.60	
Body mass (kg)	68.39		9.05		13.23	
BMI ($kg.m^{-2}$)	23.03		2.26		9.81	
Somatotype	2.9 - 5.1 - 2.3		1.01 - 1.14 - 0.96		34.93 - 22.54 - 41.31	
Limb girth (cm)	**L**	**R**	**L**	**R**	**L**	**R**
	54.60	54.63	4.08	3.93	7.46	7.19

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

STATISTICAL PROCEDURES

All data collected was reduced and analysed using Statistica™ 7. Initially, general descriptive statistics were calculated as to provide general information regarding the sample as a whole. Through the use of Shapiro-Wilks tests, the normality of the data collected was ensured. Following this, 2 way covariant ANOVAs were calculated. 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

Results will be presented graphically, with the use of mean values accompanied by standard deviations. For each variable, results from the overall ANOVA regarding the effects of time and leg dominance will be stated initially, with further analysis of statistical differences following. With regards to the physical parameters, all values discussed are representative of a combined mean of the dominant and non-dominant limbs unless stated otherwise. Concentric and eccentric data for each muscle group (knee extensors and knee flexors) will be displayed separately. Significance bars indicate statistically significant differences in collected responses, utilising a 95% confidence interval.

PHYSIOLOGICAL PARAMETERS

Physiological parameters such as heart rate serve as an effective index in order to evaluate exercise intensity and physiological responses to exercise (Lin et al., 2009). Therefore, the physiological stress associated with soccer match-play is assessed through the collection of heart rate data during the 90 minute soccer-specific fatigue protocol in order to allow for comparisons with other soccer-specific research.

Heart rate

As seen in Figure 9, the participants elicit similar heart rates during both halves of SAFT^{90} performance with mean heart rates of 162 (±13) bt.min^{-1} and 160 (±15) bt.min^{-1} for the first and second half respectively. No statistical significance ($p>0.05$) is observed with regards to the heart rate responses collected during the first half (T15, T30, T45) and the second half (T60, T75, T90). Heart rate responses recorded at the start of the second half (T60) remain significantly elevated relative to responses collected before the first half (T0).

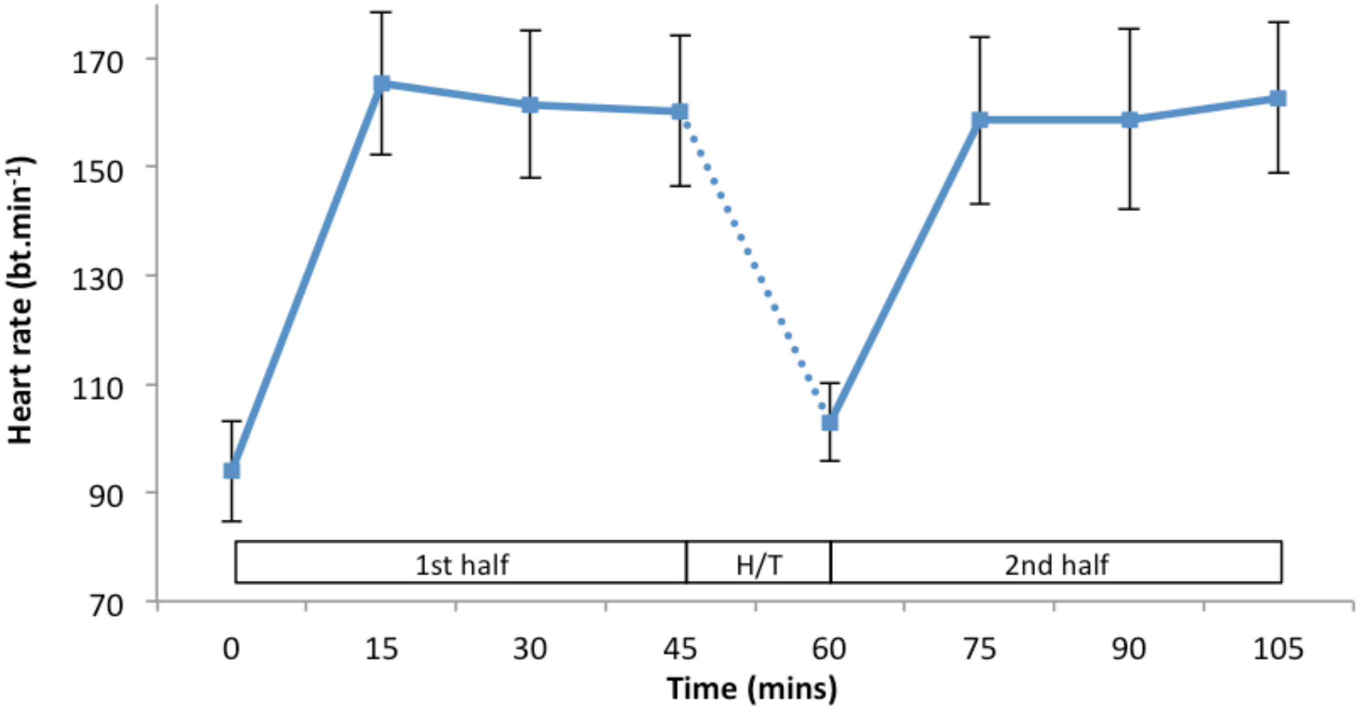


Figure 9: Mean (±SD) heart rate responses elicited during SAFT90.

PHYSICAL PARAMETERS

Data from the isokinetic assessment of muscle strength in soccer players can be employed to determine general muscle strength profiles as well as possible effects of race and position of play on muscular strength.

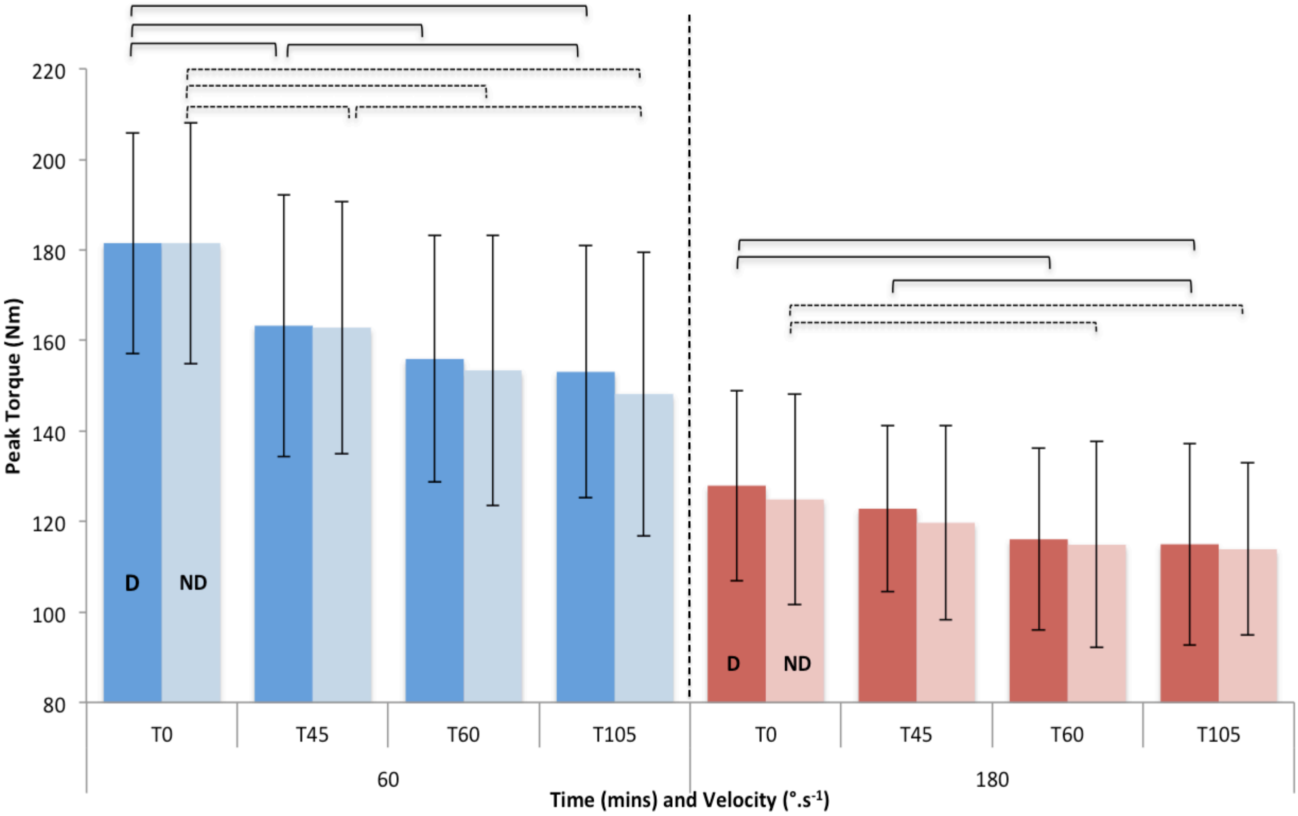
Isokinetic quadriceps strength (extensors)

Concentric peak torque

The overall ANOVA indicates that time results in significant changes in concentric quadricep (conQ) peak torque values. However, no significant effect of leg dominance is observed.

ConQ peak torque for both limbs and both isokinetic testing velocities is found to decrease significantly as a function of time ($p<0.05$). A 17.01% reduction in conQ torque is observed at 60°.s^{-1} over the duration of the protocol ($p<0.05$), with a 10.17% reduction occurring following the completion of the first half ($p<0.05$). The significant reduction following the performance of the first 45 minutes indicate that the first half has the greatest effect on conQ peak torque. While at 180°.s^{-1} a 9.48%

reduction is observed overall (p<0.05). At both isokinetic speeds, significant reductions (p<0.05) in conQ peak torque are illustrated following the passive half time interval when compared to T0 .



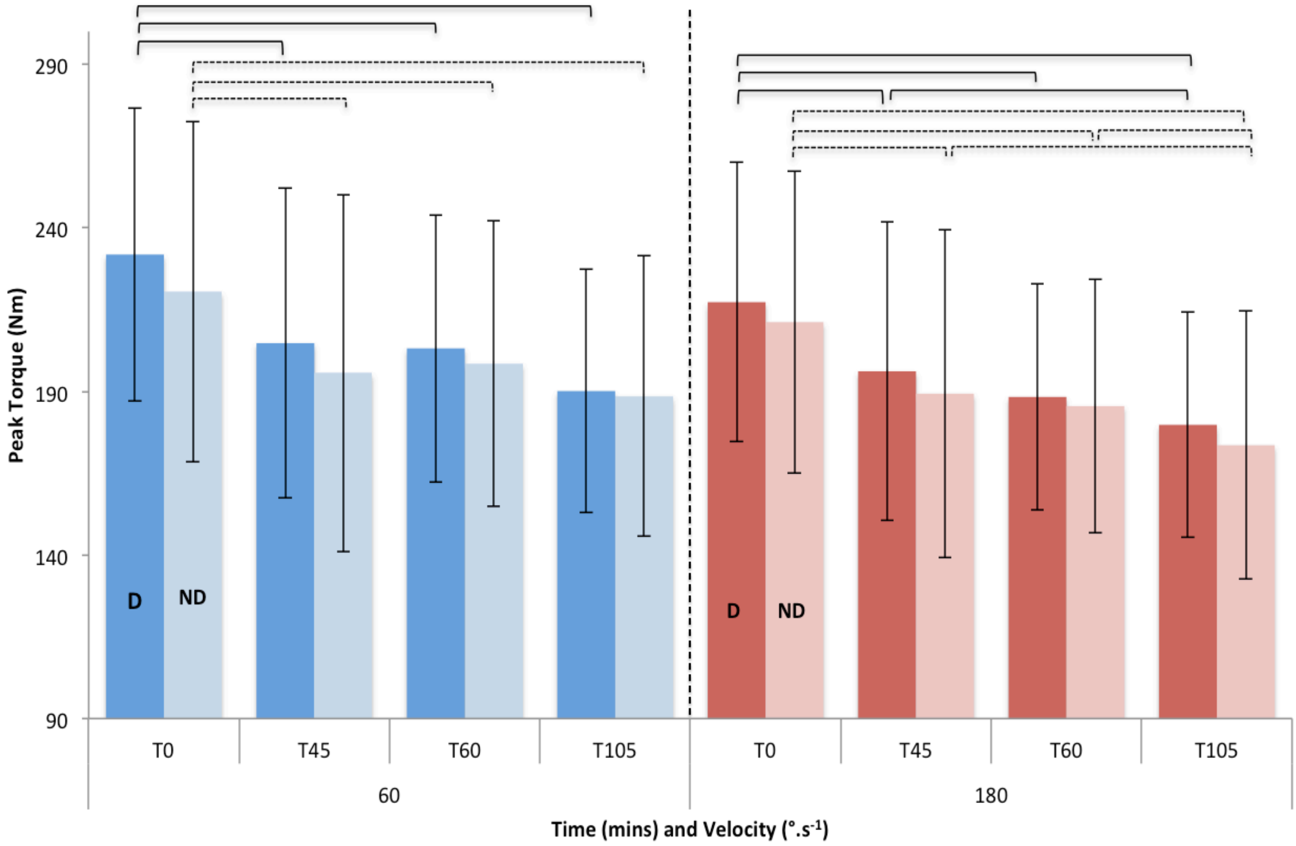
Where: —— Significant difference in dominant limb (p<0.05)
……. Significant difference in the non-dominant limb (p<0.05)

Figure 10: Concentric quadriceps peak torque (Nm) in both the dominant (D) and non-dominant (ND) limb, at isokinetic speeds of 60°.s^{-1} and 180°.s^{-1}.

Eccentric peak torque

The overall ANOVA for eccentric quadriceps (eccQ) peak torque demonstrates that time results in significant changes. However, no significant effect of leg preference is observed.

EccQ peak torque data illustrate a decrease as a function of time at both isokinetic testing speeds. At 60°.s^{-1}, a 16.26% overall reduction in eccQ torque is observed (p<0.05), with an 11.48% reduction (p<0.05) occurring after the first half and a 5.07% (p>0.05) reduction observed following the completion of the second half of the protocol. At the faster isokinetic velocity, an overall decrease of 17.53% in eccQ force is observed following the completion of the protocol ($p<0.05$). A 10.04% ($p<0.05$) and 4.78% decrease in peak torque is illustrated after the first half and second halves respectively. At both testing velocities, significant reductions in peak torque are observed after half time when compared to T0 ($p<0.05$).



Where: —— Significant difference in dominant limb ($p<0.05$)

······· Significant difference in the non-dominant limb ($p<0.05$)

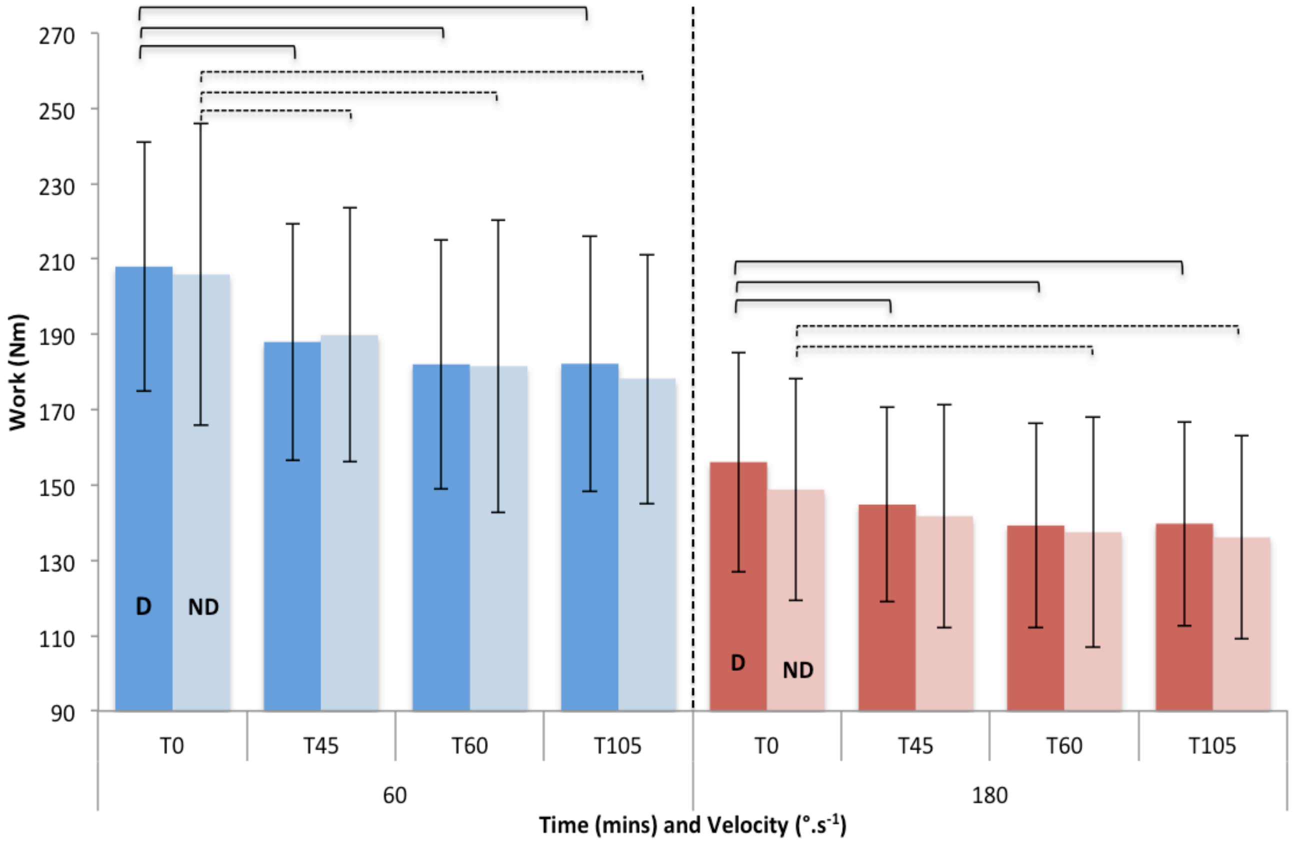
Figure 11: Eccentric quadriceps peak torque (Nm) in both the dominant (D) and non-dominant (ND) limb, at isokinetic speeds of 60°.s^{-1} and 180°.s^{-1}.

Concentric work

The overall ANOVA shows that time results in significant changes in conQ work. However, leg dominance has no significant effect on the conQ work data elicited.

ConQ work for both limbs and both isokinetic testing velocities is found to decrease significantly ($p<0.05$) over time. An overall 12.96% reduction in conQ work is observed at 60°.s^{-1}, while a 9.53% reduction is illustrated at 180°.s^{-1}. At 60°.s^{-1}, a

8.72% reduction in torque occurs following the completion of the first half. At both isokinetic speeds, significant reductions in conQ work are observed following the passive half time interval when compared to T0.



Where: — Significant difference in dominant limb ($p<0.05$)
······· Significant difference in the non-dominant limb ($p<0.05$)

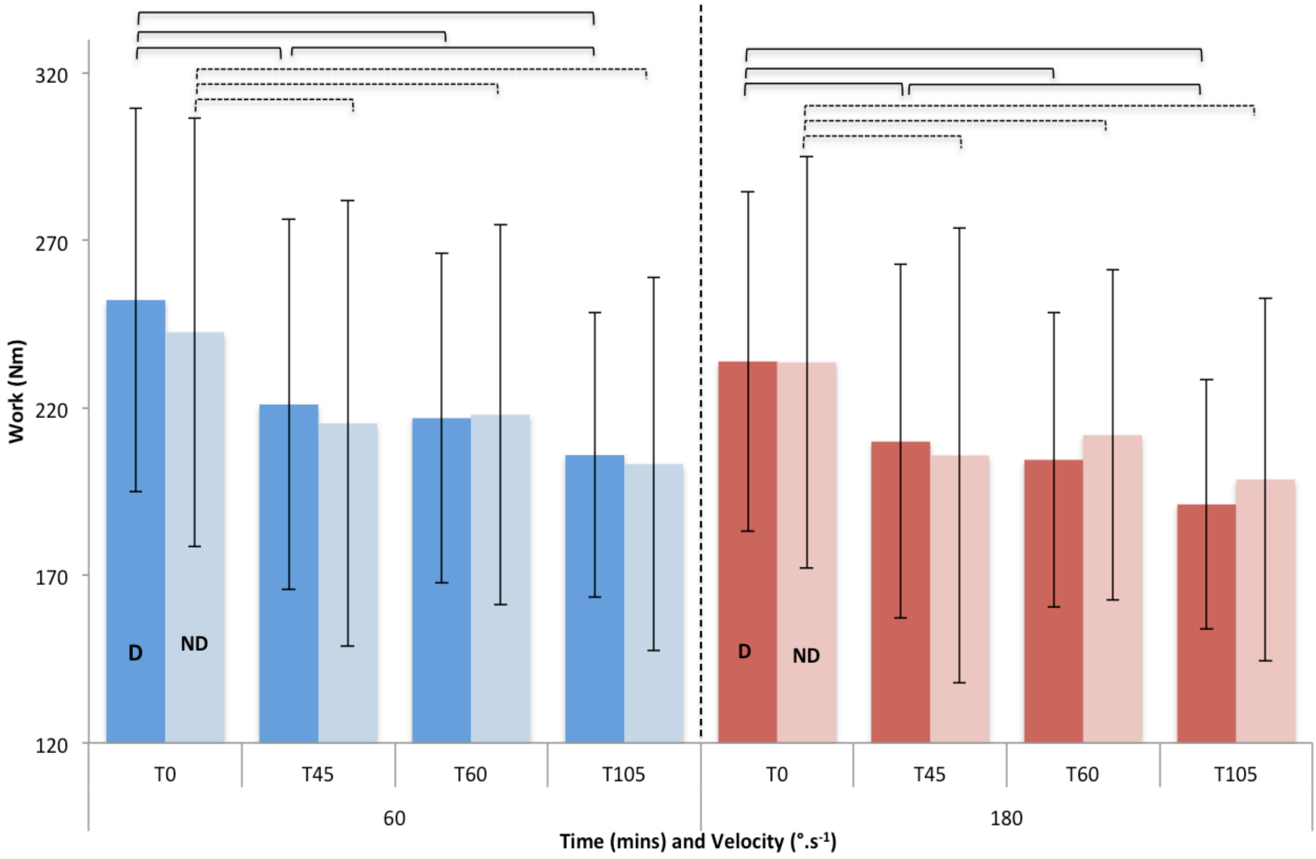
Figure 12: Concentric quadriceps work (Nm) in both the dominant (D) and non-dominant (ND) limb, at isokinetic speeds of 60°.s^{-1} and 180°.s^{-1}.

Eccentric work

The overall ANOVA for quadriceps work in the eccentric modality indicates that time results in significant changes. However, no significant effect of leg dominance is observed for eccQ work throughout protocol performance.

EccQ work is demonstrated to decrease over time at both 60°.s^{-1} and 180°.s^{-1}. At the slower testing velocity, a 17.29% overall reduction in eccQ work is present, with a 11.78% ($p<0.05$) reduction after the completion of the first half. At the faster velocity, a 16.61% overall decrease in eccQ work is observed, with a 11.06% ($p<0.05$)

reduction observed after the first half. Following the 15 minute passive half time interval, work is significantly reduced at both testing velocities when compared to T0.



Where: —— Significant difference in dominant limb ($p<0.05$)
······· Significant difference in the non-dominant limb ($p<0.05$)

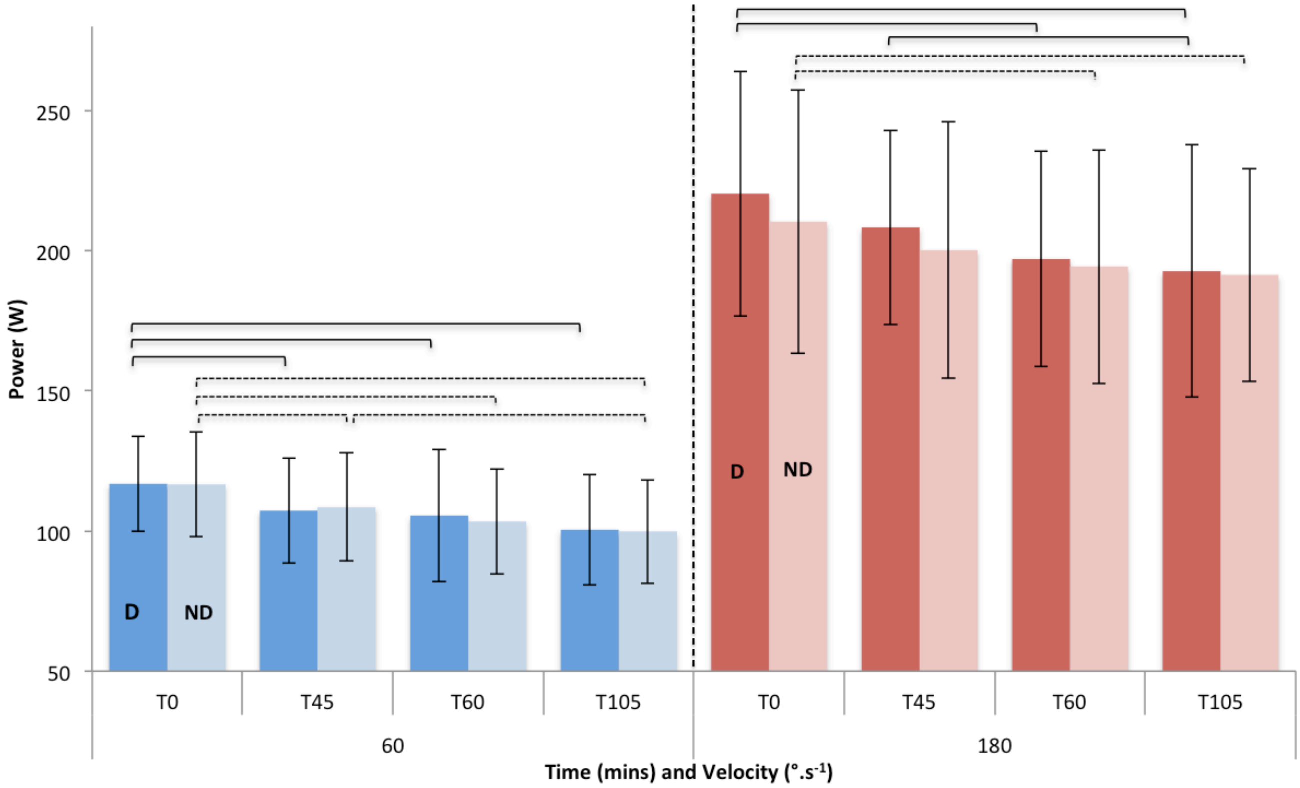
Figure 13: Eccentric quadriceps work (Nm) in both the dominant (D) and non-dominant (ND) limb, at isokinetic speeds of $60°.s^{-1}$ and $180°.s^{-1}$.

Concentric power

The overall ANOVA shows significant changes in conQ power output as a function of exercise duration. Significant effects of leg dominance on conQ power output are absent.

ConQ power output for both limbs and both isokinetic testing velocities is found to decrease significantly ($p<0.05$) as a function of time. An overall 14.32% reduction in conQ power output is illustrated at $60°.s^{-1}$ ($p<0.05$), while a 10.82% reduction is illustrated at $180°.s^{-1}$ ($p<0.05$). At the slower testing velocity, power output is found to decrease by 9.83% following the completion of the first half of SAFT^{90} ($p<0.05$).

Significant reductions (p<0.05) in conQ power, at both testing speeds, are observed after the passive half time interval, relative to T0.



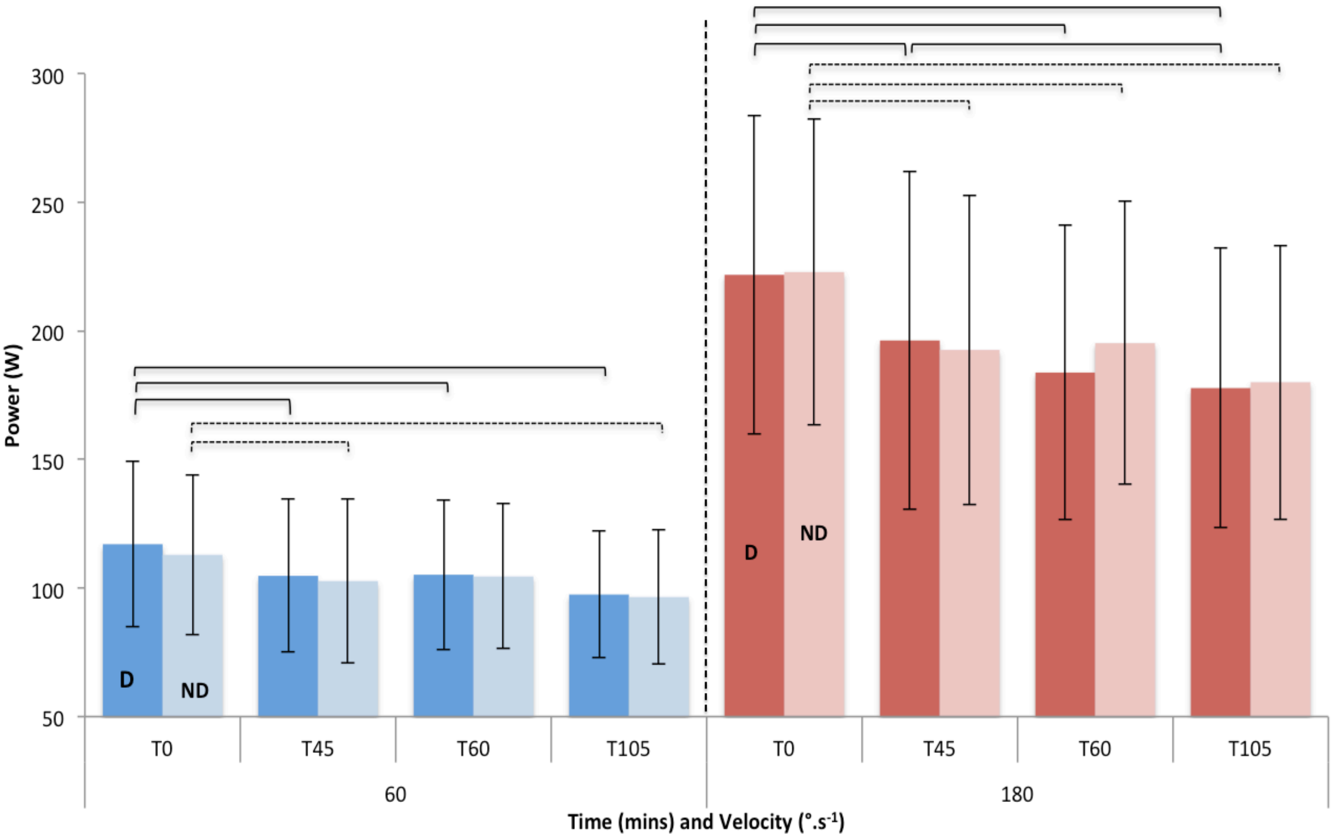
Where: — Significant difference in dominant limb (p<0.05)
······· Significant difference in the non-dominant limb (p<0.05)

Figure 14: Concentric quadriceps power (W) in both the dominant (D) and non-dominant (ND) limb, at isokinetic speeds of 60°.s^{-1} and 180°.s^{-1}.

Eccentric power

The overall ANOVA regarding eccQ power output indicates that time results in significant changes in recorded values. However, no significant effect of leg preference is illustrated.

As a function of exercise duration, eccQ power output is found to decrease at both 60°.s^{-1} and 180°.s^{-1} (p<0.05). At the slower testing velocity, a 15.65% overall reduction in eccQ power is observed, with a 9.83% (p<0.05) reduction detected after the completion of the first half and a 6.68% (p>0.05) reduction occurring following the completion of the second half of the protocol. At the faster velocity, an overall decrease in eccQ power of 19.54% is observed following the completion of the protocol ($p<0.05$). A 12.55% ($p<0.05$) reduction is apparent after the first half and a 4.78% ($p>0.05$) decrease is observed following the completion of the second half.



Where: —— Significant difference in dominant limb ($p<0.05$)
······· Significant difference in the non-dominant limb ($p<0.05$)

Figure 15: Eccentric quadriceps power (W) in both the dominant (D) and non-dominant (ND) limb, at isokinetic speeds of 60°.s^{-1} and 180°.s^{-1}.

Following the 15 minute half time interval, eccQ power in both limbs at 180°.s^{-1} illustrates significant differences ($p<0.05$) when compared to start of the protocol (T0). However at 60°.s^{-1}, the aforementioned changes are only significant in the dominant limb ($p<0.05$).

Concentric angle at peak torque

The overall ANOVA found no significant effect of exercise duration on conQ angle at peak torque. Furthermore, no significant effect of leg dominance is demonstrated in conQ APT data collected during the performance of the soccer-specific protocol.

