THE EFFECT OF CONCRETE AND ARTIFICIAL TURF SURFACES ON LOWER LIMB MUSCLE FATIGUE AMONG UFS NETBALL PLAYERS

by

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DECLARATION

I, Dr. Gawie van Jaarsveld, hereby declare that the work on which this dissertation is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work or any part of it has been, is being, or has to be submitted for another degree in this or any other University.

It is being submitted for the degree of Masters of Sport Medicine in the School of Medicine in the Faculty of Health Sciences of the University of the Free State, Bloemfontein.

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ABSTRACT

Objective: The present study sought to determine the effect of synthetic and concrete surface on lower limb muscle fatigue on UFS netball players. Fatigue increases the risk for injuries and play surfaces with less absorbing qualities leads to an increased incidence of injuries. The hypothesis of this study was that the less absorbing concrete surface will have a more significant effect on lower limb muscle fatigue by means of jumping performance and muscle activation, which leads to an increased incidence of injuries.

Design: This study was an experimental crossover study, which assessed lower limb muscle fatigue on two different netball play surfaces (concrete and synthetic turf).
Nine netball players from the University of the Free State senior netball team where recruited. The vertical jump performance (jump height, peak power, peak velocity) were measured with a Tendo power analyser and lower limb muscle activation with surface Electromyography. Measurements were taken before and after a fatiguing protocol on the two separate surfaces over the span of two days.

Results: The results did not find any significant change in vertical jumping performance or muscle activation after the fatiguing protocol on the two separate surfaces, except for a significant decrease of Tibialis Anterior (TA) activation after the fatiguing protocol (FP) on the concrete surface during the propulsion phase of the vertical jump (VJ) ($p = 0.03$). There was however also a significant difference in muscle activation of Semitendinosis (ST) prior the FP on the two separate surfaces during the landing phase of the VJ ($p = 0.03$).

Conclusion: This study could not determine that the less absorbing concrete surface had a more significant effect on muscle fatigue than the synthetic surface. It could however be postulated 1) that the concrete surface had a greater effect on the post-activation potentiation and jumping performance than the synthetic surface; 2) the differences in activation of the ST before and after the FP on the synthetic surface during the landing phase of the jump was possibly due to a change in biomechanics in response to the surface and should be investigated in future research, and 3) the concrete surface had a significant effect on TA activation during the propulsion of the jump, but whether the change is brought on by fatigue and whether TA shows the first signs of fatigue compared to other muscle groups is still debatable.

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LIST OF ABBREVIATIONS

ACL	Anterior cruciate ligament
AJ	Abalakov jump
ARV	Averaged rectified value
BF	Bicep Femoris
BW	Body weight
cm	Centimetre
CNS	Central nervous system
CMJ	Countermovement jump
DVJ	Drop vertical jump
EMG	Electromyography
sEMG	Surface Electomyography
EMGFT	Electromyographic fatigue threshold
FP	Fatiguing protocol
GN	Gastrocnemius
GRF	Ground reaction force
Kg	Kilogram
LLIP	Lower-limb injury prevention
M	Meter
MVC	Maximal volantry contraction
MUP	Muscle unit potential
MFPV	Muscle fiber propagation velocity
MUAP	Motor unit action potential
N	Newton
N.s	Newton seconds (unit for impulse)
NFL	National Football league
NMC	Neuromuscular control
PAP	Post-activation potentation
RF	Rectus Femoris
RLC	Regulatory light chains
RMS	Root mean squared value
s	Seconds
SD	Standard deviation
SENIAM	Surface electromyography for a non-invasive assessment of muscles
SJ	Squat jump
ST	Semitendinosis

TA	Tibialis Anterior
TFL	Tensor Fasciae Latae
vGRF	Vertical ground reaction force
VM	Vastus Medialis
VMO	Vastus Medialis Oblique
uV	Micro volt

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Chapter 1
INTRODUCTION

1.1 SCOPE OF RESEARCH

Netball is a high-strategy, high intensity sport that requires the precise execution of technical motor skills with and without the ball. Netball also requires the application of tactical knowledge when making decisions during many explosive sprints, abrupt stops, change of direction and landing movements (Bock-Jonathan *et al*., 2007; McManus *et al*., 2006; Venter, 2005). Literature (Hume and Steele, 2000) stated that given the physical demands of netball, there is a heightened risk of injury and thus a need to better appreciate the risk factors involved.

Muscle fatigue is defined as a failure to maintain the required or expected force in a muscle and is accompanied by changes in muscle electric activity (Dimitrova and Dimitrov, 2003) which often alters the biomechanical and neuromuscular function of a limb (Benjaminse *et al*., 2008). These changes become deterministic factors in the safety of sports such as netball involving dynamic movements where coordinated eccentric muscle contractions are pivotal in energy absorption and force dissipation (Otago, 2004).

Previous research has shown that the musculoskeletal system displays a reduced capacity to attenuate impact forces in the presence of muscle fatigue, resulting in a significant increase in the dynamic loading experienced by the human musculoskeletal system (Voloshin *et al*., 1998). These decreased abilities to attenuate the impact forces increase the injury potential when greater stress is placed on passive structures such as menisci and ligaments (Hewitt, 1996). Bearing in mind the nature of netball and the fact that a netball player has to contend with numerous sprints and jump landings with its associated ground reaction forces (GRF), it is important to consider the effect of the playing surface on muscle fatigue.

Understanding how impact forces can be minimized, one has to look at the impulse momentum relationship. Given that momentum ($kg.m.s^{-1}$) is determined by a person's body mass and the velocity with which he or she collide with the ground and the direct relationship with impulse (force x time), the GRF experienced by a person during landing can be altered if the impulse and momentum is attenuated over a greater time (Robertson, 2004). Therefore, a softer landing surface will increase the time over which the impulse has to be controlled, resulting in lower GRFs compared to a landing under identical circumstances onto a harder surface. Harder play surfaces would require more eccentric muscle force to contend with the higher GRFs and would be more tiresome on the neuromuscular system.

The effect of play surfaces on injury potential have been illustrated through various studies, as seen in the association of harder play surfaces on overuse injuries (Brukner, 2012) and high friction play surfaces on anterior cruciate ligament (ACL) injuries (Olsen *et al.*, 2003; Orchard *et al.*, 2005). Twofold increases in injury potential for elite male soccer players have also been reported when playing on artificial turf compared to grass (Arnason *et al.*, 2008). While the fact that play surfaces have an effect on injury potential is undisputed, conclusive evidence on the mechanisms through which the play surfaces affect the neuromuscular and musculoskeletal system's ability to prevent injuries remains scarce. While muscle fatigue may be a contributing factor to injuries (McLean and Samorezov, 2009), limited research has been done to compare muscle fatigue on different play surfaces. As far as could be established, no research has been done to investigate the effect of different netball play surfaces on muscle fatigue among netball players.

1.2 AIM OF RESEARCH

The aim of this study was to assess the effect of different netball play surfaces on lower limb muscle fatigue.

1.3 RESEARCH QUESTIONS

In order to achieve the aims set out in Section 1.2, the following research questions were asked:

1) Is there a significant difference in jump performances following a netball simulated fatiguing protocol on different play surfaces?
2) Is there a significant difference in lower limb surface electromyography (EMG) activity following a netball simulated fatiguing protocol on different play surfaces?

1.4 DISSERTATION SYNTHESIS

This dissertation consists of a brief introduction (Chapter 1), followed by an overview of relevant literature (Chapter 2) which informed the problem statement and subsequent research topic, the methodology, data analysis and interpretation thereof. Chapter 3 provides an account of the research process preceding data collection, the data collection process itself, as well as data processing and analysis procedures. Chapter 4 reports on the results from the research project which is followed by Chapter 5 which discuss the findings in relation to the literature, the implications thereof and the limitations of the study. The empirical part of the dissertation is brought to a close with Chapter 6 which summarise the main findings and concludes with recommendations for further research. The final chapter (Chapter 7) reflects on the research process, lessons learned and personal growth achieved through this process.

Chapter 2

LITERATURE REVIEW

This chapter will review the literature relevant to the research aims set out in Section 1.2. An overview of netball with its sport-specific skills and associated risks will be explored. Thereafter, landing and associated factors in relation to netball injuries will be investigated. The different surfaces and lower limb muscle fatigue will highlight what could typically be expected in an electromyography (EMG) analysis of this sport-specific skill. Finally, literature relevant to inform sound methodological approaches (Chapter 3) to achieve the aims of this research will also be reviewed.

2.1 INTRODUCTION

Netball is a dynamic, fast, skillful and predominantly female team sport. Netball is also popular in Commonwealth countries including South Africa where it is played on a daily basis in schools, clubs and at regional level. Venter (2005) reported that there are approximately half a million secondary school (age 16 – 19) players and 9 700 adult players in South Africa. A national netball league is played on a weekly basis and the national netball team participates internationally on a regular basis (Venter, 2005).

According Murphy *et al* (2003) prevention and intervention of sport injuries have become focal points for researchers and clinicians. Many injury risk factors, both extrinsic (those outside of the body) and intrinsic (those from within the body), have been suggested. Extrinsic risk factors include level of competition, skill level, shoe type, use of ankle tape or brace, and playing surface. Intrinsic risk factors include age, sex, previous injury and inadequate rehabilitation, aerobic fitness, body size, limb dominance, flexibility, limb girth, muscle strength, reaction time, postural stability, anatomical alignment, and foot morphology (Taimela *et al*., 1990).

Despite the highly publicized and controversial recognition of injury resulting from netball, only limited well conducted studies have documented the incidence and nature of netball injuries. To date, epidemiological research on netball injuries originates mainly from Australia, New Zealand and South Africa (Langeveld *et al*., 2014; Mcgrath and Ozanne-smith, 1998) despite the fact that netball is originally a British game played by several countries within the Commonwealth.

2.2 NETBALL

2.2.1 Nature of netball

Venter (2005) described netball as a team sport played by seven players. It is an interval type game played for 60 minutes, with predominantly high intensity, short bursts of movements and less intense recovery periods. Movements that typical occur includes short sprints of 2-3m at a time, jumping, pivoting and catching. It is a physically demanding game that requires a player to be well conditioned in high levels of endurance, strength, speed, power, agility and flexibility. Netball has also been described as a game reliant on rapid acceleration to "break free" from an opponent, sudden and rapid changes in direction in combination with leaps to receive a pass, intercept a ball or rebound after attempting a goal (Steele and Milburn, 1987b).

Many of the skills involve explosive movements, quick changes of directions, different types of passes plus a variety of ways to receive and dispose of the ball. Jumping and landing activities forms a major skill component of netball, including deceleration and twisting and hyperextension of the knee after landing from a jump and is particularly dangerous maneuvers governing most netball landings (Otago, 2004).

According to Ferreira and Spamer (2010) a defect in certain parameters such as biomechanics, anthropometry and physical/motor abilities (agility, balance and explosive power) could influence a netball player's susceptibility to injury, as well as the player's physical performance during a game. Even the current rules related to stepping at landing from a jump restrict the player to taking only one step after landing and contribute to the high incidence of lower limb muscle injuries especially anterior cruciate ligament (ACL) injuries (Chappell *et al*., 2007).

According to Hopper *et al.* (1992) the nature of landing techniques in netball is complex as they are influenced by both extrinsic and intrinsic factors. The extrinsic factors include the position of the team and opposition players, height and direction of movement towards the ball, footfall patterns, receipt and disposal of the ball, and the relationship between the court surface and the shoe. Hopper *et al.* (1992) also stated that besides these external factors, the player is also required to integrate the intrinsic demands of neuromuscular coordination, spatial orientation and proprioception during this complex task of landing and generate an appropriate intrinsic response to the extrinsic perturbations. Ultimately, the natural landing process of vertical jumps possessing considerable horizontal force and velocity components is restricted by the "footwork rule" which only allows one-and-a-half steps (at most) following a jump while in possession of the ball. This restriction calls for rapid deceleration brought about by substantial eccentric lower limb muscle contractions to control the momentum and impulse of the ground reaction force, while retaining sufficient stability to avoid infringement of the footwork rule (Hopper *et al*., 1992).

It is well known that epidemiological studies provide the proof of risks for sports injuries, as well as the effects of preventative and therapeutic intervention. Most sporting activities entail a certain amount of risk of injury, even if reasonable preventative measures are put in place to prevent these injury risks. According to literature (Drawer and Fuller, 2002) governing bodies should be aware of the risks in sport and steps should be taken to limit these injury risks.

2.3 NETBALL INJURIES

2.3.1 Injuries sustained by netball players

The majority of injuries sustained by netball players occur at the lower limbs, specifically the ankle and knee joints (Ferreira and Spamer, 2010; Hopper and Elliott, 1993; Hopper *et al*, 1995a; Hopper *et al*., 1995b; Smith *et al*., 2005 and Langeveld *et al*., 2014). Hopper (1986) investigated the incidence of netball injuries and conditions related to these injuries on Western Australia netball players with the ultimate aim to implement preventative measures. The body parts most commonly injured were the ankle (58.2%), knee (15.2%) and fingers (13.3%) (Hopper, 1986). In a more recent South-African survey, different results were found. The most common injuries were the ankle joint (36.1%), knee (18.5%) and wrist, hand and fingers (16.1%) (Langeveld *et al*., 2014). It was also found that incorrect landing techniques, slips and falls were among the most common mechanism of injury (Hopper, 1986).

Elite players are at higher risk for sustaining an injury due to the increased neuromuscular and musculoskeletal demand associated with an increase in level of play (Hopper, 1986). While no relationship was evident between the position of play and the injury incidence, a strong relationship was noted between the occurrences of new and recurrent injuries and the quarter of play in which it occurred (Hopper, 1986).

Hopper (1986) also stated that bona fide first time injuries mostly occurred during the first quarter of play, which was attributed to possible inadequate warm-ups, while re-injuries mostly occurred during the second quarter of play and were attributed to overstraining and fatigue. However, the study indicates that there was a statistical significant association between the type of injury and the quarter of occurrence of injury. New injuries were more frequent and occur during the first quarter, whereas the chronic injuries recurred during the second quarter. However, no significant relationship was found between the type of injury and the time of injury occurrence within each quarter of play (Table 2.1) (Hopper, 1986). Interestingly, different results were found in the more recent South-African survey by Langeveld *et al.* (2014). Most of the injuries occurred between the middle 30 min of the game and peaked during the third quarter. This could be contributed to the fact that in recent game play, fresh substitutes are made in the last quarter of the game that is less prone to injury (Langeveld *et al*., 2014).

Table 2.1: Injury occurrence (%) according to quarter of play

Type of injury	Quarter of play				
	1st	2nd	3rd	4th	Total
New injury	31.3	18.8	23.2	26.8	71.3
Reinjury	13.3	35.6	28.9	22.2	28.7

Hopper, (1986).