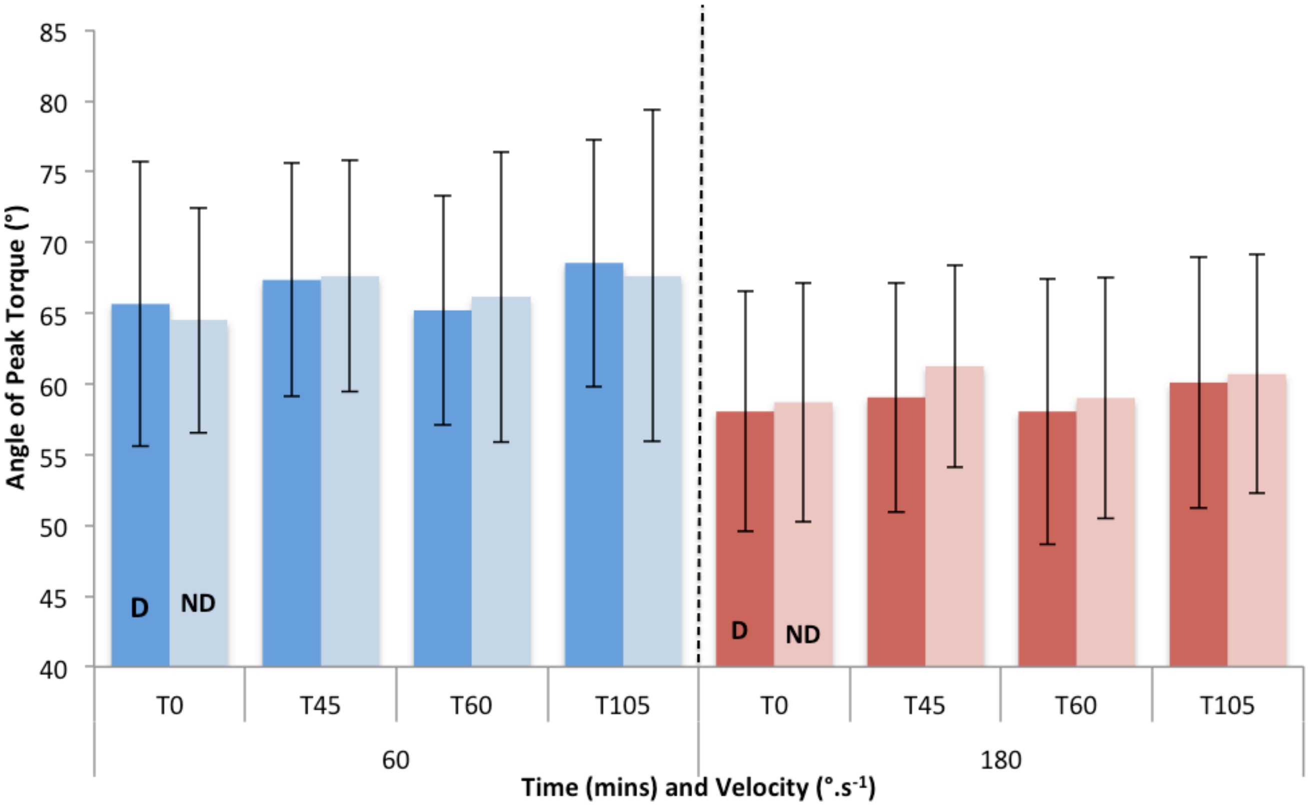


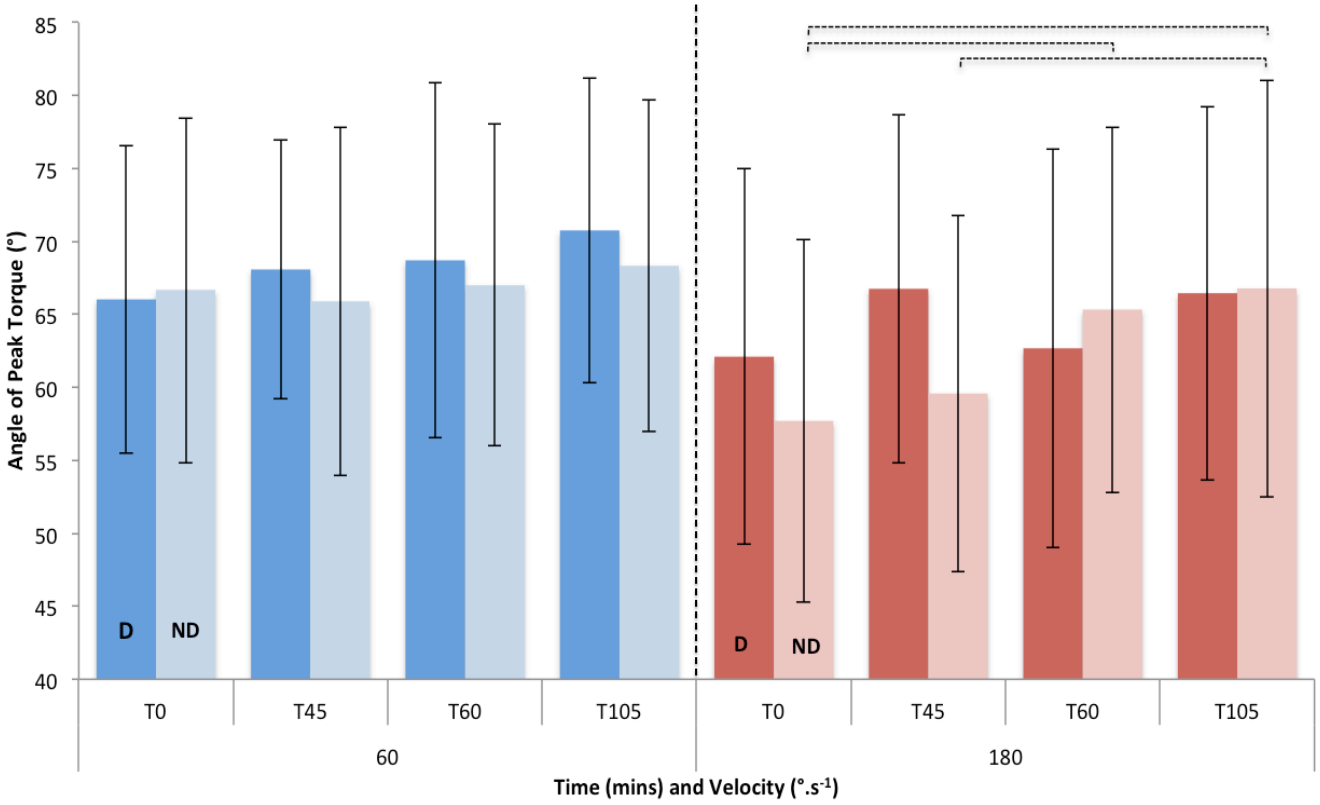
Figure 16: Concentric quadriceps angle at peak torque (°) in both the dominant (D) and non-dominant (ND) limb, at isokinetic speeds of 60°.s^{-1} and 180°.s^{-1}.

ConQ angle at peak torque (APT) for both limbs and both isokinetic testing velocities is illustrated to increase as a function of time. However, these increases in APT are determined not to be statistically significant.

Eccentric angle at peak torque

At 180°.s^{-1}, the overall ANOVA indicates significant changes in eccQ angle at peak torque as a function of time. Although an increase at 60°.s^{-1} is illustrated, eccQ APT data are not found to change significantly. In addition, the overall ANOVA indicates the presence of a significant effect of leg dominance, as well as an interaction effect between time and leg preference at 180°.s^{-1}.

EccQ APT for the non-dominant limb is found to increase as a function of time at a testing velocity of 180°.s^{-1}, with an overall increase of 11.21% occurring ($p<0.05$). Although not significant, the dominant limb at 180°.s^{-1}, as well as both limbs at 60°.s^{-1} appear to follow a similar trend to the aforementioned changes.



Where: ······· Significant difference in the non-dominant limb ($p<0.05$)

Figure 17: Eccentric quadriceps angle at peak torque (°) in both the dominant (D) and non-dominant (ND) limb, at isokinetic speeds of 60°.s^{-1} and 180°.s^{-1}.

With regards to leg dominance, significant differences in eccQ APT are demonstrated at T45, while at a isokinetic velocity of 180°.s^{-1}. The eccQ APT of the dominant leg is detected to be significantly greater than that of the non-dominant leg (66.75 ±11.94° vs. 59.58 ±12.23°) (Table X).

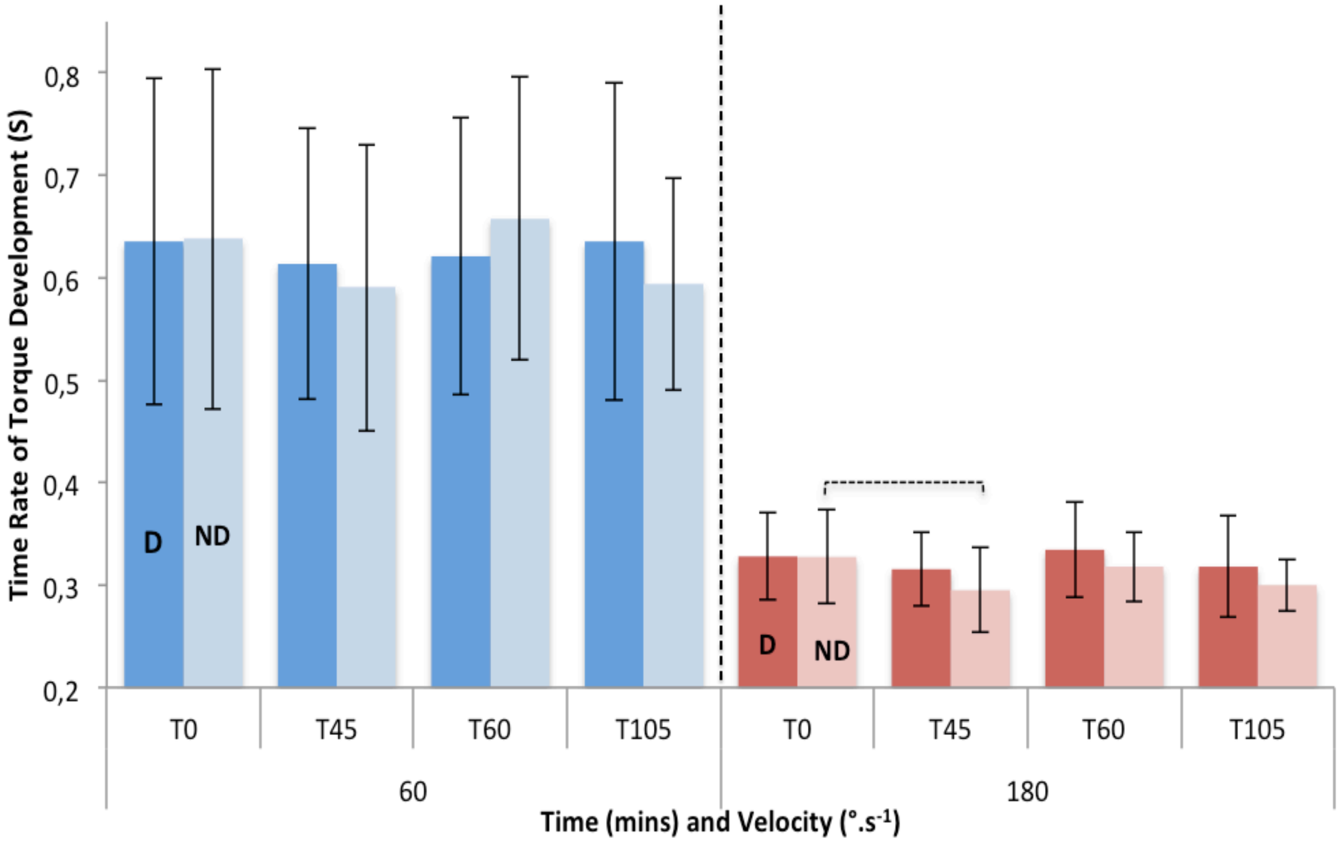
Table X: Mean (±SD) eccentric quadriceps angle at peak torque.

		T0	T45	T60	T105
60 °.s^{-1}	D	66,03 (10,53)	68,08 (8,89)	68,70 (12,17)	70,75 (10,43)
	ND	66,65 (11,83)	65,88 (11,92)	67,03 (11,04)	68,35 (11,37)
180 °.s^{-1}	D	62,10 (12,87)	66,75 (11,94)	62,68 (13,65)	66,45 (12,81)
	ND	57,70 (12,41)	59,58* (12,23)	65,33 (12,53)	66,78 (14,28)

Where: * denotes significant statistical differences ($p<0.05$)

Concentric time rate of torque development

The overall ANOVA shows time results in a significant change in conQ time rate of torque development at the more functional isokinetic testing velocity. Significant effects of leg dominance on conQ TRTD data are shown not to be present.



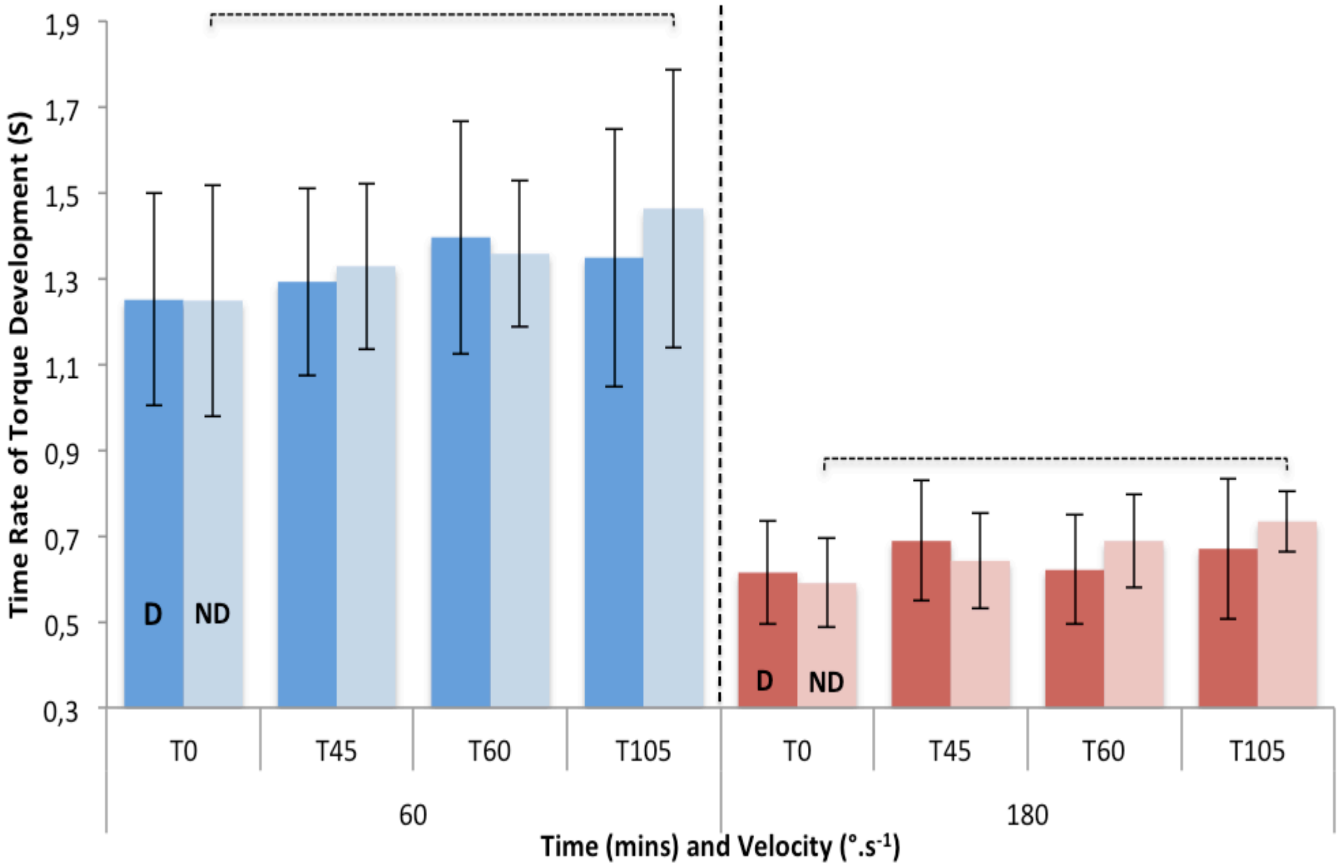
Where: ······· Significant difference in the non-dominant limb ($p<0.05$)

Figure 18: Concentric quadriceps time rate of torque development (s) in both the dominant (D) and non-dominant (ND) limb, at isokinetic speeds of 60°.s^{-1} and 180°.s^{-1}.

At 180°.s^{-1}, conQ time rate of torque development (TRTD) in the non-dominant leg is found to decrease by 6.87% following the completion of the first half ($p<0.05$). In both limbs at 180°.s^{-1}, and in the non-dominant limb 60°.s^{-1}; conQ TRTD data is illustrated to decrease after the first 45 minutes of the protocol, increase following the 15 minute half time interval, and decrease again after the second half of the protocol.

Eccentric time rate of torque development

The overall ANOVA indicates a significant change in eccQ time rate of torque development as a function of protocol duration. However, no significant effect of leg preference on eccQ TRTD is present.



Where: ······· Significant difference in the non-dominant limb ($p<0.05$)

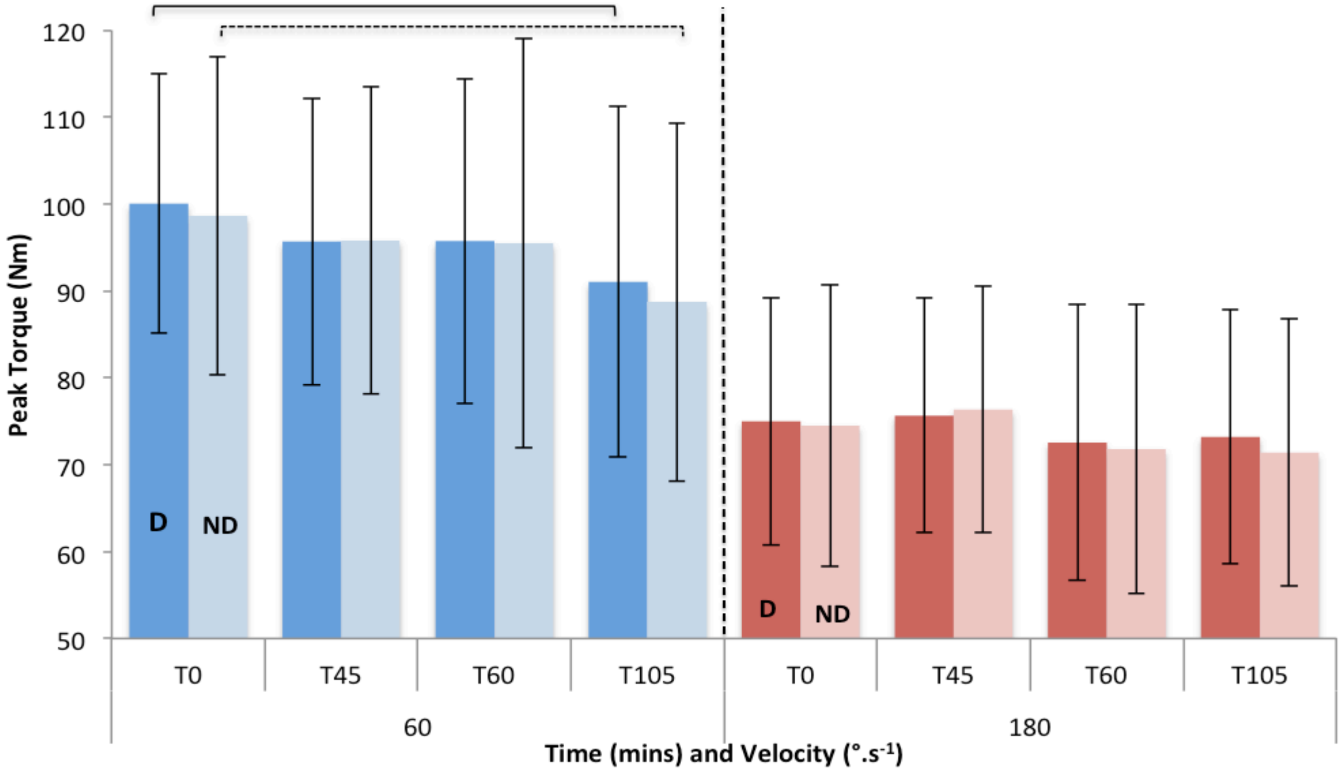
Figure 19: Eccentric quadriceps time rate of torque development (s) in both the dominant (D) and non-dominant (ND) limb, at isokinetic speeds of 60°.s^{-1} and 180°.s^{-1}. (n=11)

Although significant differences between the dominant and non-dominant limb are not observed, statistically significant changes in eccQ TRTD are only observed in the non-dominant limb ($p<0.05$).

Isokinetic hamstrings strength (flexors)

Concentric peak torque

The overall ANOVA indicates that time results in significant changes in conH peak torque values at 60°.s^{-1}. No significant effect of leg preference is observed with regards to the hamstrings musculature in the concentric modality.



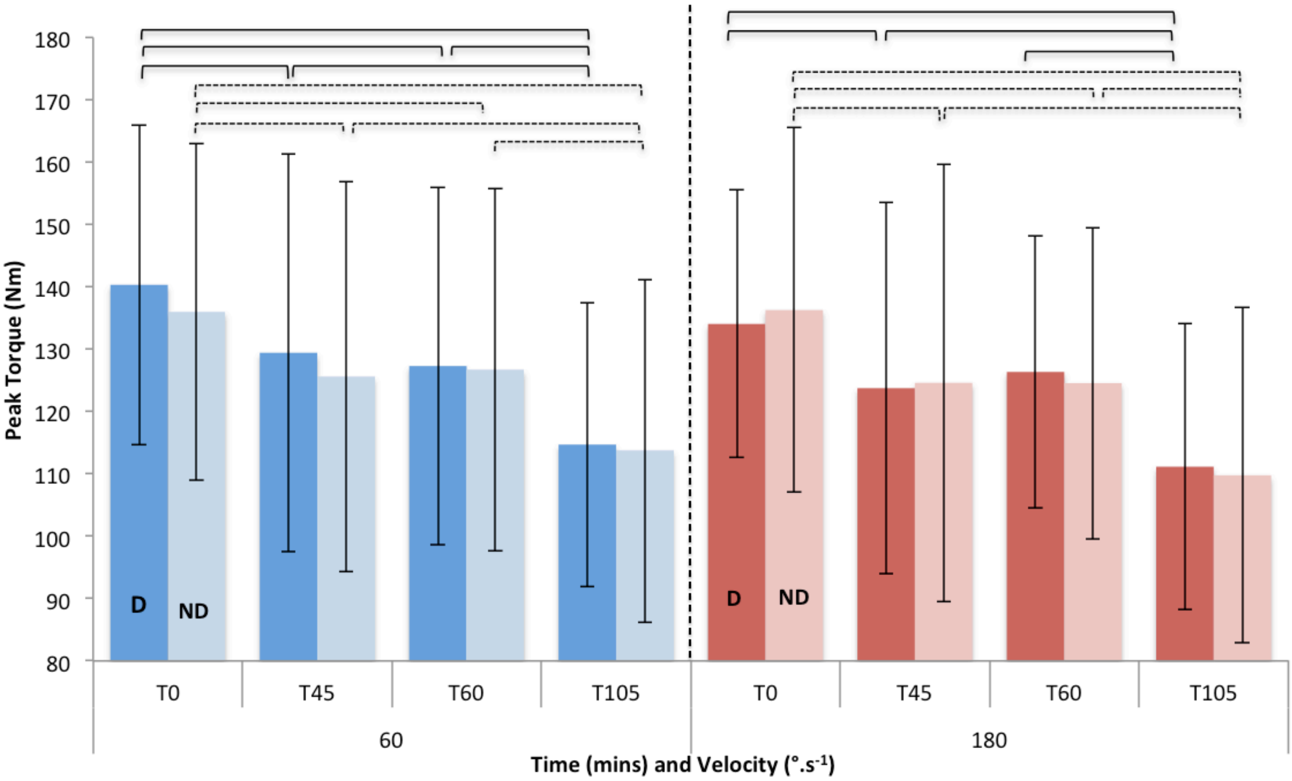
Where: —— Significant difference in dominant limb ($p<0.05$)
······· Significant difference in the non-dominant limb ($p<0.05$)

Figure 20: Concentric hamstring peak torque (Nm) in both the dominant (D) and non-dominant (ND) limb, at isokinetic speeds of 60°.s^{-1} and 180°.s^{-1}.

ConH peak torque is illustrated to decrease as a function of time at isokinetic velocities of 60°.s^{-1} and 180°.s^{-1}. At the slower testing velocity, a 9.54% overall reduction in conH peak torque is observed, with a 3.60% ($p>0.05$) reduction occurring after the completion of the first half and a 5.79% ($p>0.05$) reduction occurring following the completion of the second half of the protocol. At the faster velocity, an overall decrease of 3.28% in conH peak torque is observed following the completion of the protocol.

Eccentric peak torque

The overall ANOVA shows a significant change in eccH peak torque as a function of exercise duration. A lack of significant effects for leg dominance are observed throughout the performance of SAFT^{90}.



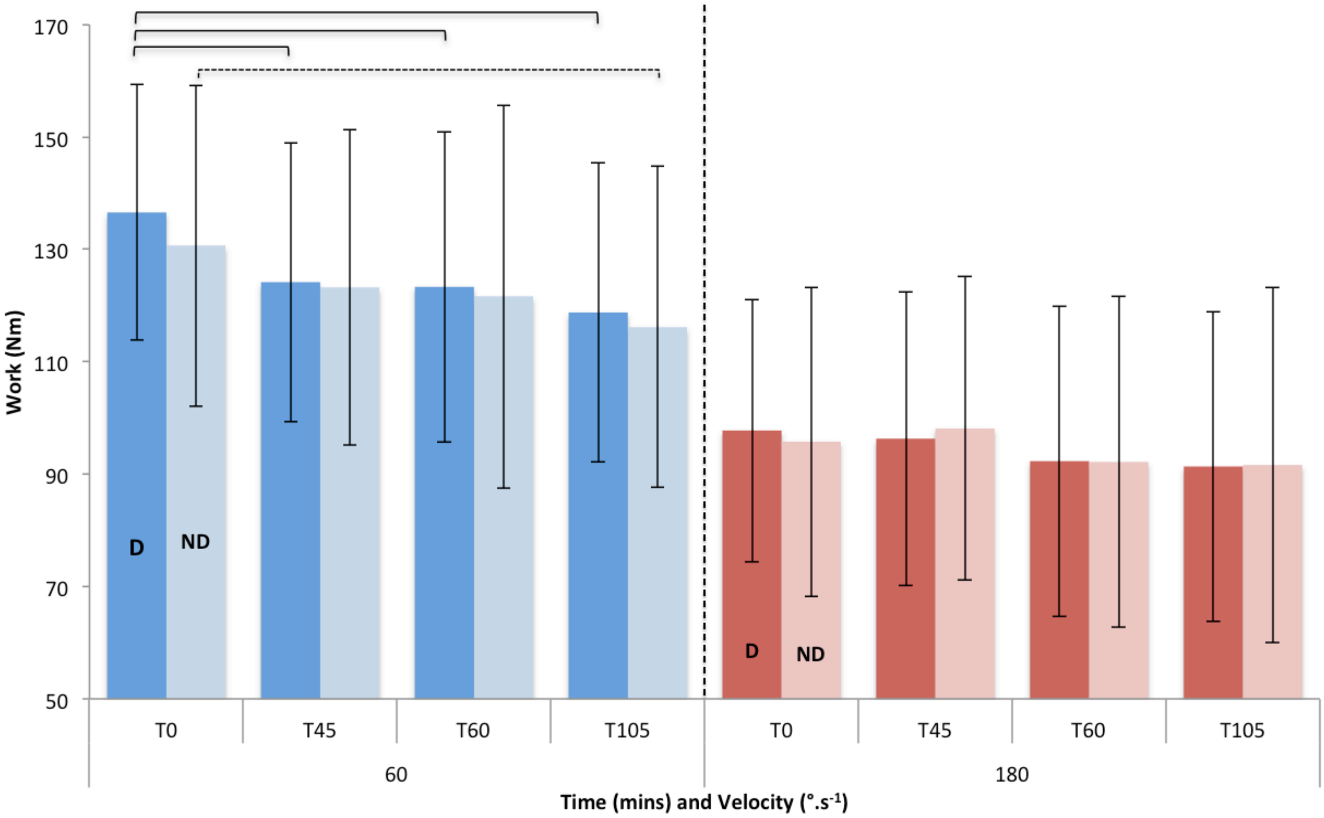
Where: — Significant difference in dominant limb (p<0.05)
······· Significant difference in the non-dominant limb (p<0.05)

Figure 21: Eccentric hamstring peak torque (Nm) in both the dominant (D) and non-dominant (ND) limb, at isokinetic speeds of 60°.s^{-1} and 180°.s^{-1}.

EccH peak torque decreases as a function of time at both isokinetic testing speeds. At 60°.s^{-1}, a 17.34% overall reduction in eccH torque is illustrated ($p<0.05$). Furthermore, significant reductions in eccH peak torque are observed after both the first (7.73%) and second (9.25%) halves ($p<0.05$). At the faster isokinetic velocity, an overall decrease in eccH force of 18.27% is demonstrated ($p<0.05$). Moreover, a 8.13% and 11.09% decrease in peak torque is observed after the first and second halves respectively ($p<0.05$). Following the 15 minute half time interval, eccH peak torque at 60°.s^{-1} is illustrates a significant difference ($p<0.05$) when compared to start of the protocol (T0). However at 180°.s^{-1}, the abovementioned changes are only significant in the non-dominant limb ($p<0.05$).

Concentric work

An ANOVA of overall effects indicates significant changes in conH work as a function of time, while at an isokinetic velocity of 60°.s^{-1}. No significant effect of leg dominance is present, regardless of testing speed.



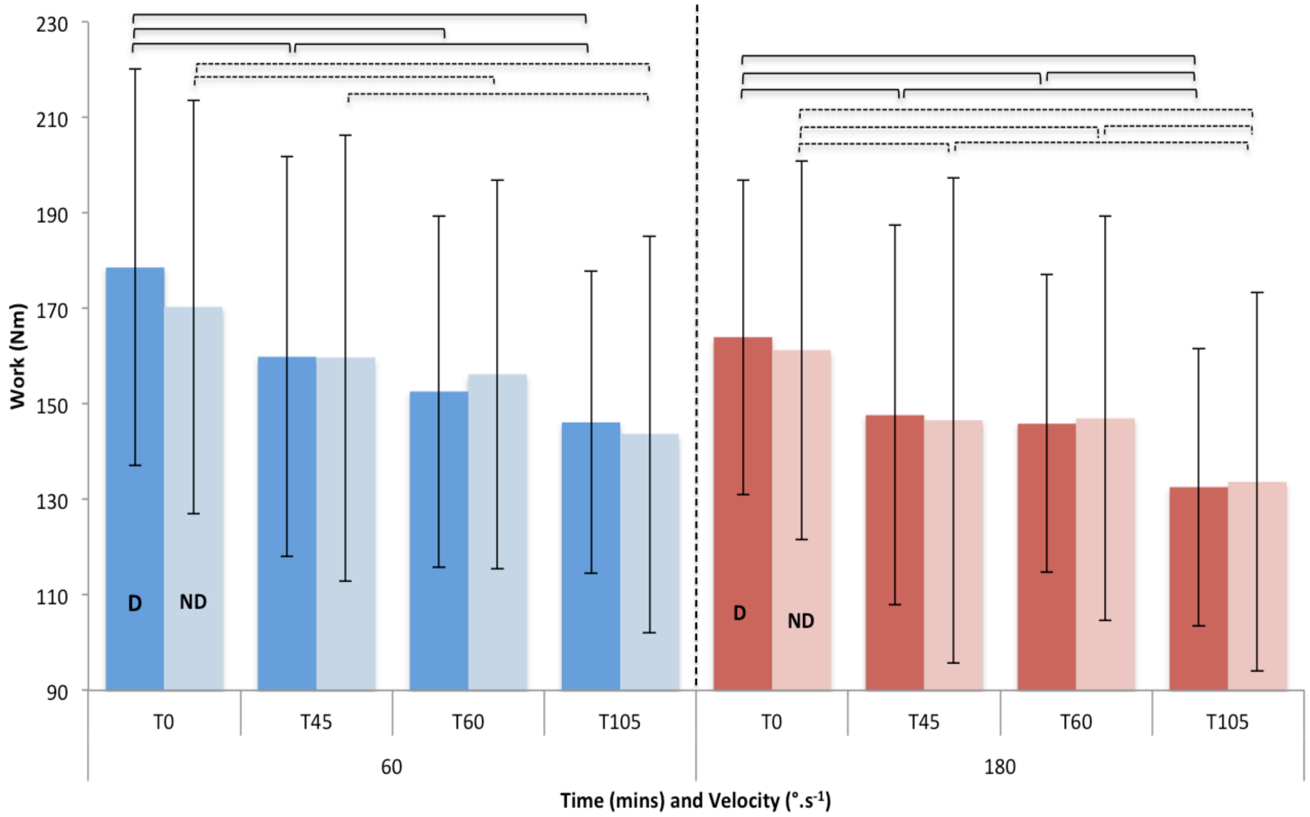
Where: — Significant difference in dominant limb ($p<0.05$)
······· Significant difference in the non-dominant limb ($p<0.05$)

Figure 22: Concentric hamstring work (Nm) in both the dominant (D) and non-dominant (ND) limb, at isokinetic speeds of 60°.s^{-1} and 180°.s^{-1}.

At an isokinetic testing velocity of 60°.s^{-1}, a 12.05% overall reduction ($p<0.05$) in conH work is observed. At the faster velocity, an overall decrease of 5.45% in conH work is observed. However, the reduction in conH work at 180°.s^{-1} is demonstrated not to be significant.

Eccentric work

The overall ANOVA shows significant changes in eccH work values elicited during fatigue protocol performance. However, significant effects of leg preference are absent.



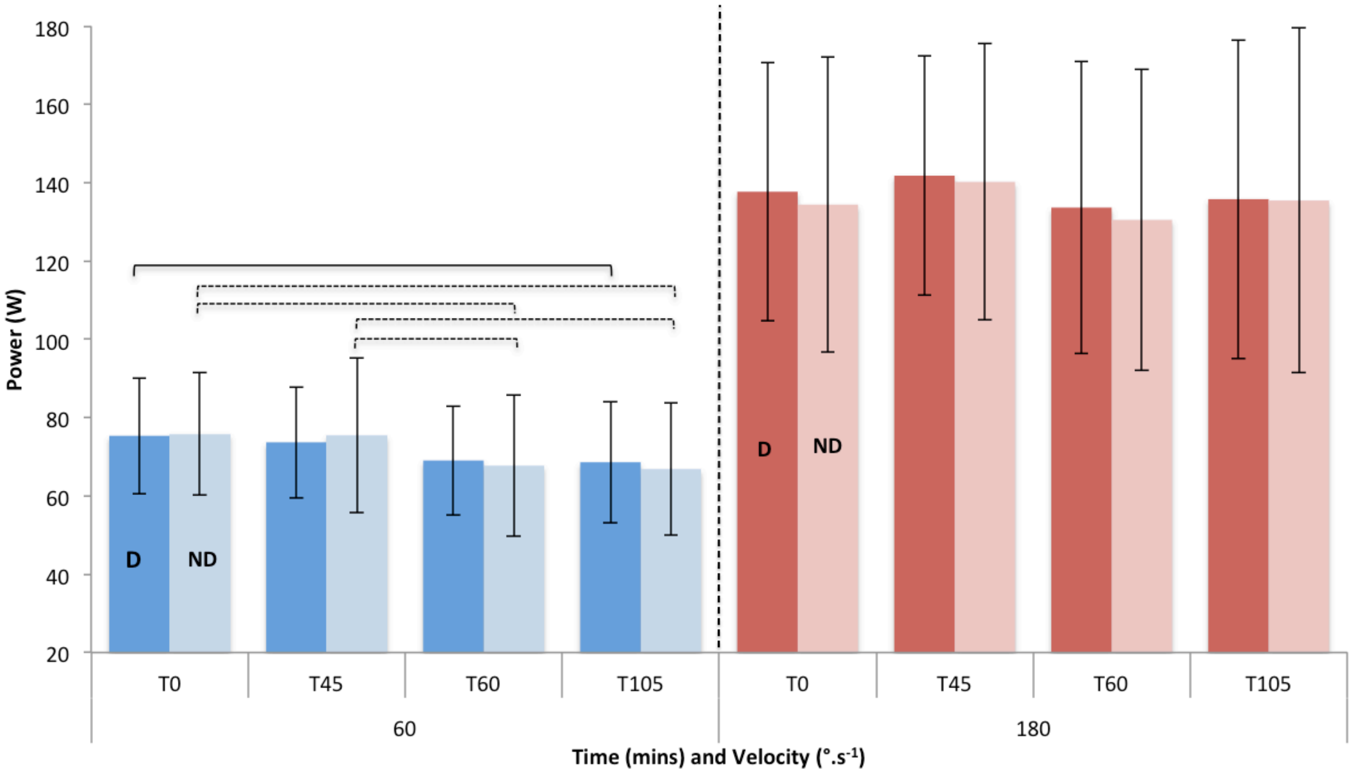
Where: —— Significant difference in dominant limb ($p<0.05$)
······· Significant difference in the non-dominant limb ($p<0.05$)

Figure 23: Eccentric hamstring work (Nm) in both the dominant (D) and non-dominant (ND) limb, at isokinetic speeds of 60°.s^{-1} and 180°.s^{-1}.