The objective of the recent study by Langeveld *et al.* (2014) was to assess the incidence and severity of injuries in a cohort of elite South African netball players. A high incidence of 500.7 injuries per 1000 playing hours was reported. Most injuries occurred to the ankle joint (34%), followed by the knee (18%), fingers, hand and wrist (15%). Ligaments were the most commonly injured structures. However, the majority of injuries were minor. Factors associated with injuries included tournament play, previous injury, lack of core stability, neuromuscular and proprioceptive training. Therefore, Langeveld *et al*. (2014) recommended in his study that training modalities such as core stability, neuromuscular control and biomechanics (improved landing technique) should be incorporated in netball players' training programmes for the prevention of injuries. Finch *et al*. (2011) stated in this regard that before efficient injury-prevention measures including exercise training programs, can be successfully incorporated into usual player safety behaviors and practices, it is necessary to know about likely barriers towards, and motivators for, their uptake. To date, there has been surprisingly little attention given to these factors in relation to the delivery and uptake of exercise training interventions for injury prevention, with only one study in netball reporting beliefs related to specific exercise training programs for lower-limb injury prevention (LLIP) among netball coaches (Saunders *et al*., 2010).

Interestingly, Langeveld *et al*. (2014) reported that there was a tendency for injuries to increase in each quarter of the game, with the majority of injuries occurring in the middle 30 minutes, reaching a peak in the third quarter (26%). The final quarter showed a decrease in the amount of injuries that occurred. Players in goal defence also sustained the majority (22%) of injuries, which corresponds with findings in the limited literature, followed by injuries in players playing in the centre position (17.6%) (Hopper *et al*., 1995a). There was however no significant association in Langeveld *et al*. (2012) study between the position of the player and the time of injury (r = 0.1131; p = 0.1073), which is also in accordance with the literature (Hopper *et al*., 1995a).

As reported in earlier studies, ligaments were the most commonly injured structures in netball players (Finch *et al*., 2002; Hopper and Elliot, 1993; Hopper *et al*., 1995a; Hume and Steel, 2000; McManus *et al*., 2006). The same tendency occurs in South Africa where Langeveld *et al*. (2014) indicated that ligaments were involved in 46.8% of the total injuries in his study. Bruising/haematomas were found to be the second most common injuries that were sustained (14.8%), followed by muscle (12.3%), meniscus (8.9%) and other bone injuries (5.4%). Eighty-nine per cent (89%) of ankle injuries involved the ligaments, of which 38% were to the lateral ligament complex and 4.9% to the deltoid ligament. The majority of injuries at the knee were sustained to the menisci (36.1%). Haematomas/bruising (19.4%) and lacerations (11.1%) also occurred at the knee joint. Injuries to the medial collateral ligament (2.5%), lateral collateral ligament (1.2%), anterior cruciate ligament (0.6%) and patellofemoral pain were uncommon (Figures 2.1 and 2.2).

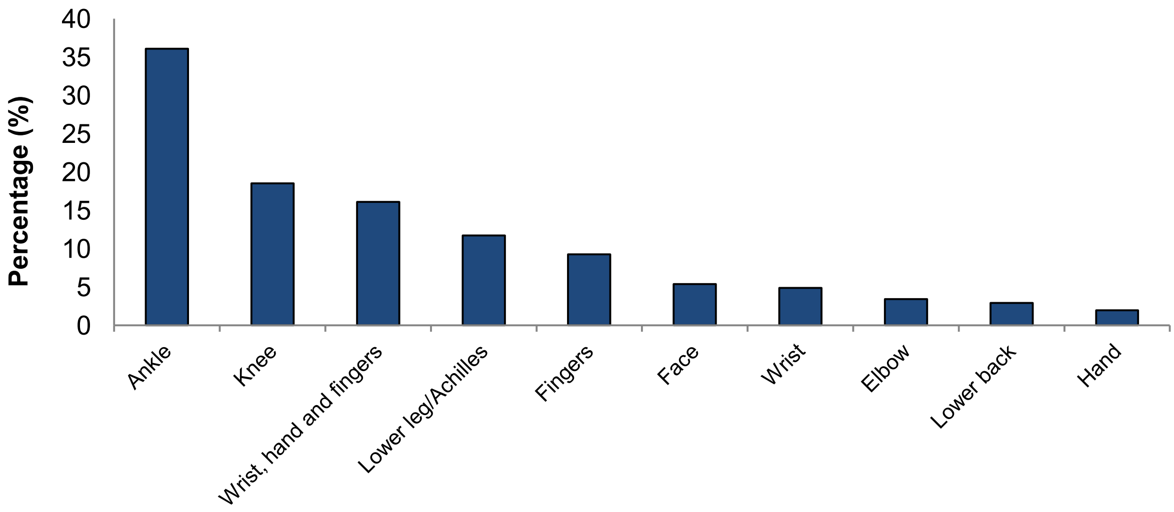

Figure 2.1 Anatomical injury sites in South African elite netball players (Langeveld et al., 2014).

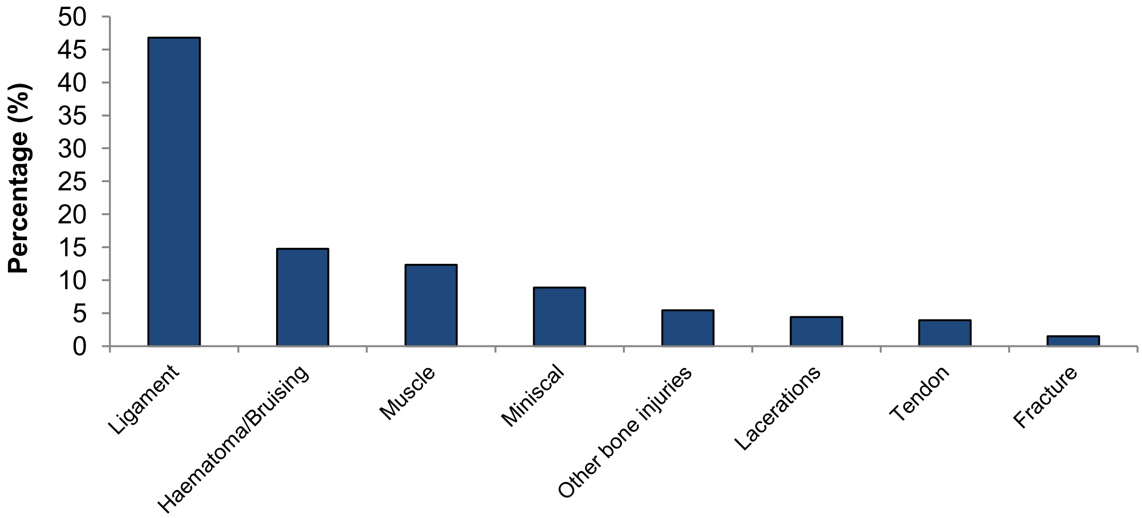

Figure 2.2 Frequency of different injury types (Langeveld et al., 2014).

In the study of Langeveld *et al.* (2014) the ankle suffered the majority (36.1%) of the serious injuries, where a player was not able to compete for longer than 7 days. This is in contrast to the results of Hopper *et al*. (1995a), where a higher number of serious knee injuries were found. Ferreira and Spamer (2010) concluded that the body parts mostly affected by injuries in netball were the ankle joint (39.13%), followed by the knee joint (28.26%) and thirdly the cervical region (8.69%).

2.3.2 Injuries sustained by netball players on different surfaces

A higher incidence of injuries was noted on surfaces (butamin and plexipave) possibly due to impropriate frictional characteristics between play surface and treads on the netball shoes (Hopper, 1986). Another study done by Hopper *et al.* (1999) indicates that the lateral ligaments of the ankle are the most common sites of injury in netball, mostly when landing from a jump, with the ankle and subtalar joints most commonly in a position of plantar flexion and inversion respectively. The study further found that the forces associated with landings in netball have been shown to be considerable. It is apparent that muscle activity and movement at lower limb joints can influence the magnitude of impact forces and resultant joint loadings during landing from a jump and subsequent injuries.

The playing surface is an extrinsic factor that can play a major role in injury rates (Pasanen *et al*., 2008). The hardness and the surface-to-shoe interface resistance seem to be two factors that need to be considered in sports injuries. An increase in resistance of the interface seems to be a risk factor for traumatic injuries in sports that require rotational movements (Pasanen *et al*., 2008). It is the opinion of Murphy *et al*. (2003) that the hardness of the surface can influence the ground reaction forces and can contribute to overloading of tissues, for example bone, ligaments, muscle and tendons.

Other studies on the incidence of injuries on different play-surfaces have also shown that harder play surfaces are associated with overuse injuries (Brukner, 2012) while play surfaces with higher friction have an increased risk for ACL injuries (Olsen *et al*., 2003; Orchard *et al*., 2005). A study done by Arnason *et al.* (2008) found a twofold increase in the incidence of injuries on artificial turf compared with grass or gravel in elite male soccer athletes. A recent study (Dragoo *et al*., 2012) reported that the rate of ACL injury on artificial surfaces is 1.39 times higher than the injury rate on grass surfaces in National Football league (NFL) players and that non-contact ACL injuries occurred more frequently on artificial turf surfaces. Previous researchers hypothesized that more injuries may occur on artificial turf compared to other surfaces because of its stiffness and the increased frictional force at the shoe/surface interface (Inklaar, 1994).

Potential mechanisms for differing injury patterns on different surfaces include increased peak torque properties and rotational stiffness properties of shoe-surface interfaces, differing foot loading patterns, decreased impact attenuation properties and detrimental physiological responses compared with natural turf (Orchard *et al*., 2005). A study done by Olsen *et al*. (2003) concluded that playing on wooden floors resulted in a lower injury incidence than on artificial floors. The study also indicated that there could be differences in incidence between the different types of artificial floors as well.

It has to be acknowledged that the friction theory, as described in the section above, is only a hypothesis and more research is needed to determine why play surfaces with different friction and absorbing qualities cause a higher incidence of injuries. It is uncertain whether play surfaces with different friction and absorption qualities have an effect on the magnitude of muscle fatigue and the subsequent higher risk of injuries it entails. While it is known that muscle fatigue may be a contributing factor to injuries (McLean and Samorezov, 2009), no research has been done to compare muscle fatigue on different play-surfaces, as far as could be established.

2.3.3 Injuries sustained per playing hours in netball

Langeveld *et al*. (2014) also calculated the injury rate in South African Netball players at 500.7 injuries per 1000 playing hours. The direct probability that a player could sustain an injury was calculated at 0.15 per player. Ninety-one per cent (91%) of the injuries were acute and 8.8% of the injuries were recurrent or chronic in nature. Ninety-five per cent (95%) of the injuries were sustained during matches played at these tournaments. Three per cent (3%) of injuries were sustained during warm up and 2% during a practice session. In 60.8% of the cases there was contact with another player that lead to the injury.

In a study of netball players 10 years and older (Victoria, Australia), the incidence of injuries were calculated at 9.49 injuries per 1000 players (0.0095 injuries per player), which is 17 times lower than the results of Otago and Peak, (2007). In this study, data were collected by means of claims that were made to a medical insurance company. If data is collected in this manner, there is the potential of only serious injuries being identified and of underreporting causing collection bias. Other studies also reported much lower injury rates of 11.3 to 14 injuries per 1000 playing hours among non-elite players over one to two seasons (Finch *et al*., 2002; McManus *et al*., 2006; Stevenson *et al*., 2000).

There is evidence to suggest that players in A-sections and in higher age groups, who by implication have higher levels of skill, are more susceptible to injury (Hopper and Elliot, 1993; Hopper *et al*., 1995a; Hopper *et al*., 1995b). Evidence exists that injury rates in sport are higher in tournaments than compared to games played during the course of a season (Arnason *et al.,* 2004; Hawkins and Fuller, 1999; Hägglund *et al*., 2003; Junge *et al*., 2004a; Junge *et al*., 2004b; Yoon *et al*., 2004). This, as well as the exclusion of minor injuries, can explain the low injury rate of 0.054 injuries per player found in players who were competing during the course of a 14-week season (Hopper *et al*., 1995a). Inclusion criteria for earlier studies were that the players had to be free from any sport injuries for the past three months (Finch *et al*., 2002; McManus *et al*., 2006; Stevenson *et al*., 2000). Previous injuries could leave an athlete vulnerable to recurrent injuries (Murphy *et al*., 2003; Thacker *et al*., 1999). The probability of injury was 0.23 per player participating in the Australian netball championships, while the risk of injury was calculated at 0.14 injuries per player during the New South Wales netball championships (Hopper and Elliot, 1993; Hume and Steele, 2000). Both these studies were conducted at netball tournaments of similar age categories.

The results of Langeveld *et al.* (2014) (0.15 injuries per player) supports the premise that higher injury rates occur at netball tournaments when compared to games played during the course of the season. It is clear that methodological differences between these studies, especially the method of collection of injury data and the definition of injury have a significant influence on the outcomes and make studies difficult to compare. Epidemiological data on sports injuries should be interpreted with this in mind.

2.4 GROUND REACTION FORCES

The process of catching a pass in netball generally involves running to meet the pass and suddenly stopping on either one or two feet. The speed at which these actions occur can affect the range of joint motion, muscle activity and ground reaction forces (Steele, 1990).

2.4.1 The vertical jump

Jumping, as described by (Slinde, 2008), is a movement that requires complex motor coordination between upper- and lower-body segments and is a common activity in sport. During a vertical jump, the jumper must overcome body weight (BW) which is the combined effect of body mass and the downward gravity (BW = mass x gravity). Based on Newton's third law of physics, enough muscular force should be produced against the ground to create a reacting force (ground reaction force, GRF) acting on the body which is large enough to overcome BW and propel the body's centre of mass upward.

2.4.2 Mechanics of the vertical jump

The vertical jump is an essential part of netball specific skills that a player needs to develop. The vertical jump includes the countermovement jump and the squat jump (SJ) (Kopper *et al*., 2013). The drop vertical jump (DVJ) is also described as part of a vertical jump and requires an athlete to drop off a static box, land, immediately execute a maximal vertical jump toward a target, and finish with a second landing.

In a countermovement jump (CMJ) as explained by Linthorne (2001), the jumper starts from an upright standing position, makes a preliminary downward movement by flexing at the knees up to 90 degrees and hips, then immediately and vigorously extends the knees and hips again to jump vertically up off the ground as high as possible. A countermovement jump is an example of a movement that benefits from the ‘‘stretch–shorten cycle.’ The muscles are said to be ‘‘pre-stretched’’ before shortening in the desired direction that enhances the force production and work output of the muscles in the subsequent movement. Countermovement jumps can be performed either with arm swing or with the hands placed on the hips. Jumps with arm swing have shown to contribute with 8–11% of the jumping height and thus give a more positive effect on the outcome.

Marcovic et *al*. (2014) concluded that both body size (in CMJ and SJ) and countermovement depth (in CMJ) confound the relationship between the muscle power output with the performance of maximum vertical jumps. Regarding routine assessments of muscle power from jumping performance and vice versa, the use of CMJ is recommended, while peak power rather than average power, should be the variable of choice.

Research done by Kopper *et al*. (2013) investigating vertical jump in terms of range of movement of different joints in the lower limb, concluded that muscles, in short range of motion, contract isometrically and work is done on elastic elements resulting in elastic energy storage that provides increased potential to attain high acceleration at the beginning of joint extension and can result in considerably higher positive work than that in jumps without countermovement. The Abalakov jump (AJ) is also a CMJ, but it is performed with a measuring tape attached to a belt, which is placed on the hip. Jump height is calculated by the difference between pre- and post jump measurements, similar to the method used to measure jump height in this study. In this particular study the CMJ was used without arm swing. The reason for that is firstly is that, it is the most common type of jump performed in netball kinematics, and secondly, the focus was entirely on muscular fatigue of the lower limb (Kopper *et al*., 2013).

2.4.3 Vertical and horizontal braking forces

According to Neal and Sydney-Smith (1992) ground reaction forces consist of vertical and horizontal (braking) components. The magnitude of these forces, along with their repetitive nature, may contribute to the relatively high incidence of lower extremity injuries in netball players.

Epidemiological evidence (McGrath and Ozanna-Smith, 1998; Steele and Lafortune, 1989) indicates that most netball related injuries particularly in adults occur to the lower extremities, predominantly to the ankles and knees and as a result of inadequate landing or falling. Given this association it is critical to look at factors which impinge on the landing technique. The technique a player uses to land after receiving a pass in netball is influenced by several factors including: the type of pass to be caught, the speed of the player's approach to the pass, positioning of opposition players, movements required following the landing action, the material properties of the court surface, and the footwear worn by the player (McGrath and Ozanna-Smith, 1998; Steele and Lafortune, 1989).

Otago (2004) investigated landings in netball to ascertain whether or not an extra step on landing would significantly alter the forces on the body and also investigate the landings that were least stressful on the body. Eighteen State or Under 21 netball players participated as subjects in his study. The subjects performed five different landing conditions at two pass heights. The five landing conditions were three legal landings consisting of a pivot, a run-on and a two foot landing. The other two landings used an extra step technique for the pivot and run-on landings. The range of values for peak vertical ground reaction force were from 3.53 to 5.74 body weight (BW) and for peak braking force the range was from 0.83 to 1.75 BW. No significant differences were found between each respective legal and extra step techniques. The run-on techniques exhibited lower peak forces, longer attenuation times and lower loading rates than the pivot or two foot landing conditions. The data clearly showed that there were no advantages to be gained from taking an extra step for either the pivot or run-on landing techniques. The run-on technique of landing appears to be most beneficial to reducing loads on the lower limb. A change to the footwork rules cannot be recommended based on the results of his study.

Steele's (1988) study found that an increased passing height significantly decreased the braking forces and therefore decreased the horizontal load on the lower extremities. However, higher passes significantly increased the vertical forces at landing. Passing height also influenced the landing technique. Players tended to land on the forefoot more than the heel after receiving a high pass. Alterations to pass height also significantly influenced the orientation of the lower extremities. Steele (1988) concluded that changes to pass height without consideration for landing technique, may not help to reduce GRF generated at landing.

The effect of passing height on GRF in netball was also examined by Neal and Sydney-Smith (1992) under three separate conditions: chest pass with heel landing, chest pass with forefoot landing and high pass with forefoot landing. However, the change in pass height did not affect the magnitude of either the peak vertical GRF, initial impact force or breaking force (BF) recorded in the forefoot landing trials. Neither did the change to passing height affect the times to peak vertical GRF, peak vertical impact force or peak BF. It is interesting to note that Neal and Sydney-Smith (1992) reported contradictory findings to Steele (1988) and Steele and Milburn (1988) reports which show significant differences in one or more of these parameters.

2.5 LANDING TECHNIQUE AND FOOTFALL PATTERN IN NETBALL

Landing is a fundamental component of most netball skills and movements, such as rebounding after an attempt to goal, leaping to catch a pass, or to steady the body after a defensive deflection (Steele, 1990). Steele and Milburn (1987a), also indicated that to land efficiently, a player should: flex at the knee of the landing limb to absorb the impact forces over a greater time period and thus reduce the jarring effects at landing, thereby lowering the body's centre of gravity and enhancing stability.

Steele and Milburn (1988c) also found in landing trials on different playing surfaces that the initial foot-ground contact was made with the heel in 95.8% of cases. However, Steele and Milburn (1989c) reported that after receiving a high pass, most netball players made initial contact with the forefoot. It is important to note that forefoot landings significantly lowered initial peak vGRF and braking force, while producing a longer time to peak vGRF, therefore potentially decreasing the risk of injury (Steele and Milburn, 1988c).

A similar study by Hopper *et al*. (1992) did an analysis of footfall patterns during an international netball game as compared to laboratory setting, and found similar and different results compared to the above literature. Forefoot landing were much lower and made 57.3 -, hind foot 8.1-, planted 24.7-, outside border 2.5 % respectively. The study also found that overhead catches more often resulted in a jump (58%) with a forefoot landing (88.4%). Hind foot landing was 5.8% which is a potential dangerous motion that increases the risk for injuries. Weather the percentage of hind foot landings will increase on a surface with higher friction and stiffer absorbing qualities still needs to be investigated.

2.5.1 Landing technique, player position and somatotyping

No significant correlations were reported by Steele and Milburn (1988a) between anthropometric measures (height, weight), lower extremity characteristics (strength alignment, flexibility) and kinematic variables demonstrated during landing. However, heavier players were recommended to pay attention to developing landing skills, particularly for the non-dominant side.

In related studies (Steele and Milburn, 1988a) it was found that the goal-defensive players mostly revealed ectomorphic characteristics compared to other positions, and made the most jumps to make a catch compared to other positions (31%) and mostly lands with the right foot (58%) and were the position who mostly land on the hind foot (10%) compared to other positions. This potentially puts goal-defensive players at an increased risk for injuries. Midfield players mostly revealed heavier mesomorphic characteristics. It was however found that they made the least number of jumps (24.8%) to make a catch compared to other positions, but revealed hind foot landing frequencies similar (to slightly less) than the goal-defensive players (9.8%). This also puts mid-field players at an increased risk for lower-limb injuries.

2.5.2 Landing technique and knee alignment

An incorrect landing technique in netball is one of the main contributing factors in ankle and knee injuries (Hopper and Elliot, 1993; Hopper *et al*., 1995a; Hopper *et al*., 1995b; Hume and Steele, 2000). There is growing evidence that improvements in neuromuscular control (NMC) and biomechanics (improved landing technique) contribute to injury prevention (Hu *et al*., 2006, McLean *et al*., 2004; McLean *et al*., 2005; Powers, 2007). Hume *et al*. (1996) stated that landing with incorrect knee alignment and single leg support was reported to stress the ligamentous structures of the knee and the surrounding musculature and therefore could predispose a player to lower extremity overuse injuries. Previous support for this statement was also reported by Downey (1986) who stated that genu recurvatum or knee hyperextension was often observed with ankle equinus deformity (Hopper and Elliott, 1993).

Otago, (2004) have also investigated rule changes that could reduce ground reaction forces that would lead to a decrease in moment angles in the knee which in turn lowers the risk of ACL injuries. According to Yu and Garret (2007) ACL injuries occur when excessive shear forces are applied to the ACL. However, a non-contact ACL injury occurs when poor movement patterns cause an athlete to place high enough forces or moments on the ligament that exceed the amount of tension it can sustain (Boden *et al.,* 2010*)*. Therefore it is of crucial importance to understand how the ACL is loaded through movement and what the mechanisms and risks for injury is (Hewett *et al.,* 1999; Myer *et al.,* 2008). Improvement of neuromuscular control can limit the risk of knee injuries. This is of particular importance due to high-risk manoeuvres such as jumps and landings, quick acceleration and deceleration, and rotational movements that occur in netball (Ferreira and Spamer, 2010).

2.5.3 Landing technique and lower limb muscle fatigue

According to Fabre *et al*. (2012) it is well known that the extent and origins of neuromuscular fatigue differ according to the type of muscle contraction, the muscular group involved, the exercise duration, exercise intensity, and the environmental conditions. However, among the environmental conditions, the effect of the playing surface has received little attention in the literature.

Muscle fatigue is defined as a failure to maintain the required or expected force in a muscle (Edwards, 1981), while (Vollestad, 1988) described it as ‘‘any exercise-induced reduction in the capacity to generate force or power output’’. Neuromuscular mechanisms related to fatigue remain to be completely elucidated. Muscle fatigue can arise from many points of the body and can be divided into central and peripheral fatigue. The central factors of fatigue comprise decreases in the voluntary activation of the muscle, which is due to decreases in the number of recruited motor units and their discharge rate. However, the peripheral factors of muscle fatigue include alterations in neuromuscular transmission and muscle action potential propagation and decreases in the contractile strength of the muscle fibers.

Fabre *et al*. (2012) concluded that fatigue is usually described as a time-dependent exercise induced reduction in the maximal force generating capacity of the muscle. This complex phenomenon is the result of the combination of many factors from the central (nervous) to the peripheral (muscular) level. Research showed that the level of aerobic fitness would be a risk factor for injury because, once fatigued, most athletes alter their muscle recruitment patterns. This altered recruitment pattern, in turn, may alter the distribution of forces acting on the articular, ligamentous, and muscular structures (Murphy *et al*., 2003).

Mechanical shock during landing from a height must be attenuated by the musculoskeletal system (Voloshin *et al.* 1998). When the external loads become too great for the body to adequately attenuate, the probability of injury increases. Shock attenuation is achieved both passively (soft tissues and bone) and actively (eccentric muscle action). This active mechanism is thought to be far more significant than the passive mechanism in attenuating shock. It is thought that a fatigued muscle will be less able to protect the body effectively from impact forces and thus the body will be predisposed to overuse impact-related injuries (Voloshin *et al*., 1998). This loss in protection may be due to a variety of changes that occur with fatigue, including both central (neural drive) and peripheral (contractile machinery) mechanisms (Coventry *et al*., 2006).

Previous research investigating landing protocols that have investigated joint mechanics and shock attenuation found that while the hip generally has the greatest joint moment and power during two-legged landings, the knee has the greatest joint excursion and performs the greatest amount of work (Decker and Torry, 2003; DeVita and Skelly, 1992).

The effects of fatigue during locomotor activities have demonstrated different responses in both GRF magnitudes and lower extremity control strategies in a recent study by James *et al.* (2010). The reason for these different responses is unknown. Fatigue alters GRF magnitudes during the impact and eccentric braking phases of locomotor activities and cause alterations in segmental control and joint and system stiffness and so could alter the load on passive structures. Data have suggested that GRF magnitudes increase during fatigued hopping, landing, and sub-maximum drop jumping. This can be explained by increased pre-activation of stabilizing musculature in order to increase joint or system stiffness and changes in body geometry at initial contact (James *et al*., 2010).

James *et al.* (2010) found that fatigue increased GRF first peak magnitudes and decreased GRF second peak, second peak loading rate, and impulse values. They observed increases (large effect sizes) in the Vastus Medialis (VM) and Gastrocnemius (GN). In addition, they found two different fatigue protocols affect neuromuscular and kinematic landing performance characteristics differently and so could also have an effect on the injury incidence profile. The discrepancy in GRF responses suggests that the neuromuscular system is either affected differently under various fatiguing conditions or responds differently to the neuromuscular impairment, possibly optimizing on different performance factors. Currently, there is limited evidence that suggests under which circumstances participants respond to fatigue with less stiffness and reduced GRF or more stiffness and increased GRF.

Voloshin *et al.* (1998) investigated the effect of fatigue on its further propagation and modification along the musculoskeletal system. At a higher location along the skeleton, the ability to attenuate the foot strike initiated shock wave is preserved longer and the wave amplitude becomes significant longer after exposure to fatigue. Due to this longer exposure to the shock wave, the biomechanics of the body are modified in order to reduce the dynamic loading on the higher parts of the skeleton, with a possible aim of preventing significant loading on the spine and head.

A study (Bahr and Krosshaug, 2005) described that the mechanical properties of human tissue, such as stiffness (stress–strain relation) and ultimate strength, govern how the body responds to physical loads, both related to fatigue. They differ for each tissue and are dependent on the nature and type of load, its rate, the frequency of load repetition, the magnitude of energy transfer, and intrinsic factors such as age, sex, and physical condition. It is the relation between load and load tolerance that determines the injury outcome of an event. The key point to consider with regard to biomechanical factors is that they must explain how the event either resulted in a mechanical load in excess of that tolerated under normal circumstances or reduced the tolerance levels to a point at which a normal mechanical load cannot be tolerated. (Referring to the comprehensive model for injury caution) (Bahr and Krosshaug, 2005).

2.5.4 Effect of lower limb muscle fatigue on vertical jump mechanics

Kellis (2009) concluded that individuals with fatigued knee extensors landed with lower vGRF and a higher knee flexion angle. This was accompanied by an antagonist inhibition strategy around the knee and a quadriceps dominant strategy. In contrast, knee flexor fatigue had no effects on vertical GRF but it was accompanied by increased activation of VM, Biceps Femoris (BF) and GN and an increased Quadriceps: Hamstring ratio during the pre-activation phase. It is concluded that fatigue responses during landing are highly dependent on the muscle, which is fatigued.

2.5.5 Effect of lower limb muscle fatigue on injury potential

Studies have shown that both fatigue and decision making, factors synonymous with sports participation, promote high-risk lower limb joint neuromechanical adaptations that may manifest within the resultant cause of injury present as a worst case scenario for high-risk dynamic landing strategies (Chappell *et al*., 2007). Considering both central and peripheral processing mechanisms are compromised in the presence of fatigue, poor perceptions, decisions, reactions and resultant movement strategies may be more likely when in a fatigued state. Altered knee joint biomechanics, and in particular increased out of plane hip and knee motions and loads and sagittal plane ankle motions, are common postural outcomes when individuals are exposed to either factor during dynamic sports landings.

Borotikar (2008) concluded that neuromuscular fatigue promotes significant decreases in initial contact hip flexion and significant increases in initial contact hip internal rotation, and in peak stance (0–50%) phase knee abduction, knee internal rotation and ankle supination positions during the execution of dynamic single leg landings. The study further found that fatigue-induced modifications in lower limb kinematics observed at maximum (100%) fatigue during single leg landings are already evident at the 50% fatigue level, which can already lead to an increased risk for injuries. They also discovered that fatigue-induced changes in initial contact hip flexion and internal rotation, and peak stance (0–50%) phase knee abduction positions are significantly more pronounced during unanticipated compared to anticipated single leg landing tasks, suggesting substantial degradation in both peripheral and central processing mechanisms.