EccQ work is observed to decrease over time at both 60°.s^{-1} and 180°.s^{-1}. At the slower testing velocity, a 16.95% overall reduction in eccH work is observed ($p<0.05$). At the faster velocity, an overall decrease in eccH work of 18.14% is indicated following the completion of the protocol ($p<0.05$). A 9.54% reduction in eccH work is observed after the first half ($p<0.05$), with a similar 8.17% decrease observed following the second half ($p<0.05$). Following the 15 minute passive half time interval, work is significantly reduced at both testing velocities when compared to T0 ($p<0.05$).

Concentric power

The overall ANOVA indicates that time results in significant changes in conH power output while at the slower isokinetic testing velocity. Significant effects of leg dominance on conH power data are absent regardless of testing velocity.



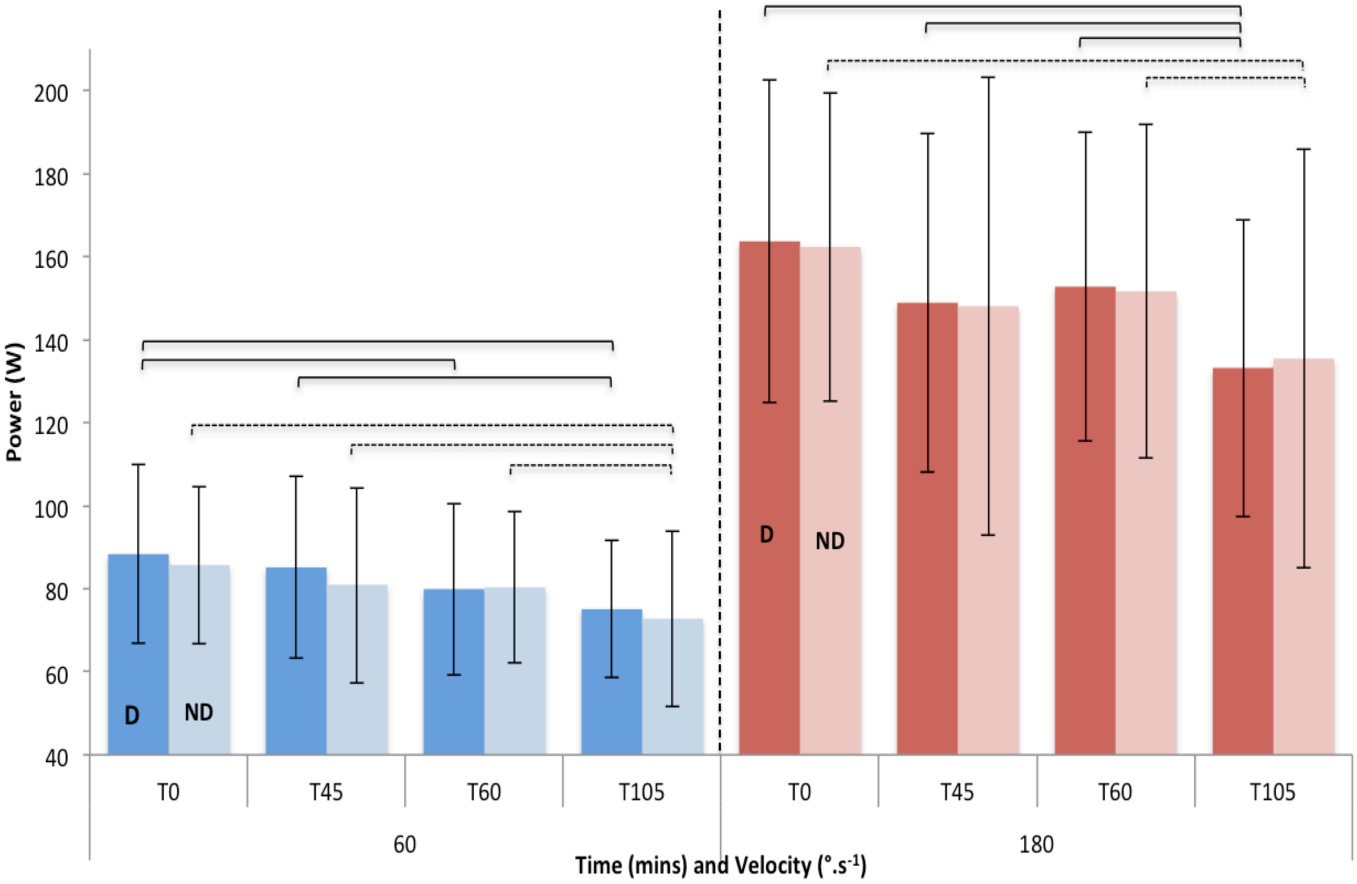
Where: —— Significant difference in dominant limb ($p<0.05$)
······· Significant difference in the non-dominant limb ($p<0.05$)

Figure 24: Concentric hamstring power (W) in both the dominant (D) and non-dominant (ND) limb, at isokinetic speeds of 60°.s^{-1} and 180°.s^{-1}.

ConH power output is illustrated to decrease as a function of time at an isokinetic velocitiy of 60°.s^{-1} ($p<0.05$). More specifically, a 10.41% overall reduction in conH power is observed as a function of exercise duration. At the faster velocity, no significant changes in conH power output are observed over time. Following the 15 minute half time interval, a significant reduction in conH power output is indicated when compared to the end of the first half of SAFT^{90} (8.29%). However, this reduction is only statistically significant in the non-dominant limb at 60°.s^{-1} ($p<0.05$).

Eccentric power

The overall ANOVA demonstrates significant changes in eccH power output as a function of time. However, no significant effects of leg dominance on eccentric hamstring power are observed.



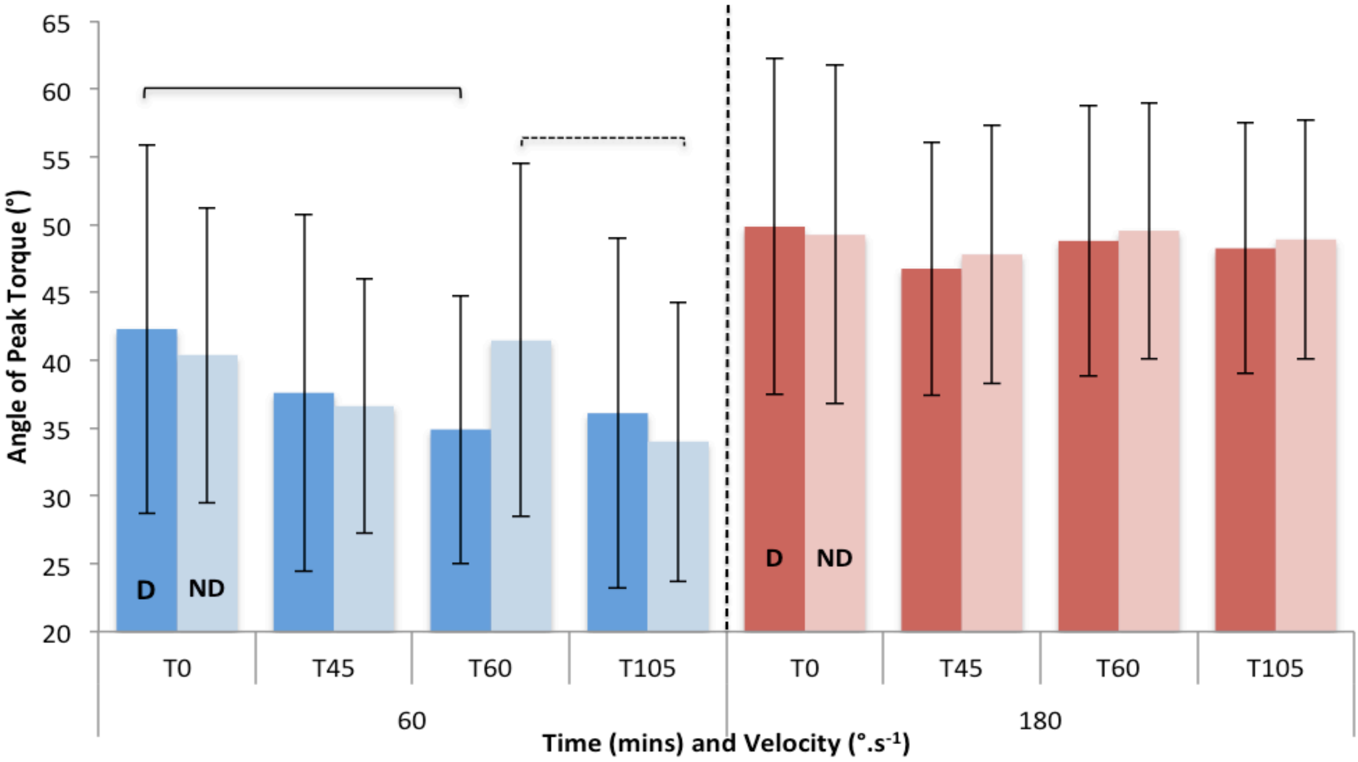
Where: ── Significant difference in dominant limb ($p<0.05$)
······· Significant difference in the non-dominant limb ($p<0.05$)

Figure 25: Eccentric hamstring power (W) in both the dominant (D) and non-dominant (ND) limb, at isokinetic speeds of 60°.s^{-1} and 180°.s^{-1}.

EccH power output decreases as a function of time at both 60°.s^{-1} and 180°.s^{-1}. At the slower testing velocity, a 15.03% overall reduction in eccH power is demonstrated ($p<0.05$). At the faster velocity, an overall decrease of 17.60% in eccH power is observed following the completion of the protocol ($p<0.05$), with a 11.60% decrease illustrated after the second half ($p<0.05$).

Concentric angle at peak torque

The overall ANOVA indicates significant changes in conH angle at peak torque as a function of time, while at 60°.s^{-1}. Significant effects of leg preference are present in the conH APT data elicited. An interaction effect of time and leg dominance is also indicated at 60°.s^{-1}.



Where: — Significant difference in dominant limb ($p<0.05$)
······· Significant difference in the non-dominant limb ($p<0.05$)

Figure 26: Concentric hamstring angle at peak torque (°) in both the dominant (D) and non-dominant (ND) limb, at isokinetic speeds of 60°.s^{-1} and 180°.s^{-1}.

ConH APT is found to decrease overall by 15.18% as a function of time at a testing velocity of 60°.s^{-1} ($p>0.05$). Dominant limb conH APT is observed to be significantly different to data collected before exercise performance ($p<0.05$). Similarly at 60°.s^{-1}, conH APT in the dominant limb is illustrated to decrease significantly during the second half ($p<0.05$).

Table XI: Mean (±SD) concentric hamstring angle at peak torque.

		T0	T45	T60	T105
60 ^{o}.s^{-1}	D	42,30 (13,58)	37,60 (13,14)	34,90 (9,89)	36,10 (12,88)
	ND	40,35 (10,85)	36,65 (9,39)	41,50* (13,03)	34,00 (10,30)
180 ^{o}.s^{-1}	D	49,85 (12,38)	46,75 (9,33)	48,80 (9,99)	48,25 (9,22)
	ND	49,25 (12,48)	47,80 (9,51)	49,55 (9,44)	48,90 (8,83)

Where: * denotes significant statistical difference ($p<0.05$)

With regards to leg dominance, significant differences in conH APT are observed at T60, while at a isokinetic velocity of 180°.s^{-1}. The conH APT of the non- dominant leg is indicated to be significantly greater than that of the dominant leg (41.50 ±13.03° vs. 34.90 ±9.89°) (Table XI).

Eccentric angle at peak torque

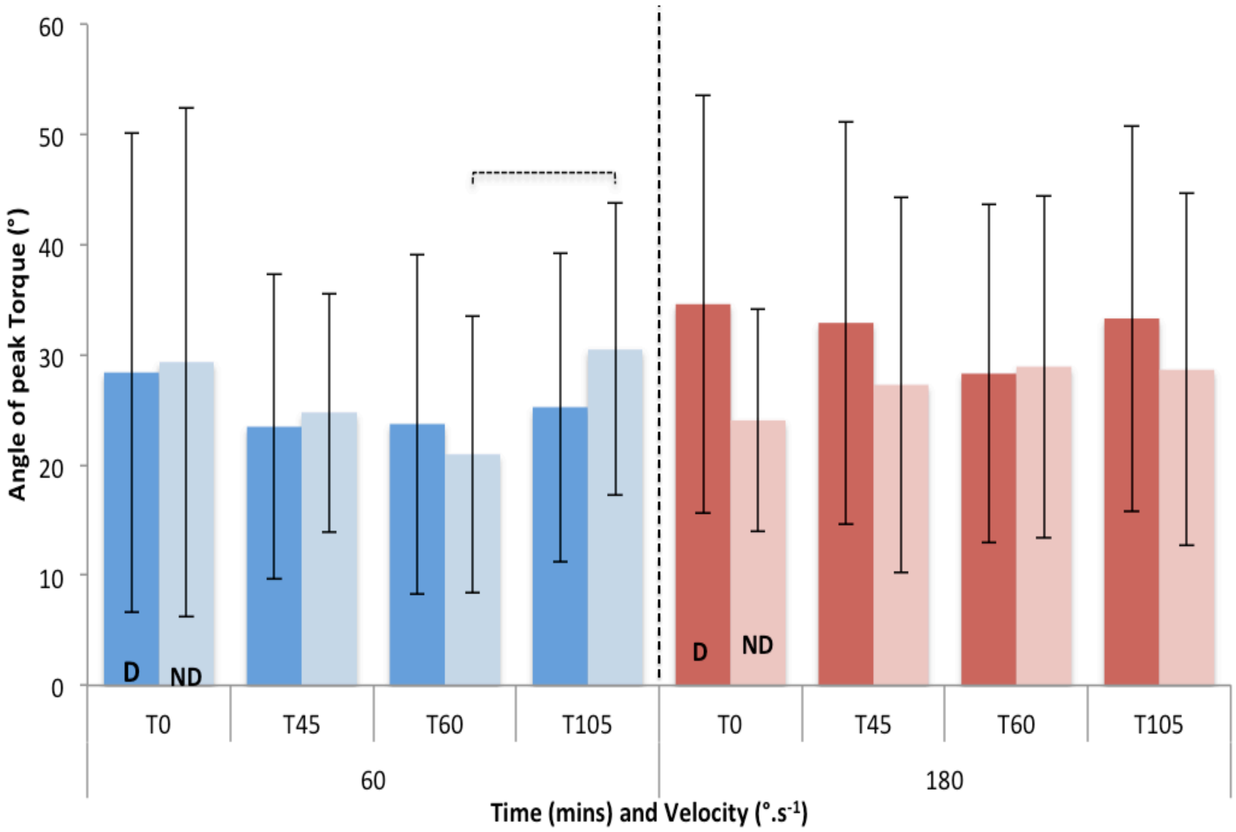
The overall ANOVA shows no significant change in eccH angle at peak torque as a function of time, regardless of testing velocity. However, the overall effects ANOVA indicates a significant effect of leg dominance.

Table XII: Mean (±SD) eccentric hamstring angle at peak torque.

		T0	T45	T60	T105
60 ^{o}.s^{-1}	D	28,40 (21,75)	23,48 (13,80)	23,73 (15,43)	25,25 (14,02)
	ND	29,33 (23,10)	24,73 (10,81)	20,98 (12,55)	30,53 (13,26)
180 ^{o}.s^{-1}	D	34,60 (18,95)	32,90 (18,26)	28,30 (15,33)	33,30 (17,50)
	ND	24,05* (10,07)	27,28 (17,03)	28,93 (15,53)	28,65 (15,98)

Where: * denotes significant statistical difference ($p<0.05$)

With regards to leg preference, significant difference in eccH APT is indicated before the start of the SAFT^{90} protocol, while at a isokinetic velocity of 180°.s^{-1}. The eccH APT of the dominant leg is detected to be significantly greater than that of the non-dominant leg (34.60 ±18.95° vs. 24.05 ±10.07°) (Table XII).



Where: ······· Significant difference in the non-dominant limb ($p<0.05$)

Figure 27: Eccentric hamstring angle at peak torque (°) in both the dominant (D) and non-dominant (ND) limb, at isokinetic speeds of 60°.s^{-1} and 180°.s^{-1}.

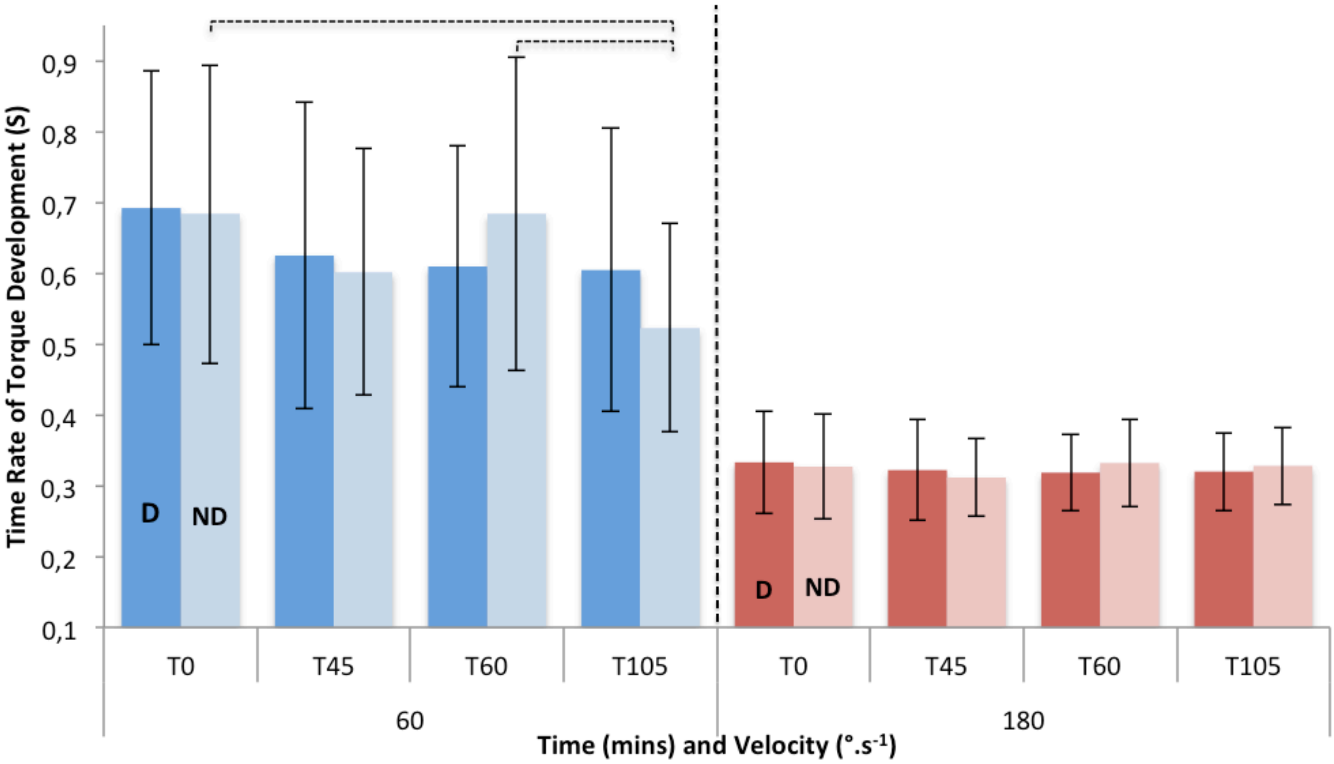
At both isokinetic testing speeds, no significant overall increase in eccH APT is observed ($p>0.05$). At 60°.s^{-1} a significant increase in the non-dominant limb is demonstrated between T60 and the end of the protocol.

Concentric time rate of torque development

The overall ANOVA indicates a significant reduction in conH TRTD in the non-dominant limb at 60°.s^{-1}, as a function of protocol duration. In addition, the general ANOVA indicates no significant effects of leg dominance during protocol performance.

ConH TRTD is demonstrated to decrease as a function of time at both 60°.s^{-1} and 180°.s^{-1}. At the slower testing velocity, a 18.25% overall decrease is observed. However, this change is only significant in the non-dominant limb ($p<0.05$). A significant decrease in non-dominant conH TRTD is also indicated between T60 and

T105 ($p<0.05$). At the faster velocity, an overall decrease of 1.82% in conH APT is observed following the completion of the protocol ($p>0.05$).



Where: ······· Significant difference in the non-dominant limb ($p<0.05$)

Figure 28: Concentric hamstring time rate of torque development (s) in both the dominant (D) and non-dominant (ND) limb, at isokinetic speeds of 60°.s^{-1} and 180°.s^{-1}.

Eccentric time rate of torque development

The overall ANOVA indicates no significant change in eccH time rate of torque development as a function of time. However, a significant effect of leg preference is noted at the faster isokinetic velocity.

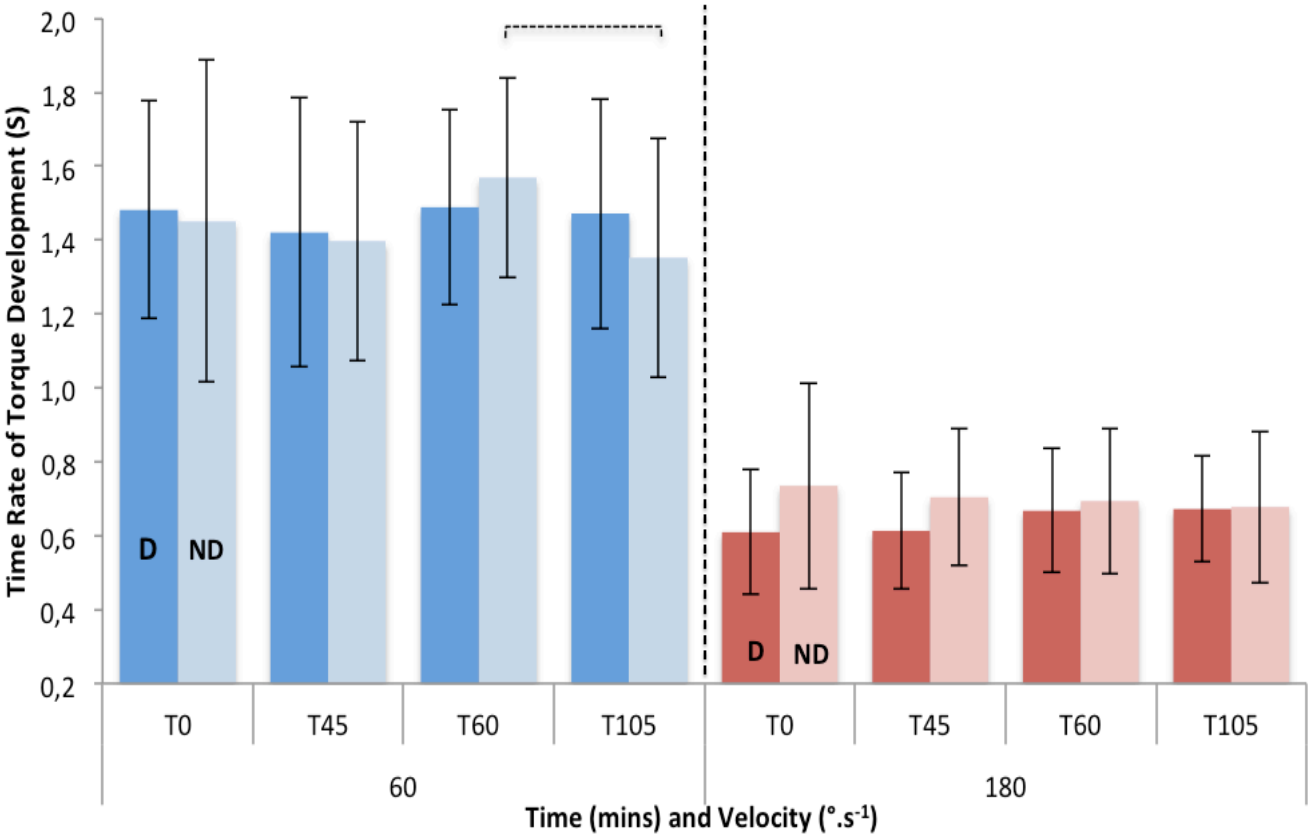
A significant effect of leg dominance on eccH TRTD is demonstrated prior the start of the SAFT^{90} protocol, while at a isokinetic velocity of 180°.s^{-1}. The eccH TRTD of the non-dominant limb is illustrated to be significantly greater than that of the dominant limb (0.74 ±0.28s vs. 0.61 ±0.17s) (Table XIII).

Table XIII: Mean (±SD) eccentric hamstring time rate of torque development.

		T0	T45	T60	T105
60 °.s^{-1}	D	1,48 (0,29)	1,42 (0,36)	1,49 (0,26)	1,47 (0,31)
	ND	1,45 (0,44)	1,40 (0,32)	1,57 (0,27)	1,35 (0,32)
180 °.s^{-1}	D	0,61 (0,17)	0,61 (0,16)	0,67 (0,17)	0,67 (0,14)
	ND	0,74* (0,28)	0,70 (0,18)	0,69 (0,20)	0,68 (0,21)

Where: * denotes significant statistical difference (p<0.05)

At both isokinetic testing speeds, no significant overall effect of time is observed for eccH TRTD data. However, at 60°.s^{-1} a significant decrease of 7.47% in non-dominant eccH TRTD is observed between T60 and the end of the protocol (p<0.05).



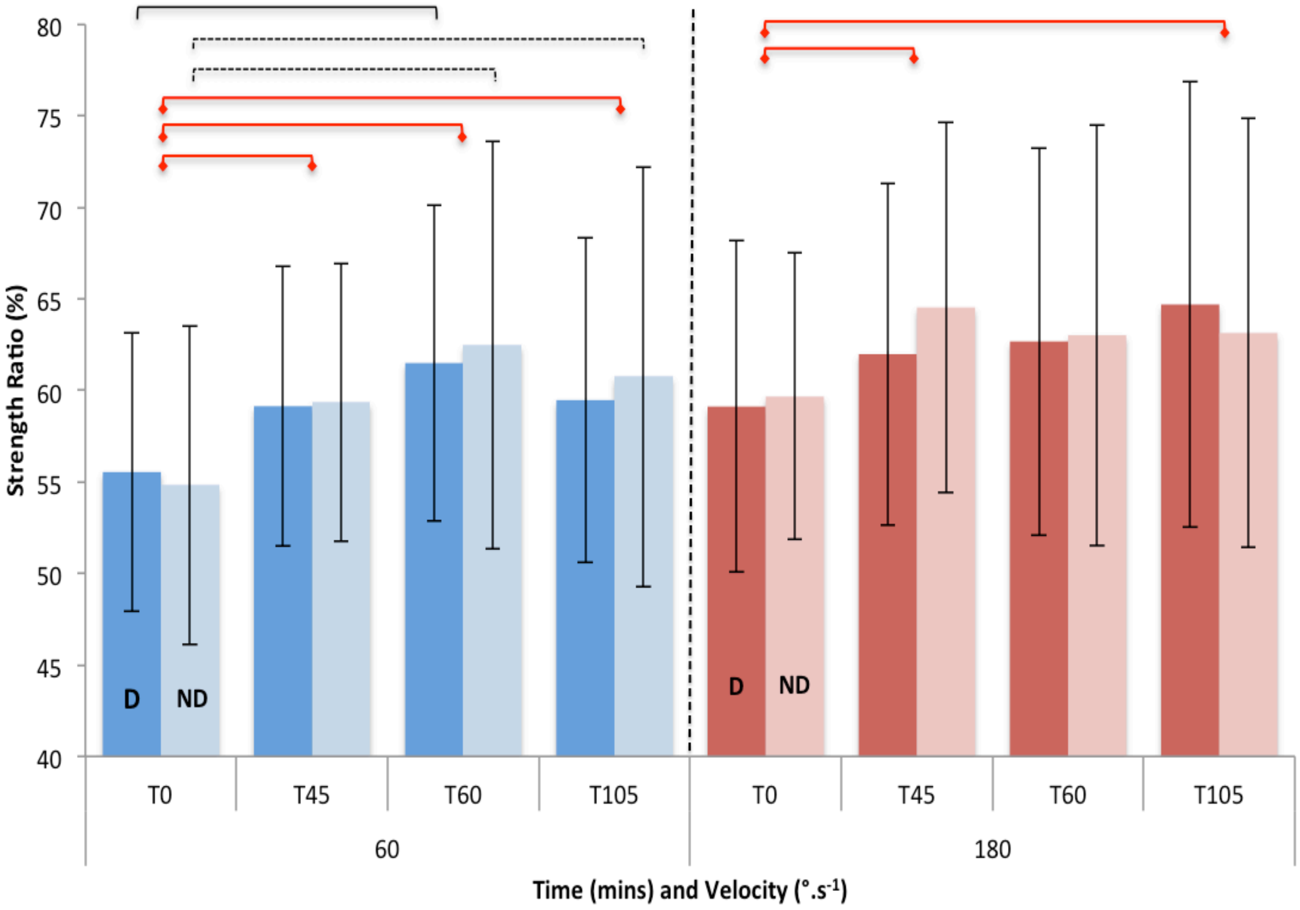
Where: ······· Significant difference in the non-dominant limb (p<0.05)

Figure 29: Eccentric hamstring time rate of torque development (s) in both the dominant (D) and non-dominant (ND) limb, at isokinetic speeds of 60°.s^{-1} and 180°.s^{-1}.

Hamstrings to quadriceps ratio (H:Q)

Conventional H:Q

The overall ANOVA indicates a significant change in the conventional H:Q ratio as a function of exercise duration. Significant effects of leg dominance on conventional H:Q are absent throughout experimental procedures testing.



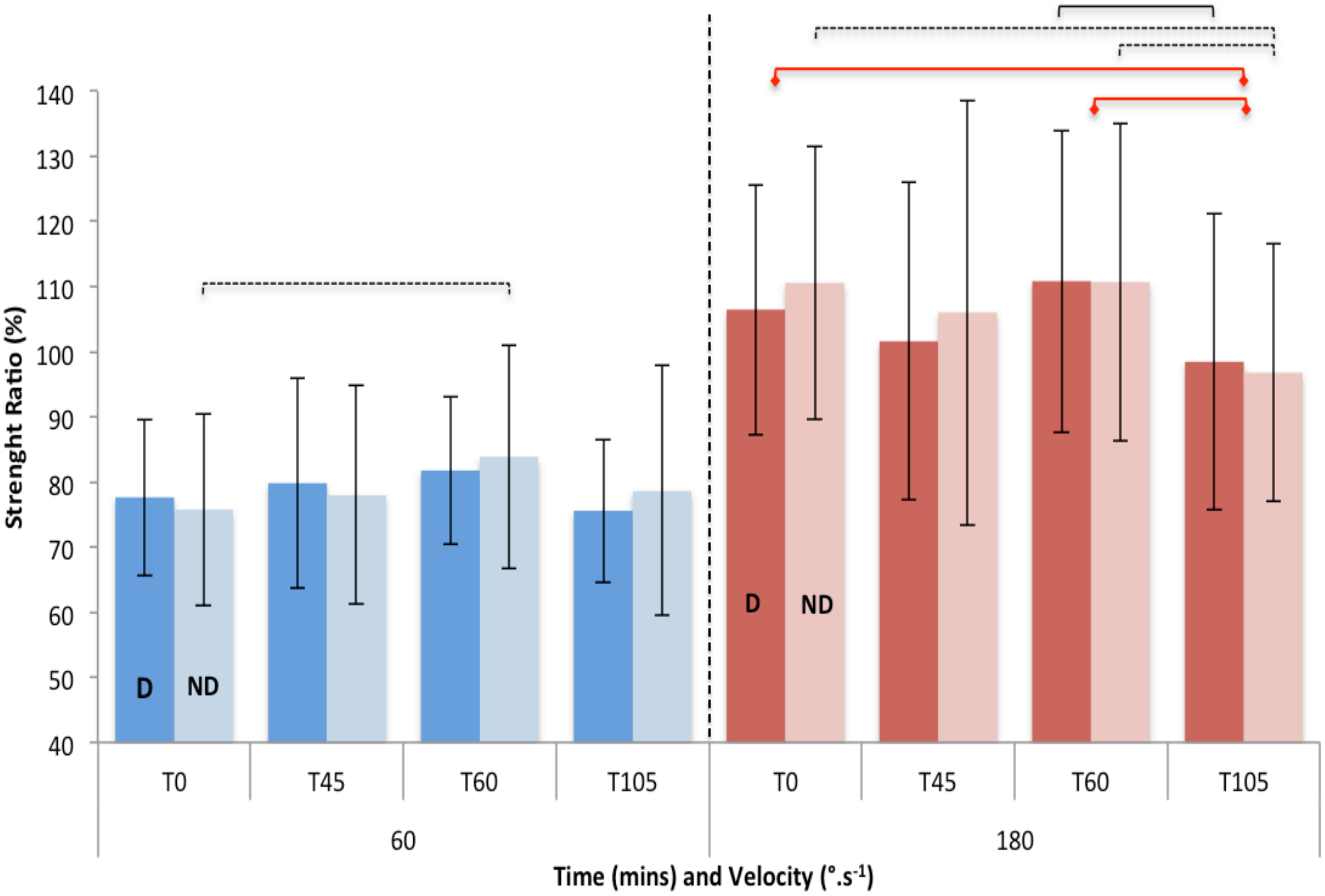
Where: — Significant difference in dominant limb ($p<0.05$)
…… Significant difference in the non-dominant limb ($p<0.05$)
— Significant difference overall (D+ND) ($p<0.05$)

Figure 30: Conventional hamstring:quadriceps ratio in both the dominant (D) and non-dominant (ND) limb, at isokinetic speeds of 60°.s^{-1} and 180°.s^{-1}.