Research done by Fabre *et al*. (2012) evaluated the effect of the playing surface properties on the development of neuromuscular fatigue in tennis. Before and after each tennis match (playing duration of 45 min, i.e., corresponding approximately to a 3-h game) the maximal voluntary contraction (MVC) force of the plantar flexors, the maximal voluntary activation level, the maximal compound muscle action characteristic, and the EMG activity were determined on the Soleus and lateral Gastrocnemius muscles. Interestingly, statistical analysis did not reveal any significant difference ($p < 0.05$) between playing surfaces. The maximal voluntary contraction was similarly reduced after the game (HARD, -9.1 ± 8.7%; CLAY, -4.3 ± 19.9%) and was associated with alterations of the contractile properties of the plantar flexor muscles. Faber *et al*. (2012) stated that the implication of central factors was less clear, as evidenced by the significant reduction ($p < 0.05$) of the H-reflex on the relaxed lateral Gastrocnemius (HARD, -16.2 ± 33.3%; CLAY, -23.9 ± 54.0%) and Soleus (HARD, -16.1 ± 48.9%; CLAY, -34.9 ± 35.9%) and the insignificant reduction of the activation level. In addition, the reflex responses evoked during MVC were also not significantly modified by the exercise. According to the study (Fabre *et al*. 2012) these results suggest that the ground surface properties influence neither the extent nor the origin of neuromuscular fatigue in tennis. The moderate force decrement observed in the current study was mainly associated with peripheral fatigue.

2.6 RECOMMENDED LANDING TECHNIQUES

Although the landing action adopted by the player will be determined by the type of catch attempted (a pass thrown high or low, slow or fast) there are fundamental principles that can be applied in any landing situation (Steele and Milburn, 1987a).

Research (Mcgrath and Ozanne-smith, 1998) stated that in order to possibly decrease both the magnitude and rate of loading of horizontal and vertical components of GRF, at landing and therefore minimize musculoskeletal stress, the player should:

- Land with the foot neutrally aligned thereby eliminating excessive ankle adduction-abduction, internal rotation or dorsiflexion.
- Ensure adequate hip and knee flexion.
- Eliminating an exaggerated 'striding out' position by reducing the foot-hip displacement.
- Land with the feet apart to give a firm support base.
- Land with the body upright.
- Cushion the land by bending the knees, hips and ankles slightly on impact.
- Try for a balanced, 'soft' landing.
- Body weight should be over the feet, with shoulders level.
- When landing with two feet simultaneously, weight should be distributed on both feet.
- For one foot land, quickly bring the other foot down, to evenly distribute the weight between the two.
- Allow time for a balanced position to be taken before releasing the ball to a team mate (McGrath and Ozanna-Smith, 1998).

2.7 METHODOLOGICAL CONSIDERATIONS

There are different ways of inducing lower limb muscle fatigue and ways of measuring the extent of the muscle fatigue. In most research done, surface electromyography (sEMG) was the modality of choice to measure the extent of fatigue. In the paragraphs below the use of EMG is the recording of the electrical activity of muscles and different fatiguing protocols from relevant studies are described.

2.7.1 Electromyography

EMG is the recording of the electrical activity of muscles, and therefore constitutes an extension of testing the integrity of the motor system. Massó *et al*. (2010) stated the fact that sEMG can analyse dynamic situations makes it of special interest in the field of sports. According to research (Massó *et al*., 2010) the improvement in the efficiency of a movement involves the correct use of the muscles, in terms of both economy of effort and effectiveness, as well as in the prevention of injury.

EMG recordings can be divided into two types depending on the place of the recording electrodes; sEMG and intramuscular electromyography (González-izal *et al*., 2012). sEMG is more widely used in sports science research as intramuscular EMG is an invasive technique that can cause discomfort to the participants. sEMG can thus be defined as the electromyographic analysis that makes it possible to obtain an electrical signal from a muscle in a moving body.

There was a need to standardized method with regards to sEMG procedure as there was discrepancy between the methods developed among the different groups of users and hindered further growth of sEMG as a suitable measuring tool. To make the results more comparable and to create a large common body of knowledge on the use of sEMG in the various fields of application the European concerted action SENIAM (surface EMG for a non-invasive assessment of muscles) was started in 1996. The general goal was to develop recommendations on key items to enable a more useful exchange of data obtained with sEMG, including sensors, sensor placement, signal processing and modeling (Hermens 2000).

A study by Rainoldi *et al.* (2004) did further research regards the positioning of sEMG electrodes according to the SENIAM guidelines and emphasized accurate electrode placement as failure to adhere to these guidelines can lead to misleading results. The results of the study have shown that while optimum electrode placement requires finding the innervation zone (IZ) for each subject, for some muscles, electrodes can be placed, according to landmarks, between the IZ and the tendon termination without first finding IZ. For this reason the guidelines provided in this particular literature was used in this study.

According to research by Massó *et al.* (2010) the advantages of surface electrodes allows a global recording of the muscle under investigation. They are non-invasive and there are no limitations in relation to the surface studied or the recording time. Unfortunately, only the study of superficial musculature is possible as the signal from deep muscles are unreliable to interpret. Surface electromyography requires the skin to be correctly prepared as to minimise artefacts during the measuring process. Another limitation is the fact that in some dynamic actions there can be displacement and modification of the volume of the muscle being analysed. A change in the relative position of the muscle in relation to the electrode means that the same spatial relationship is not maintained between them, which affects the intensity of the signal that is recorded. Because of this, the best conditions for carrying out a sEMG, depending on the use and application required, are those that are similar to those needed for an isometric type of study (Massó *et al*., 2010).

In a related study by Rahnama *et al.* (2006), it was stated that prolonged exercise decreases the lower limb muscles' ability to generate force. This is usually associated with a lowering in the M-wave amplitude, a change in activation level as indicated by the root mean square of the EMG signal, and modification of the twitch contractile properties resulting in decreased torque generated around the joints to bring about flexion or extension (Rahnama *et al*., 2006). However, the change in M-wave amplitude during muscle fatigue seems to be more complicated, as seen in other studies which found minimal changes in the M-wave amplitude in fatigued muscles (Baker *et al*., 1993; Dimitrova and Dimitrov, 2003) and limited association with muscle force, power and torque (González-izal *et al*., 2012). Therefore, looking at the M-wave amplitude in isolation can be misleading. Other variables such as the area of muscle unit potential (MUP) (Dimitrova and Dimitrov, 2003) or a shift in the median frequency (Allison and Fujiwara, 2002) could also be useful as a fatigue index. More recent research has shown that the averaged rectified value (ARV) and the root mean squared value (RMS) are good indicators of muscle fatigue (González-izal *et al*., 2012), but still has to be correlated with decreased muscle force or torque (González-izal *et al*., 2012).

According to Massó *et al.* (2010) electrophysiological changes take place linked to the development of a fatigue process that produces observable changes in the electromyographic traces. This is of special interest in sports medicine as by this technique we can determine the existence or absence of a fatiguing process, analyse its development over time and compare its behaviour in different situations.

The fact that sEMG can analyse dynamic situations makes it of special interest in the field of sports, particular in terms of muscular fatigue, based on the analysis of the frequency of the electromyographic traces observed. However, EMG does not provide muscular force parameters, but is rather an indicator of the muscular effort made by a particular muscle. It is important to stress that the relationship between EMG activity and effort is only qualitative (Massó *et al*., 2010).

Stegeman *et al.* (2000) defined sEMG interference pattern as a linear summation of the motor unit action potential (MUAP) trains. Motor unit action potential can be described as the mathematical convolution of the firing moments with the MUAP wave shape. A sEMG model that describes the interference pattern should therefore consider both the firing behavior and the MUAP wave shapes. Analysis of changes in MUP or M-wave size and shape with fatigue suggests peripheral factors that contribute (together with the central factors) to changes in amplitude and spectral characteristics of EMG signals.

Bouillard *et al.* (2011) described the concept of the electromyographic fatigue threshold (EMGFT) which is defined as the highest power output (or the highest force level) that can be maintained without neuromuscular fatigue. The concept of EMGFT is based on the principle that neuromuscular fatigue induces a decrease in action potential muscle conduction velocity, an increase in synchronization and force loss, which can be compensated by recruitment of additional motor units. These phenomena may induce an increase in EMG amplitude when force or power output remains constant. The protocol was designed to determine the rate of rise in the EMG amplitude (i.e., EMG slope) as a function of time. EMGFT should be considered as a valid tool to assess muscle function/fitness level.

Research by Dimitrova and Dimitrov (2003) observed a reduction in frequency of the sEMG when a contraction was sustained and a consistent increase in the amplitude of surface recorded EMG. The reason is that muscle fiber propagation velocity (MFPV) decreases with fatigue and that EMG power spectrum shifts during fatigue, mainly owing to a slowdown of MFPV. The amplitude changes seem to be more complicated and contradictory since data on increased, almost unchanged, and decreased amplitude characteristics of the EMG, M-wave or MUP during fatigue can be found in the literature. Further research done by (González-izal *et al*., 2012) confirmed that is not feasible to relate changes in sEMG signals to muscle fatigue or changes in power, force or torque loss.

2.7.2 Measuring and inducing lower limb muscle fatigue

In the literature a large number of protocols were used to induce muscle fatigue according to the specific outcomes of the research (Bisiaux and Moretto, 2008; Callaghan *et al*., 2009; Rahnama *et al*., 2006; Schmitz *et al*., 2014). A few of the protocols observed are being highlighted in the paragraphs below.

A study by Rahnama *et al.* (2006) used a soccer-specific intermittent exercise protocol, which provided a fatiguing exercise estimated to be equivalent in intensity to playing a game. The exercise protocol was performed on a programmable motorized treadmill and consisted of the different exercise intensities that are observed during soccer match-play (e.g., walking, jogging, running hard or cruising, sprinting). The EMG activity was monitored three times (prestart, half-way and post-exercise) each over a 3-min period and showed a significant decrease in muscle activation in Bicep Femoris (BF), Rectus Femoris (RF), TA but not in GC muscle. Treadmill running biomechanics and the type of surface however is not comparable to a soccer field and a simulated soccer game. Due to the outcome of this study this particular fatiguing protocol (FP) will be invalid.

In a study by Bisiaux and Moretto (2008) blood lactate concentration and heart rate was effectively used as a measuring tool and regarded as a good measure of acidosis and thus of the muscular fatigue induced by exercise. Control of the exercise intensity enabled them to induce similar fatigue levels from one subject to another. Measurements were taken before, just after and 30 min after a 30-min fatiguing protocol that included running on a 400m tract at 80% of their maximum aerobic running speed. A prerecorded sound-tract and cones were used to impose the running speed. The heart rate and lactate concentration increased significantly after the FP. The measurement of heart rate and lactate could therefore be used as a reliable tool to confirm that a certain level of fatigue has been reach, but was however not included in this study.

In a study done by Callaghan *et al.* (2009) the subjects were asked to sustain an isometric contraction lasting 60 s at a level of 60% of their maximal voluntary concentric muscle contraction using a dynamometer. The study found a good correlation between muscle fatigue and numerous EMG parameters, except for median frequency slope. In a related study done by Kellis and Kouvelioti (2009), the fatigue test included performance of two sets of consecutive concentric efforts of the knee extensors or flexors at 120 degrees on a dynamometer apparatus until the subjects could no longer produce 30% of the maximum momentum. During the test subjects received standardized verbal instructions to maintain maximal effort throughout the test. A dynamometer however is an unnatural movement to induce fatigue and as the focus of this study was to determine the extent of fatigue while playing netball, the decision was made to exclude the above from the FP.

In recent related study by Schmitz *et al*. (2014) a FP was developed to simulate a training session or game on the specific playing court. In one study numerous shuttle runs, CMJ and sprints were incorporated for two 45min halves while measurements were taken. In the other study a simulated game was played for the duration of an actual match. In both studies fatigue was effectively produced and the changes in biomechanics and muscle activation measured. In future research this type of FP could be used as an effective tool to induce muscle fatigue.

Chapter 3

METHODS

3.1 INTRODUCTION

This chapter will describe the research protocol underpinning data collection to achieve the aim stated in Section 1.2. A description of the research participants, instruments and methods used as well as more detailed information on data processing and analysis will be given. In preparation for this study, literature was collected from electronic databases such as Kovsiekat, Pubmed, EbscoHost, ScienceDirect, as well as relevant academic journals and textbooks to inform methodological considerations.

3.2 STUDY PARTICIPANTS

After obtaining ethical approval (Section 3.9) and permission from the Vice Rector for academic affairs as well as the head coach of the netball team to approach student athletes for participation in the envisaged study, ten (n = 10) elite netball players were recruited from the Free State Netball Squad. One participant withdrew from the study the day prior to data collection, resulting in nine (n = 9) participants to be included in the study using the following criteria:

3.2.1 Inclusion criteria

1. Participants had to be female
2. Participants had to be included in the Free State netball squad for the 2013 season
3. Participants had to be healthy
4. Participants had to between the ages of 18 - 25 at the time of data collection
5. Participants had to be free from injury
6. Participants must be able and willing to give consent in Afrikaans or English

3.2.2 Exclusion criteria

1. Persons who were male
2. Persons younger than 18 years and older than 25 years
3. Persons not included in the Free State netball squad for in the 2013 season
4. Persons rehabilitating from an injury
5. Persons suffering with an illness
6. Persons with a history of contact allergic dermatitis
7. Persons unwilling or unable to give consent in Afrikaans or English

3.3 STUDY DESIGN

This study was an experimental crossover study, which assessed lower limb muscle fatigue on two different netball play surfaces (concrete and synthetic turf).

3.3.1 Research participant information

Before participation in the study each participant was asked to read an information sheet and sign a consent form. Basic anthropometric information was obtained on the first day of data collection (Appendix A.4).

3.3.2 Anthropometric measures

Upon arrival on the first day of data collection, the age (years), length (cm) and body mass (kg to the nearest first decimal) were recorded. The Heath and Carter anthropometrical assessment was used.

Skinfold measurements were taken by a Level 1 Anthropometrist using the International Standards for Anthropometric assessment (Marfell-Jones *et al*., 2006) as guideline. The measurements were taken on the right side of the body in an upright standing position, with exception of the Medial Calf skinfold, which was taken in the sitting position (Carter and Heath, 1990). The following six skinfold measurements were collected for calculation of estimated body fat percentage:

Triceps

Definition: The most posterior part of the Triceps when viewed from the side at the marked mid acromial-radial level.

Subject position: When marking the sites for the Triceps skinfold the subject assumes the anatomical position.

Location: The Tricep skinfold site marked over the most posterior part of the Tricep muscle when viewed from the side at the marked mid acromial-radial level.

Subscapular

Definition: The site 2 cm along a line running laterally and obliquely downward from the Subscapular landmark at a 45° angle.

Subject position: The subject assumes a relaxed standing position with the arms hanging by the sides.

Location: Use a tape measure to locate the point 2 cm from the Subscapular in a line 45° laterally downward.

Suprailiac

Definition: The site at the center of the skinfold raised immediately above the marked Iliocristale.

Subject position: The subject assumes a relaxed position with the left arm hanging by the side and the right arm abducted to the horizontal.

Location: This skinfold is raised immediately superior to the iliac crest. Align the fingers of the left hand on the iliac crest landmark and exert pressure inwards so that the fingers roll over the iliac crest. Substitute the left thumb for these fingers and relocate the index finger a sufficient distance superior to the thumb so that this grasp becomes the skinfold to be measured. Mark the center of the raised skinfold. The fold runs slightly downwards anteriorly as determined by the natural fold of the skin.

Abdominal/Para-Umbilicus

Definition: The site 5 cm to the right hand side of the omphalion (midpoint of the navel).

Subject position: The subject assumes a relaxed standing position with the arms hanging by the sides.

Location: This is a vertical fold raised 5 cm from the right hand side of the omphalion.

Anterior mid thigh

Definition: The site at the mid-point of the distance between the Inguinal fold and the anterior surface of the patella on the midline of the thigh.

Subject position: The subject assumes a seated position with the torso erect and the arms hanging by the sides. The knee of the right leg should be bent at a right angle.

Location: The measurer stands facing the right side of the seated subject on the lateral side of the thigh. The site is marked parallel to the long axis of the thigh at the mid-point of the distance between the Inguinal fold and the superior margin of the anterior surface of the patella (while the leg is bent). The Inguinal fold is the crease at the angle of the trunk and the thigh. If there is difficulty locating the fold the subject should flex the hip to make a fold. Place a small horizontal mark at the level of the mid-point between the two landmarks. Now draw a perpendicular line to intersect the horizontal line. This perpendicular line is located in the midline of the thigh. If a tape is used be sure to avoid following the curvature of the surface of the skin.

Medial calf

Definition: The site on the most medial aspect of the calf at the level of the maximal girth.

Subject position: The subject assumes a relaxed standing position with the arms hanging by the sides. The subject’s feet should be separated with the weight evenly distributed.

Location: The level of the maximum girth is determined and marked with a small horizontal line on the medial aspect of the calf. The maximal girth is found by using the middle fingers to manipulate the position of the tape in a series of up or down measurements to determine the maximum girth. View the marked site from the front to locate the most medial point and mark this with an intersecting vertical line.

Care was taken to accurately locate the anatomical landmarks and associated skinfolds, as advised by Marfell-Jones *et al*. (2006). Anthropometric measurements were collected using a pressure calibrated skinfold caliper and body fat percentages calculated using the Carter (1982) equation:

Body fat percentage = (sum of the 6 skinfolds X 0.1548) + 3.58.

3.3.3 Data collection

A similar study on cricket players (Hassani *et al*., 2006) formed the basis to the approach followed for data collection. The netball players participating in this study were each allocated a participant number. A computer randomly assigned the participants to one of the two testing surfaces on the first day of data collection. On Day 1, participants 1, 2, 5, 6 and 9 were tested on the synthetic turf while participants 3, 4, 7 and 8 were tested on the concrete surface. On Day 2 (24 hours later), the two groups swopped around and were tested on the other surface. Special attention was given to consistency in the procedure followed for data collection over the two testing days.

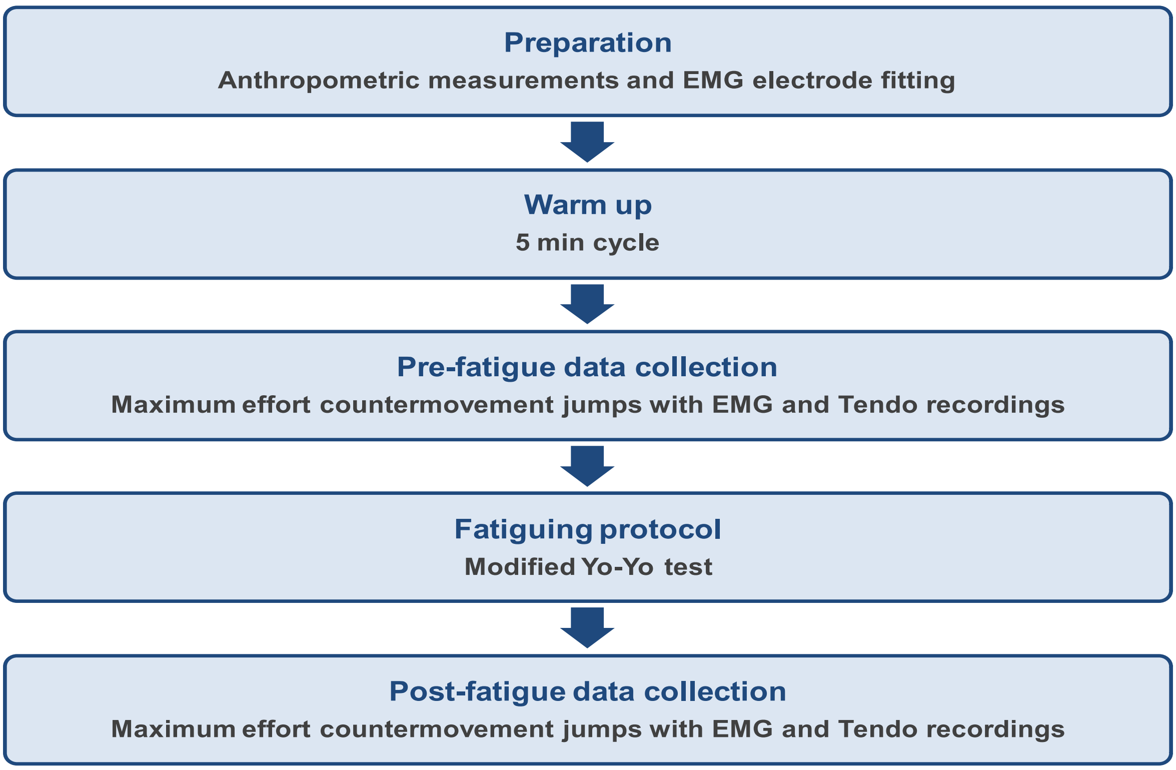

Figure 3.1 Schematic representation of the data collection process

3.3.3.1 Electromyography

To minimise artefact and erroneous EMG interpretations, special care was taken during preparation of the participants in accordance with Rainoldi *et al*. (2004). The following lower limb muscles actively involved in the stabilisation of the ankle and knee joint during dynamic movements such as jumping were selected for EMG measurements:

- Rectus Femoris (RF)
- Tensor Fasciae Latae (TFL)
- Bicep Femoris (BF)
- Vastus Medialis Oblique (VMO)
- Semitendinosis (ST)
- Tibialis Anterior (TA)
- Gastrocnemius (GC)

Electrodes were placed on the right side in accordance with the standardised recommendations from the international Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) project (Hermens, 2000). A single Biokineticist, experienced in surface EMG measurements, performed the EMG electrode placements to ensure consistent electrode placements and eliminate inter-observer variability. Each electrode site was prepared by cleaning it with an alcohol wipe and slightly abrading it to maintain a low inter-electrode resistance of less than 1000Ω. Each electrode site was also marked with a permanent marker to optimise repeatability of the electrode placements over the two days of data collection. Electrodes were taped to the skin using adhesive Transpore® tape and wearing a soft cotton tubigrip sock over the whole leg to keep the electrodes from falling off and minimise movement artefacts. Two disc electrodes (Ag-Ag/Cl) were used for each muscle and placed with an inter-electrode distance of two centimetres (Hermens, 2000). Bearing in mind the dynamic nature of the movement being assessed, surface EMG activity was recorded at 1500Hz to avoid signal loss (Konrad, 2006).

Table 3.1 Surface electromyography electrode placements

Muscle	Electrode placement
Rectus Femoris	Mid-way between the anterior superior iliac spine and the superior border of the patella
Tensor Faciae Latae	Muscle bulk midway between the anterior inferior iliac spine and greater trochanter
Bicep Femoris	Over the long head, half-way between the ischial tuberosity and lateral femoral epicondyle
Vastus Medialis Oblique	Muscle bulk superior and medial to the patella
Tibialis Anterior	Over the area of greatest muscle bulk lateral to the crest of the tibia on the proximal half of the leg
Gastrocnemius	lateral head over the area of greatest muscle bulk on the lateral calf

Hermens (2000)

3.3.3.2 Warm-up

Prior to commencement of data collection, participants cycled for 5 minutes on a Monark cycle ergonometer against a 1kg resistance and cadence of 60 repetitions per minute. This was followed by a rest period of 4 minutes before the pre-fatigue data were collected.

3.3.3.3 Pre-fatigue data collection

Baseline data were obtained using a maximum effort countermovement jump with arms akimbo to isolate the outcome variables as a function of the lower limb muscles. After fitting a Tendo Weightlifter Analyzer (Multistation Net-V-104 model), participants were given the opportunity to perform three maximum effort jump trials. The trial with the highest peak vertical velocity during propulsion was chosen for analyses. Peak vertical velocity was chosen over jump height as determinant factor for trial selection to minimise the effect of movement artefact (originating from the Tendo waist band) on jump height measurements. The surface EMG data served as process variables while the maximum jump height, peak vertical velocity and peak power during propulsion served as outcome variables.

The simultaneous collection of EMG and Tendo data were managed by an experienced Biokineticist and Sport Scientist respectively.

3.3.3.4 Fatiguing protocol

An adapted Yo-Yo aerobic fitness test with intermittent maximum effort vertical jumps was used to mimic functional movements specific to netball (Crockett, 2011) and induce fatigue. The equipment used included the Yo-Yo test CD, a CD player and demarcation cones. Cones were placed at three points; -5 meters, 0 meters and 20 meters (Figure 3.2).

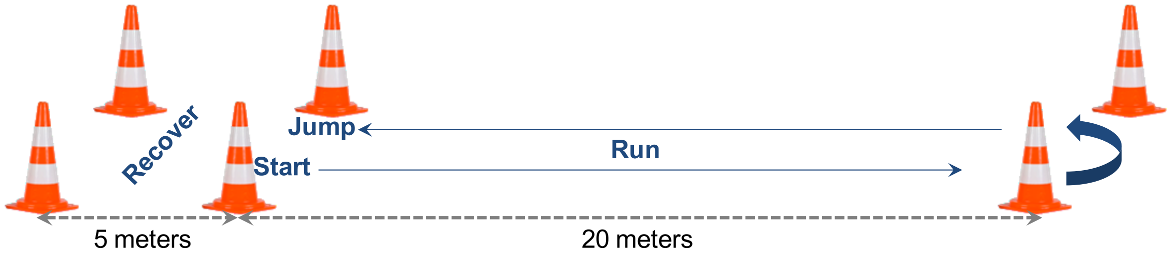

Figure 3.2 Modified Yo-Yo test setup

Participants started with toes behind the start line (0 meters), and began running the first 20 meters when instructed by an audio cue played through the Yo-Yo test CD. The participant turned on the 20 meter line and returned to the starting point (40 meters in total) where a maximum effort bilateral vertical jump was performed. Following the vertical jump, an active recovery lasting 5 seconds were performed during which the participant had to walk or jog around the recovery cone placed at 5 meters from the starting line in the opposite direction (Figure 3.2), return to the starting line and wait for the next shuttle to begin. The time allowance to complete a shuttle run and jump decreased systematically. Each participant attempted to do as many as possible shuttle runs until she were too fatigued to keep up with the pace dictated by the Yo-Yo test CD.

The number of shuttle runs achieved by each participant was recorded as reference for the following day's data collection to ensure consistency in the exertional effort associated with the fatigue protocol on each surface. When the participants were unable to keep up the pace needed to complete a shuttle run within the time dictated by the Yo-Yo test CD, it was assumed that the lower limb muscles reached a state of fatigue.

3.3.3.5 Post-fatigue data collection

After completing the fatiguing protocol (FP) the participant immediately moved over to the adjacent testing station where the same procedure as the pre-fatigue data collection (Section 3.3.3.3) was followed. The post-FP measurements were taken immediately following the FP before recovery could set in (Kenney *et al*., 2011).

3.4 MEASUREMENT

3.4.1 Measurement instruments

A second generation Noraxon TeleMyo direct transmission system were used to collect raw EMG data at 1500Hz which were fed directly into a laptop computer. A Tendo weightlifter analyzer Multistation Net-V-104 model was used during vertical jumps to measure peak power (Watt), peak vertical velocity ($m.s^{-1}$) and jump height achieved. Over the past 10 years, many studies have examined peak power output during training using a Tendo Weightlifting Analyzer (TENDO Sports Machines; Trencin, Slovak Republic) (Hoffman *et al*., 2009; Jennings *et al*., 2005; Jones *et al*., 2008; Rhea *et al*., 2008). In short, the Tendo Weightlifting Analyzer is a linear position transducer which attached to a barbell, athlete or weight stack. By entering the mass of the external load before each set, a microprocessor is able to calculate power output and movement velocity as well as the linear distance (jump height) measured by the transducer (Stock *et al*., 2011) during propulsion. Previous studies aimed at assessing the validity and reliability of the Tendo weightlifter analyzer found high intraclass correlation coefficients ranging from 0.85 to 0.99 and concluded that this instrument is a reliable system for measuring movement velocity and estimating power output (Garnacho-Gestano *et al.*, 2015).

3.4.2 Data processing

For this study, peak power was normalized to body mass ($Watt.kg^{-1}$). Surface EMG data were processed using the MyoResearch XP Master Edition (version 1.07) software. Processing of the data was informed by guidelines from the International Society of Electrophysiology and Kinesiology (Merletti and Torino, 1999). The EMG signals were rectified and smoothed using a moving average of 25ms to avoid detectable delays (Merletti and Torino, 1999). Care was taken to isolate the EMG data corresponding to the vertical jump with the greatest vertical velocity which was chosen for analysis. Considering that the body is unloaded during the flight phase of the jump, a clear distinction could be made between propulsion, flight and landing. The TFL muscle proved to be consistently inactive during flight which made this muscle the ideal determinant for defining the different phases for separate analyses of the propulsion and landing.

Although normalization of the EMG signal can be obtained through the expression of the signal amplitude as a percentage of the maximum voluntary contraction (MVC), estimates of the MVC tend to be inaccurate without appropriate training beforehand (Merletti and Torino, 1999). Due to the associated logistic barrier in combination with recommendations from literature (Masuda *et al*., 1998; Merletti and Torino, 1999) advising against the use of percentage of maximum voluntary contractions (MVC) to assess fatigue during dynamic movements, alternative assessments methods were considered. The average rectified value (ARV) over the time interval for the propulsion and landing phase (respectively) were identified as a suitable measure as it best describes the gross innervations input of selected muscles for a given task during comparative analyses (Konrad, 2006).

3.4.3 Pilot study

A pilot study was performed on two female netball players from the University netball team who were not part of the Free State netball squad and therefore did not meet all the required inclusion criteria. EMG measurements and fatiguing protocols were done according to the processes described above. During the pilot study, isokinetic testing was also included with the aim of correlating the EMG measurements with knee flexion/extension forces. Unfortunately the seat interfered with the EMG signals and a consequent decision was made to exclude isokinetic testing from the data collection protocol. The inclusion of the Tendo weightlifter analyzer was in response to the exclusion of the isokinetic testing.

3.4.4 Measurement errors

EMG measurements took place over two days. Implementing this procedure ensured that the participants recovered from the muscle fatigue when the second measurement took place. This was in agreement to a similar study done by Hassani *et al*. (2006). In order to minimise the effect of temperature and humidity as well as the circadian cycle, measurements took place on the same time of the day since changes in these variables have been shown to have an effect on muscle fatigue (Kenney *et al*., 2011). By controlling the time of day when data collection took place, the measurement error would have been minimal with a negligible effect on the outcomes of the results.