Conventional H:Q is found to increase overall as a function of time at both 60°.s^{-1} and 180°.s^{-1}. At the slower testing velocity a 8.95% overall reduction in the conventional H:Q ratio is illustrated ($p<0.05$), with a 7.37 % increase observed after the first half ($p<0.05$). In both limbs, the 15 minute passive half time interval results in a significantly higher conventional strength ratio than when compared to T0 ($p<0.05$). At the faster velocity, an overall increase in conventional H:Q ratio of 7.62% is demonstrated following the completion of the protocol. Moreover, a 6.51% increase in conventional H:Q is observed after the completion of the first half.

Functional H:Q

At 180°.s^{-1}, the overall ANOVA indicates significant changes in the functional strength ratio as a function of time. Significant effects of leg preference on functional H:Q data are absent, regardless of testing velocity.



Where: — Significant difference in dominant limb ($p<0.05$)

⋯⋯ Significant difference in the non-dominant limb ($p<0.05$)

— Significant difference overall (D+ND) ($p<0.05$)

Figure 31: Functional hamstring:quadriceps ratio in both the dominant (D) and non-dominant (ND) limb, at isokinetic speeds of 60°.s^{-1} and 180°.s^{-1}.

At an isokinetic testing speed of 60°.s^{-1}, no significant change in the overall functional H:Q is illustrated. However, functional H:Q is determined to be significantly greater in the non-dominant limb following the half time interval, relative to T0 ($p<0.05$). At 180°.s^{-1}, a 10.04% overall decrease in the functional H:Q ratio is observed. After the completion of the first half of the protocol, a 4.35% reduction in the ratio occurred ($p>0.05$). Furthermore, the completion of the second half results in a 12.10% reduction in functional H:Q ($p<0.05$).

SOMATOTYPE

Competitive soccer players are required to possess physiological and morphological characteristics that are applicable specifically for the sport of soccer as well as to their playing position (Hazir, 2010)

Table XIV: Somatotype ratings of participants (n=20).

	Mean	**SD (±)**
Overall	2.9 - 5.1 - 2.3	1.01 - 1.14 - 0.96
Defenders (n=8)	2.6 - 5.0 - 2.6	0.68 - 1.08 - 1.00
Midfielders (n=7)	3.1 - 4.9 - 2.2	1.22 - 1.09 - 0.99
Forwards (n=5)	3.1 - 5.4 - 2.2	1.25 - 1.47 - 0,99

As seen in Table XIV, participants from the current research are observed to have somatotype ratings reflecting the balanced mesomorph category. With regards to position of play, all three outfield positions reflect a balanced mesomorph somatotype category.

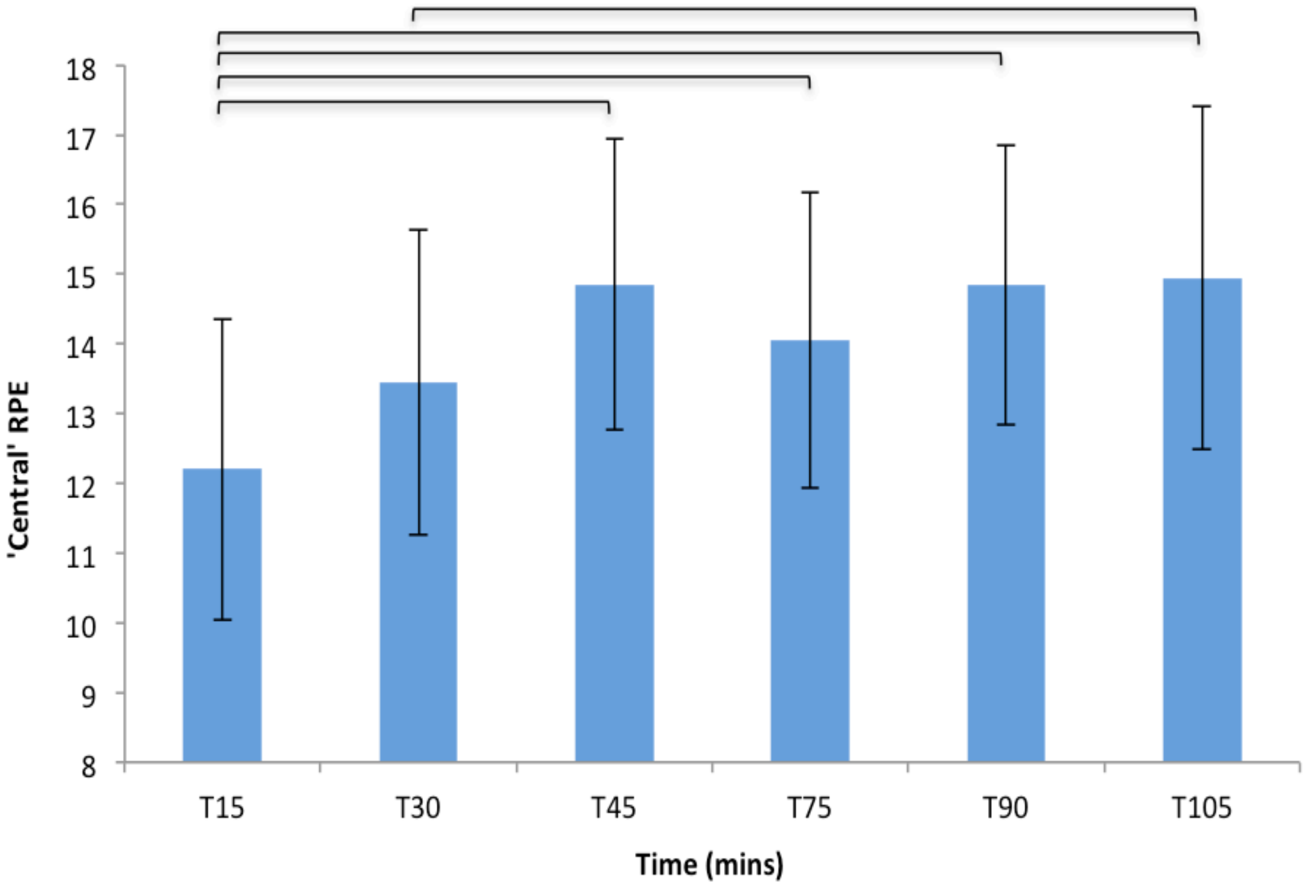
PSYCHOPHYSICAL PARAMETERS

Perceptual measures of exertion and discomfort may be as valuable as measures of physiological and biomechanical functioning when quantifying feelings of pain and fatigue (Pandolf 1975). This is as perceptual responses give an indication of an individual's subjective feelings of fatigue, exertion and discomfort. Therefore, perceptual ratings are integral if a holistic understanding of the effects of soccer-specific fatigue is to be obtained.

Ratings of Perceived Exertion (RPE)

Central' RPE

The subjective ratings of 'Central' exertion are illustrated to significantly ($p<0.05$) increase over time. Significant increases in ratings are observed during the first half, as well as from the start of the protocol until its completion (T15 to T105). During the second half of the protocol 'Central' RPE is indicated to increase, however this increase is not found to be significant.

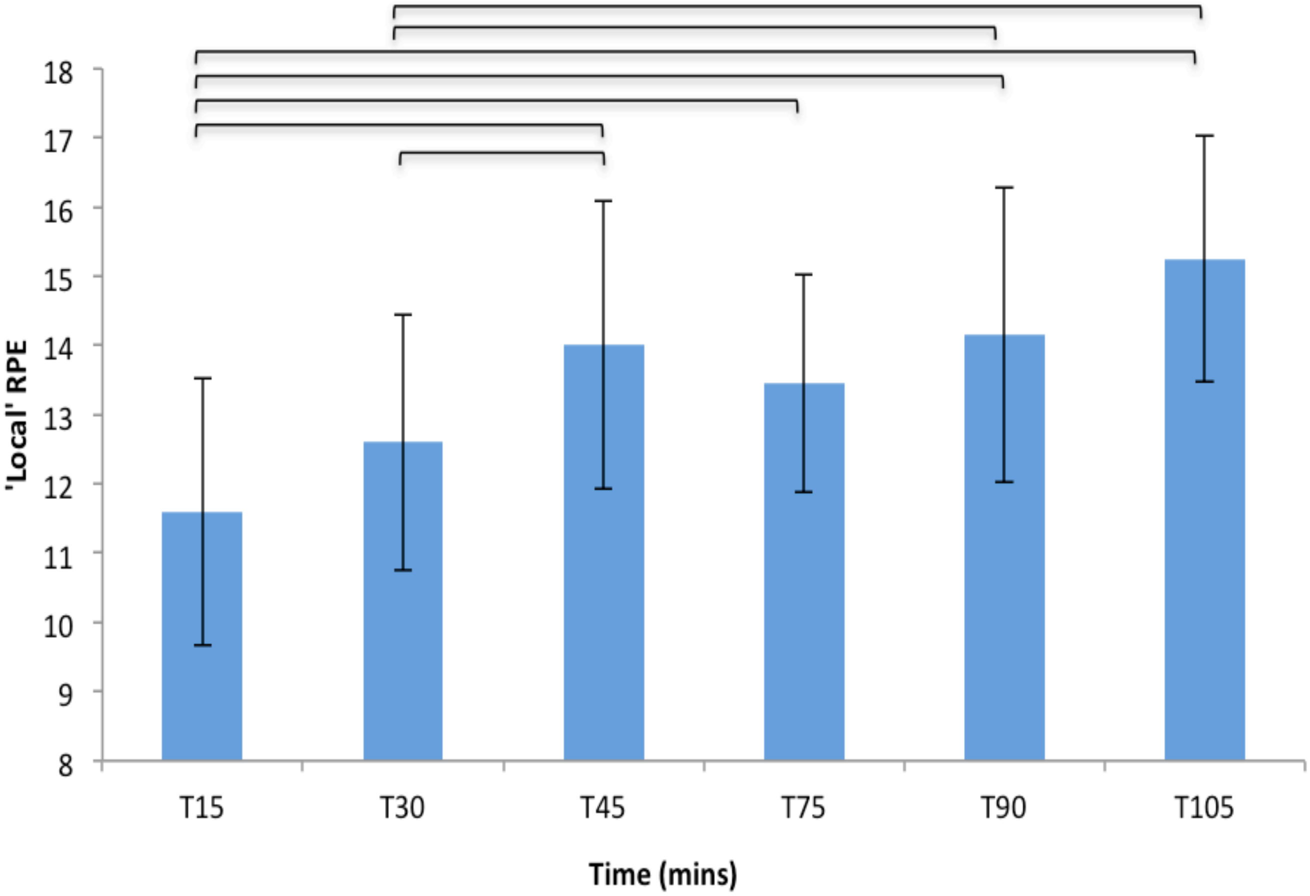


Where: —— Significant difference ($p<0.05$)

Figure 32: Mean (±SD) 'Central' ratings of perceived exertion (RPE) over time.

'Local' RPE

Significant increases in 'Local' exertion ratings are observed throughout the 90 minute soccer-specific protocol ($p<0.05$). Significant increases are observed during the first. as well as from the start of the protocol until its completion ($p<0.05$). Ratings of ‘Local’ RPE displayed similar values to that of ‘Central’ RPE. However, greater variability in the ‘Central’ RPE responses is evident when compared to the ‘Local’ RPE responses.



Where: — Significant difference in dominant limb ($p<0.05$)

Figure 33: Mean (±SD) ‘Local’ ratings of perceived exertion (RPE) over time.

Body Discomfort

Throughout the protocol, participants most commonly experience discomfort in the anterior and posterior leg musculature, as well as the feet and lower back (Table XV). With regards to the posterior leg musculature: Discomfort in the shins and the quadriceps are reported more frequently during the second half of the protocol than during the initial 45 minute period. A range of moderate to fairly high ratings are reported for both the shins and quadriceps muscle groups. With regards to the posterior leg musculature: Discomfort in the calves and hamstrings is reported more frequently during the second half of the protocol when compared to the first half. Higher ratings of discomfort are experienced in the hamstrings during the second half. In addition, discomfort reported in the calves is also higher during the second half of the protocol. The frequency of reports for discomfort in the feet is higher during the second half, with only one player reporting discomfort in the first half. Discomfort in the lower back is reported consistently throughout the course of the 90 minute protocol, with reports of moderate to high discomfort occurring during the initial 30 minutes of the first half.

Table XV: Perceptual ratings of body discomfort; frequency of rating as well as mean rating (in brackets).

	T15	**T30**	**T45**	**H/T**	**T75**	**T90**	**T105**
Feet	1 (7)	1 (7)	1 (9)		2 (8)	2 (8)	3 (6)
Ankles	3 (5)						1 (2)
Calves	1 (4)	1 (2)	2 (6)		4 (3)	2 (7)	1 (7)
Shins	2 (7)	3 (6)	2 (6)		2 (6)	3 (5)	3 (7)
Knees	1 (8)						1 (5)
Hamstrings		1 (2)	2 (5)		5 (5)	3 (6)	4 (5)
Quadriceps		4 (7)	3 (6)		3 (5)	5 (6)	5 (5)
Lower back	4 (7)	4 (5)	2 (5)		2 (3)	2 (5)	2 (5)
Upper back		1 (5)	2 (5)				2 (7)

Where: H/T= Half time

MULTIVARIATE ANALYSES

Limb Girth and Isokinetic Variables

Weak positive correlations are observed with regards to the peak isokinetic torque, work and power output values recorded before the start of the protocol (T0) when correlated with limb girth. However, a very weak negative correlation is indicated for eccentric power in the non-dominant limb at the faster isokinetic testing velocity.

Table XVI: Correlation coefficient (R^2) for limb girth and peak torque, work and power output.

			Quadriceps		Hamstrings	
			Concentric	**Eccentric**	**Concentric**	**Eccentric**
Peak Torque	**60°.s^{-1}**	**D**	0,16520	0,09412	0,06778	0,21413
		ND	0,15891	0,11972	0,26677	0,13465
	180°.s^{-1}	**D**	0,33672	0,07741	0,05820	0,17579
		ND	0,29498	0,02282	0,28876	0,20497
Work	**60°.s^{-1}**	**D**	0,30621	0,15254	0,01884	0,07312
		ND	0,14962	0,18652	0,17831	0,08947
	180°.s^{-1}	**D**	0,29669	0,18840	0,01241	0,09973
		ND	0,25968	0,07682	0,08119	0,07103
Power	**60°.s^{-1}**	**D**	0,27435	0,04861	0,00598	0,00084
		ND	0,20726	0,02208	0,12485	-0,00715
	180°.s^{-1}	**D**	0,40173	0,06819	0,02104	0,00266
		ND	0,32938	0,00264	0,18622	0,08611

Where: D= dominant limb, ND= non-dominant limb

Heart Rate and 'Central' Ratings of Perceived Exertion

As seen in Figure 34, there is a strong negative relationship between 'Central' RPE and heart rate during the first half (R=0.90). However, during the performance of the second half of the SAFT^{90} protocol, there is a weak positive correlation between the two variables.

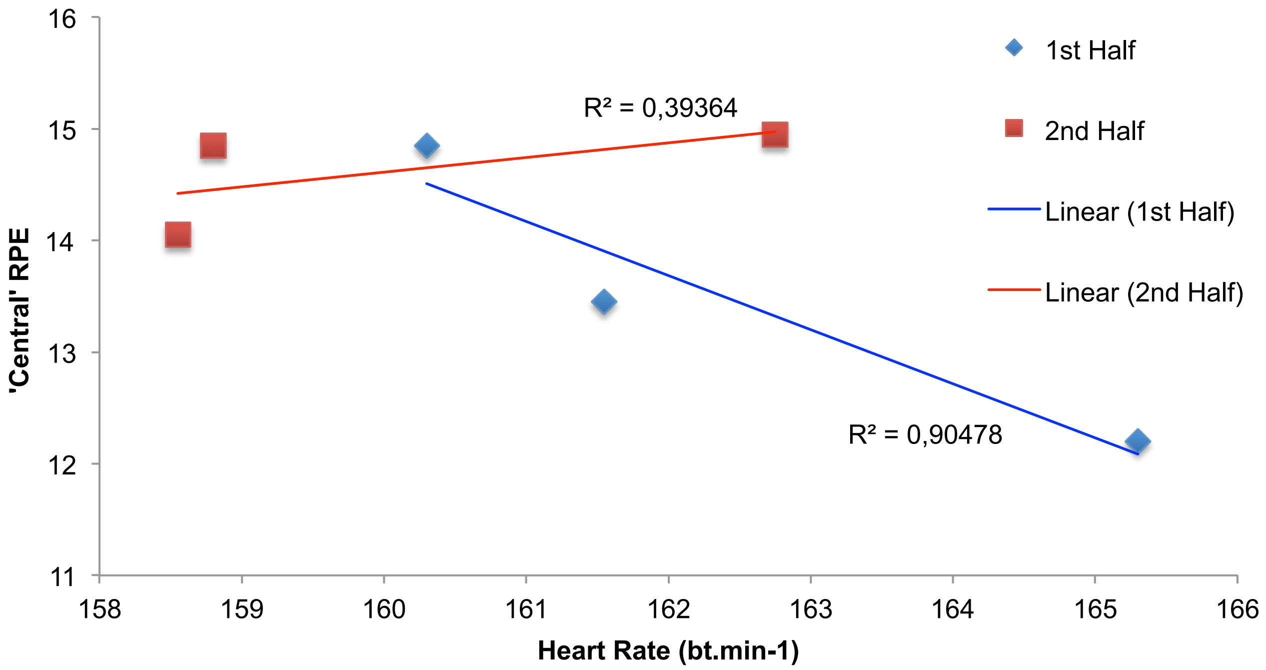


Figure 34: Relationship between ‘Central’ RPE and heart rate.

CONCLUSION

The performance of a 90 minute soccer-specific fatigue protocol results in a number of physiological, physical and psychophysical changes. Significant changes in both concentric and eccentric isokinetic variables of the knee flexors and extensors highlights the effect of muscular fatigue on performance in soccer match-play. Increases in psychophysical data such as ‘Central’ and ‘Local’ ratings of exertion indicate the perceived effort which is required from players in order to continue to exercise at intermittent intensities throughout both halves of play. Heart rate data collected during experimentation illustrates the high intensity at which athletes are required to perform and maintain during match-play. Over time, isokinetic variables such as peak torque, work and power are demonstrated to decrease significantly, with no statistical difference observed between the dominant and non-dominant limbs. Changes in the angle at peak torque and time to peak torque are observed as a function of time, with significant differences in leg dominance present at a number of isokinetic testing intervals. Significant reductions in eccentric hamstring peak torque and the functional strength ratio towards the end of both halves indicate that players are at an increased risk of musculoskeletal injury during this period. Thus, highlighting the negative influence of muscular fatigue on soccer performance.

SUMMARY OF RESULTS

Table XVII: Summary of physical, physiological and psychophysical variables

	Isokinetic data							
	60				180			
Variable	**T0-T45**	**T45-T60**	**T60-T105**	**T0-T105**	**T0-T45**	**T45-T60**	**T60-T105**	**T0-T105**
ConQ PT	10,17	4,16	2,23	17,01	4,06	4,59	0,83	9,48
EccQ PT	11,48	-0,29	5,07	16,26	10,04	2,72	4,78	17,53
ConQ Work	8,72	3,45	0,79	12,96	6,03	3,21	0,28	9,53
EccQ Work	11,78	0,31	5,20	17,29	11,06	-0,14	5,69	16,61
ConQ Power	7,56	3,06	3,70	14,32	5,14	3,98	1,69	10,82
EccQ Power	9,83	-1,04	6,86	15,65	12,55	2,21	4,78	19,54
ConQ APT	-3,73	2,80	-3,73	-4,65	-3,04	2,78	-3,21	-3,47
EccQ APT	-0,96	-1,34	-2,54	-4,84	-5,45	-1,39	-4,36	-11,21
ConQ TRTD	5,46	-6,05	4,04	3,46	6,86	-6,41	5,26	5,72
EccQ TRTD	-4,88	-5,35	-2,26	-12,48	-10,42	1,74	-7,85	-16,53
ConH PT	3,60	0,15	5,79	9,54	-1,67	5,12	-0,17	3,28
EccH PT	7,73	0,37	9,25	17,34	8,13	-0,94	11,09	18,27
ConH Work	7,41	0,94	3,71	12,05	-0,47	5,14	0,78	5,45
EccH Work	8,42	3,08	5,45	16,95	9,54	0,43	8,17	18,14
ConH Power	1,33	8,29	0,99	10,41	-3,64	6,56	-2,61	0,31
EccH Power	4,60	3,28	7,15	15,03	8,92	-2,29	10,97	17,60
ConH APT	10,16	-2,60	7,62	15,18	4,59	-3,83	1,21	1,97
EccH APT	16,50	6,06	-19,19	3,38	-2,60	5,03	-8,06	-5,63
ConH TRTD	10,83	-4,83	12,25	18,25	4,02	-2,58	0,38	1,82
EccH TRTD	3,97	-8,23	7,96	3,70	2,41	-3,26	0,85	0,00
Fun H:Q	-2,89	-5,04	7,38	-0,55	4,35	-6,40	12,10	10,04
Con H:Q	-7,37	-4,98	3,40	-8,95	-6,51	0,69	-1,80	-7,62
	Heart rate data							
1st half	162 (±13) bt.min^{-1}							
2nd half	160 (±15) bt.min^{-1}							
	RPE data							
Central	Increase during 1st and 2nd halves							
Local	Increase during 1st and 2nd halves							

Where: Values for isokinetic variables indicate percentage change during selected intervals (positive values indicate a decrease over time, while negative values indicate an increase over time).

CHAPTER V

DISCUSSION

INTRODUCTION

A number of different experimental procedures and testing protocols have been utilised in order to simulate competitive soccer match-play, as well as accurately and reliably measure the responses associated with this form of activity. The current study utilised a simulation protocol which considers the mechanical demands of the multidirectional intermittent running characteristics specific to soccer performance, replicating the acceleratory and deceleratory demands typical of match-play.

While the current study utilised a multidirectional, field based fatigue protocol, most soccer-specific fatigue studies have utilised treadmill running simulations (Rahnama et al., 2003; Greig 2008; Greig and Siegler, 2009). Small et al. (2010) suggest that treadmill based soccer-specific fatigue protocols fail to replicate the intermittent and multidirectional nature of soccer match-play. Furthermore, research focussing on the quantification of the fatigue imposed by the performance of the SAFT^{90} protocol has failed to utilise isokinetic testing speeds comparable to those of the present study. The abovementioned factors make comparisons of the present study with previous soccer-specific research difficult.

PHYSIOLOGICAL PARAMETERS

Heart rate

As expected, the mean heart rate elicited during the first half (162 ±13 bt.min^{-1}) was similar to that of the second half (160 ±15 bt.min^{-1}). As soccer involves an intermittent activity pattern, preventing the occurrence of a physiological steady state (Noakes, 2001), cardiovascular drift was absent. As expected, heart rate was found to rapidly increase in response to exercise at the start of both halves (Figure 9, pg 65). Heart rate responses recorded before the start of the protocol were significantly lower when compared to heart rate responses collected before the start of the second half. This indicates that participants were not able to return to a reference resting heart rate following the exertion required during the first half.

Heart rate responses elicited during the performance of the 90 minute soccer-specific protocol were found to be similar to those of match-play and other laboratory based simulations (Table IV, pg 45). Furthermore, the mean heart rate during the both halves were found to be the same as heart rate responses elicited by semi-professional players performing SAFT^{90} (Lovell et al., 2008) as well as Danish amateur players during match-play (Mohr et al., 2004). A slightly higher mean heart rate of 168 bt.min^{-1} was observed by Drust et al. (2000) in response to an intermittent treadmill protocol. However, the use of a treadmill protocol rather than a multidirectional field protocol may have resulted in heart rate responses not representative of soccer match-play due to a larger amount of time spent performing high intensity activities (Small et al., 2010). As the physiological responses to other protocols are comparable, it is suggested that the participants experienced the workload in a similar manner to those of previous research, allowing for the meaningful comparison of physical data.

INFLUENCE OF PERFORMANCE TIME ON PHYSICAL PARAMETERS

Isokinetic quadriceps strength (extensors)

Peak torque

Concentric

Concentric quadriceps peak torque values reported in other studies have varied substantially, ranging from values similar to those recorded in the current study (Greig, 2008) to substantially higher values (Rahnama et al., 2003). At 60°.s^{-1}, conQ peak torque before the start of the SAFT^{90} protocol (181.48 ±25.53 Nm) was similar to values recorded in professional soccer players (182 ±31 Nm) (Greig, 2008). In contrast, Rahnama et al. (2003) recorded higher pre-exercise (224 ±37 Nm vs. 181.48 ±25.53 Nm) and post-exercise (192 ±43 Nm vs. 159.60 ±29.65 Nm) conQ peak torque values in amateur soccer players from Europe. This large difference may be attributed to small sample size used by Rahnama et al. (2003), or differences in body mass. While Rahnama et al. (2003) recruited players with a mean body mass of 74.8 (±3.6) kg, the present study recruited a cohort of players with a lower body mass (68.39 ±9,05 kg). Increased body mass has been shown to have a positive effect on force production (Bennell et al., 1998). However, moderate differences in favour of Rahnama et al. (2003) persist when relativised for body mass. Due to a dearth in the availability of conQ peak torque data at 180°.s^{-1}, comparisons with previous data cannot be made. Nonetheless, at this isokinetic testing velocity the current research indicated a pre-exercise peak torque value of 126.38 ±22.12 Nm, and a post-exercise peak torque value of 114.04 ±20.63 Nm.

During the performance of SAFT^{90} conQ peak torque was found to significantly decrease as a function of time, for both isokinetic velocities tested (Figure 10, pg 66). The observed changes over time are in agreement with those of Rahnama et al. (2003) who illustrated significant reductions in conQ peak torque of amateur European players. At 60°.s^{-1}, reductions in conQ peak torque of 17.01% and 15.44% were observed during the present study and Rahnama et al. (2003) respectively. Research by Greig (2008) contradicts these findings as no significant reduction in the conQ peak torque was observed in professional European players. Similarly, utilising the same protocol as the current research, Small et al. (2010) found no significant reduction in the conQ peak torque of semi-professional players over time. The highlighted differences between Small et al. (2010) and the current study may be attributed to the playing level of the participants. While the current study involved a sample of amateur players, Small et al. (2010) made use of a sample of semi-professional European players.

Eccentric

Data on the eccQ peak torque producing capacity of soccer players remains lacking. Both Greig (2008) and Small et al. (2010) did not report on the eccentric action of the quadriceps during their testing procedures, while Rahnama et al. (2003) utilised isokinetic velocities different to those of the current research. At an isokinetic testing velocity of 60°.s^{-1}, the current research indicated pre-exercise conQ strength of 226.14 ±48.37 Nm, and a post-exercise conQ strength of 189.36 ±40.02 Nm. At 180°.s^{-1}, the performance of the match simulation resulted in a decrease from a pre-exercise value of 214.23 ±44.45 Nm to a post-exercise value of 176.66 ±37.69 Nm.

In a similar manner to conQ peak torque, eccQ peak torque data indicated a significant decrease over time (Figure 11, pg 67). At isokinetic velocities of 60°.s^{-1} and 180°.s^{-1}, eccQ peak torque was observed to decrease by 16.26% and 17.53% respectively. Correspondingly, Rahnama et al. (2003) observed significant (albeit smaller) overall reductions in eccQ peak torque responses, with a 6.85% decrease indicated at 120°.s^{-1}. However, further research relating to the quantification of eccQ peak torque values in response to soccer-specific fatigue is required in order to allow for comparisons across different populations.

Concentric and eccentric

Both conQ and eccQ data collected during the first half of the 90 minute fatigue protocol indicated significant reductions in the force generating capacity of the quadriceps (Figure 35, pg 100). At 60°.s^{-1}, conQ peak torque was observed to decrease by 10.17% (of a total 17.01%), while eccQ was observed to decrease by 11.48% (of a total 16.62%). These findings for conQ are in agreement with Rahnama et al. (2003), where a 9.91% reduction in conQ peak torque was observed during the first half, at the same testing velocity. Comparisons of changes in eccQ peak torque during the first half of play remains difficult as previous research (Greig, 2008; Small et al., 2010; Lovell et al., 2011) has failed to quantify changes in eccQ strength over time. However, at a testing velocity of 120°.s^{-1}, Rahnama et al. (2003) did not observe significant reductions in eccQ peak torque as a result of the first half. Nevertheless, the current research illustrates that the performance of the first half resulted in the greatest negative contribution to the observed overall reduction in quadriceps strength.

Following the half time interval and prior to the second half of protocol performance, conQ peak torque at both velocities and eccQ peak torque at 180°.s^{-1} was found to decrease. A reduction indicates a reduced capacity for muscular force production during the initial phase of the second half of match-play (Bangsbo, 1994). The findings support research by Mohr et al. (2004) and Lovell et al. (2007, 2011), who observed similar reductions in concentric quadriceps strength in response to match-play simulations. In addition, conQ peak torque after half time was significantly reduced relative to T0 at both testing speeds. This indicated that conQ and eccQ muscle strength did not recover to pre-exercise levels during the half time interval. Although quadriceps strength was not expected to return to pre-exercise levels, the 15 minute half time interval is traditionally thought to allow players to recover partially from the exertions required during the first half. However, the results from the current research, as well as other soccer-specific research, indicated that a recovery in quadriceps strength did not occur during half time. The reduction in quadriceps strength supported the increased risk of injury observed during the early stages of the second half suggested by Woods et al. (2004).

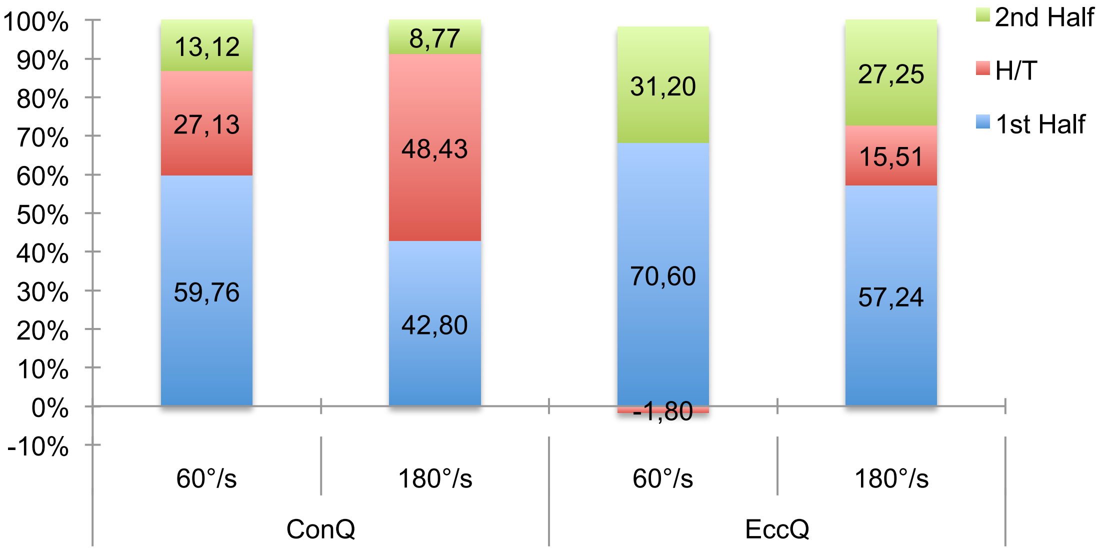


Figure 35: Percentage contribution to the overall reduction in peak torque observed in the quadriceps.

The performance of the second half resulted in further decreases in both conQ and eccQ peak torque. Although the decrease observed during the second half was indicated not to be significant, these changes contribute further to the overall reduction in the torque producing capacity of the quadriceps musculature. While changes in conQ peak torque were only observed to significantly decrease during the first half of the present study, Rahnama et al. (2003) observed significant reductions in conQ peak torque during both the first and second halves of play. At 60°.s^{-1}, these authors illustrated a 7.18% decrease in conQ peak torque during the second half, compared to the 2.23% observed in the present study. As mentioned previously, the comparison of eccQ strength changes over time with other research remains challenging. However at 120°.s^{-1}, eccQ peak torque data recorded by Rahnama et al. (2003) contradicts the findings of the present study as significant reductions were observed during the performance of the second half.

It would appear that the level of play may be an important factor in the time dependant changes in quadriceps peak torque, with amateur players experiencing greater concentric fatigue in the quadriceps musculature than semi-professional and professional players. However, further research is required in order to better understand the influence of playing level on changes in muscular strength over time, as researchers have failed to quantify eccQ peak torque in professional and semi-professional players.

The current research suggests that amateur athletes appear to experience muscular fatigue in the quadriceps muscle group to a greater extent than semi-professional and professional soccer players. The observed changes in peak torque indicate an increased risk of injury in amateur athletes, as reductions in muscular strength are highlighted as a potential etiological factor in muscle strain injury causation (Garrett, 1996). Furthermore, the amateur African Black participants in the present study are suggested to fatigue in a similar manner to the amateur European players recruited by Rahnama et al. (2003).

Work

The performance of the 90 minute soccer match simulation resulted in significant reductions in both conQ and eccQ work. Of the overall 12.96% reduction in conQ work at 60°.s^{-1}, 8.72% occurred as a result of the first half (Figure 12, pg 68). Similarly in the eccentric modality, 11.78% of a total 17.29% and 11.06% of a total 16.61% reduction occurred during the first half, at 60°.s^{-1} and 180°.s^{-1} respectively (Figure 13, pg 69). During the half time interval conQ work at only 60°.s^{-1} and eccQ work at both velocities was found to decrease. Furthermore, significant differences between post-half time measures (T60) and pre-exercise measures (T0) indicate that work was not able to recover to pre-exercise levels during half time. The performance of the second half resulted in further decreases in both concentric and eccentric work, however, these changes were not found to be significant.