Measurement errors pertaining to the comparison of the different surfaces to each other were minimised by keeping the surface on which the pre-FP and post-FP testings were performed constant. Through this, the effects of the different surfaces were contained to the FP alone and any potential differences in measurements could be attributed to the effect of the surface on muscle fatigue.

To avoid a loss in electrode adhesion and minimise movement artefact, the electrodes was taped to the skin using Transpore® tape while wearing a soft cotton tubigrip sock over the whole right leg. Inter-electrode distances have a significant effect on surface EMG amplitudes (González-izal *et al*., 2012). To minimise discrepancy between measurements during the two occasions, a tiny permanent pen mark was made where the electrode was placed on the skin on the first day of measurement, as a guide for electrode placement on the following measurement occasion. As shoe-surface interface has an effect on muscle fatigue (Inklaar, 1994), the participants was asked to wear the same footwear on both measurement occasions. Because a lack of sleep and calorie intake have an effect on muscle fatigue (Kenney *et al*., 2011) the participants were asked to take a good night's rest and calorie intake before data collection commenced (Appendix A.2).

3.5 ANALYSIS

The Department of Biostatistics, University of the Free State, made a considerable contribution to the planning of the study design, approach to data collection and analyses to ensure suitability and integrity of the eventual data sets for the envisaged comparisons. Statistical analyses were informed mainly by Fallowfield *et al*. (2005) who provided guidelines for using statistics and sport and exercise science research. Normality of each data set was determined through a Shapiro-Wilk test ($p \leq 0.05$) to determine whether the mean and standard deviation (SD), or the median and quartiles should be reported. Due to the small sample size used this study, a Mann-Whitney U test ($p \leq 0.05$) tests were used for comparative analyses as a precaution to avoid Type 1 errors.

3.6 IMPLEMENTATION OF FINDINGS

The envisaged implementation of the findings from this study were aimed towards the contribution of knowledge informing conditioning programs, injury prevention strategies and ultimately construction planning of new netball courts.

3.7 ETHICAL ASPECTS

3.7.1 Ethical approval

Ethical approval were sought from and granted by the Ethics Committee of the Faculty of Health Sciences, University of the Free State (ECOFS 188/2012, Appendix A.1). Additional permission from the Vice Rector for academic affairs, the Dean of the Faculty of Health Sciences as well as the head coach of the Free State netball team was obtained to approach student athletes for participation in the study.

After obtaining permission from the above authorities, an information sheet (Appendix A.2) which provided a detailed explanation of the envisaged study and the potential risks associated with participation were provided to potential participants. Emphasis was placed on the fact that their participation would be completely voluntary and all information was to be treated confidentially. The possibility for developing allergic contact dermatitis from the attached EMG electrodes could not be excluded and had to be mentioned to the participants. Fortunately, no such cases were reported. Participants were also informed about the necessity for placing a pen mark on the skin to ensure consistent electrode placements over the two days.

Participants were given the opportunity to ask questions prior to signing a written informed consent form (Appendix A.3). The information sheet and informed consent were available in both English and Afrikaans to offer the participants the opportunity to make an informed decision to take part in the research study. Participating in the study was completely voluntary and refusal to take part did not lead to any penalty or loss of benefits she was otherwise entitled to. Each participant had the right to withdraw from the study at any stage.

Chapter 4
RESULTS

4.1 INTRODUCTION

This chapter reports on the demographic information of the participants involved in this study together with the findings prior to and following the fatiguing protocol (FP) (Section 3.3.3.4) on both the concrete and synthetic surfaces. Even though the vast majority of data sets displayed a normal distribution, the few abnormally distributed data sets occurring within the electromyography (EMG) data motivated that the quartile distributions around the median were reported for all EMG data sets to keep the presentation style consistent. For the normally distributed outcome variable sets, the average and standard deviation (SD) were reported.

4.2 DEMOGRAPHICS

Table 4.1 Anthropometric information for participants

Anthropometric measurement	Mean ± SD
Body mass (kg)	68.8 ± 6.0
Height (cm)	1.76 ± 0.05
Fat percentage (%)	19.8 ± 3.3

The mean body mass of the participants was 68.8 ± 6.0 kg with a mean height of 1.76 ± 0.05 m. After calculation using the Heath and Carter method (Section 3.3.2) the participants displayed a mean fat percentage of 19.8 ± 3.3 %.

4.3 OUTCOME MEASURES

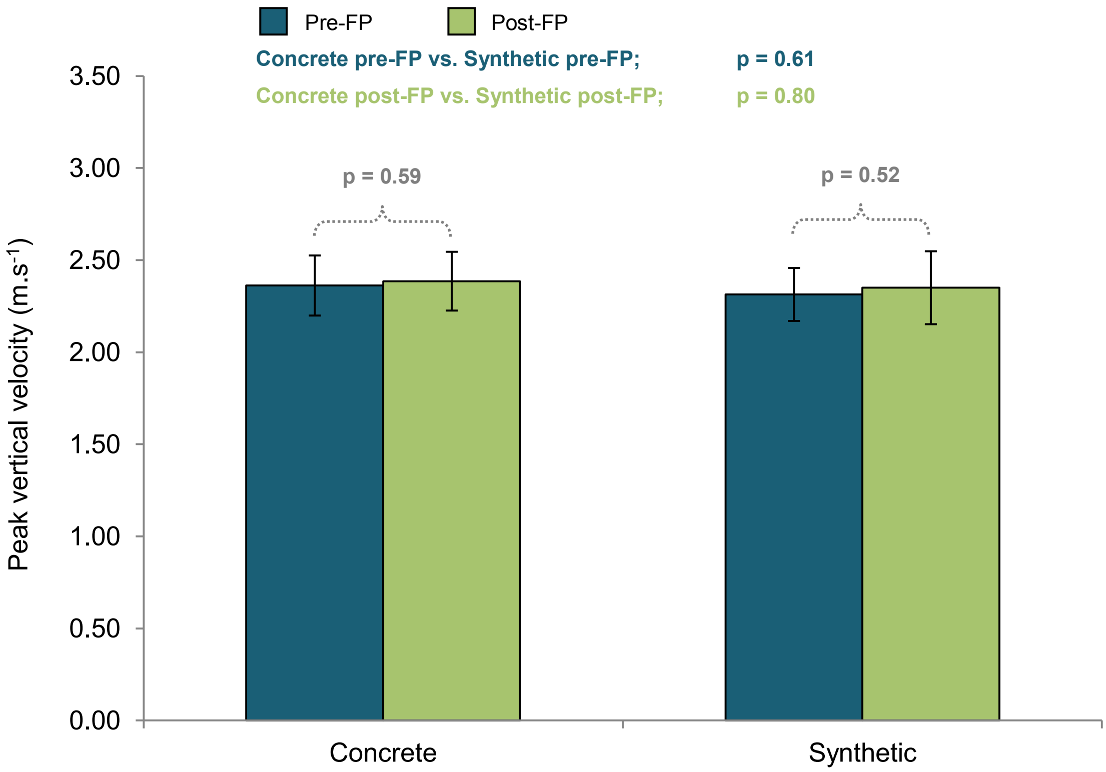

Figure 4.1 Peak vertical velocity achieved during propulsion of the vertical jump

Peak vertical velocities of 2.36 ± 0.16 $m.s^{-1}$ were reached during propulsion on the concrete surface prior to the FP. Following the FP, peak vertical velocities of 2.39 ± 0.14 $m.s^{-1}$ were reached on the concrete surface, which was similar (p = 0.59) to that prior to the FP. On the synthetic surface, similar (p = 0.52) peak vertical velocities of 2.31 ± 0.16 $m.s^{-1}$ and 2.35 ± 0.20 $m.s^{-1}$ were reached prior to and following the FP respectively. When comparing the pre-FP velocities from the respective surfaces to each other, no difference (p = 0.61) was seen. This was also true when comparing the post-FP velocities (p = 0.80) to each other.

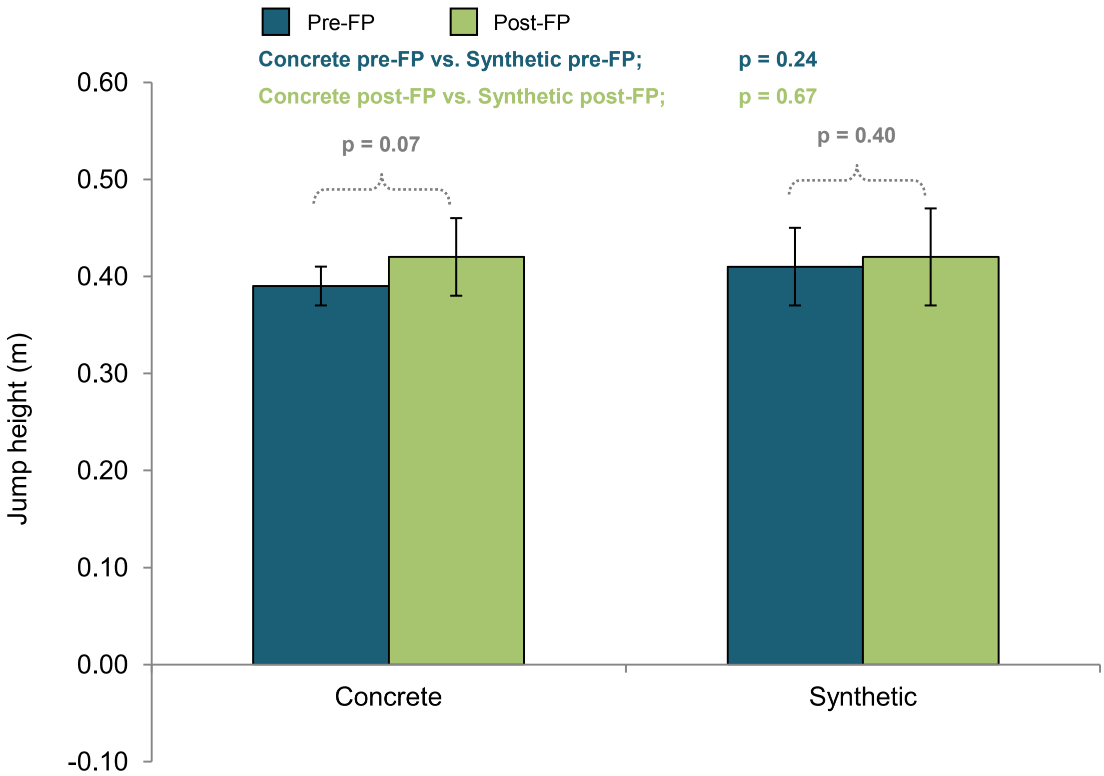

Figure 4.2 Maximum vertical jump height achieved

The mean maximum vertical jump height achieved was 0.39 ± 0.13 m prior to the FP on concrete surface, while a height of 0.42 ± 0.04 m was achieved after the FP which tended towards being significantly higher (p = 0.07) in comparison to the jump height prior to the fatiguing protocol. On the synthetic surface, similar (p = 0.40) heights were achieved before (0.41 ± 0.04 m) and after (0.42 ± 0.05 m) the FP. When comparing the jump heights achieved prior to the FP, no difference was seen (p = 0.24) between the surfaces, which is also true when comparing the post-FP results (p = 0.67).

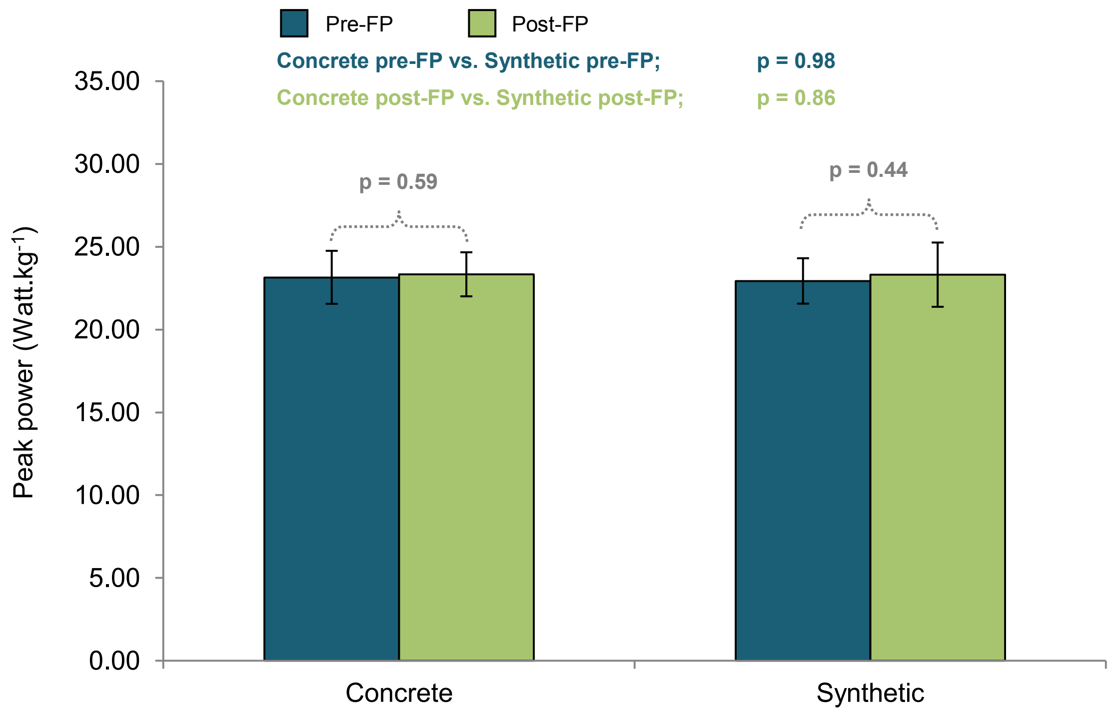

Figure 4.3   Peak power achieved during the propulsion phase of the vertical jump

On the concrete surface, peak power obtained during the propulsion phase of the vertical jump measured at 23.15 ± 1.6 Watt.kg^{-1} before the FP and 23.33 ± 1.37 Watt.kg^{-1} after the FP which was similar ($p = 0.59$) when comparing these results. On the synthetic surface, similar ($p = 0.44$) peak powers were achieved before (22.93 ± 1.33 Watt.kg^{-1}) and after (23.31 ± 1.94 Watt.kg^{-}1) the FP. There were no differences in peak power measurements between the surfaces, either before ($p = 0.98$) or after ($p = 0.86$) the FP.

4.4 ELECTROMYOGRAPHY

The average rectified value (ARV) were computed as the mean amplitude of the rectified EMG over a specified period of time (Konrad, 2006) and reported for the propulsion and landing phases respectively (Section 3.4.2).