Regardless of testing modality and isokinetic speed, the first half resulted in the largest decrements in work (Figure 36, pg 102). Given that a decrease in work done can be used as an indicator of the perception of muscular fatigue (Byrne et al., 2001), the first half had the greatest negative influence on performance. The reduction in eccQ and conQ work as a consequence of the passive 15 minute period provides further evidence, in addition to a reduction in peak torque, of the negative influence of half time. The performance of the second half continued a similar trend of reductions in work, however with smaller decrements in work when compared to the first half. The half time break was able to slow the rate of change in eccQ work, however, the same period had a detrimental effect on conQ work.

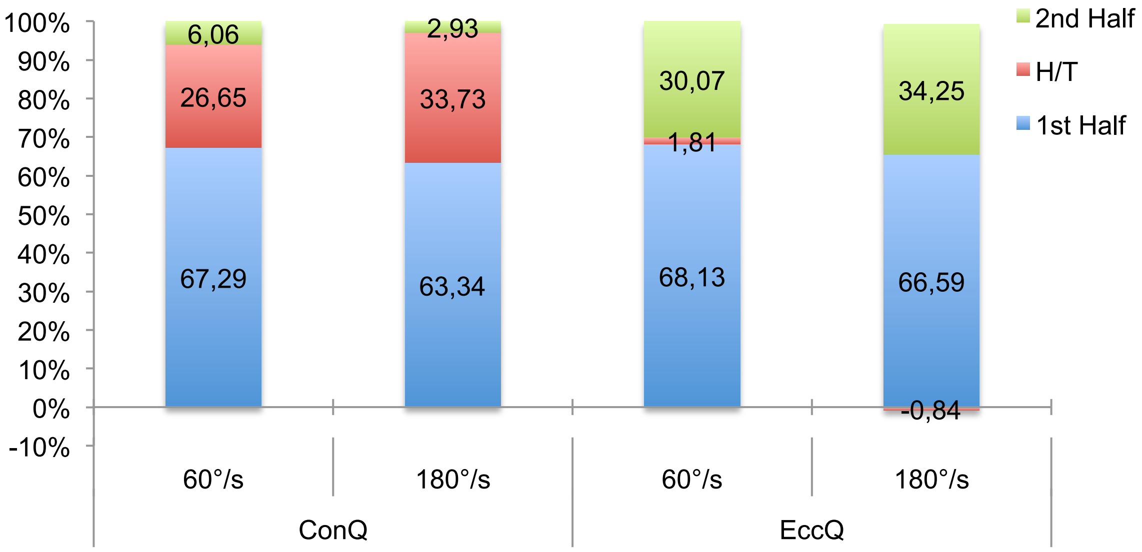


Figure 36: Percentage contribution to the overall reduction in work observed in the quadriceps.

Power

The current study illustrated both conQ power (Figure 14, pg 70) and eccQ power (Figure 15, pg 71) to decrease significantly as a function of time. A decrease implies that the 90 minute protocol impaired the rate at which the quadriceps musculature is able to produce force. A reduced power generating capacity is an important indicator of muscular fatigue (Capranica et al., 1992).

The first half resulted in the greatest reduction in power output, demonstrated by significant reductions in eccQ power and conQ power (at 60°.s^{-1}) following the first half (Figure 37, pg 103). No significant changes in conQ or eccQ power were observed as a consequence of half time. However, power output after half time was significantly reduced relative to T0. This indicates that power in both the concentric and eccentric modality did not recover to pre-exercise levels during the passive half time break. During the half time period, conQ power was found to decrease by 3.06% and 3.98%, at 60°.s^{-1} and 180°.s^{-1} respectively. Similarly, eccQ power was found to decrease by 2.21% while at the faster testing velocity. These changes in quadriceps power indicate a reduction in muscular power generating capacity following half time. These findings are in agreement with Lovell et al. (2011) who reported a decrement in the physical performance of soccer players during the initial phase of the second half of match-play. The performance of the second half of the simulation resulted in further reductions in power output, however, not to the extent of the changes observed during the first half. Therefore, the first half had the greatest negative influence on performance, however, the second half further contributes to the overall reduction in power observed. In a similar manner to work, the half time break slowed the rate of decrease in eccQ power, but had a detrimental effect on conQ power.

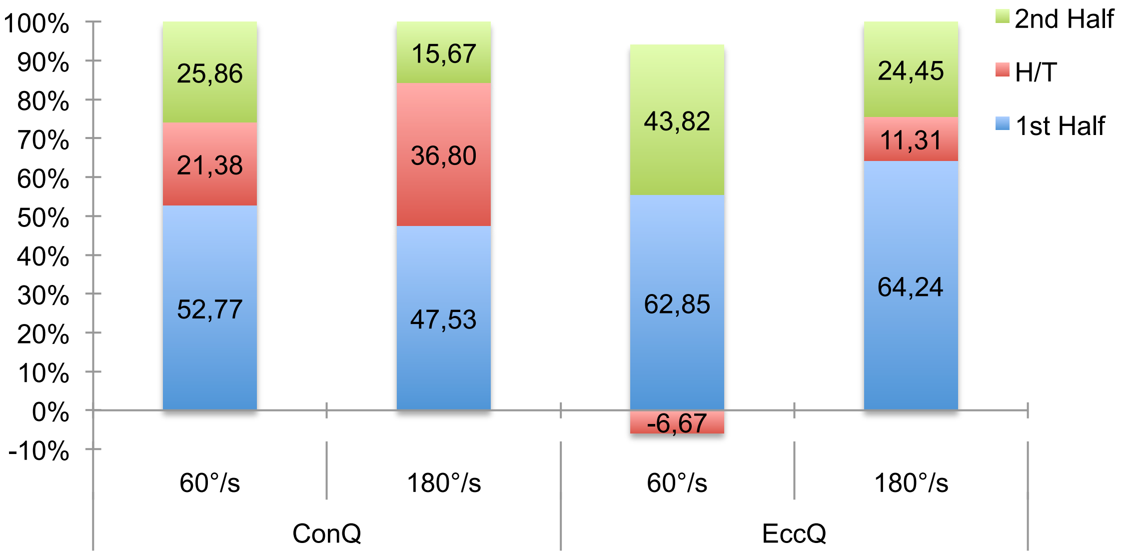


Figure 37: Percentage contribution to the overall reduction in power observed in the quadriceps.

Angle at peak torque

Concentric

ConQ angle at peak torque was observed to increase as a function of time, however, these changes were not found to be significant (Figure 16, Pg 72). Over the course of the match simulation, conQ APT increased by 4.65% and 3.47% at 60°.s^{-1} and 180°.s^{-1} respectively. The increase in conQ APT was similar to changes observed by Small et al. (2010) in response to SAFT^{90}, who observed an overall increase in APT of 5%. The fatigue induced during protocol performance resulted in a shift in the optimum length for peak muscle tension in the direction of longer muscle lengths

(Small et al., 2010). A number of theories have attempted to explain the observed increase in APT (Small et al., 2010). The ‘popping sarcomere hypothesis’ by Morgan (1990) proposes that muscle fibers may be stretched to a length where there is no overlap between contractile filaments and tension is placed on passive muscular components. The half time interval allowed conQ APT to recover, returning to shorter optimum muscle lengths at both testing speeds. Although a change in APT in response to half time was observed, the effects of such a change remain unclear due to a lack of understanding of the effects of such changes on performance and the risk of muscle strain injury. Therefore, it is evident that further research investigating the relative importance of changes in APT for concentric muscle action is required.

Eccentric

EccQ APT was found to increase by 4.84% at 60°.s^{-1}, and 11.21% at 180°.s^{-1}. However, significant changes were only observed in the non-dominant limb at the faster testing velocity (Figure 17, pg 73). Data relating to the effect of soccer-specific fatigue on eccQ APT remains limited. To the author’s knowledge, Small et al. (2010) is the only study to report the effects of soccer-specific fatigue on knee flexor and extensor angles at peak torque. Furthermore, Small et al. (2010) failed to quantify quadriceps APT in the eccentric modality. Small et al. (2010) observed that eccentric hamstring fatigue resulted in a shift in APT towards longer muscle lengths. The eccQ APT values recorded during the present study appear to follow the aforementioned trend as APT was found to increase over time. The half time interval resulted in a shift in optimum length towards longer muscle lengths. EccQ APT was observed to increase by 1.34% and 1.39%, at 60°.s^{-1} and 180°.s^{-1} respectively. Due to a lack of research highlighting the effects of changes in eccQ APT, it remains unclear whether half time has a positive or negative influence on performance and risk of injury.

Time rate of torque development

Concentric

Time rate of torque development, or time to peak torque, is an indication of a muscles functional ability to produce force quickly (Aagaard et al., 2002). During soccer performance, which requires rapid changes in direction (Svensson and Drust, 2005), the ability to generate force rapidly is of importance. Research focussed on the effect of muscular fatigue on TRTD remains lacking. It is believed that muscular fatigue results in a decrease in a muscle's ability to generate tension rapidly (Aagaard et al., 2002) and consequently may have a negative impact on performance. ConQ TRTD was not indicated to change significantly overall, however, a significant reduction was observed in the non-dominant limb following the completion of the first half at 180°.s^{-1}. Overall increases in conQ TRTD of 3.46% at 60°.s^{-1} and 5.72% at 180°.s^{-1} are contradictory to Aagaard et al. (2002). This is as conQ TRTD at both testing speeds was observed to decrease following the completion of the first half (shorter time to peak torque), increase as a result of half time (longer time to peak torque), and once again decrease throughout the performance of the second half (Figure 18, pg 74).

Eccentric

EccQ TRTD data demonstrated an increase as a function of time by 12.48% and 16.53%, at 60°.s^{-1} and 180°.s^{-1} respectively. These findings are in accordance with Aagaard et al. (2002) as muscular fatigue increased the time required for the quadriceps to generate torque also increased. The overall increase in eccQ TRTD was observed to be significant at both speeds in the non-dominant limb (Figure 19, pg 75). The effect of half time remains unclear with regards to eccQ TRTD as half time has a negative impact at 60°.s^{-1} and a positive impact at 180°.s^{-1}. It would therefore appear that the non-dominant limb might elicit greater changes than the dominant limb, increasing any muscular asymmetries that may exist.

Isokinetic hamstrings strength (flexors)

Peak torque

Concentric

At 60°.s^{-1}, peak conH torque values recorded before the start of protocol performance (99.35 ±16.61 Nm) were illustrated to be lower than those reported in amateur European players (126.5 ±22 Nm) (Rahnama et al., 2003). Similarly, following the completion of the 90 minute protocol, conH peak torque values collected during the present study were lower than those recorded by Rahnama et al. (2003) (89,88 ±30.38 Nm vs. 105.5 ±26 Nm). This large difference may be once again be attributed to small sample size, or differences in the body mass of the players used by Rahnama et al. (2003) compared to the present study. When relativised for body mass, the conH peak torque data collected by Rahnama et al. (2003) remains notably superior to those collected during the present study.

During the performance of the soccer-specific fatigue protocol, conH peak torque was demonstrated to decrease as a function of time. An overall decrease of 9.54% ($P<0.05$) was observed at 60°.s^{-1}, while a 3.28% ($p>0.05$) decrease was observed at 180°.s^{-1} (Figure 20, pg 76). These findings are in agreement with Rahnama et al. (2003) and Lovell et al. (2011) who observed significant reductions in conH peak torque in response to fatigue protocols, utilising European amateur and semi-professional players respectively. However, the 9.54% overall reduction in eccH torque observed in the present study at 60°.s^{-1} was lower than that of Rahnama et al. (2003) (16.60%). Similarly, Lovell et al. (2011) observed a 13.39% reduction in conH peak torque in semi-professional players as a result of muscular fatigue induced by the $SAFT^{90}$ protocol. The present study serves to confirm the findings of Rahnama et al. (2003) as a similar trend in conH peak torque decrease was observed as a result of the $SAFT^{90}$ protocol. At 60°.s^{-1}, the results from the current study conflict with Greig (2008), who illustrated no significant effect for time irrespective of testing speed. However at the faster isokinetic speed, conH peak torque responses from the present study are in agreement with Greig (2008) as no significant changes were observed over time. Similar to Rahnama et al. (2003), Greig (2008) utilised a treadmill fatigue protocol and as such may not truly reflect match-play demands.

According to various authors, African runners are suggested to have a lower physiological capacity than their European counterparts, but have the ability to perform at a higher percentage of their capacity (Bosch et al., 1990; Weston et al., 1999; Larsen, 2003). ConH data collected during the present study indicated a similar trend, where the cohort of amateur Black African players had a lower ability to generate concentric hamstring torque, but fatigued at a slower rate than amateur European soccer players. The ability of African athletes to fatigue at a slower rate than European athletes, while performing similar workloads, has important implications for injury risk. The implications of different fatigue rates between different racial groups on the incidence of injury needs to be explored further in future research.

Although not significant, concentric peak torque values were observed to decrease by 3.60% while at 60°.s^{-1}. Similarly, numerous authors have failed to observe significant reductions in conH strength over time (Greig, 2008; Small et al., 2010; Lovell et al., 2011). However, these results are conflicting with those of Rahnama et al. (2003) where a significant reduction at 60°.s^{-1} was illustrated during the first half. Therefore, during the present study, the performance of the first half resulted in a negligible negative contribution to the observed overall reduction in hamstring strength (Figure 38, pg 107).

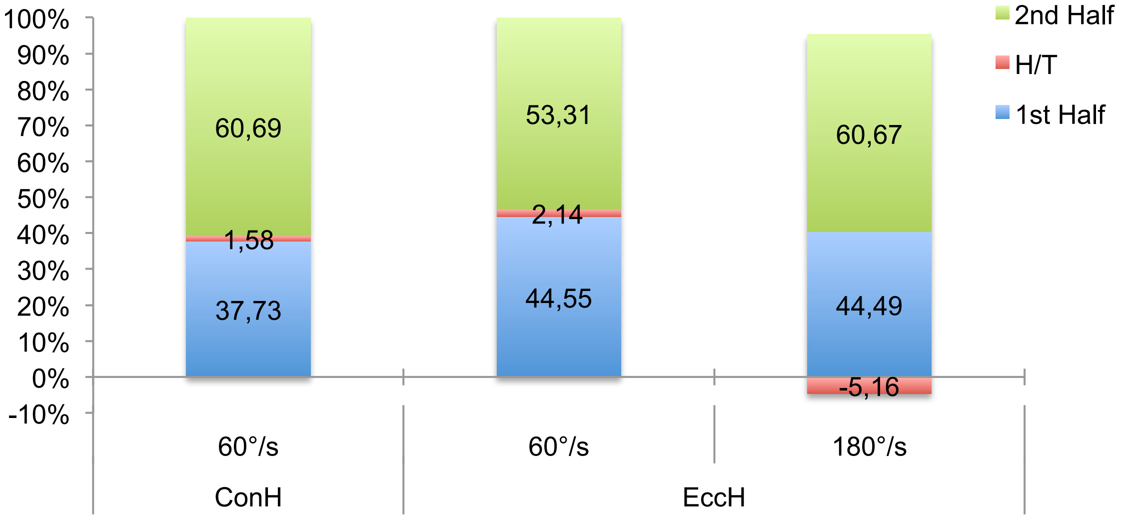


Figure 38: Percentage contribution to the overall reduction in peak torque observed in the hamstrings.

The half time interval had no significant effect on conH peak torque generation. However, peak torque was found to remain constant following the completion of the half time break while at 60°.s^{-1}, and decrease by 5.12% at 180°.s^{-1}. At an isokinetic velocity of 120°.s^{-1}, Lovell et al. (2011) observed a 9.20% ($p>0.05$) reduction in conH peak torque of semi-professional European players during half time, in response to the same intermittent protocol utilised in the present study. Therefore, the half time interval may have less of a detrimental effect on torque producing ability in amateur African players when compared to semi-professional European players.

Similarly to the first half, the second half failed to result in significant reductions in conH peak torque values regardless of testing velocity. A lack of significant changes in the conH peak torque data elicited during the second half is in agreement with Greig (2008), while utilising identical testing velocities, as well as Small et al. (2010)

and Lovell et al. (2011) at 120°.s^{-1}. Contrastingly, Rahnama et al. (2003) observed a significant effect of the second 45 minute period on conH strength values. When compared, these data suggest a greater resistance to conH fatigue in Black African players, when compared to the amateur European players utilised by Rahnama et al. (2003). At 60°.s^{-1}, a greater decrease in conH peak torque was observed during the second half of the soccer-specific protocol, relative to the reduction indicated during the first half (7.79% vs. 3.36%). Therefore, the performance of the second 45 minute period had a greater impact on concentric hamstring peak torque than the first half, although neither decrease was statistically significant.

The current research indicated a reduction in the concentric torque generating capacity of the hamstrings musculature over time. The observed changes have implications for competitive performance and may increase the risk of injury as the game progresses (Rahnama et al., 2003). Although the concentric hamstring torque data collected are lower than those previously reported, the data suggests that African amateur players may experience a lower decrease in conH peak torque generating ability (resistance to conH fatigue) over time when compared to European amateur as well as semi-professional players. Although it must be noted that other differences between the two sample groups may be a contributing factor to these findings, the responses do suggest that future research attempting to investigate the differences between European and African soccer players with appropriately matched groups is required.

Eccentric

Eccentric hamstring peak torque data reported by numerous authors has varied substantially across isokinetic testing speeds and the competitive level of players. However, direct comparisons can only be made between the current study and Greig (2008) as few authors have utilised isokinetic testing speeds corresponding to those utilised in the current study. At an isokinetic testing speed of 60°.s^{-1}, pre-exercise eccH peak torque values of 138.16 ±26.32 Nm and 144 ±34 Nm were reported in the current study and in European professional players by Greig (2008) respectively, compared to post-exercise eccH peak torque values of 114.20 ±25.18 Nm and 118 ±23 Nm. At 180°.s^{-1}, before the start of a soccer-specific fatigue protocol the current study indicated eccH peak torque responses of 135.17 ±25.34 Nm, with 154 ±37 Nm reported in European professional players (Greig, 2008). While post-exercise peak torque values of 110.47 ±24.87 Nm and 125 ±21 Nm were reported in the present study and Greig (2008) respectively. When relativised for body mass; data collected at 60°.s^{-1} indicated a greater magnitude in favour of the present study, while data collected at 180°.s^{-1} was indicated to be similar during both studies.

EccH peak torque was observed to decrease significantly as a function of time, regardless of testing velocity (Figure 21, pg 77). An isokinetic velocity of 60°.s^{-1} indicated an overall reduction of 17.34%. Although Greig (2008) observed a similar 18.10% reduction in eccentric peak torque, these changes are not statistically significant. At 180°.s^{-1}, the present research illustrated an overall reduction in eccH peak torque of 18.27%. These results are in agreement with Greig (2008) and Greig and Siegler (2009), who observed an 18.8% decrease in the eccH peak torque in responses to a soccer-specific treadmill fatigue protocol, while utilising a sample of professional soccer players from Europe.

A number of researchers have utilised an isokinetic testing speed of 120°.s^{-1} in order to attempt to quantify the temporal changes in eccH muscle strength resulting from fatigue. At this velocity Rahnama et al. (2003) observed a 16.8% ($p<0.05$) reduction in the eccH strength of amateur European soccer players. Similarly, through the use of the SAFT^{90} protocol, Small et al. (2010) and Lovell et al. (2011) observed 16.8% ($p<0.05$) and 20.66% ($p<0.05$) reductions in the peak torque of semi-professional European players. Although not directly comparable, the observed reductions in eccH peak torque at both isokinetic testing velocities are similar to those reported elsewhere.

The performance of the first half of the SAFT90 protocol resulted in significant changes in eccH peak torque. The eccH data collected during the first 45 minute period indicate a 7.73% and 8.13% decrease, at 60°.s^{-1} and 180°.s^{-1} respectively. Similarly, numerous authors have observed significant reductions in eccH peak torque as a result of first half performance (Rahnama et al., 2003; Small et al., 2010; Lovell et al., 2011). At an isokinetic speed of 120°.s^{-1}, the aforementioned authors observed eccH strength decreases during the first half of 5.2% to 10.9%. However at both 60°.s^{-1} and 180°.s^{-1}, Greig (2008) failed to observe significant reductions during the first half. In Black African amateur, European amateur and European semi-professional players, the performance of the first half significantly contributed to the overall decrease in eccentric hamstring strength. However, Greig (2008) did not observe decrements during the initial 45 minute period in professional European players.

At both testing velocities, significant changes in eccH peak torque, when comparing measures after the first half (T45) and after half time (T60) were not observed. This is in agreement with Greig (2008), who failed to observe significant reductions in eccH peak torque following half time. Lovell et al. (2011) reported a decrement in physical performance during the initial 15 minute period of the second half. Utilising the SAFT^{90} protocol, the aforementioned researchers observed significant reduction of 5.84% in eccH peak torque following the passive half time interval. However, no such changes were observed during the current study. Peak torque after half time was significantly reduced relative to T0, at both testing speeds. For example, at $60°.s^{-1}$, eccH peak torque after half time (126.98 ±28.86 Nm) was significantly reduced relative to pre-exercise values (138.16 ±26.33 Nm). Therefore, the half time break did not result in a recovery of eccH muscle strength to pre-exercise values. These findings are similar to Greig (2008), where significant changes in peak torque were observed with regards to pre-test values and values recorded after half time. The present investigation indicated that participants failed to recover eccentric strength to pre-exercise values and, therefore, failed to mediate the fatigue imposed during the performance of the first half. This provides evidence that players may be sub-optimally prepared for the second half, accounting for the increased incidence of injury observed during this period (Hawkins et al., 2001). Consideration should be given to active re-warm up strategies during the half time interval aimed at reducing the increased risk of injury during the early stages of the second half (Greig, 2008; Greig and Siegler, 2009; Lovell et al., 2011).

In a similar manner to the first half, the performance of the second half resulted in significant decreases in eccH peak torque. At the selected isokinetic speeds of $60°.s^{-1}$ and $180°.s^{-1}$, decrements of 9.25% and 11.09% respectively were observed during this period. These results are in agreement with Rahnama et al. (2003), Small et al. (2010) and Lovell et al. (2011), where significant reductions of between 5.45% and 8.8% (at $120°.s^{-1}$) were observed during this period. However, the observed decreases in the present study are greater than those indicated by the abovementioned authors. At 60°.s^{-1} and 180°.s^{-1}, Greig (2008) did not observe a significant reduction in eccH strength during the performance of the second half. Therefore, both the first and second halves contribute significantly to the overall decrease in eccentric hamstring strength observed (Figure 38, pg 107). Although not consistent with the eccH responses of professional European players, the changes observed in the cohort of amateur black African players are similar to amateur and semi-professional European players.

The temporal changes in eccentric hamstring strength observed in the present study supports epidemiological data, with hamstring injuries more likely to occur within the latter stages of both halves of competitive soccer match-play (Rahnama et al., 2003; Greig, 2008; Small et al., 2010; Lovell et al., 2011). The intermittent, multidirectional activity profile of soccer match-play requires large amounts of acceleration and deceleration (Small et al., 2009). During such activities, the hamstring musculature is required to cope with large internal forces as well as rapid changes in muscle length and mode of contraction (Pull and Ranson, 2007). A decrease in eccentric strength of the knee flexors, as a result of muscular fatigue, is acknowledged as a fundamental etiological factor associated with hamstring muscle strain injuries (Stanton and Purdam, 1989; Garrett, 1996). Muscular fatigue may induce physiological changes to the muscle, and alter coordination, technique or concentration (Croisier, 2004). The susceptibility to muscular strain injury is likely to increase during explosive ballistic movements such as accelerations and decelerations during sprinting (Greig, 2008). If a player’s force producing capacity is reduced by muscular fatigue, then the altered mechanics of high speed sprinting may increase the risk of muscular strain injury. Therefore, fatigued hamstring muscles may have insufficient eccentric strength to decelerate the lower limb during sprinting, resulting in an eccentric overload and damage to the muscle (Lovell et al., 2008).

The current research suggests that African Black amateur soccer players experienced eccentric muscular fatigue in the hamstring muscle group in a similar manner to Amateur, semi-professional and professional European soccer players. Further research utilising a multidirectional soccer-specific fatigue protocol as well as comparable isokinetic testing velocities is required in order to allow further comparisons to be made across levels of play as well as region of play.

Work

ConH and eccH work was seen to decrease as a function of time throughout the performance of the 90 minute soccer specific protocol. Significant overall reductions in conH work were observed at 60°.s^{-1} (10.41%) while significant reductions in eccH work were observed at both testing velocities (16.95% at 60°.s^{-1} and 18.14% at 180°.s^{-1}). EccH work at 180°.s^{-1} was found to be significantly reduced following both halves of play, with 9.54% and 8.17% reductions in work observed after the first and second halves respectively. ConH data indicated no significant decrease in conH work following the half time break at both testing velocities. However at 180°.s^{-1}, an overall 5.14% reduction in conH work was observed following half time. Furthermore, conH work at 60°.s^{-1} in the dominant limb was found to be significantly reduced following half time, relative to T0 (Figure 22, Pg 78). This indicates that work failed to recover to pre-exercise levels during the passive 15 minute break. Similarly, the half time break resulted in non-significant decreases in eccH work, with a 3.08% reduction observed at 60°.s^{-1}. EccH work, regardless of testing speed, was found to be significantly different following half time in relation to T0 (Figure 23, Pg 79). Therefore, the compulsory half time break did not allow for eccH work to return to pre-exercise levels. Although such values were not expected to return to baseline strength values recorded prior to exercise, it is traditionally thought that the half time interval allows for some degree of recovery to occur. However, the current data indicated the contrary as half time not only failed to allow conH and eccH work to recover but in fact had a detrimental effect on a player's ability to do work early in the second half.

Greig (2008) states that a decrease in work, resulting from muscular fatigue, is most evident towards the end of matches with a reported 5-10% decrease in total distance covered in the second half. Byrne et al. (2001) state that a decrease in work done can be used as an indicator of the level of muscular fatigue experienced. In the present study, both eccentric and concentric hamstring work was observed to decrease over time (Figure 39, pg 113). Therefore, towards the end of both halves of play, players have a significantly increased risk of injury due to the decreased work done by the hamstrings in contributing to human locomotion.

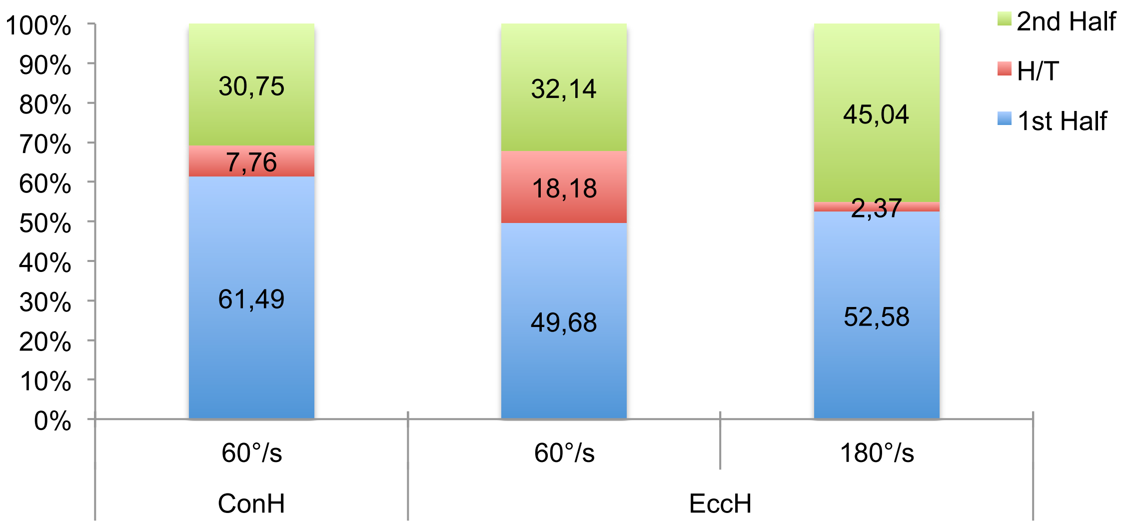


Figure 39: Percentage contribution to the overall reduction in work observed in the hamstrings.

Power

Both conH and eccH power output were demonstrated to decrease overall in response to the SAFT^{90} protocol. Although this response was observed to be significant at both testing speeds in the eccentric modality, conH power was only observed to significantly decrease at 60°.s^{-1}, with a 10.41% reduction in conH power indicated (Figure 24, pg 80). In the eccentric modality, a 15.03% and 17.60% were observed at 60°.s^{-1} and 180°.s^{-1} respectively (Figure 25, pg 82). This shows that the rate at which the hamstring musculature is able to produce force was significantly impaired by soccer-specific fatigue. In addition to the overall changes in eccH power, significant reductions were observed following the completion of the second half. A reduction in eccH power of 10.97% (at 180°.s^{-1}) indicates that the fatigue induced by the second half had a significantly greater impact on performance than that of the first half (Figure 40, pg 114). Reductions in conH power were observed following the completion of the half time interval regardless of testing speed. In addition, this difference in power illustrated between T45 (74.60 ±16.98 W) and T60 (68.40 ±15.97 W) was determined to be significant in the non-dominant limb. In addition, eccH power at 60°.s^{-1} was found to decrease following the completion of the half time break. This finding highlights the negative influence of half time on conH power, potentially increasing the risk of injury in the initial period of the second half. Contrastingly, eccH power at 180°.s^{-1} was observed to recover by 2.29% following the half time interval. Furthermore, significant differences in pre-exercise and post-half time values were only illustrated for eccH in the dominant limb and for conH in the non-dominant limb. Therefore, further research is required in order to clarify the effect of half time on power output.

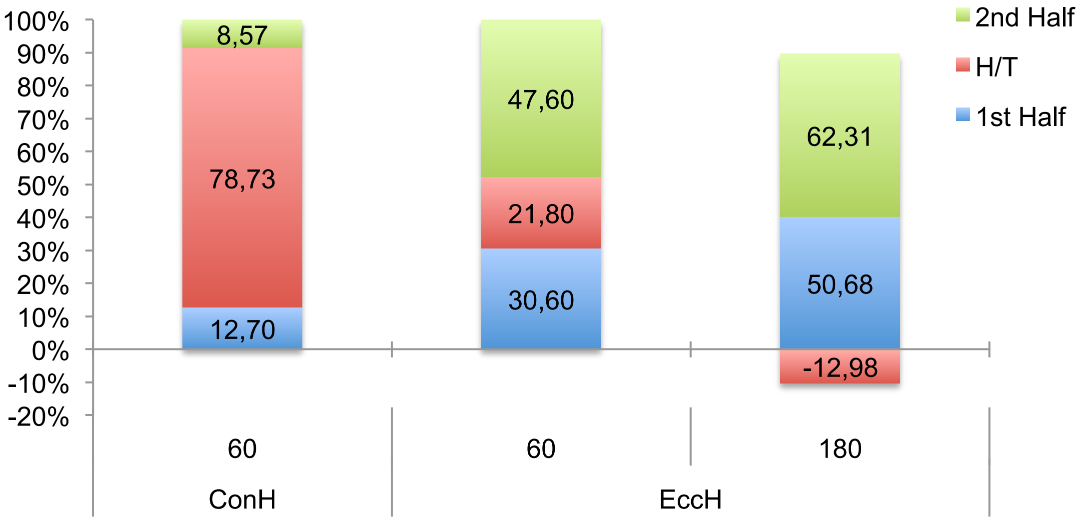


Figure 40: Percentage contribution to the overall reduction in power observed in the hamstrings.

Angle at peak torque

Concentric

ConH APT was observed to decrease as a function of exercise performance (Figure 26, Pg 82). Overall reductions in conH APT of 15.18% ($p>0.05$) and 1.97% ($p>0.05$) were illustrated at 60°.s^{-1} and 180°.s^{-1} respectively. This indicated that concentric fatigue resulted in a shift of the hamstrings optimum length for peak torque towards shorter muscle lengths. During the present study, the changes observed in conH APT are conflicting with the changes in quadriceps APT in response to concentric muscular fatigue. While conH APT data indicated a shift towards shorter muscle lengths, conQ data illustrated a shift towards longer muscle lengths. The apparent shift in optimum length is in accordance with Small et al. (2010), where conH APT was found to decrease ($p<0.05$), in response to SAFT^{90}. ConH APT at 60°.s^{-1} was observed to decrease significantly following the start of the second half, but only in the non-dominant limb. At the faster isokinetic velocity, no significant changes were observed in conH APT responses. Therefore, further research is required in order to better understand the effects on fatigue on APT, as well understand why and for what purpose such changes in optimum muscle length occur. Half time resulted in no significant changes in conH APT at both speeds. Significant changes observed in the dominant limb at the end of half time, relative to pre-testing values, indicated that the 15 minute passive break failed to allow APT to return to pre-exercise levels. However, as this difference was only observed in one limb and conH APT was found to increase during half time at 180°.s^{-1}, the effect of half time on conH APT remains uncertain.

Eccentric

EccH APT at 60°.s^{-1} was observed to decrease overall by 3.38%, while eccH APT was observed to increase by a more notable 5.63% at 180°.s^{-1} (Figure 27, pg 84). The changes in eccH APT observed by Small et al. (2010) are in agreement with the present study's findings at 180°.s^{-1}. These findings suggest that, as a consequence of eccentric fatigue, the optimum length for peak tension in the hamstrings shifted towards longer muscle lengths. Evidence of a shift towards longer muscle lengths when fatigued was further demonstrated by a significant increase in the eccH APT of the non-dominant limb at 60°.s^{-1}. No significant effects were indicated for eccH APT in response to the passive half time break. Although APT was detected to decrease by 6.06% (60°.s^{-1}) and 5.03% (180°.s^{-1}), the effect of such changes are marginal. More importantly, it is unclear whether the observed changes in APT are beneficial or detrimental to performance.

Time rate of torque development

EccH TRTD was indicated to decrease in response to the fatigue protocol, regardless of mode of contraction (Figure 29, pg 86). In the concentric modality a notable decrease of 18.25% was observed overall at 60°.s^{-1}, which was deemed to be significant in the non-dominant limb (Figure 28, pg 85). Similarly in the non-dominant limb, a significant reduction in conH TRTD was observed following the start of the second half. In the eccentric modality at 60°.s^{-1}, a 3.70% decrease in eccH APT was observed with a significant reduction between the start and end of the second half. These findings indicate a reduced capacity of the hamstrings functional ability to produce both concentric and eccentric force quickly towards the latter stages of match-play (Aagaard et al., 2002). The half time interval resulted in a recovery of TRTD values, regardless of contraction modality and speed of contraction. At 60°.s^{-1}, a 4.83% and 8.23% increase was illustrated in conH and eccH TRTD respectively. However, no significant effects of the passive half time interval were observed. The increase in TRTD values suggests a potential positive influence of half time on the ability of the hamstrings to generate force rapidly during the early stages of the second half.