4.4.1 Electromyography during the propulsion phase of the vertical jump

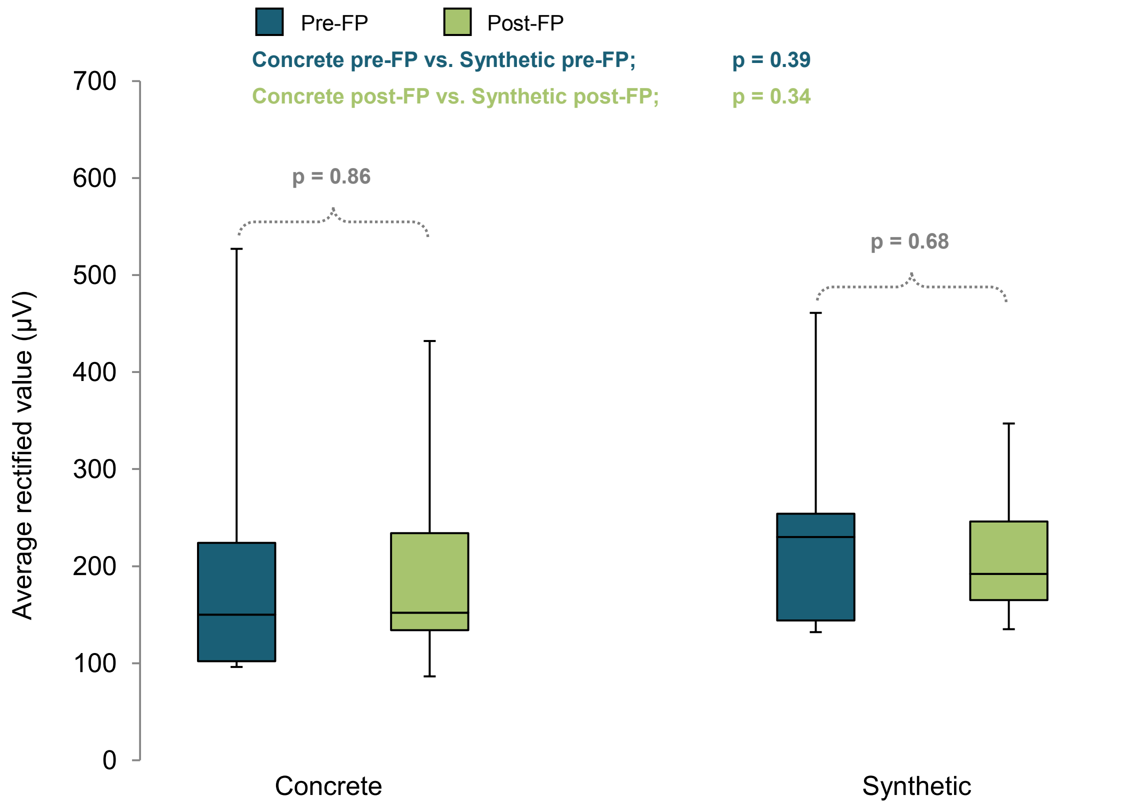

Figure 4.4.1 Average rectified value (ARV) of Rectus Femoris EMG amplitudes during the propulsion phase

During the propulsion phase of the vertical jump prior to the FP on the concrete surface, the Rectus Femoris (RF) muscles displayed a median ARV amplitude of 150.00 μV (Q_1:102.00 ; Q_3:224.00 μV) which did not change significantly ($p = 0.86$) following the FP. Median ARV amplitudes of 152.00 μV (Q_1:134.00 ; Q_3:234.00 μV) were measured from the RF muscles during the post-FP propulsion. Prior to the FP on the synthetic surface, the RF muscles displayed a median ARV amplitude of 230.00 μV (Q_1: 144.00 ; Q_3: 254.00 μV). After the FP on the synthetic surface, median ARV amplitudes of 192.00 μV (Q_1: 165.00 ; Q_3: 246 μV) were displayed which were similar ($p = 0.68$) to the pre-FP measurements. When comparing the pre- and post-FP measurements from the concrete surfaces with the corresponding measurements from the synthetic surfaces, no significant differences were noted either in the pre-FP measurements ($p = 0.39$) or the post-FP measurements ($p = 0.34$) of the RF muscles during propulsion.

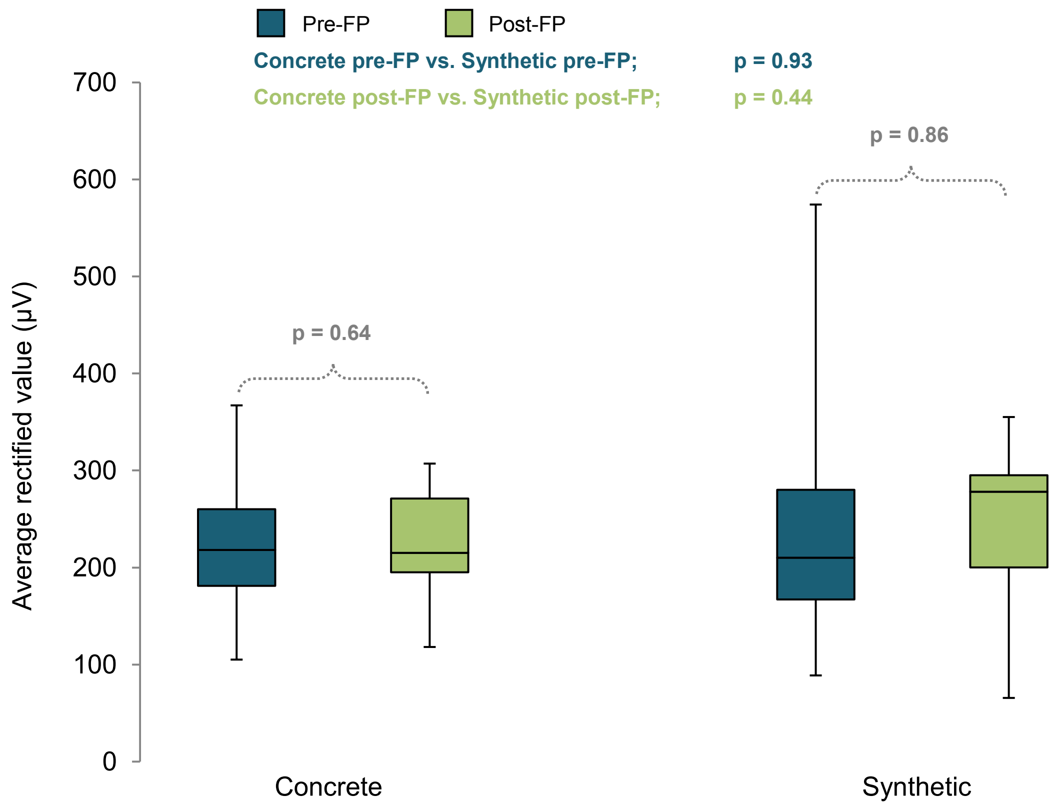

Figure 4.4.2 Average rectified value (ARV) of Vastus Medialis Oblique EMG amplitudes during the propulsion phase

During the propulsion phase of the vertical jump prior to the FP on the concrete surface, the Vastus Medialis Oblique (VMO) muscles displayed a median ARV amplitude of 218.00 µV (Q_1:181.00 ; Q_3:260.00 µV) which did not change significantly ($p = 0.64$) following the FP. Median ARV amplitudes of 215.00 µV (Q_1:195.00 ; Q_3:271.00 µV) were measured from the VMO muscles during the post-FP propulsion. Prior to the FP on the synthetic surface, the VMO muscles displayed a median ARV amplitude of 210.00 µV (Q_1: 167.00 ; Q_3: 280.00 µV). After the FP on the synthetic surface, median ARV amplitudes of 278.00 µV (Q_1: 200.00 ; Q_3: 296.00 µV) were displayed which were similar ($p = 0.86$) to the pre-FP measurements. When comparing the pre- and post-FP measurements from the concrete surfaces with the corresponding measurements from the synthetic surfaces, no significant differences were noted either in the pre-FP measurements ($p = 0.93$) or the post-FP measurements ($p = 0.44$) of the VMO muscles during propulsion.

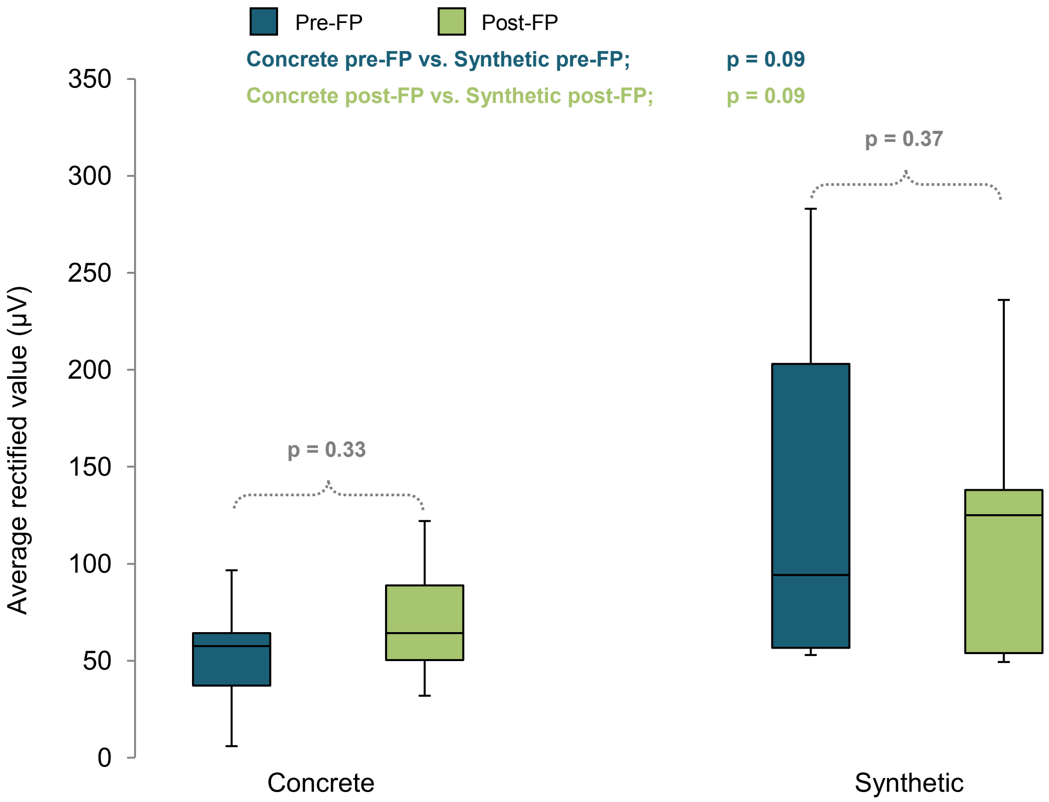

Figure 4.4.3 Average rectified value (ARV) of Tensor Fasciae Latae EMG amplitudes during the propulsion phase

During the propulsion phase of the vertical jump prior to the FP on the concrete surface, the Tensor Fasciae Latae (TFL) muscles displayed a median ARV amplitude of 57.50 µV (Q_1:37.13 ; Q_3:64.20 µV) which did not change significantly ($p = 0.33$) following the FP. Median ARV amplitudes of 64.20 µV (Q_1:50.30 ; Q_3:88.80 µV) were measured from the TFL muscles during the post-FP propulsion. Prior to the FP on the synthetic surface, the TFL muscles displayed a median ARV amplitude of 94.20 µV (Q_1: 56.60 ; Q_3: 203 µV). After the FP on the synthetic surface, median ARV amplitudes of 125.00 µV (Q_1: 53.90 ; Q_3: 138.00 µV) were displayed which were similar ($p = 0.37$) to the pre-FP measurements. Although statistical significance were not reached, both the pre-FP and post-FP ARV measurements tended towards being higher on the synthetic turf ($p = 0.09$) compared to the concrete surfaces.

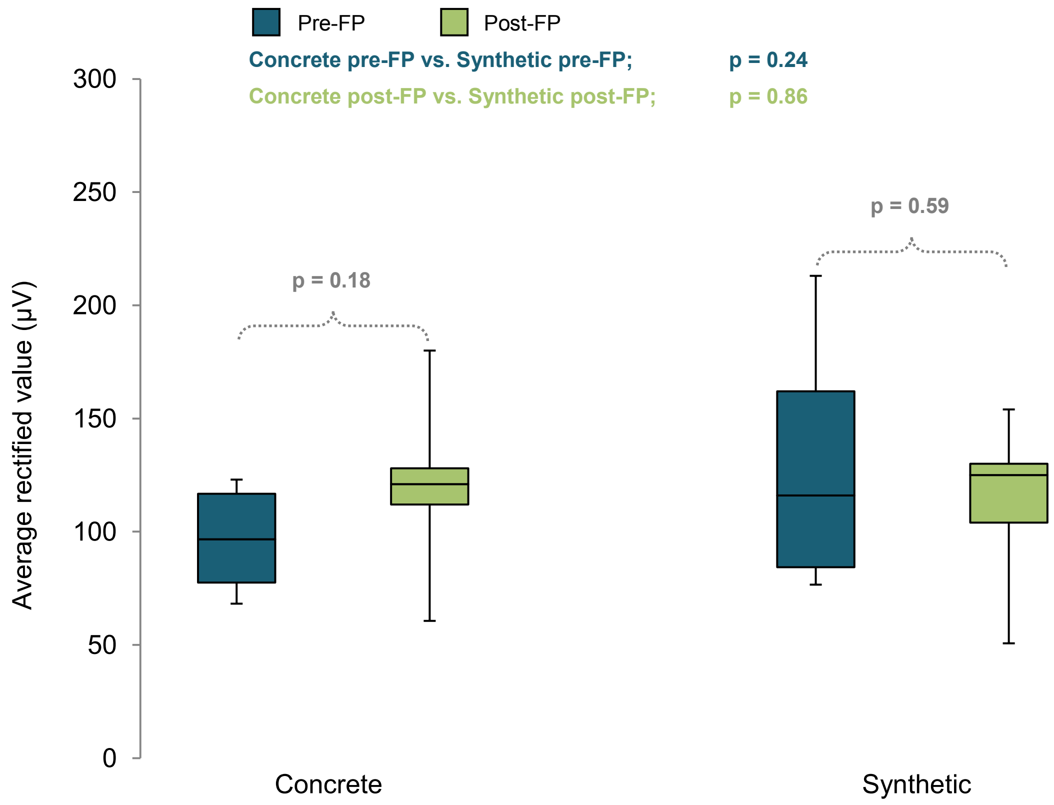

Figure 4.4.4 Average rectified value (ARV) of Bicep Femoris EMG amplitudes during the propulsion phase

During the propulsion phase of the vertical jump prior to the FP on the concrete surface, the Bicep Femoris (BF) muscles displayed a median ARV amplitude of 96.65 µV (Q_1:77.53 ; Q_3:116.75 µV) which did not change significantly ($p = 0.18$) following the FP. Median ARV amplitudes of 121.00 µV (Q_1:112.00 ; Q_3:128.00 µV) were measured from the BF muscles during the post-FP propulsion. Prior to the FP on the synthetic surface, the BF muscles displayed a median ARV amplitude of 116.00 µV (Q_1: 84.30 ; Q_3: 163.00 µV). After the FP on the synthetic surface, median ARV amplitudes of 125.00 µV (Q_1: 104.00 ; Q_3: 130.00 µV) were displayed which were similar ($p = 0.59$) to the pre-FP measurements. When comparing the pre- and post-FP measurements from the concrete surfaces with the corresponding measurements from the synthetic surfaces, no significant differences were noted either in the pre-FP measurements ($p = 0.24$) or the post-FP measurements ($p = 0.86$) of the BF muscles during propulsion.