Hamstrings to Quadriceps ratio (H:Q)

Strength indices in both the eccentric and concentric modes were used to investigate strength imbalances about the knee, previously reported as a risk factor for hamstring muscular strain injury (Woods et al., 2004).

Conventional H:Q

Conventional H:Q was observed to increase with increasing exercise duration, at both isokinetic testing speeds (Figure 30, pg 87). At 60°.s^{-1} and 180°.s^{-1}, the conventional strength ratio increased by 8.95% ($p>0.05$) and 7.62% ($p<0.05$) respectively. In addition, significant increases were illustrated following the completion of the first half. At 180°.s^{-1}, the results were in disagreement with Greig (2008) where no significant differences in the conventional ratio were observed in professional European players. At 60°.s^{-1} however, the results from the current study were in agreement with Greig (2008) as no significant main effect for time was indicated. Similarly, while utilising the SAFT^{90} protocol, Small et al. (2010) observed no significant changes in the conventional strength ratio over time while at a testing speed of 120°.s^{-1}. According to various authors (Aagaard et al., 1998; Kong and Burns, 2010), the conventional strength ratio of a healthy knee ranges from 50-80% depending on angular velocity. The conventional H:Q results from the current study, ranging from 54.81% to 64.70%, fall into the previously mentioned healthy range. Comparisons between the aforementioned authors and the current study are difficult as research utilising isokinetic velocities similar to the current study fail to make use a multidirectional fatigue protocol (Greig, 2008), and researchers utilising the SAFT^{90} protocol failed to use testing velocities similar to the present study (Small et al., 2010).

While at a testing velocity of 60°.s^{-1}, conventional strength ratio data recorded in the cohort of amateur African Black players was similar to data recorded in Professional European players, as significant changes were not illustrated in response to a soccer-specific fatigue protocol. At 180°.s^{-1}, African amateur players displayed a decrease in the conventional H:Q as a function of time. The cause of such an increase, in contrast to conventional H:Q data recorded at other less functional velocities, can only be speculated. Future research conducted using similar functional isokinetic velocities is required in order to better understand the changes in the conventional strength ratio in other populations of soccer players. However, as the ratio does not provide adequate information of the agonistic-antagonistic relationship of the knee musculature, the conventional ratio is suggested to merely indicate a qualitative similarity between the hamstring and quadriceps muscles (Aagaard et al., 1998). Therefore, the traditional ratio provides little information of potential increases in risk of hamstring strain injury in response to soccer-specific fatigue.

Functional H:Q

Functional strength data recorded at an isokinetic testing velocity of 60°.s^{-1} remains lacking. Nevertheless, the current study indicated a pre-exercise functional strength ratio of 76.70% ±13.38, with a value of 77.12% ±15.06 indicated after the completion of the 90 minute soccer-specific protocol. At an isokinetic testing velocity of 180°.s^{-1}, functional strength ratio data collected during the present study was found to be notably higher than those of professional European players collected by Greig (2008). Namely; pre-testing measures (108.53 ±20.10% vs. 105 ±22%), half time measures (103.81 ±28.49% vs. 87 ±16%) and post-exercise measures (97.63 ±21.28% vs. 81 ±13%).

The slow isokinetic velocity (60°.s^{-1}) indicated no significant overall effect of time with regards to the functional knee strength ratio. These findings are in accordance with Greig (2008) in professional European players. At the more functional isokinetic velocity of 180°.s^{-1}, a significant 10.04% overall reduction in the functional H:Q ratio was observed during the performance of SAFT^{90} (Figure 31, pg 88). These findings are in agreement with functional H:Q responses measured at 120°.s^{-1} (Rahnama et al., 2003; Small et al., 2010), as well as 180°.s^{-1} and 300°.s^{-1} (Greig, 2008). Greig

(2008) observed a notably larger decrease in the functional H:Q ratio when compared to the present study (22.86%). However, similar reductions in the overall functional strength ratio were observed by Rahnama et al. (2003) and Small et al. (2010), 12.99% and 15.00% respectively.

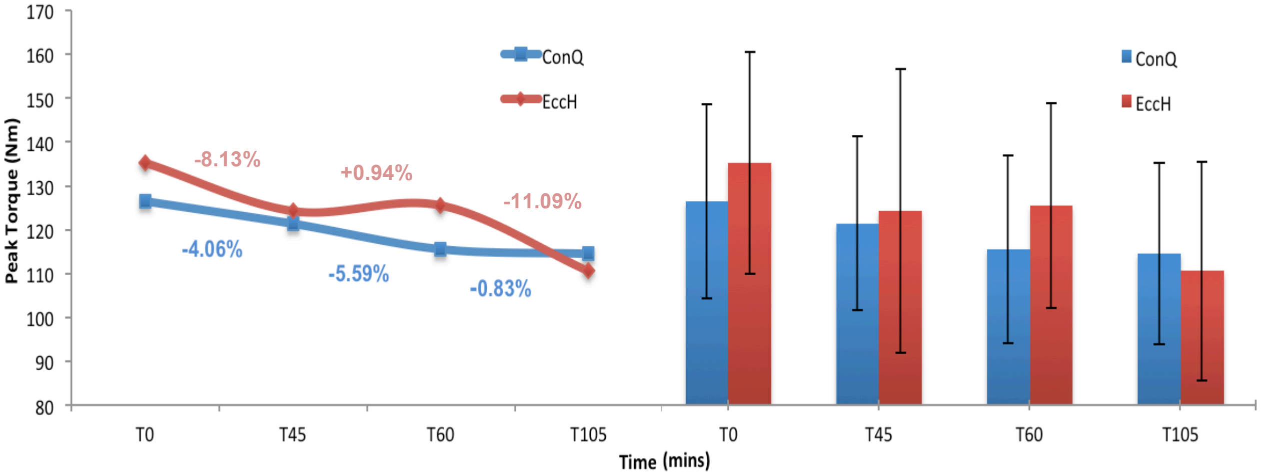


Figure 41: Percentage decrease and absolute value decrease for concentric quadriceps (conQ) and eccentric hamstrings (eccH) over time.

At 180°.s^{-1}, the present study indicated the incidence of a significant reduction in functional H:Q responses during the second half, while a significant reduction was absent during the first half. The significant decrease in the functional strength ratio (eccH:conQ) occurs during the second half as conQ strength was observed to fatigue at a slower rate than eccH strength. ConQ peak torque was indicated to decrease by only 0.83% during the performance of the second half, while eccH peak torque was indicated to decrease by a considerably greater 11.09% (Figure 41, pg 118). Similarly, conQ and eccH peak torque data collected during the first half indicated a similar trend, although to a lesser extent. Concomitantly, functional strength ratio data demonstrated an overall decrease of 4.35% after the performance of the first half, and a 12.01% decrease after the performance of the second half. More specifically, the functional strength ratio was found to decrease from pre-exercise values of 110.76 ±23.78% to post-exercise values of 97.63 ±21.28%. Contrastingly, both Greig (2008) and Small et al. (2010) observed a significant reduction in the functional ratio in the first half (and not in the second half).

The passive half time interval was found not to result in significant changes in functional H:Q at both speeds. These changes in the functional H:Q ratio are in agreement with Lovell et al. (2011) who failed to illustrate significant effects of time on functional strength ratio indices of semi-professional European players. While not significant, the current study indicated increases of 5.04% and 6.40% at the prescribed isokinetic velocities of 60°.s^{-1} and 180°.s^{-1}. The observed changes indicate a potential positive effect of the half time interval on the functional strength ratio. Furthermore at 180°.s^{-1}, no significant differences were observed following the half time break, relative to T0. This indicates that during the half time interval the functional strength ratio was able to recover to values comparable with pre-exercise measures. These findings are consistent with those of Greig (2008), who observed no such differences in functional H:Q at speeds of 60°.s^{-1} or 180°.s^{-1}, in response to a treadmill running protocol.

Considering the previously mentioned function of the hamstrings during sprinting (Croisier, 2004; Croisier et al., 2008), it is feasible that strength imbalances between the hamstrings and quadriceps may predispose an individual to muscular strain injuries (Bennell et al., 1998). Reductions in the functional strength ratio may indicate that the hamstrings have insufficient muscular strength to decelerate the forward movement of the knee and hip caused by quadriceps contraction. Therefore, the present study indicates an increased risk of injury towards the later stages of both halves due to reductions in the functional H:Q ratio at the end of both halves. Injury prevention strategies need to consider reducing the negative impacts of fatigue on the function of the hamstring musculature (Small et al., 2010). A greater resistance to fatigue in the hamstrings will positively affect the functional strength ratio, reducing the associated risk of injury.

According to Aagaard et al. (1998) the ideal functional H:Q ratio should be 1.0, indicating the ability of the hamstrings to resist forces generated by the quadriceps. The functional H:Q values recorded during the present study indicated strength ratio values comparable with the ideal values proposed. Furthermore, the values elicited by the cohort of Black African amateur players were notably higher than those elicited by professional European players (Greig, 2008). The overall reduction observed in the present study (10.04%) was similar to values elicited by amateur European players (12.99%) (Rahnama et al., 2003), as well as semi-professional European players (15.00%) (Small et al., 2010). However, professional European players were observed to experience notably larger reductions in the functional strength ratio than those indicated by the aforementioned authors.

FATIGUE PROFILE AND MECHANISMS OF PERFORMANCE REGULATION

The mechanisms by which performance is controlled, as well as what factors limit maximal performance, remains controversial (Noakes, 2001). However, Noakes (2001) proposes the influence of the ‘central governor’ whereby the brain uses environmental conditions, present physical condition, physiological feedback, knowledge of the endpoint, and past experiences in order to control physical performance levels during exercise (St Claire Gibson and Noakes, 2001; Noakes et al., 2005). This central regulation of exercise intensity is proposed to occur in order to avoid exercise being terminated and ultimately catastrophic physiological failure (Noakes et al., 2005). Ultimately, the subconscious brain regulates performance, based on a pacing strategy, to allow an athlete to continue exercising in the most efficient way while ensuring internal homeostasis and a metabolic and physiological reserve capacity is maintained (St Clair Gibson and Noakes, 2004).

Peak torque and work data for the concentric quadriceps, eccentric quadriceps and concentric hamstrings decreased in a curvilinear manner, with responses decreasing sharply during the first half, followed by lower relative decreases during the remainder of the 90 minute soccer-specific protocol (Figure 42a, pg 121). This suggests that some form of down regulation may have occurred whereby large decrements in strength were initially offset by smaller decrements towards the end of the protocol. Although tentative, this may indicate the existence of some form of protective mechanism due to the presence of a central governor (Noakes et al., 2005). However, without measures of performance and muscle recruitment during the soccer-specific fatigue protocol this is merely speculative. Supposing this down regulation occurred, it is plausible that fewer muscle fibers or different muscles were being recruited in order to avoid further eccentric damage. This down regulation has also been implicated in fatigue development in other skilled-based sports such as cricket (Duffield et al., 2009).

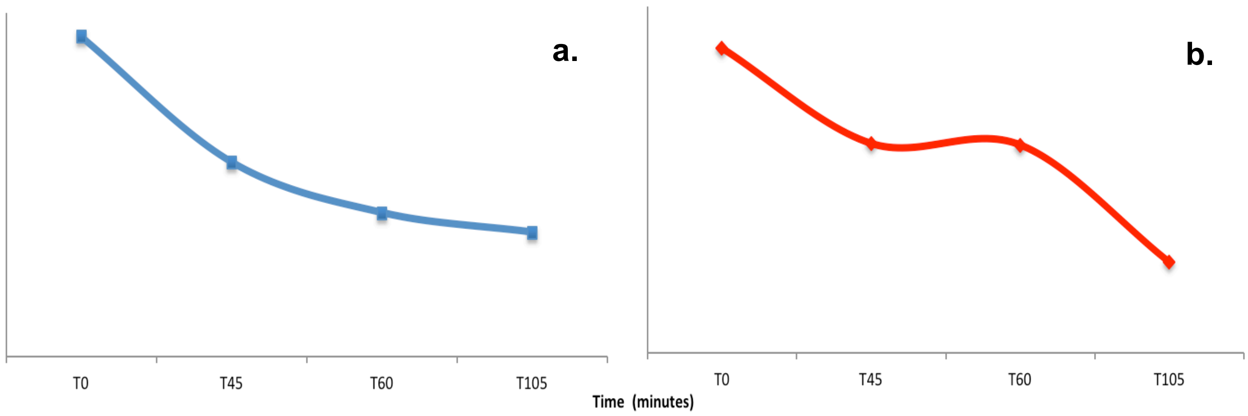


Figure 42: Comparison of fatigue profiles associated with conQ, eccQ and conH responses (a), with eccH responses (b).

In contrast, eccentric hamstring peak torque and work data indicated significant reductions during both the first and second halves (Figure 42b, pg 121). These data suggest that during the course of the 90 minute match simulation the hamstrings were unable to resist eccentric fatigue as effectively as concentric muscle fatigue. Alternatively, players may have altered their running style with the onset of fatigue, which would result in greater eccentric demands being placed on the hamstrings later on in the protocol. This would amplify levels of fatigue and predispose players to subsequent injury (Croisier, 2004). It is evident that further research investigating the role of down regulation in the fatigue profile of soccer-specific protocols is necessary.

INFLUENCE OF LEG DOMINANCE ON PHYSICAL PARAMETERS

Isokinetic quadriceps strength (extensors)

Peak torque, work, power and time rate of torque development

Researchers have shown the presence of bilateral differences in quadriceps peak torque in adolescent soccer players (Leatt et al., 1987; Kellis et al., 2001; Voutselas et al., 2007). However, the results from the current study are in agreement with Rosene et al. (2001), in intercollegiate athletes, and Rahnama et al. (2003), in amateur soccer players, as no bilateral differences in quadriceps strength were observed. However, as Rahnama et al. (2003) utilised a treadmill running protocol where equal load is placed on both limbs, the findings of the current study served as a tentative indication that even with a multidirectional protocol no bilateral differences exist. In addition to a lack of bilateral differences associated with peak torque responses, work, power, and time rate of torque development data also failed to indicate the presence of an effect of leg dominance throughout the performance of the 90 minute fatigue protocol, regardless of testing speed and modality.

Therefore, the multidirectional soccer-specific protocol placed similar amounts of concentric and eccentric load on both limbs. Both the dominant and non-dominant limbs, when exposed to similar workloads, fatigued at similar rates and therefore developed a similar musculoskeletal risk of injury as the match progresses.

Angle at peak torque

Concentric

Leg dominance had no significant effect on conQ APT. However, at the faster, more functional isokinetic velocity APT in the dominant leg was always lower than that of the non-dominant leg. As the effects of changes in optimum muscle length remains unclear, the presence bilateral differences, although not significant, may result in either positive or negative effects on performance and risk of injury. Further research is required in order to better understand the impact of changes in conQ APT on the risk of injury in soccer players.

Eccentric

EccQ APT data indicated significant bilateral differences during the performance of SAFT^{90}. Although these data indicated a number of differences between the dominant and non-dominant limb, a significant difference was only observed at the end of the first half, at 180°.s^{-1} (Table X , pg 73). Similarly, following the end of the first half at 60°.s^{-1}, the non-dominant limb was demonstrated to have a lower angle at peak torque when compared to the dominant limb. Little is known about the effect of changes in APT on the risk of muscular strain injuries (Small et al., 2010). Therefore the effect of significant differences in APT between dominant and non-dominant limbs on the risk of injury can only be speculated. Future research is required in order to understand the role of changes in optimum muscle length for peak tension, and how this may influence injury risk.

Isokinetic hamstring strength (extensors)

Peak torque, work and power

With regards to concentric hamstrings peak torque, a lack of significance for the effect of leg dominance is in agreement with Rahnama et al. (2003), who observed no effect of leg dominance during a 90 minute treadmill simulation protocol. As these differences associated with leg dominance were not found to be significant, their effect on performance and risk of injury is negligent. In contrast, researchers have illustrated significant bilateral differences in concentric knee flexor moments in adolescent soccer players (Gur et al., 1999; Tourny-Chollet et al., 2000; S. Kellis et al., 2001). However, no fatigue protocol was utilised in order to quantify the changes in muscular strength in response to fatigue.

Similarly for eccentric hamstring peak torque, Tourny-Chollet et al. (2000) and Rahnama et al. (2003) observed no significant effect of leg dominance in response to soccer-specific fatigue. The present study illustrated a decline in strength of the non-dominant limb similar to that of the dominant limb. In contrast to the findings of the present study, significant differences in bilateral eccH peak torque have been observed in soccer players (Leatt et al., 1987; Kellis et al., 2001). Although the above authors observed bilateral differences in eccH peak torque, researchers failed to measure the time dependent changes as a consequence of soccer-specific fatigue.

Work and power, in a similar manner to peak torque, indicated a lack of bilateral differences regardless of testing speed and modality. As a result the current study can conclude that the soccer-specific fatigue protocol, utilised in order to simulate soccer match-play conditions, caused both the dominant and non-dominant limbs to fatigue at similar rates. Therefore, the risk of muscular strain injuries during soccer performance is suggested to be similar in both limbs.

Angle at peak torque

Concentric

A significant bilateral difference in conH APT at $60°.s^{-1}$ was observed during the performance of the soccer-specific fatigue protocol. Although a number of bilateral differences were observed, a significant difference was only indicated following the completion of half time, at the slower velocity (Table XI, pg 83). ConH APT of the dominant limb (34.90 ±9.89°) was significantly lower than that of the non-dominant limb (41.50 ±13.03°). This finding suggests that the non-dominant limb was able to recover to a greater extent during the half time interval. As previously stated, as the effect of changes in APT on performance is poorly understood, the effect of the observed bilateral difference remains indefinite.

Eccentric

While at the fast isokinetic testing speed, a bilateral difference in eccH APT was observed in pre-exercise measures (Table XII, pg 83). In this incidence, the APT of the dominant limb (34.60 ±18.95°) was significantly greater than that of the non-dominant limb (24.05 ±10.07°). Following the completion of the first half, a notable bilateral difference in favour of the dominant limb was still apparent. However, the half time interval resulted in a marked reduction in the previously observed differences. The difference was then re-established following the completion of the protocol. This suggests that the half time interval had a greater effect on the dominant limb than the non-dominant limb. The implications of the observed bilateral differences requires further research into role of changes in optimum muscle length in order to ascertain if the observed effect is positive or negative in nature.

Time rate of torque development

Changes in conH time rate of torque development during the performance of the SAFT^{90} protocol indicated no significant effect of leg dominance. However, eccentric hamstring data demonstrated a significant effect of leg dominance with regards to pre-exercise TRTD at $180°.s^{-1}$ (Table XIII, pg 86). The TRTD of the non-dominant limb ($0.74 \pm 0.28°.s^{-1}$) was greater than that of the dominant limb ($0.61 \pm 0.17°.s^{-1}$). Furthermore, subsequent isokinetic assessments illustrated that bilateral differences in TRTD in favour of the non-dominant limb were maintained, but were not indicated to be significant. This suggests that the non-dominant limb, although more susceptible to concentric fatigue, may be more resistant to changes in eccentric TRTD resulting from fatigue induced by the protocol.

Hamstrings to Quadriceps ratio (H:Q)

Significant effects of leg dominance for both the conventional and functional strength ratios were not observed during the present study, regardless of isokinetic testing speed. Therefore, the fatigue induced during the performance of the 90 minute soccer-specific fatigue protocol was similar in both limbs. A lack of significant bilateral differences in functional strength ratio data is in agreement with Rahnama et al. (2003), where bilateral differences in the functional H:Q ratios of amateur European players were absent in response to a treadmill fatigue protocol. Therefore, the risk of injury associated with strength imbalances about the knee was illustrated to be comparable in both limbs.

SOMATOTYPE

The Black African amateur soccer players participating in the current study were found to have a mean somatotype rating of 2.9 - 5.1 - 2.3 (±1.01 - 1.14 - 0.96) and are thus classified as balanced mesomorphs (Table XIV, pg 89). These findings are in agreement with those of Hazir (2010). In comparison to the somatotype ratings of Nigerian soccer players (Mathur et al., 1985), modern South African amateur players possess a greater dominance in endomorphy, a decreased dominance in mesomorphy and a decreased dominance in ectomorphy. When compared to amateur European players (Rogan et al., 2011), South African amateurs were indicated to have a lower relative fatness, but similar musculoskeletal and linearity components.

With regards to position of play, defenders were found to have a smaller endomorphic component than their European counterparts and a larger ectomorphic component. Midfield players were found to have a larger ectomorphic component than European soccer players. Finally, forwards were found to be similar to European amateur players of the same position. Regardless of minor differences in somatotype, soccer players in general appear to be categorised as balanced mesomorphs. Future research focussing on the comparison of both professional and amateur European and African soccer players is important in order to determine if differences in somatotype ratings influence the risk of soccer related injury.

PSYCHOPHYSICAL PARAMETERS

Ratings of Perceived Exertion (RPE)

‘Central’ and ‘Local’ RPE

‘Central’ and ‘Local’ ratings of perceived exertion were similar throughout the performance of SAFT^{90}. Therefore, participants found the intermittent activity profile of the soccer-specific fatigue protocol equally taxing on the cardiovascular and muscular systems.

‘Central’ RPE values were illustrated to increase as a function of first and second half exercise duration (Figure 32, pg 90). ‘Central’ RPE ratings recorded following the completion of the first (15 ±2.08) and second (15 ±2.46) halves were significantly higher than measures shortly after the start of exercise (T15= 12 ±1.70). These findings are similar to those of Drust et al. (2000) who observed RPE ratings of 15 in university soccer players, in response to a single simulated half. Therefore, the performance of the first and second 45 minutes of SAFT^{90} resulted in a concomitant increase in ‘Central’ RPE with half duration.

‘Local’ RPE values were demonstrated to increase significantly in response to soccer-specific fatigue (Figure 33, pg 91). ‘Local’ ratings of subjective exertion observed after the performance of the first half (14 ±2.08) and second half (15 ±1.77) were found to be significantly increased relative to measures shortly after the start of exercise (T15= 12 ±1.93). Similarly to ‘Central’ responses, the performance of the first and second halves of SAFT^{90} was associated with increases in ‘Central’ RPE as a function of half duration.

The half time interval resulted in a decrease in both ‘Central’ and ‘Local’ RPE values relative to T45. In the present study, participants were required to remain seated during the half time interval, reflecting typical behaviour during competition. As players were passive during this period, “Central’ and ‘Local” responses were observed to recover somewhat.

In addition to the influence of physiological factors on ‘Central’ and ‘Local’ RPE, subconscious processes analysing external feedback such as exercise duration and intensity have also been indicated to effect subjective reports of exertion (Albertus et al., 2005). Previous experience of the activity may have influenced the subjective rating of exertion expressed by the players, the memory of soccer-specific fatigue may have allowed for the estimation of reserve capacity and tolerance levels, thereby informing whether the player has capacity to continue, and in doing so, altered the RPE values (St Clair Gibson et al., 2003).

Body Discomfort

Due to the nature of muscular fatigue resulting from an intermittent activity profile, as well as the multidirectional nature of SAFT^{90} and the utility movements required during its performance (Small et al., 2010), participants most commonly experienced discomfort in the anterior and posterior leg musculature. More specifically, discomfort of the shins and quadriceps (anterior), and the calves and hamstrings (posterior) were frequently reported throughout the performance of SAFT^{90} (Table XV, pg 92).

A higher number of ratings associated with the hamstrings and quadriceps were expected, as both these muscle groups are relied upon to control movement, acceleration and deceleration in particular. However, the hamstrings were expected to be taxed to a greater degree than the quadriceps musculature due to their role during intermittent activity such as soccer performance (Greig, 2008; Greig and Siegler, 2009). However, during the present study both the hamstrings and quadriceps discomfort were similar, particularly during the second half.

As the performance of the 90 minute protocol required rapid turning and change of direction, players adopted a stooped posture, which may account for the lower back discomfort.

MULTIVARIATE ANALYSES

Limb Girth and Isokinetic Variables

No strong correlations, negative or positive, were indicated between dominant and non-dominant limb girth and pre-exercise isokinetic variables in the corresponding limb (Table XVI, pg 93). Hence, limb girth provides little or no indication of the ability to produce eccentric or concentric torque at isokinetic velocities of 60°.s^{-1} and 180°.s^{-1}. However, further exploration into this area may be of importance as the ability to estimate the force producing capacity and resistance to muscular fatigue from limb girth may be useful in injury prevention.

Heart Rate and 'Central' Ratings of Perceived Exertion

Early studies have demonstrated strong correlations between 'Central' ratings of perceived exertion and heart rate values elicited during dynamic continuous exercise (Nicholas et al., 2000). In the present study, no such relationship was illustrated in both the first and second half measures (Figure 34, pg 94). Furthermore, a strong negative correlation (R^2=0.90) between 'Central" RPE and heart rate was observed in the second half. It can only be presumed that the participants recruited for the present study failed to understand the function of the scale and how changes in perceived exertion relate to the levels of cardiovascular strain, despite written and verbal explanations, as well as the opportunity to ask questions prior to protocol performance. However, Noakes (2001) suggests that ratings of perceived exertion should be used cautiously.

CONCLUSION

The performance of the 90 minute soccer-specific fatigue protocol resulted in a number of physiological, physical and psychophysical changes. The extent of changes in the aforementioned responses in the Black African amateur players recruited were similar to those of both amateur and professional players competing in competitive soccer leagues all around the world. Heart rate responses elicited during the first and second halves were indicated to be similar. Isokinetic variables collected throughout the performance of $SAFT^{90}$ demonstrated a number of significant changes over time. Peak isokinetic torque, work and power of both the quadriceps and hamstrings were illustrated to decrease significantly as a function of exercise duration. These findings indicate that muscular fatigue is induced by both the first and second halves of the multidirectional, intermittent fatigue protocol. Furthermore, significant reductions in eccentric hamstrings peak torque, as well as the functional strength ratio indicate an increased risk of muscular hamstring strain injury towards the latter stages of both halves of competitive match-play. During experimental procedures testing, significant changes in angle at peak torque and time to peak torque were also observed in both the hamstrings and quadriceps muscle groups.

No significant bilateral differences in peak torque, work, power and strength ratios were observed, while significant bilateral differences in angle of peak torque and time rate of torque development between the dominant and non-dominant limbs were observed at certain intervals. The lack of bilateral differences in peak torque, work, power and H:Q ratios indicate that the fatigue protocol induced similar levels of muscular fatigue in both limbs.

The passive half time interval resulted in a potential negative influence in several isokinetic variables. However, eccentric peak torque, as well as the functional strength ratio, indicated no such adverse effect.

The amateur Black African soccer players utilised in the present study were demonstrated to have somatotype ratings corresponding to the balanced mesomorph category.

Participants perceived the SAFT^{90} protocol to be equally taxing on the cardiovascular and musculoskeletal systems of the body. Body discomfort experienced during protocol performance was localised to the lower extremities. Participants most frequently reported discomfort in; the shins, quadriceps, calves and hamstrings.

CHAPTER VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

Whilst the intermittent sport of soccer is the most popular sport in the world, scientific research aimed at better understanding the relationship between fatigue and injury causation remains lacking (Hawkins et al., 2001). Muscular fatigue is evident during the course of a competitive soccer match, where players are required to perform at submaximal intensities but have a reduced ability to perform maximally (Rahnama et al., 2003). The deterioration of eccentric hamstring muscle strength, as a result of soccer-specific fatigue, supports epidemiological data indicating an increased risk of strain injury during the latter stages of both halves of match-play (Greig, 2008). However, research is required in order to document fatigue rates and thigh injury risk in African Black soccer players. The existence of biomechanical and physiological differences between European athletes and their African counterparts (Larsen, 2003) may render research on the risk of thigh injuries conducted in European regions meaningless within a Black African population. In addition, the development of muscular asymmetries, as a result of one sided activities common to soccer performance, are considered to be an important predictor in thigh injury causation (Kellis et al., 2001). However, bilateral differences in hamstring and quadriceps muscle strength in soccer players remains poorly understood. Therefore, the primary objective of the current study was to quantify the temporal changes in muscle strength as a result of a simulated soccer match, in both the dominant and non-dominant legs of amateur Black African Players.

SUMMARY OF PROCEDURES

Players were required to attend two testing sessions. The purpose of the initial testing session was to collect specific demographic, anthropometric and physiological data, as well as an injury history from each player. In addition, all experimental procedures were explained to the participants. The first session allowed for each participant to be habituated to the experimental procedures, including; the soccer-specific fatigue protocol, isokinetic dynamometer, heart rate belt, and psychophysical rating scales. Finally, each participant was provided with a list of pre-test instructions to adhere to.

During the second experimental session, players were required to perform a 90 minute soccer match-play simulation. The SAFT^{90} protocol, designed and validated by Lovell et al. (2008), replicates the fatigue response to competitive soccer match-play. Similar to match situations, the protocol is divided into two 45 min periods interceded by a 15 minute half time period. The free running protocol was designed to include multidirectional and utility movements, and frequent acceleration and deceleration as is inherent to soccer performance. On arrival, players were fitted with a heart rate monitor and instructed to perform a standardized warm up consisting of a five minute cycle and five minutes of self selected stretches. Following the completion of the warm up, players performed the first set of isokinetic thigh muscle function tests on both the dominant and non-dominant limbs, at the prescribed testing speeds of $60°.s^{-1}$ and $180°.s^{-1}$, in both the concentric and eccentric testing modalities. Each set, consisting of three repetitions at each modality and speed, was followed by a 30 second rest period. After the completion of the initial isokinetic assessment, each player was required to perform the first half of the match simulation. Isokinetic assessments were conducted prior to exercise, immediately after first 45 minutes, after 15 min half time break and immediately on completion of the soccer-specific simulation. After the completion of the final isokinetic assessment, players were instructed to perform a short cool down.

Acknowledging the importance of attempting to obtain a holistic approach to research, the following dependant variables were collected:

Physical parameters: Isokinetic related variables (peak torque, work, power, conventional and functional strength ratios, angle of peak torque, time rate of torque development)

Physiological parameters: Heart rate

Psychophysical parameters: ‘Central’ and ‘Local’ RPE, Body discomfort ratings.

SUMMARY OF RESULTS

The cohort of amateur Black African soccer players recruited for participation in the present study were indicated to have the following mean demographic characteristics; age of 21.80 (±2.31) years, stature of 172.12 (±6.20) cm, body mass of 68.38 (±9.05) kg, BMI of 23.03 (±2.26) kg.m^{-2}, and somatotype ratings reflecting the balanced mesomorph category.

Heart rate responses elicited during the first half of the simulation protocol were found to be similar to those elicited during the second half. Heart rate responses were observed to increase significantly ($p<0.05$) in response to the start of both halves, and remain elevated (but showing no further significant increase) during the performance of the remainder of the fatigue protocol. ‘Central’ and ‘Local’ ratings of perceived exertion were illustrated to increase during both the first and second halves of the match simulation. Overall, a significant ($p<0.05$) increase in ‘Central’ and ‘Local’ RPE was observed as a function of time. The passive half time interval resulted in a decrease in both ‘Central’ and ‘Local’ RPE ratings, although these changes were not significant.

Isokinetic variables recorded for both the knee extensors and flexors, in both concentric and eccentric modalities, were illustrated to vary over time. Peak torque, work and power decreased as a function of time in both the quadriceps and the hamstrings. Typically, these responses were observed to decrease significantly ($p<0.05$) during the performance of the first half, with no significant decrease observed during the remainder of the 90 minute protocol. However, eccentric hamstring responses were observed to decrease significantly ($p<0.05$) during the performance of both the first and second halves. The functional hamstring to quadriceps ratio was observed to decrease significantly ($p<0.05$) with time. Conversely, the conventional hamstring to quadriceps ratio was found to increase throughout protocol performance. The passive half time interval did not result in significant reductions in all isokinetic variables collected during the performance of the soccer-specific fatigue protocol, regardless of isokinetic testing velocity. No significant effects of leg dominance were observed with regards to the aforementioned variables. Angle at peak torque and time rate of torque development were also indicated to change as a function of time for both muscle groups.

Significant ($p<0.05$) effects of leg dominance were observed for both variables at certain time intervals.

During the performance of SAFT^{90}, participants experienced a range of body discomfort intensities in a number of regions. The most commonly reported sites were the lower extremities, more specifically the feet, ankles, calves, shins, quadriceps and hamstrings. In addition, discomfort in the lower back was reported consistently throughout the 90 minute protocol.

STATISTICAL HYPOTHESES

Hypothesis 1: The first statistical hypothesis proposes that no differences in the physical responses to the soccer-specific fatigue protocol will be observed over time, regardless of leg dominance.

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

Quadriceps:

- Concentric peak torque, eccentric peak torque, concentric work, eccentric work, concentric power, eccentric power, eccentric angle at peak torque, concentric time rate of torque development and eccentric time rate of torque development

Hamstrings:

- Concentric peak torque, eccentric peak torque, concentric work, eccentric work, concentric power, eccentric power, concentric angle at peak torque and concentric time rate of torque development

Strength ratios:

- Functional strength ratio and conventional strength ratio

Hypothesis 2: The second statistical hypothesis proposes that no differences in the physical responses will be observed between the dominant and non-dominant limb, throughout the soccer-specific fatigue protocol.

With regards to the second statistical hypothesis, significant differences between the dominant and non-dominant limb force the rejection of the null hypothesis for the following variables;

Quadriceps:

- Eccentric angle at peak torque

Hamstrings:

- Concentric angle at peak torque, eccentric angle at peak torque and concentric time rate of torque development

Conversely, a lack of significant differences between the dominant and non-dominant limb leads the null hypothesis to be tentatively accepted for the following variables;

Quadriceps:

- Concentric peak torque, eccentric peak torque, concentric work, eccentric work, concentric power, eccentric power, concentric angle at peak torque, concentric time rate of torque development and eccentric time rate of torque development

Hamstrings:

- Concentric peak torque, eccentric peak torque, concentric work, eccentric work, concentric power, eccentric power and eccentric time rate of torque development

Strength ratios:

- Functional strength ratio and conventional strength ratio

CONCLUSION

It is clear that the performance of a soccer match-play simulation resulted in significant changes in physical, physiological and psychophysical responses in Black African amateur players. Isokinetic peak torque, work and power (regardless of leg dominance, testing speed and isokinetic modality) indicated a decreased ability of players to perform over time. The intermittent activity profile was perceived to be similarly demanding on both the musculoskeletal and cardiovascular systems.

Discomfort during the performance of the simulation protocol was reported in the lower back and lower extremities, inferring a large amount of musculoskeletal strain in these areas.

Peak torque and work data for the concentric quadriceps, eccentric quadriceps and concentric hamstrings may indicate the existence of some form of protective mechanism (down regulation) due to the presence of a central governor (Noakes et al., 2005). In contrast, eccentric hamstring data suggest that the hamstrings were unable to resist eccentric muscle fatigue as effectively as concentric muscle fatigue. Alternatively, the onset of fatigue may cause players to adopt altered running styles, placing greater eccentric demands on the hamstrings.

The overall reduction in eccentric hamstrings strength observed in the cohort of amateur Black African soccer players, in response to the performance of a 90 minute soccer-specific fatigue protocol, was indicated to be similar to that of amateur European (Rahnama et al., 2003), semi-professional (Small et al., 2010; Lovell et al., 2011), and professional European soccer players (Greig, 2008; Greig and Siegler, 2009). Furthermore, changes in the functional strength ratio were also illustrated to be similar to those reported by the aforementioned authors. Therefore, the risk of hamstring strain injuries, due to the observed reduction in eccentric hamstring strength and the functional H:Q ratio, is suggested to be similar regardless of playing level and race.

The exaggerated load placed on the hamstring musculature of both limbs, due to eccentric muscle action in response to a soccer-specific fatigue protocol characterised by rapid changes in speed and direction, is an injury risk factor for all players. Decreased eccentric knee flexor strength is acknowledged as a fundamental etiological factor associated with hamstring injury, with fatigue identified as a key predisposing factor for such injuries (Rahnama et al., 2003). In order to reduce the risk of hamstring strain injuries during the course of a 90 minute soccer match, particularly during the latter stages of both halves, players should perform hamstring injury prevention training. Particular emphasis on eccentric hamstring muscle strength training allows for the improvement of eccentric force generation as well as a greater resistance to fatigue.

RECOMMENDATIONS

In order to decrease the prevalence of hamstring injuries within competitive soccer match-play, further research is required in order to better understand the implications of repeated eccentric muscle actions. This will facilitate the understanding of hamstring injury causation and allow preventative intervention strategies to be developed aiming to decrease the incidence of injury and re-injury within competitive soccer. Moreover, such research will allow for further understanding of how factors such as level of play (amateur, semi-professional, professional), race (eg: Caucasian vs. Black), and position of play (defence, midfield, attack) may influence injury risk, as well as what forms of training and injury prevention interventions may be effective in reducing the risk of hamstring strain injuries.

Acknowledging the difficulties associated with field based studies, particularly those in an intermittent and contact orientated environment, more *in situ* research is required in order to accurately assess the physical, physiological and psychophysical demands placed on players during soccer performance. Such information will further aid in the understanding of muscle strain injuries commonly associated with soccer match-play. The incorporation of contact situations as well as kicking of balls may provide a more accurate simulation of the demands placed on each player.

Future soccer-specific studies should consider recruiting a larger sample of outfield players in order to allow for a greater generality of findings and improved statistical power. Furthermore, a more homogeneous group of subjects (defenders/ midfielders/ attackers) should be recruited in order to strengthen the validity of these findings.

The activity profile performed by the recruited cohort of amateur university soccer players was based on time-motion data from elite playing levels in Europe. Time-motion analysis data should be representative of the study sample to which it was applied. Future research focusing on amateur players should consider the activity profile of amateur soccer match-play.

With regards to isokinetic testing velocity, only two testing speeds were utilized in the current study, $60°.s^{-1}$ and $180°.s^{-1}$. The use of a faster, functional isokinetic velocity such as $300°.s^{-1}$ may add valuable insight into changes in isokinetic variables at leg velocities more representative of soccer-specific activities. The use of a functional isokinetic speed may allow for a better understanding of changes in skeletal muscle in response to fatigue, and how a reduction in performance influences the risk of muscle strain injuries.

As the influence of the passive half time interval remains unclear, future research should consider the use of a number of different half time warm up strategies. The application of re-warm up interventions shortly before the start of the second half may emphasise the suggested negative influence of a passive 15 minute break on performance early in the second half.

The current research may have indicated the down regulation of a number of physical responses during the 90 minute protocol. However, little is known about the influence of the central governor on performance in sports such as soccer, which require intermittent exertion from players. Future research aimed at better understanding the influence of central regulation and the impact of down-regulation on performance and risk of injury is required. The use of performance related variables such as sprint times, as well as an indication of changes in muscle recruitment patterns over time, may facilitate a better understanding of the subconscious pacing strategies utilised by players during soccer performance.

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APPENDIX A: GENERAL INFORMATION

Letter of information

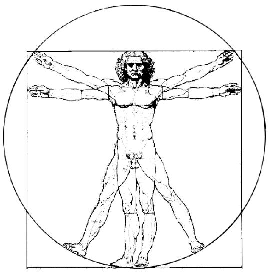
Participant consent form

Instructions to participant for RPE

Physical activity screening questionnaire

Pre-test instructions

Equipment checklist



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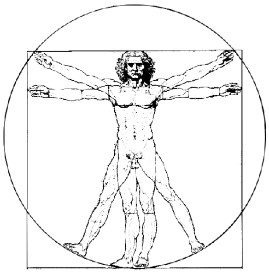


HUMAN KINETICS & EGRGONOMICS
Cell: 0824402771• Fax: (046) 622 3803 • E-mail: g07j0897@campus.ru.ac.za

Dear Participant

Thank you for showing interest in my Masters research entitled, “The influence of soccer-specific fatigue on the risk of thigh injuries in amateur Black African players”. This letter of information will explain the aim of the project, the procedures to be followed, as well as the potential risks and benefits (personal and scientific in nature) associated with the research. Please read it carefully and ensure that you understand its contents before signing the consent form.

The purpose of the current research is to investigate the impact of soccer-specific fatigue on the ability to produce both eccentric and concentric muscular force and how these changes affect the risk of hamstring and quadricep injury in both the dominant and non-dominant legs.

PROCEDURES

You will be required to attend two testing sessions in the Human Kinetics and Ergonomics Department of Rhodes University, Grahamstown. The first session will involve a verbal briefing, habituation to the isokinetic dynamometer, heart rate monitor and the SAFT^{90} protocol, and the measurement of basic anthropometric and demographic data such as; age, stature, body mass, skin folds, limb girth, bone breadth, playing position, experience, injury history, as well as reference heart rate. You will also be issued with a list of pre-test instructions, which you are asked to please adhere to.

The following testing session will be used for data collection. First you will do a standardised warm up consisting of cycling, stretching and jogging. You will then be required to perform the SAFT^{90} soccer simulation protocol. This protocol involves two

45 minute periods of work with a 15 minute half time break in between, identical to that of a soccer match. At various stages of the protocol you will be performing a number of isokinetic tests on the dynamometer, while heart rate data will be collected throughout the 90 minute protocol. Following the completion of the protocol, a cool down consisting of stretches will be performed.

It is very important that you are free from illness and injury as this will impact negatively on the data collected. If you are suffering from an injury or illness, please be honest and report it to the researcher. It is highly unlikely that you will incur any injuries during or as a result of this research as the procedures are non invasive. Possible risks may include slight muscular discomfort and fatigue, which will dissipate quickly. Please note that you are able to withdraw from the study at any point should you wish to do so.

Your data will be kept anonymous and that at no time will your name be used. The data collected will be used for statistical purposes and a copy of the data will be kept anonymously in the Human Kinetics and Ergonomics Department and may be used for teaching and research purposes.

Following the completion of data collection, I will gladly discuss the results of the project with you. Thank you for the interest that you have shown and please do not hesitate to contact me if you have any queries.

Yours sincerely

Robert Jones

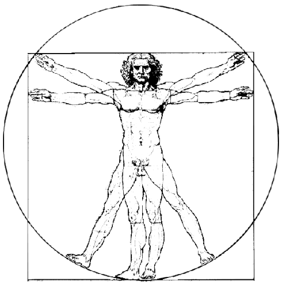
B.Sc. (hons.) (Human Kinetics and Ergonomics)

M.Sc. Student

INSTRUCTIONS TO SUBJECTS FOR RPE:

During the performance of the 90 minute soccer-specific fatigue protocol you will be asked to estimate how hard you feel you are working, a degree of perceived exertion. Every 15 minutes you will be asked to select a number on the scale presented to you which corresponds to your rating on perceived exertion. You will be required to give a ‘central’ rating of perceived exertion, corresponding to how your cardiovascular system is feeling. In addition, you will also be required to give a ‘local’ rating of perceived exertion; this will correspond to how your lower limb musculature is feeling. The scale ranges from 6 to 20, with 6 indicating minimal/no discomfort and 20 indicating the greatest discomfort you have ever experienced. 20 should only be rated if you are unable to continue any longer.

It is important that you try and estimate honestly and as objectively as possible. Do not underestimate the degree of exertion you experience, but do not overestimate it either. Please try to be as accurate as possible.



INFORMED CONSENT FORM:

I, ………………………………………….............have been fully informed of the research project entitled:

The influence of soccer-specific fatigue on the risk of thigh injuries in amateur Black African players

I have read the information sheet and understand the testing procedure that will take place. I have been told about the risks as well as benefits involved, as well as what will be expected of me as a subject. I understand that all information gained from this project will be treated confidentially, that I will remain anonymous at all times and that data obtained may be used and published for statistical or scientific purposes. All testing procedures, associated risks and the benefits from partaking in this study have been verbally explained to me as well in writing. I have had ample opportunity to ask questions and to clarify any concerns or misunderstandings. I am satisfied that these have been answered satisfactorily.

In light of this, and in agreeing to participate in this study, I accept joint responsibility together with the Human Kinetics and Ergonomics Department, in that should any accident or injury occur as a direct result of the protocols being performed during the study, the Human Kinetics and Ergonomics Department will be liable for any costs with may ensure and will reimburse the subject to the full amount. I.e. doctors consultation, medication etc. The department will, however, waiver any legal recourse against the researchers of Rhodes University, from any and all claims resulting from personal injuries sustained whilst partaking in the investigation due negligence on the part of the subject or from injuries not directly related to the study itself. This waiver shall be binding upon my heirs and personal representatives.

I have read and understood the above information, as well as the information provided in the letter accompanying this form.

I therefore consent to voluntarily participate in this research project.

SUBJECT (OR LEGAL REPRESENTATIVE):

______________________	_________________	___________
(Print name)	(Signed)	(Date)

PERSON ADMINISTERING INFORMED CONSENT:

______________________	_________________	___________
(Print name)	(Signed)	(Date)

WITNESS:

______________________	_________________	___________
(Print name)	(Signed)	(Date)

WITNESS:

______________________	_________________	___________
(Print name)	(Signed)	(Date)

PHYSICAL ACTIVITY SCREENING QUESTIONNAIRE

Name: ____________________

Subject Code: _________________

MEDICAL HISTORY

Tick any of the following conditions, diseases or disorders that you have in the past or are presently being treated for, by a physician or health care professional.

☐ Heart problems
☐ Peripheral vascular disorders
☐ High/low blood pressure
☐ Epilepsy

☐ Anemia
☐ Asthma
☐ Emphysema
Migra☐

☐ Eye Problems
☐ Hypoglycemia
Diab☐s
Hyp☐hyroidism

☐ Other (specify) ____

Have you had any recent medical problems? If so give details below.

____

____

____

Are you currently suffering from any orthopedic disorder problem? If so briefly describe the problem.

____

____

____

Are there any other concerns medical or otherwise that you feel are worth mentioning?

____

____

____

Please indicate any prescribed or over-the-counter medication you are currently taking or have taken in the last 6 months.

____

____

____

OTHER HABITS

Please tick the appropriate box.

Do you smoke?

☐ Yes ☐ No

If yes, how many cigarettes per day?

☐ >40 ☐ 20-40 ☐ 10-19 ☐ 1-9

EXERCISE HISTORY

Do you exercise regularly?

☐ Yes ☐ No

How many days per week do you normally spend performing at least 30 minutes of moderate to strenuous exercise?

☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7

Do you experience shortness of breath or chest discomfort with exercise?

☐ Yes ☐ No

Can you jog 5km continuously at a moderate pace without discomfort?

☐ Yes ☐ No

Provide a rough average of the number of organized/scheduled physical activity sessions you participate in during the week. Tick the appropriate block (s) and fill in the number of sessions.

☐ Soccer_____ ☐ Gym_____ ☐ Jogging ____ ☐ Rugby_____

☐ Fitness ____ ☐ Swimming_____ ☐ Other ______

PRE-TEST INSTRUCTIONS:

Please inform the researcher of any factors that you think may influence your results on the day of testing. Note, that if you are injured or have any lower limb problems it is advised that you do not participate in this study. For standardisation purposes please adhere to the following requests:

24 HOURS PRIOR TO TESTING:

1) Refrain from drinking alcohol 24 hours before testing.
2) Refrain from strenuous exercise 24 hours before testing.
3) If possible, please do not take any medication 24 hours before testing (i.e. aspirin, cold/ flu tablets, or pain killers). Please inform the researcher of any use of medication.

ON THE DAY OF TESTING:

1) Eat a good meal roughly 2 hours before testing
2) You are required to wear athletic trainers during testing (no soccer boots or shin guards required).
3) Please wear athletic clothing, ie: sports shorts and a t-shirt

EQUIPMENT CHECKLIST:

1) Cybex turned on and working
2) PC and speakers turned on and working
3) SAFT90 mp3
4) Skinfold callipers
5) Bicondylar callipers
6) Tape measure
7) 2 stopwatches
8) SAFT90 course setup
9) RPE Scale
10) Body Discomfort Chart and Scale
11) Heart rate monitor
12) Data collection sheets

APPENDIX B: DATA COLLECTION

Order of procedure

Rating of Perceived Exertion Scale

Body Discomfort Map and Scale

Data Collection sheet

Somatotype measurement sheet

Condition Randomisation

ORDER OF PROCEDURE:

Session 1:

1) Welcome participant
2) Introduction
3) Fit HR monitor to participant
4) Give subject letter of information to read
5) Complete informed consent form
6) Complete physical activity screening questionnaire
7) Complete participant information forms
8) Habituate to RPE and Body Discomfort use
9) Habituation to isokinetic procedures (60/180 + H/Q + Ecc/Conc)
10) Explanation of protocol and equipment
11) Describe pre-test instructions
12) Ask if there are any questions

Session 2:

1) Welcome participant
2) Fit HR monitor to participant (Beep= Start stopwatch #1)
3) Perform warm up (5 min cycle and 5 min self selected stretches)
4) Re-familiarisation with SAFT90
5) Queries addressed
6) Selection of limb to be tested 1st (D/ND)

		Testing modality			
		Con (quads)	Con (hams)	Ecc (quads)	Ecc (hams)
Isokinetic speed	60 $^{o}.s^{-1}$	1	2	5	6
	180 $^{o}.s^{-1}$	3	4	7	8

7) Isokinetic testing (T0)
    - 1 practice repetition (submaximal)
    - 3 repetitions
    - 30 seconds rest between each set (1/2 - 3/4 – 5/6 – 7/8)
8) Begin 1st half of SAFT90 (Start stopwatch #2 + Mark stopwatch #1)
    - Min 15 (RPE + Body Discomfort)
    - Min 30 (RPE + Body Discomfort)
    - Min 45 (RPE + Body Discomfort)
9) End 1st half of SAFT90 (Stop stopwatch #2 + Mark stopwatch #1)
10) Isokinetic testing (T45)

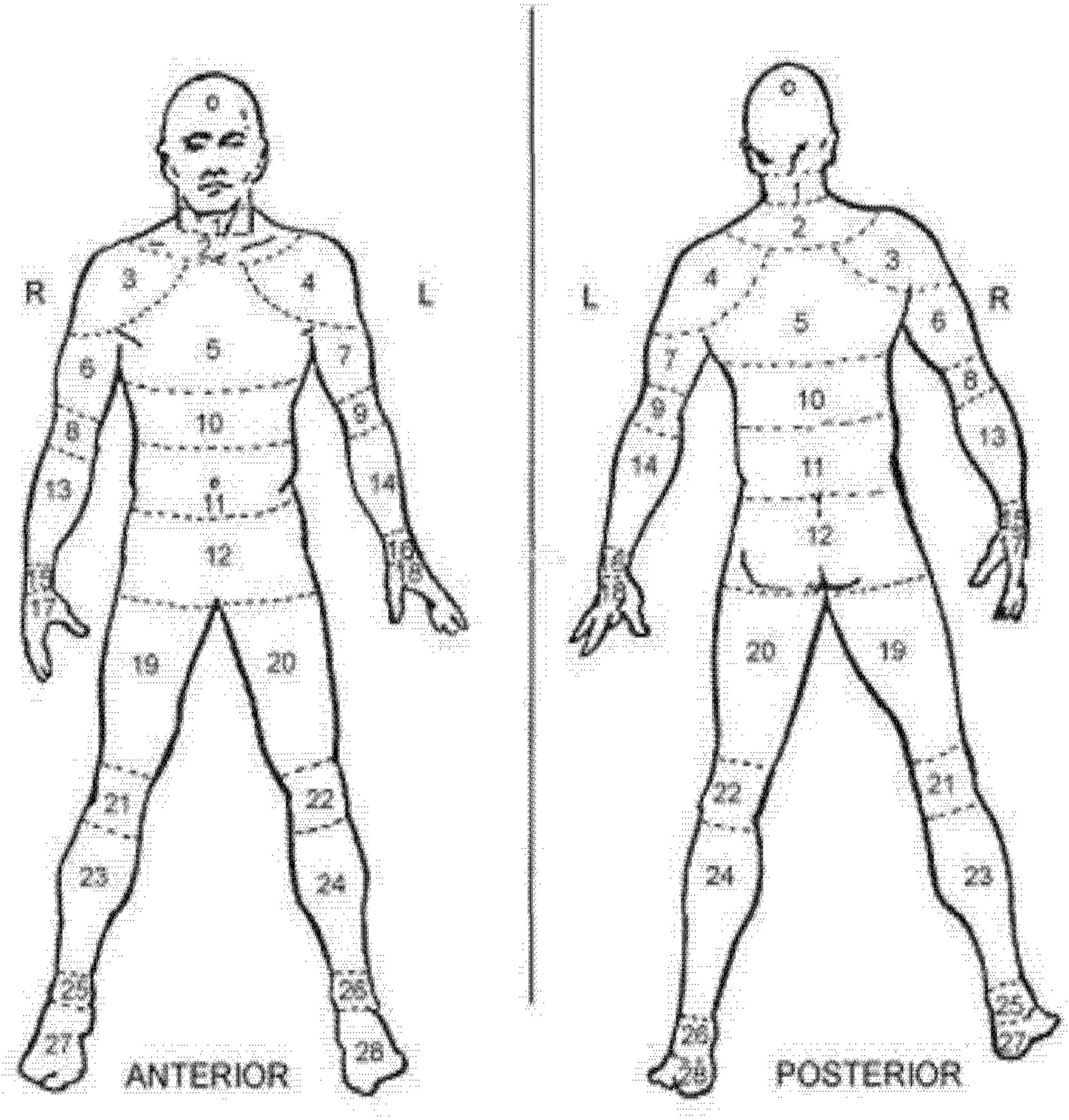
11) Begin 15 minute Half time interval (Start stopwatch #2 + Mark stopwatch #1)
12) End 15 minute Half time interval (Stop stopwatch #2 + Mark stopwatch #1)
13) Isokinetic testing (T60)
14) Begin 2nd half of SAFT90 (Start stopwatch #2 + Mark stopwatch #1)
    - Min 60 (RPE + Body Discomfort)
    - Min 75 (RPE + Body Discomfort)
    - Min 90 (RPE + Body Discomfort)
    - Min 105 (RPE + Body Discomfort)
15) End 2nd half of SAFT90 (Stop stopwatch #2 + Mark stopwatch #1)
16) Isokinetic testing (T105)
17) Short cool down and self selected stretches

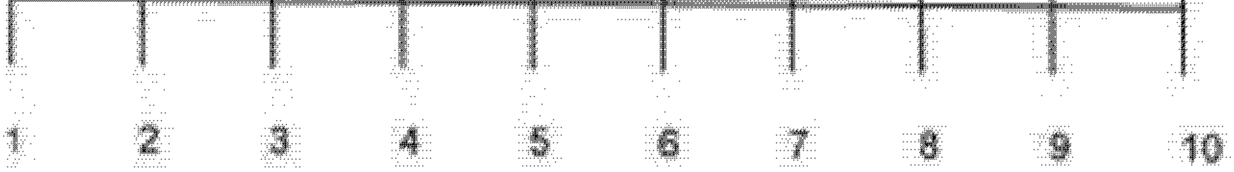
RATINGS OF PERCEIVED EXERTION (RPE):

RPE SCALE

6.	
7.	VERY, VERY LIGHT
8.	
9.	VERY LIGHT
10.	
11.	FAIRLY LIGHT
12.	
13.	SOMEWHAT HARD
14.	
15.	HARD
16.	
17.	VERY HARD
18.	
19.	VERY, VERY HARD
20.	

BODY DISCOMFORT MAP AND RATING SCALE:





LOW INTENSITY HIGH INTENSITY

DATA COLLECTION FORM:

Participant Code:	

Dominant limb	
L	R
Limb tested 1st	
L	R

	Isokinetic limits	
	X	**O**
Right		
Left		

Time	**Heart Rate**	**Mark**	**RPE**		**Body discomfort**
			Central	**Local**	
Isokinetic Test (T0)					
0 min	—		—	—	—
15 min	—	—			
30 min	—	—			
45 min	—				
Isokinetic Test (T45)					
H/T 0 min	—		—	—	—
H/T 15 min	—		—	—	—
Isokinetic Test (T60)					
60 min	—				
75 min	—	—			
90 min	—	—			
105 min	—				
Isokinetic Test (T105)					

Notes:

SOMATOTYPE DATA:

	1	2	Mean
Skinfolds:			
Triceps			
Subscapular			
Supraspinale			
Medial calf			
Bicep			
Limb girths:			
Arm flexed			
Calf tensed			
Bone breadths:			
Humerus			
Femur			
Height:			
Weight:			

Somatotype: - -

CONDITION RANDOMISATION:

Participant	Limb tested 1st	Limb tested 2nd
1	non-dominant	dominant
2	non-dominant	dominant
3	non-dominant	dominant
4	dominant	non-dominant
5	dominant	non-dominant
6	non-dominant	dominant
7	dominant	non-dominant
8	dominant	non-dominant
9	non-dominant	dominant
10	dominant	non-dominant
11	dominant	non-dominant
12	dominant	non-dominant
13	non-dominant	dominant
14	dominant	non-dominant
15	non-dominant	dominant
16	non-dominant	dominant
17	dominant	non-dominant
18	non-dominant	dominant
19	non-dominant	dominant
20	non-dominant	dominant

APPENDIX C: SUMMARY REPORTS

Statistical Analyses

PT-ConQ

60

Tukey HSD test; variable DV_1 (PT-Con-Quads.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 102.10, df = 57.000

	DOMINANC	TIME	{1} - 181.50	{2} - 163.25	{3} - 155.90	{4} - 153.05	{5} - 181.45	{6} - 162.80	{7} - 153.40	{8} - 148.15
1	1	1		0.000139	0.000131	0.000131	1.000000	0.000136	0.000131	0.000131
2	1	2	0.000139		0.311543	0.044465	0.000140	1.000000	0.058817	0.000494
3	1	3	0.000131	0.311543		0.985711	0.000131	0.391241	0.993460	0.249391
4	1	4	0.000131	0.044465	0.985711		0.000131	0.063600	1.000000	0.786212
5	2	1	1.000000	0.000140	0.000131	0.000131		0.000136	0.000131	0.000131
6	2	2	0.000136	1.000000	0.391241	0.063600	0.000136		0.083079	0.000739
7	2	3	0.000131	0.058817	0.993460	1.000000	0.000131	0.083079		0.722569
8	2	4	0.000131	0.000494	0.249391	0.786212	0.000131	0.000739	0.722569	

180

Tukey HSD test; variable DV_1 (PT-Con-Quads.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 60.114, df = 57.000

	D	T	{1} - 127.90	{2} - 122.80	{3} - 116.05	{4} - 114.95	{5} - 124.85	{6} - 119.70	{7} - 114.85	{8} - 113.85
1	1	1		0.439872	0.000377	0.000177	0.914961	0.029674	0.000170	0.000139
2	1	2	0.439872		0.128120	0.043380	0.990232	0.908053	0.038980	0.012529
3	1	3	0.000377	0.128120		0.999827	0.014972	0.810213	0.999691	0.985207
4	1	4	0.000177	0.043380	0.999827		0.003895	0.532018	1.000000	0.999827
5	2	1	0.914961	0.990232	0.014972	0.003895		0.427155	0.003435	0.000988
6	2	2	0.029674	0.908053	0.810213	0.532018	0.427155		0.505264	0.268047
7	2	3	0.000170	0.038980	0.999691	1.000000	0.003435	0.505264		0.999909
8	2	4	0.000139	0.012529	0.985207	0.999827	0.000988	0.268047	0.999909	

PT-EccQ

60

Tukey HSD test; variable DV_1 (PT-Ecc-Quads.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 248.92, df = 57.000

	D	T	{1} - 231.83	{2} - 204.72	{3} - 203.15	{4} - 190.10	{5} - 220.45	{6} - 195.62	{7} - 198.53	{8} - 188.63
1	1	1		0.000156	0.000138	0.000131	0.322446	0.000131	0.000131	0.000131
2	1	2	0.000156		0.999984	0.085179	0.049357	0.606947	0.915387	0.040605
3	1	3	0.000138	0.999984		0.171808	0.021152	0.799904	0.982162	0.089311
4	1	4	0.000131	0.085179	0.171808		0.000133	0.952637	0.694358	0.999990
5	2	1	0.322446	0.049357	0.021152	0.000133		0.000277	0.001306	0.000132
6	2	2	0.000131	0.606947	0.799904	0.952637	0.000277		0.999021	0.852169
7	2	3	0.000131	0.915387	0.982162	0.694358	0.001306	0.999021		0.501247
8	2	4	0.000131	0.040605	0.089311	0.999990	0.000132	0.852169	0.501247	

180

Tukey HSD test; variable DV_1 (PT-Ecc-Quads.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 133.23, df = 57.000

	D	T	{1} - 217.28	{2} - 196.15	{3} - 188.30	{4} - 179.78	{5} - 211.18	{6} - 189.30	{7} - 185.50	{8} - 173.55
1	1	1		0.000137	0.000131	0.000131	0.705239	0.000131	0.000131	0.000131
2	1	2	0.000137		0.396490	0.000988	0.003057	0.572085	0.087952	0.000132
3	1	3	0.000131	0.396490		0.293129	0.000132	0.999994	0.994213	0.003857
4	1	4	0.000131	0.000988	0.293129		0.000131	0.173969	0.766614	0.683755
5	2	1	0.705239	0.003057	0.000132	0.000131		0.000134	0.000131	0.000131
6	2	2	0.000131	0.572085	0.999994	0.173969	0.000134		0.965900	0.001660
7	2	3	0.000131	0.087952	0.994213	0.766614	0.000131	0.965900		0.035865
8	2	4	0.000131	0.000132	0.003857	0.683755	0.000131	0.001660	0.035865	

PT-ConH

60

Tukey HSD test; variable DV_1 (PT-Con-Hams.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 57.044, df = 57.000

	DOMINANC	TIME	{1} - 100.05	{2} - 95.700	{3} - 95.750	{4} - 91.050	{5} - 98.650	{6} - 95.850	{7} - 95.500	{8} - 88.700
1	1	1		0.608676	0.622443	0.008847	0.998966	0.649754	0.553329	0.000461
2	1	2	0.608676		1.000000	0.525713	0.917843	1.000000	1.000000	0.085276
3	1	3	0.622443	1.000000		0.511976	0.924423	1.000000	1.000000	0.081100
4	1	4	0.008847	0.525713	0.511976		0.045649	0.484723	0.581031	0.975019
5	2	1	0.998966	0.917843	0.924423	0.045649		0.936532	0.887944	0.002624
6	2	2	0.649754	1.000000	1.000000	0.484723	0.936532		1.000000	0.073289
7	2	3	0.553329	1.000000	1.000000	0.581031	0.887944	1.000000		0.103688
8	2	4	0.000461	0.085276	0.081100	0.975019	0.002624	0.073289	0.103688	

180

Tukey HSD test; variable DV_1 (PT-Con-Hams.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 27.483, df = 57.000

	DOM	TIME	{1} - 75.000	{2} - 75.650	{3} - 72.550	{4} - 73.200	{5} - 74.500	{6} - 76.350	{7} - 71.800	{8} - 71.400
1	1	1		0.999930	0.815801	0.957303	0.999988	0.991663	0.536665	0.384020
2	1	2	0.999930		0.576542	0.815801	0.996905	0.999885	0.299943	0.190977
3	1	3	0.815801	0.576542		0.999930	0.935455	0.315833	0.999817	0.996905
4	1	4	0.957303	0.815801	0.999930		0.993369	0.556586	0.989628	0.957303
5	2	1	0.999988	0.996905	0.935455	0.993369		0.950699	0.731268	0.576542
6	2	2	0.991663	0.999885	0.315833	0.556586	0.950699		0.130520	0.074680
7	2	3	0.536665	0.299943	0.999817	0.989628	0.731268	0.130520		0.999997
8	2	4	0.384020	0.190977	0.996905	0.957303	0.576542	0.074680	0.999997	

PT-EccH

60

Tukey HSD test; variable DV_1 (PT-Ecc-Hams.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 77.078, df = 57.000

	DOMINANC	TIME	{1} - 140.32	{2} - 129.43	{3} - 127.30	{4} - 114.70	{5} - 136.00	{6} - 125.55	{7} - 126.65	{8} - 113.70
1	1	1		0.005504	0.000552	0.000131	0.772657	0.000170	0.000306	0.000131
2	1	2	0.005504		0.994291	0.000173	0.276703	0.855481	0.972722	0.000141
3	1	3	0.000552	0.994291		0.000844	0.051697	0.998338	0.999998	0.000325
4	1	4	0.000131	0.000173	0.000844		0.000131	0.005812	0.001715	0.999961
5	2	1	0.772657	0.276703	0.051697	0.000131		0.008958	0.027848	0.000131
6	2	2	0.000170	0.855481	0.998338	0.005812	0.008958		0.999925	0.001915
7	2	3	0.000306	0.972722	0.999998	0.001715	0.027848	0.999925		0.000593
8	2	4	0.000131	0.000141	0.000325	0.999961	0.000131	0.001915	0.000593	

180

Tukey HSD test; variable DV_1 (PT-Ecc-Hams.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 85.931, df = 57.000

	DOMINANC	TIME	{1} - 134.05	{2} - 123.75	{3} - 126.35	{4} - 111.15	{5} - 136.27	{6} - 124.60	{7} - 124.55	{8} - 109.77
1	1	1		0.018581	0.167908	0.000131	0.994575	0.040951	0.039156	0.000131
2	1	2	0.018581		0.986168	0.001747	0.001889	0.999991	0.999994	0.000444
3	1	3	0.167908	0.986168		0.000197	0.026515	0.998837	0.998594	0.000142
4	1	4	0.000131	0.001747	0.000197		0.000131	0.000732	0.000768	0.999767
5	2	1	0.994575	0.001889	0.026515	0.000131		0.004613	0.004378	0.000131
6	2	2	0.040951	0.999991	0.998837	0.000732	0.004613		1.000000	0.000238
7	2	3	0.039156	0.999994	0.998594	0.000768	0.004378	1.000000		0.000245
8	2	4	0.000131	0.000444	0.000142	0.999767	0.000131	0.000238	0.000245	

Work-ConQ

60

Tukey HSD test; variable DV_1 (W-Con-Quads.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 187.34, df = 57.000

	D	T	{1} - 208.00	{2} - 188.00	{3} - 182.05	{4} - 182.20	{5} - 206.00	{6} - 189.90	{7} - 181.55	{8} - 178.15
1	1	1		0.000668	0.000134	0.000134	0.999789	0.002499	0.000133	0.000131
2	1	2	0.000668		0.864840	0.879484	0.002683	0.999850	0.809424	0.324712
3	1	3	0.000134	0.864840		1.000000	0.000148	0.613712	1.000000	0.984845
4	1	4	0.000134	0.879484	1.000000		0.000150	0.636428	1.000000	0.981176
5	2	1	0.999789	0.002683	0.000148	0.000150		0.010213	0.000142	0.000132
6	2	2	0.002499	0.999850	0.613712	0.636428	0.010213		0.537393	0.139321
7	2	3	0.000133	0.809424	1.000000	1.000000	0.000142	0.537393		0.993299
8	2	4	0.000131	0.324712	0.984845	0.981176	0.000132	0.139321	0.993299	

180

Tukey HSD test; variable DV_1 (W-Con-Quads.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 81.606, df = 57.000

	D	T	{1} - 156.10	{2} - 144.80	{3} - 139.25	{4} - 139.75	{5} - 148.80	{6} - 141.70	{7} - 137.45	{8} - 136.10
1	1	1		0.005032	0.000135	0.000139	0.194156	0.000245	0.000132	0.000131
2	1	2	0.005032		0.528413	0.643733	0.853448	0.957429	0.187454	0.064533
3	1	3	0.000135	0.528413		1.000000	0.029788	0.988639	0.998342	0.953686
4	1	4	0.000139	0.643733	1.000000		0.047337	0.997209	0.992219	0.903358
5	2	1	0.194156	0.853448	0.029788	0.047337		0.222740	0.004751	0.001114
6	2	2	0.000245	0.957429	0.988639	0.997209	0.222740		0.810707	0.516914
7	2	3	0.000132	0.187454	0.998342	0.992219	0.004751	0.810707		0.999755
8	2	4	0.000131	0.064533	0.953686	0.903358	0.001114	0.516914	0.999755	

Work-EccQ

60

Tukey HSD test; variable DV_1 (W-Ecc-Quads.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 230.66, df = 57.000

	D	T	{1} - 252.25	{2} - 221.07	{3} - 216.97	{4} - 205.95	{5} - 242.60	{6} - 215.47	{7} - 218.02	{8} - 203.33
1	1	1		0.000132	0.000131	0.000131	0.485016	0.000131	0.000131	0.000131
2	1	2	0.000132		0.988944	0.049681	0.001001	0.938246	0.998257	0.010969
3	1	3	0.000131	0.988944		0.314044	0.000168	0.999985	0.999999	0.104878
4	1	4	0.000131	0.049681	0.314044		0.000131	0.501924	0.210675	0.999363
5	2	1	0.485016	0.001001	0.000168	0.000131		0.000142	0.000217	0.000131
6	2	2	0.000131	0.938246	0.999985	0.501924	0.000142		0.999473	0.204327
7	2	3	0.000131	0.998257	0.999999	0.210675	0.000217	0.999473		0.062134
8	2	4	0.000131	0.010969	0.104878	0.999363	0.000131	0.204327	0.062134	

180

Tukey HSD test; variable DV_1 (W-Ecc-Quads.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 346.14, df = 57.000

	D	T	{1} - 233.90	{2} - 209.97	{3} - 204.53	{4} - 191.23	{5} - 233.63	{6} - 205.83	{7} - 211.93	{8} - 198.63
1	1	1		0.003566	0.000268	0.000131	1.000000	0.000439	0.009760	0.000134
2	1	2	0.003566		0.982235	0.045076	0.004117	0.996554	0.999978	0.537404
3	1	3	0.000268	0.982235		0.332992	0.000294	0.999999	0.910320	0.972216
4	1	4	0.000131	0.045076	0.332992		0.000131	0.224383	0.018336	0.910320
5	2	1	1.000000	0.004117	0.000294	0.000131		0.000495	0.011211	0.000134
6	2	2	0.000439	0.996554	0.999999	0.224383	0.000495		0.966650	0.921456
7	2	3	0.009760	0.999978	0.910320	0.018336	0.011211	0.966650		0.332992
8	2	4	0.000134	0.537404	0.972216	0.910320	0.000134	0.921456	0.332992	

Work-ConH

60

Tukey HSD test; variable DV_1 (W-Con-Hams.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 88.261, df = 57.000

	D	T	{1} - 136.55	{2} - 124.15	{3} - 123.30	{4} - 118.75	{5} - 130.60	{6} - 123.20	{7} - 121.55	{8} - 116.20
1	1	1		0.002561	0.001068	0.000134	0.489222	0.000967	0.000242	0.000131
2	1	2	0.002561		0.999992	0.611092	0.384315	0.999982	0.987205	0.151403
3	1	3	0.001068	0.999992		0.787297	0.235032	1.000000	0.998933	0.266175
4	1	4	0.000134	0.611092	0.787297		0.004529	0.805407	0.980390	0.988585
5	2	1	0.489222	0.384315	0.235032	0.004529		0.220424	0.064414	0.000365
6	2	2	0.000967	0.999982	1.000000	0.805407	0.220424		0.999293	0.282701
7	2	3	0.000242	0.987205	0.998933	0.980390	0.064414	0.999293		0.622158
8	2	4	0.000131	0.151403	0.266175	0.988585	0.000365	0.282701	0.622158	

180

Tukey HSD test; variable DV_1 (W-Con-Hams.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 48.851, df = 57.000

	D	T	{1} - 97.750	{2} - 96.300	{3} - 92.300	{4} - 91.350	{5} - 95.750	{6} - 98.100	{7} - 92.150	{8} - 91.600
1	1	1		0.997826	0.231231	0.092655	0.984470	1.000000	0.202779	0.120016
2	1	2	0.997826		0.616274	0.344690	0.999997	0.991659	0.571470	0.411161
3	1	3	0.231231	0.616274		0.999870	0.770912	0.168811	1.000000	0.999984
4	1	4	0.092655	0.344690	0.999870		0.497043	0.063189	0.999959	1.000000
5	2	1	0.984470	0.999997	0.770912	0.497043		0.961814	0.731202	0.571470
6	2	2	1.000000	0.991659	0.168811	0.063189	0.961814		0.146305	0.083270
7	2	3	0.202779	0.571470	1.000000	0.999959	0.731202	0.146305		0.999997
8	2	4	0.120016	0.411161	0.999984	1.000000	0.571470	0.083270	0.999997	

Work-EccH

60

Tukey HSD test; variable DV_1 (W-Ecc-Hams.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 160.22, df = 57.000

	D	T	{1} - 178.58	{2} - 159.88	{3} - 152.60	{4} - 146.12	{5} - 170.28	{6} - 159.60	{7} - 156.13	{8} - 143.60
1	1	1		0.000581	0.000132	0.000131	0.443947	0.000476	0.000144	0.000131
2	1	2	0.000581		0.611170	0.023140	0.178055	1.000000	0.981043	0.003572
3	1	3	0.000132	0.611170		0.737874	0.001219	0.656021	0.986730	0.339714
4	1	4	0.000131	0.023140	0.737874		0.000133	0.027949	0.217270	0.998330
5	2	1	0.443947	0.178055	0.001219	0.000133		0.154328	0.017467	0.000131
6	2	2	0.000476	1.000000	0.656021	0.027949	0.154328		0.987792	0.004412
7	2	3	0.000144	0.981043	0.986730	0.217270	0.017467	0.987792		0.052299
8	2	4	0.000131	0.003572	0.339714	0.998330	0.000131	0.004412	0.052299	

180

Tukey HSD test; variable DV_1 (W-Ecc-Hams.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 157.02, df = 57.000

	D	T	{1} - 163.97	{2} - 147.65	{3} - 145.85	{4} - 132.57	{5} - 161.25	{6} - 146.55	{7} - 146.95	{8} - 133.65
1	1	1		0.003025	0.000762	0.000131	0.997076	0.001294	0.001757	0.000131
2	1	2	0.003025		0.999812	0.007944	0.023335	0.999993	1.000000	0.017567
3	1	3	0.000762	0.999812		0.029220	0.006206	1.000000	0.999993	0.059390
4	1	4	0.000131	0.007944	0.029220		0.000131	0.017884	0.013383	0.999994
5	2	1	0.997076	0.023335	0.006206	0.000131		0.010517	0.014152	0.000131
6	2	2	0.001294	0.999993	1.000000	0.017884	0.010517		1.000000	0.037664
7	2	3	0.001757	1.000000	0.999993	0.013383	0.014152	1.000000		0.028723
8	2	4	0.000131	0.017567	0.059390	0.999994	0.000131	0.037664	0.028723	

Power-ConQ

60

Tukey HSD test; variable DV_1 (P-Con-Quads.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 64.164, df = 57.000

	D	T	{1} - 116.85	{2} - 107.30	{3} - 105.50	{4} - 100.45	{5} - 116.75	{6} - 108.65	{7} - 103.30	{8} - 99.700
1	1	1		0.008797	0.001005	0.000132	1.000000	0.039529	0.000166	0.000131
2	1	2	0.008797		0.996392	0.142516	0.009889	0.999460	0.760506	0.072111
3	1	3	0.001005	0.996392		0.495165	0.001129	0.915101	0.987764	0.317173
4	1	4	0.000132	0.142516	0.495165		0.000132	0.039529	0.948561	0.999990
5	2	1	1.000000	0.009889	0.001129	0.000132		0.043834	0.000172	0.000131
6	2	2	0.039529	0.999460	0.915101	0.039529	0.043834		0.419999	0.017559
7	2	3	0.000166	0.760506	0.987764	0.948561	0.000172	0.419999		0.843722
8	2	4	0.000131	0.072111	0.317173	0.999990	0.000131	0.017559	0.843722	

180

Tukey HSD test; variable DV_1 (P-Con-Quads.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 240.15, df = 57.000

	D	T	{1} - 220.35	{2} - 208.35	{3} - 197.05	{4} - 192.70	{5} - 210.35	{6} - 200.20	{7} - 194.35	{8} - 191.40
1	1	1		0.238797	0.000459	0.000142	0.464867	0.003101	0.000172	0.000135
2	1	2	0.238797		0.308564	0.044308	0.999908	0.710271	0.101389	0.021668
3	1	3	0.000459	0.308564		0.986103	0.139531	0.998109	0.999329	0.941677
4	1	4	0.000142	0.044308	0.986103		0.014445	0.787884	0.999975	0.999995
5	2	1	0.464867	0.999908	0.139531	0.014445		0.445443	0.036730	0.006585
6	2	2	0.003101	0.710271	0.998109	0.787884	0.445443		0.930511	0.625487
7	2	3	0.000172	0.101389	0.999329	0.999975	0.036730	0.930511		0.998773
8	2	4	0.000135	0.021668	0.941677	0.999995	0.006585	0.625487	0.998773	

Power-EccQ

60

Tukey HSD test; variable DV_1 (P-Ecc-Quads.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 76.677, df = 57.000

	D	T	{1} - 117.05	{2} - 104.75	{3} - 105.18	{4} - 97.475	{5} - 113.00	{6} - 102.67	{7} - 104.65	{8} - 96.575
1	1	1		0.001127	0.001800	0.000131	0.823560	0.000195	0.001013	0.000131
2	1	2	0.001127		1.000000	0.167729	0.075874	0.994985	1.000000	0.081005
3	1	3	0.001800	1.000000		0.120494	0.108842	0.984671	1.000000	0.055495
4	1	4	0.000131	0.167729	0.120494		0.000144	0.571293	0.180656	0.999980
5	2	1	0.823560	0.075874	0.108842	0.000144		0.009946	0.069489	0.000135
6	2	2	0.000195	0.994985	0.984671	0.571293	0.009946		0.996308	0.365604
7	2	3	0.001013	1.000000	1.000000	0.180656	0.069489	0.996308		0.088291
8	2	4	0.000131	0.081005	0.055495	0.999980	0.000135	0.365604	0.088291	

180

Tukey HSD test; variable DV_1 (P-Ecc-Quads.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 341.35, df = 57.000

	D	T	{1} - 221.82	{2} - 196.30	{3} - 183.82	{4} - 177.78	{5} - 222.90	{6} - 192.60	{7} - 195.25	{8} - 180.05
1	1	1		0.001410	0.000132	0.000131	1.000000	0.000263	0.000820	0.000131
2	1	2	0.001410		0.405843	0.047010	0.000810	0.998288	1.000000	0.120337
3	1	3	0.000132	0.405843		0.966878	0.000131	0.803274	0.520087	0.998046
4	1	4	0.000131	0.047010	0.966878		0.000131	0.201284	0.073766	0.999933
5	2	1	1.000000	0.000810	0.000131	0.000131		0.000197	0.000486	0.000131
6	2	2	0.000263	0.998288	0.803274	0.201284	0.000197		0.999814	0.398077
7	2	3	0.000820	1.000000	0.520087	0.073766	0.000486	0.999814		0.176838
8	2	4	0.000131	0.120337	0.998046	0.999933	0.000131	0.398077	0.176838	

Power-ConH

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Tukey HSD test; variable DV_1 (P-Con-Hams.sta) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 40.524, df = 57.000

	D	T	{1} - 75.350	{2} - 73.700	{3} - 69.050	{4} - 68.600	{5} - 75.850	{6} - 75.500	{7} - 67.750	{8} - 66.850
1	1	1		0.991328	0.052241	0.028984	0.999997	1.000000	0.008661	0.002205
2	1	2	0.991328		0.306442	0.202860	0.960886	0.985503	0.080325	0.025304
3	1	3	0.052241	0.306442		0.999999	0.027087	0.043111	0.998053	0.955813
4	1	4	0.028984	0.202860	0.999999		0.014452	0.023629	0.999885	0.987696
5	2	1	0.999997	0.960886	0.027087	0.014452		1.000000	0.004068	0.001034
6	2	2	1.000000	0.985503	0.043111	0.023629	1.000000		0.006932	0.001754
7	2	3	0.008661	0.080325	0.998053	0.999885	0.004068	0.006932		0.999831
8	2	4	0.002205	0.025304	0.955813	0.987696	0.001034	0.001754	0.999831	

180

Tukey HSD test; variable DV_1 (P-Con-Hams.sta) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 125.59, df = 57.000

	D	T	{1} - 137.70	{2} - 141.80	{3} - 133.65	{4} - 135.80	{5} - 134.40	{6} - 140.20	{7} - 130.50	{8} - 135.45
1	1	1		0.940646	0.944259	0.999438	0.981699	0.996552	0.470592	0.998260
2	1	2	0.940646		0.311822	0.691586	0.434857	0.999819	0.044884	0.628055
3	1	3	0.944259	0.311822		0.998699	0.999999	0.590899	0.985995	0.999606
4	1	4	0.999438	0.691586	0.998699		0.999926	0.915750	0.806636	1.000000
5	2	1	0.981699	0.434857	0.999999	0.999926		0.726469	0.954166	0.999990
6	2	2	0.996552	0.999819	0.590899	0.915750	0.726469		0.132687	0.879359
7	2	3	0.470592	0.044884	0.985995	0.806636	0.954166	0.132687		0.855018
8	2	4	0.998260	0.628055	0.999606	1.000000	0.999990	0.879359	0.855018	

Power-EccH

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Tukey HSD test; variable DV_1 (P-Ecc-Hams.sta) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 48.695, df = 57.000

	D	T	{1} - 88.350	{2} - 85.150	{3} - 79.925	{4} - 75.100	{5} - 85.625	{6} - 80.825	{7} - 80.350	{8} - 72.725
1	1	1		0.829759	0.007628	0.000134	0.917927	0.024801	0.013476	0.000131
2	1	2	0.829759		0.276935	0.000806	0.999999	0.517154	0.381870	0.000143
3	1	3	0.007628	0.276935		0.375207	0.183647	0.999909	0.999999	0.036942
4	1	4	0.000134	0.000806	0.375207		0.000441	0.179464	0.271375	0.959252
5	2	1	0.917927	0.999999	0.183647	0.000441		0.381870	0.265887	0.000136
6	2	2	0.024801	0.517154	0.999909	0.179464	0.381870		0.999999	0.011810
7	2	3	0.013476	0.381870	0.999999	0.271375	0.265887	0.999999		0.021876
8	2	4	0.000131	0.000143	0.036942	0.959252	0.000136	0.011810	0.021876	

180

Tukey HSD test; variable DV_1 (P-Ecc-Hams.sta) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 224.61, df = 57.000

	D	T	{1} - 163.65	{2} - 148.87	{3} - 152.75	{4} - 133.17	{5} - 162.30	{6} - 148.00	{7} - 151.57	{8} - 135.40
1	1	1		0.053862	0.311725	0.000132	0.999992	0.033263	0.197106	0.000134
2	1	2	0.053862		0.991459	0.032334	0.107163	1.000000	0.999140	0.104609
3	1	3	0.311725	0.991459		0.002929	0.481271	0.972302	0.999997	0.012151
4	1	4	0.000132	0.032334	0.002929		0.000133	0.052437	0.006281	0.999766
5	2	1	0.999992	0.107163	0.481271	0.000133		0.069173	0.331677	0.000141
6	2	2	0.033263	1.000000	0.972302	0.052437	0.069173		0.994777	0.157067
7	2	3	0.197106	0.999140	0.999997	0.006281	0.331677	0.994777		0.024606
8	2	4	0.000134	0.104609	0.012151	0.999766	0.000141	0.157067	0.024606	

APT-ConQ

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Tukey HSD test; variable DV_1 (APT-Con-Quads.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 25.234, df = 57.000

	D	T	{1} - 65.650	{2} - 67.350	{3} - 65.200	{4} - 68.550	{5} - 64.500	{6} - 67.650	{7} - 66.150	{8} - 67.650
1	1	1		0.960465	0.999992	0.605858	0.995951	0.909894	0.999984	0.909894
2	1	2	0.960465		0.873933	0.994731	0.626552	1.000000	0.994731	1.000000
3	1	3	0.999992	0.873933		0.421966	0.999846	0.781350	0.998824	0.781350
4	1	4	0.605858	0.994731	0.421966		0.196447	0.999170	0.798526	0.999170
5	2	1	0.995951	0.626552	0.999846	0.196447		0.502104	0.966322	0.502104
6	2	2	0.909894	1.000000	0.781350	0.999170	0.502104		0.980178	1.000000
7	2	3	0.999984	0.994731	0.998824	0.798526	0.966322	0.980178		0.980178
8	2	4	0.909894	1.000000	0.781350	0.999170	0.502104	1.000000	0.980178	

180

Tukey HSD test; variable DV_1 (APT-Con-Quads.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 15.788, df = 57.000

	D	T	{1} - 58.050	{2} - 59.050	{3} - 58.050	{4} - 60.100	{5} - 58.700	{6} - 61.250	{7} - 59.000	{8} - 60.700
1	1	1		0.992742	1.000000	0.729550	0.999556	0.197528	0.994703	0.421857
2	1	2	0.992742		0.992742	0.990264	0.999993	0.654673	1.000000	0.890160
3	1	3	1.000000	0.992742		0.729550	0.999556	0.197528	0.994703	0.421857
4	1	4	0.729550	0.990264	0.729550		0.951095	0.983419	0.987180	0.999738
5	2	1	0.999556	0.999993	0.999556	0.951095		0.472009	0.999998	0.753183
6	2	2	0.197528	0.654673	0.197528	0.983419	0.472009		0.628787	0.999853
7	2	3	0.994703	1.000000	0.994703	0.987180	0.999998	0.628787		0.874134
8	2	4	0.421857	0.890160	0.421857	0.999738	0.753183	0.999853	0.874134	

APT-EccQ

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Tukey HSD test; variable DV_1 (APT-Ecc-Quads.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 47.233, df = 57.000

	D	T	{1} - 66.025	{2} - 68.075	{3} - 68.700	{4} - 70.750	{5} - 66.650	{6} - 65.875	{7} - 67.025	{8} - 68.350
1	1	1		0.980298	0.919225	0.382525	0.999992	1.000000	0.999795	0.960540
2	1	2	0.980298		0.999992	0.919225	0.997833	0.970745	0.999717	1.000000
3	1	3	0.919225	0.999992		0.980298	0.980298	0.895235	0.994036	1.000000
4	1	4	0.382525	0.919225	0.980298		0.565585	0.342710	0.678358	0.953323
5	2	1	0.999992	0.997833	0.980298	0.565585		0.999963	1.000000	0.993469
6	2	2	1.000000	0.970745	0.895235	0.342710	0.999963		0.999484	0.945252
7	2	3	0.999795	0.999717	0.994036	0.678358	1.000000	0.999484		0.998657
8	2	4	0.960540	1.000000	1.000000	0.953323	0.993469	0.945252	0.998657	

180

Tukey HSD test; variable DV_1 (APT-Ecc-Quads.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 46.174, df = 57.000

	D	T	{1} - 62.100	{2} - 66.750	{3} - 62.675	{4} - 66.450	{5} - 57.700	{6} - 59.575	{7} - 65.325	{8} - 66.775
1	1	1		0.388520	0.999995	0.475273	0.460377	0.935784	0.803844	0.381621
2	1	2	0.388520		0.559047	1.000000	0.002279	0.030110	0.997673	1.000000
3	1	3	0.999995	0.559047		0.650868	0.303657	0.833426	0.918455	0.551351
4	1	4	0.475273	1.000000	0.650868		0.003506	0.043635	0.999519	1.000000
5	2	1	0.460377	0.002279	0.303657	0.003506		0.987425	0.016817	0.002199
6	2	2	0.935784	0.030110	0.833426	0.043635	0.987425		0.151425	0.029175
7	2	3	0.803844	0.997673	0.918455	0.999519	0.016817	0.151425		0.997403
8	2	4	0.381621	1.000000	0.551351	1.000000	0.002199	0.029175	0.997403	

APT-ConH

60

Tukey HSD test; variable DV_1 (APT-Con-Hams.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 41.143, df = 57.000

	D	T	{1} - 42.300	{2} - 37.600	{3} - 34.900	{4} - 36.100	{5} - 40.350	{6} - 36.650	{7} - 41.500	{8} - 34.000
1	1	1		0.302671	0.012606	0.062773	0.978058	0.119222	0.999927	0.003297
2	1	2	0.302671		0.883094	0.995383	0.872962	0.999770	0.541652	0.639155
3	1	3	0.012606	0.883094		0.998903	0.147923	0.988234	0.037830	0.999839
4	1	4	0.062773	0.995383	0.998903		0.430388	0.999994	0.155875	0.966912
5	2	1	0.978058	0.872962	0.147923	0.430388		0.606825	0.999166	0.052106
6	2	2	0.119222	0.999770	0.988234	0.999994	0.606825		0.265589	0.892736
7	2	3	0.999927	0.541652	0.037830	0.155875	0.999166	0.265589		0.010913
8	2	4	0.003297	0.639155	0.999839	0.966912	0.052106	0.892736	0.010913	

180

Tukey HSD test; variable DV_1 (APT-Con-Hams.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 47.784, df = 57.000

	D	T	{1} - 49.850	{2} - 46.750	{3} - 48.800	{4} - 48.250	{5} - 49.250	{6} - 47.800	{7} - 49.550	{8} - 48.900
1	1	1		0.845162	0.999727	0.995667	0.999994	0.980936	1.000000	0.999860
2	1	2	0.845162		0.980936	0.997116	0.944047	0.999727	0.902212	0.975072
3	1	3	0.999727	0.980936		0.999997	0.999999	0.999803	0.999972	1.000000
4	1	4	0.995667	0.997116	0.999997		0.999803	0.999999	0.998865	0.999989
5	2	1	0.999994	0.944047	0.999999	0.999803		0.997669	1.000000	1.000000
6	2	2	0.980936	0.999727	0.999803	0.999999	0.997669		0.992480	0.999629
7	2	3	1.000000	0.902212	0.999972	0.998865	1.000000	0.992480		0.999989
8	2	4	0.999860	0.975072	1.000000	0.999989	1.000000	0.999629	0.999989	

APT-EccH

60

Tukey HSD test; variable DV_1 (APT-Ecc-Hams.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 71.507, df = 57.000

	D	T	{1} - 28.400	{2} - 23.475	{3} - 23.725	{4} - 25.250	{5} - 29.325	{6} - 24.725	{7} - 20.975	{8} - 30.525
1	1	1		0.595194	0.656381	0.934983	0.999970	0.865007	0.121595	0.992808
2	1	2	0.595194		1.000000	0.997659	0.374545	0.999772	0.981279	0.164562
3	1	3	0.656381	1.000000		0.999134	0.431073	0.999949	0.968101	0.199102
4	1	4	0.934983	0.997659	0.999134		0.791477	0.999999	0.749113	0.508847
5	2	1	0.999970	0.374545	0.431073	0.791477		0.674381	0.053181	0.999827
6	2	2	0.865007	0.999772	0.999949	0.999999	0.674381		0.852479	0.385563
7	2	3	0.121595	0.981279	0.968101	0.749113	0.053181	0.852479		0.015757
8	2	4	0.992808	0.164562	0.199102	0.508847	0.999827	0.385563	0.015757	

180

Tukey HSD test; variable DV_1 (APT-Ecc-Hams.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 103.48, df = 57.000

	D	T	{1} - 34.600	{2} - 32.900	{3} - 28.300	{4} - 33.300	{5} - 24.050	{6} - 27.275	{7} - 28.925	{8} - 28.650
1	1	1		0.999489	0.518117	0.999914	0.035323	0.323960	0.646070	0.589959
2	1	2	0.999489		0.839541	1.000000	0.128645	0.656134	0.917660	0.887036
3	1	3	0.518117	0.839541		0.774621	0.887036	0.999983	0.999999	1.000000
4	1	4	0.999914	1.000000	0.774621		0.097093	0.574538	0.871146	0.832015
5	2	1	0.035323	0.128645	0.887036	0.097093		0.972257	0.796026	0.839541
6	2	2	0.323960	0.656134	0.999983	0.574538	0.972257		0.999580	0.999875
7	2	3	0.646070	0.917660	0.999999	0.871146	0.796026	0.999580		1.000000
8	2	4	0.589959	0.887036	1.000000	0.832015	0.839541	0.999875	1.000000	

TRTD-ConQ

60

Tukey HSD test; variable DV_1 (TRTD-Con-Quads.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = .00989, df = 57.000

	D	T	{1} - .63550	{2} - .61350	{3} - .62100	{4} - .63550	{5} - .63800	{6} - .59050	{7} - .65800	{8} - .59400
1	1	1		0.996730	0.999793	1.000000	1.000000	0.839205	0.996240	0.887730
2	1	2	0.996730		0.999998	0.996730	0.993633	0.995692	0.846722	0.998505
3	1	3	0.999793	0.999998		0.999793	0.999408	0.976969	0.935430	0.988577
4	1	4	1.000000	0.996730	0.999793		1.000000	0.839205	0.996240	0.887730
5	2	1	1.000000	0.993633	0.999408	1.000000		0.798871	0.998243	0.854047
6	2	2	0.839205	0.995692	0.976969	0.839205	0.798871		0.399267	1.000000
7	2	3	0.996240	0.846722	0.935430	0.996240	0.998243	0.399267		0.468599
8	2	4	0.887730	0.998505	0.988577	0.887730	0.854047	1.000000	0.468599	

180

Tukey HSD test; variable DV_1 (TRTD-Con-Quads.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = .00104, df = 57.000

	D	T	{1} - .32800	{2} - .31550	{3} - .33450	{4} - .31800	{5} - .32750	{6} - .29500	{7} - .31800	{8} - .30000
1	1	1		0.920734	0.998213	0.975448	1.000000	0.039563	0.975448	0.130005
2	1	2	0.920734		0.580725	0.999997	0.935242	0.484044	0.999997	0.793401
3	1	3	0.998213	0.580725		0.737415	0.997105	0.006435	0.737415	0.026644
4	1	4	0.975448	0.999997	0.737415		0.981627	0.335540	1.000000	0.645181
5	2	1	1.000000	0.935242	0.997105	0.981627		0.044974	0.981627	0.144634
6	2	2	0.039563	0.484044	0.006435	0.335540	0.044974		0.335540	0.999687
7	2	3	0.975448	0.999997	0.737415	1.000000	0.981627	0.335540		0.645181
8	2	4	0.130005	0.793401	0.026644	0.645181	0.144634	0.999687	0.645181	

TRTD-EccQ

60

Tukey HSD test; variable DV_1 (APT-Ecc-Quads.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = .01334, df = 30.000

	D	T	{1} - 1.2500	{2} - 1.2918	{3} - 1.3955	{4} - 1.3482	{5} - 1.2482	{6} - 1.3282	{7} - 1.3582	{8} - 1.4618
1	1	1		0.988444	0.096914	0.502491	1.000000	0.753763	0.381757	0.003737
2	1	2	0.988444		0.435047	0.941143	0.985197	0.994988	0.872960	0.031537
3	1	3	0.096914	0.435047		0.976772	0.089617	0.865187	0.994178	0.872960
4	1	4	0.502491	0.941143	0.976772		0.479653	0.999898	0.999999	0.322608
5	2	1	1.000000	0.985197	0.089617	0.479653		0.732478	0.361430	0.003398
6	2	2	0.753763	0.994988	0.865187	0.999898	0.732478		0.998520	0.157599
7	2	3	0.381757	0.872960	0.994178	0.999999	0.361430	0.998520		0.435047
8	2	4	0.003737	0.031537	0.872960	0.322608	0.003398	0.157599	0.435047	

180

Tukey HSD test; variable DV_1 (APT-Ecc-Quads.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = .00682, df = 30.000

	D	T	{1} - .61455	{2} - .68818	{3} - .62091	{4} - .67000	{5} - .59000	{6} - .64182	{7} - .68818	{8} - .73364
1	1	1		0.442546	1.000000	0.760675	0.996492	0.993299	0.442546	0.037138
2	1	2	0.442546		0.554455	0.999500	0.135884	0.885240	1.000000	0.895078
3	1	3	1.000000	0.554455		0.852683	0.985953	0.998740	0.554455	0.056299
4	1	4	0.760675	0.999500	0.852683		0.340637	0.991846	0.999500	0.620025
5	2	1	0.996492	0.135884	0.985953	0.340637		0.815763	0.135884	0.006603
6	2	2	0.993299	0.885240	0.998740	0.991846	0.815763		0.885240	0.192373
7	2	3	0.442546	1.000000	0.554455	0.999500	0.135884	0.885240		0.895078
8	2	4	0.037138	0.895078	0.056299	0.620025	0.006603	0.192373	0.895078	

TRTD-ConH

60

Tukey HSD test; variable DV_1 (TRTD-Con-Hams.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = .01125, df = 57.000

	D	T	{1} - .69200	{2} - .62500	{3} - .60950	{4} - .60450	{5} - .68350	{6} - .60150	{7} - .68350	{8} - .52300
1	1	1		0.492743	0.234044	0.174364	0.999996	0.144471	0.999996	0.000246
2	1	2	0.492743		0.999789	0.998636	0.659163	0.996698	0.659163	0.065297
3	1	3	0.234044	0.999789		1.000000	0.363811	0.999998	0.363811	0.185293
4	1	4	0.174364	0.998636	1.000000		0.283265	1.000000	0.283265	0.247477
5	2	1	0.999996	0.659163	0.363811	0.283265		0.240697	1.000000	0.000425
6	2	2	0.144471	0.996698	0.999998	1.000000	0.240697		0.240697	0.290797
7	2	3	0.999996	0.659163	0.363811	0.283265	1.000000	0.240697		0.000425
8	2	4	0.000246	0.065297	0.185293	0.247477	0.000425	0.290797	0.000425	

180

Tukey HSD test; variable DV_1 (TRTD-Con-Hams.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = .00161, df = 57.000

	D	T	{1} - .33300	{2} - .32200	{3} - .31850	{4} - .32000	{5} - .32700	{6} - .31150	{7} - .33200	{8} - .32800
1	1	1		0.987978	0.944609	0.968955	0.999756	0.691979	1.000000	0.999928
2	1	2	0.987978		0.999994	1.000000	0.999928	0.990879	0.993214	0.999756
3	1	3	0.944609	0.999994		1.000000	0.997538	0.999328	0.961918	0.995051
4	1	4	0.968955	1.000000	1.000000		0.999328	0.997538	0.980137	0.998348
5	2	1	0.999756	0.999928	0.997538	0.999328		0.922599	0.999928	1.000000
6	2	2	0.691979	0.990879	0.999328	0.997538	0.922599		0.740224	0.895615
7	2	3	1.000000	0.993214	0.961918	0.980137	0.999928	0.740224		0.999984
8	2	4	0.999928	0.999756	0.995051	0.998348	1.000000	0.895615	0.999984	

TRTD-EccH

60

Tukey HSD test; variable DV_1 (TRTD-Ecc-Hams.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = .03358, df = 57.000

	D	T	{1} - 1.4815	{2} - 1.4205	{3} - 1.4890	{4} - 1.4720	{5} - 1.4515	{6} - 1.3960	{7} - 1.5690	{8} - 1.3525
1	1	1		0.963798	1.000000	1.000000	0.999553	0.817010	0.798957	0.352252
2	1	2	0.963798		0.933823	0.986004	0.999446	0.999884	0.191333	0.936213
3	1	3	1.000000	0.933823		0.999990	0.998026	0.745424	0.862250	0.282981
4	1	4	1.000000	0.986004	0.999990		0.999965	0.890782	0.703530	0.451098
5	2	1	0.999553	0.999446	0.998026	0.999965		0.978513	0.473106	0.681841
6	2	2	0.817010	0.999884	0.745424	0.890782	0.978513		0.074747	0.994929
7	2	3	0.798957	0.191333	0.862250	0.703530	0.473106	0.074747		0.009727
8	2	4	0.352252	0.936213	0.282981	0.451098	0.681841	0.994929	0.009727	

180

Tukey HSD test; variable DV_1 (TRTD-Ecc-Hams.sta) Approximate Probabilities for Post Hoc Tests
Error: Within MSE = .01398, df = 57.000

	D	T	{1} - .60950	{2} - .61300	{3} - .66750	{4} - .67200	{5} - .73500	{6} - .70400	{7} - .69350	{8} - .67750
1	1	1		1.000000	0.776295	0.704921	0.028692	0.205191	0.340646	0.610299
2	1	2	1.000000		0.825982	0.761083	0.036901	0.245444	0.394974	0.671179
3	1	3	0.776295	0.825982		1.000000	0.619099	0.976080	0.996856	0.999995
4	1	4	0.704921	0.761083	1.000000		0.696574	0.988771	0.999086	1.000000
5	2	1	0.028692	0.036901	0.619099	0.696574		0.990704	0.952044	0.783739
6	2	2	0.205191	0.245444	0.976080	0.988771	0.990704		0.999993	0.996448
7	2	3	0.340646	0.394974	0.996856	0.999086	0.952044	0.999993		0.999874
8	2	4	0.610299	0.671179	0.999995	1.000000	0.783739	0.996448	0.999874	

RPE

‘Central’

Tukey HSD test; variable DV_1 (Spreadsheet1) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 2.3480, df = 95.000

	TIME	{1} - 12.200	{2} - 13.450	{3} - 14.850	{4} - 14.050	{5} - 14.850	{6} - 14.950
1	T15		0.112528	0.000126	0.003284	0.000126	0.000123
2	T30	0.112528		0.052721	0.816973	0.052721	0.030170
3	T45	0.000126	0.052721		0.567334	1.000000	0.999952
4	T75	0.003284	0.816973	0.567334		0.567334	0.434773
5	T90	0.000126	0.052721	1.000000	0.567334		0.999952
6	T105	0.000123	0.030170	0.999952	0.434773	0.999952	

‘Local’

Tukey HSD test; variable DV_1 (Spreadsheet4) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 1.9792, df = 95.000

	TIME	{1} - 11.600	{2} - 12.600	{3} - 14.000	{4} - 13.450	{5} - 14.150	{6} - 15.250
1	T15		0.226275	0.000127	0.001070	0.000123	0.000122
2	T30	0.226275		0.026114	0.402250	0.009589	0.000122
3	T45	0.000127	0.026114		0.817965	0.999469	0.064638
4	T75	0.001070	0.402250	0.817965		0.617940	0.001557
5	T90	0.000123	0.009589	0.999469	0.617940		0.142894
6	T105	0.000122	0.000122	0.064638	0.001557	0.142894	

Heart Rate

Repeated Measures Analysis of Variance (Spreadsheet1) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 30.89781

	SS	Degr. of - Freedom	MS	F	p
Intercept	3388113	1	3388113	3548.971	0.00
Error	18139	19	955		
TIME	119609	7	17087	270.343	0.00
Error	8406	133	63		

Tukey HSD test; variable DV_1 (Spreadsheet1) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 63.205, df = 133.00

	TIME	{1} - 94.000	{2} - 165.30	{3} - 161.55	{4} - 160.30	{5} - 102.90	{6} - 158.55	{7} - 158.80	{8} - 162.75
1	T0		0.000032	0.000032	0.000032	0.009541	0.000032	0.000032	0.000032
2	T15	0.000032		0.812287	0.489422	0.000032	0.127076	0.161079	0.972467
3	T30	0.000032	0.812287		0.999677	0.000032	0.934115	0.958299	0.999754
4	T45	0.000032	0.489422	0.999677		0.000032	0.997122	0.998928	0.978039
5	T60	0.009541	0.000032	0.000032	0.000032		0.000032	0.000032	0.000032
6	T75	0.000032	0.127076	0.934115	0.997122	0.000032		1.000000	0.706447
7	T90	0.000032	0.161079	0.958299	0.998928	0.000032	1.000000		0.767746
8	T105	0.000032	0.972467	0.999754	0.978039	0.000032	0.706447	0.767746	