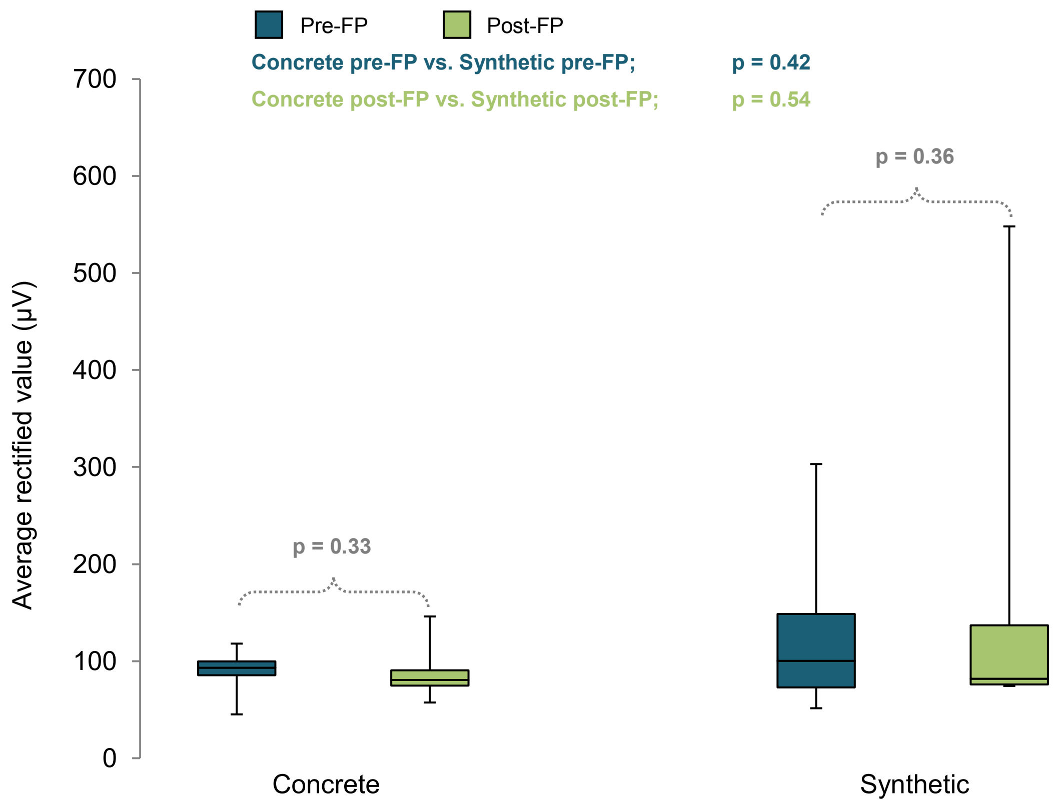

Figure 4.4.5 Average rectified value (ARV) of Semitendinosis EMG amplitudes during the propulsion phase

During the propulsion phase of the vertical jump prior to the FP on the concrete surface, the Semitendinosis (ST) muscles displayed a median ARV amplitude of 93.10 µV (Q_1:85.40 ; Q_3:99.70 µV) which did not change significantly ($p = 0.33$) following the FP. Median ARV amplitudes of 80.50 µV (Q_1:74.70 ; Q_3:90.50 µV) were measured from the ST muscles during the post-FP propulsion. Prior to the FP on the synthetic surface, the ST muscles displayed a median ARV amplitude of 100.20 µV (Q_1: 72.85 ; Q_3: 148.50 µV). After the FP on the synthetic surface, median ARV amplitudes of 81.75 µV (Q_1: 75.93; Q_3: 136.85 µV) were displayed which were similar ($p = 0.36$) to the pre-FP measurements. When comparing the pre- and post-FP measurements from the concrete surfaces with the corresponding measurements from the synthetic surfaces, no significant differences were noted either in the pre-FP measurements ($p = 0.42$) or the post-FP measurements ($p = 0.54$) of the ST muscles during propulsion.

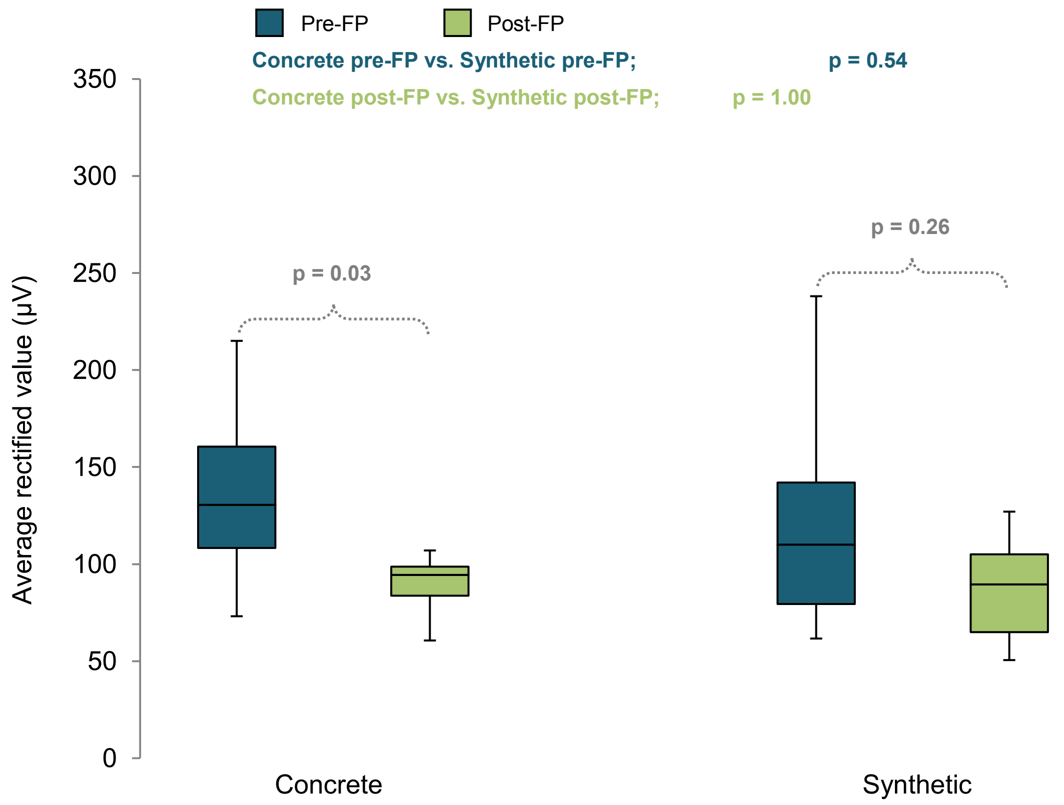

Figure 4.4.6 Average rectified value (ARV) of Tibialis Anterior EMG amplitudes during the propulsion phase

During the propulsion phase of the vertical jump prior to the FP on the concrete surface, the Tibialis Anterior (TA) muscles displayed a median ARV amplitude of 130.50 µV (Q_1:108.28 ; Q_3:160.50 µV). Median ARV amplitudes of 94.40 µV (Q_1:83.68 ; Q_3:98.65 µV) were measured from the TA muscles during the post-FP propulsion which were significantly less ($p = 0.03$) compared to the pre-FP measurements. Prior to the FP on the synthetic surface, the TA muscles displayed a median ARV amplitude of 110.00 µV (Q_1: 79.40 ; Q_3: 142.00 µV). After the FP on the synthetic surface, median ARV amplitudes of 89.50 µV (Q_1: 64.90 ; Q_3: 105.00 µV) were displayed which were similar ($p = 0.26$) to the pre-FP measurements. When comparing the pre- and post-FP measurements from the concrete surfaces with the corresponding measurements from the synthetic surfaces, no significant differences were noted either in the pre-FP ($p = 0.54$) or the post-FP ($p = 1.00$) measurements of the TA muscles during propulsion.

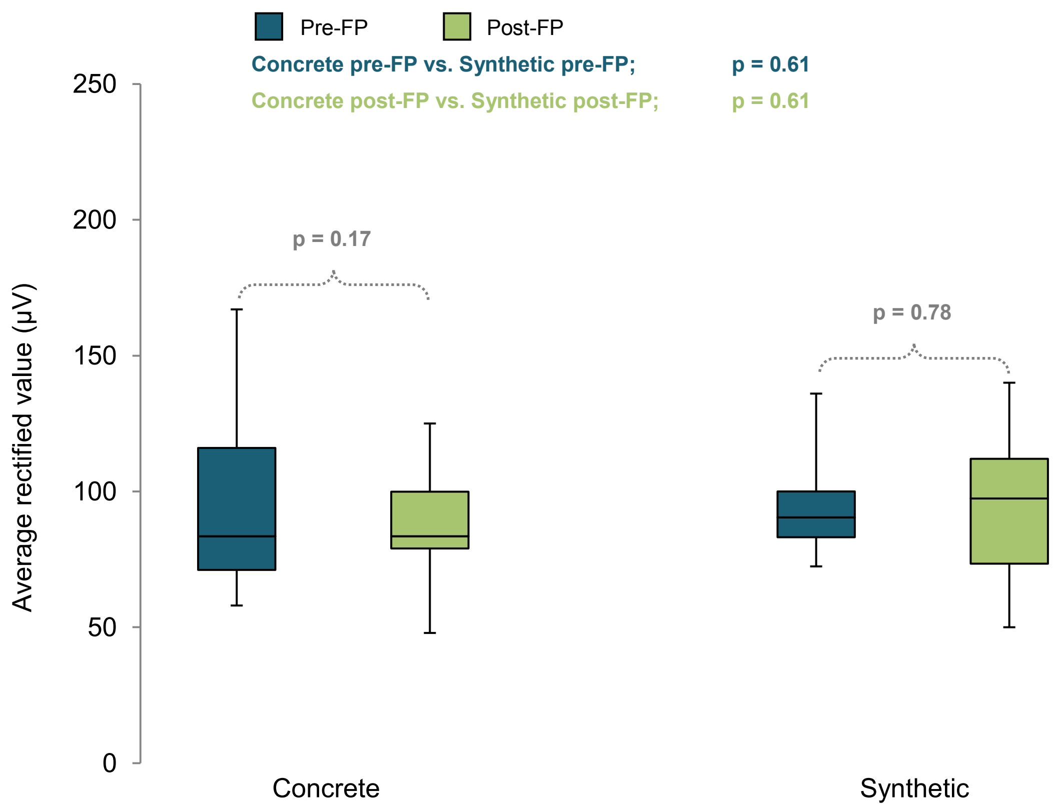

Figure 4.4.7 Average rectified value (ARV) of Gastrocnemius EMG amplitudes during the propulsion phase

During the propulsion phase of the vertical jump prior to the FP on the concrete surface, the Gastrocnemius (GN) muscles displayed a median ARV amplitude of 83.50 µV (Q_1:71.10 ; Q_3:116.00 µV) which did not change significantly ($p = 0.17$) following the FP. Median ARV amplitudes of 83.50 µV (Q_1:79.00 ; Q_3:99.90 µV) were measured from the GN muscles during the post-FP propulsion. Prior to the FP on the synthetic surface, the GN muscles displayed a median ARV amplitude of 90.45 µV (Q_1: 83.13 ; Q_3: 100.00 µV). After the FP on the synthetic surface, median ARV amplitudes of 97.40 µV (Q_1: 73.40 ; Q_3: 112.00 µV) were displayed which were similar ($p = 0.78$) to the pre-FP measurements. When comparing the pre- and post-FP measurements from the concrete surfaces with the corresponding measurements from the synthetic surfaces, no significant differences were noted either in the pre- or post-FP measurements ($p = 0.61$) of the GN muscles during propulsion.

4.4.2 Electromyography during the landing phase of the vertical jump

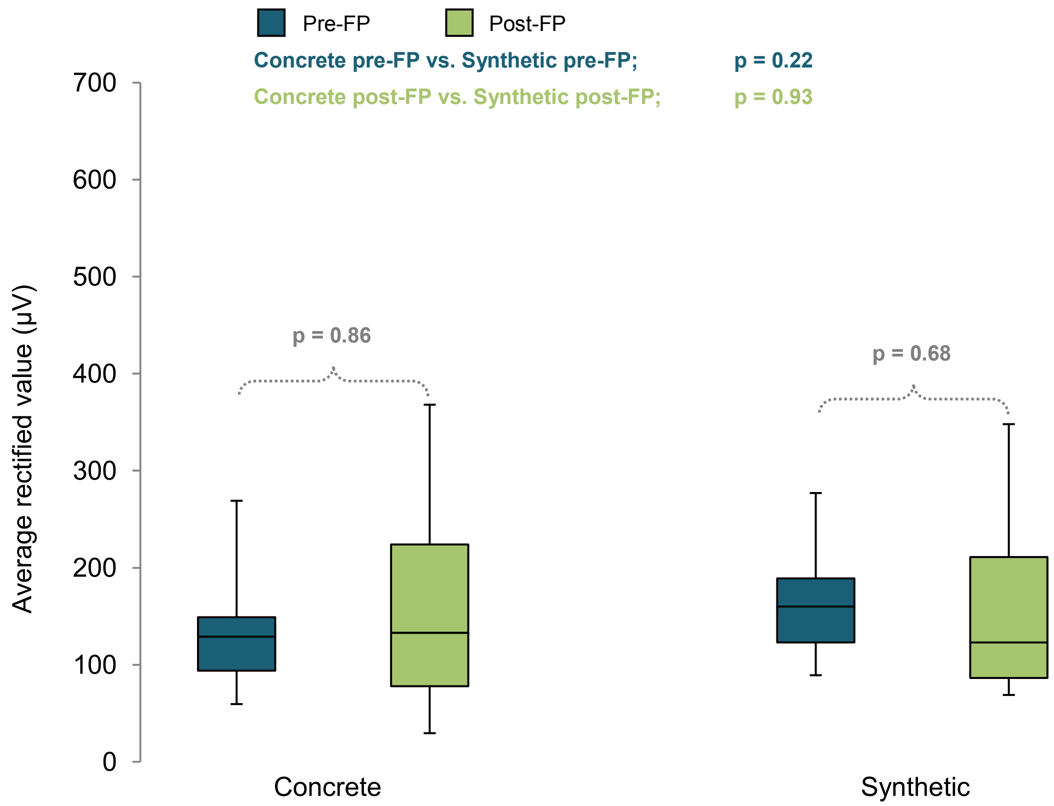

Figure 4.4.8 Average rectified value (ARV) of Rectus Femoris EMG amplitudes during the landing phase

During the landing phase of the vertical jump, prior to the FP on the concrete surface, the RF muscles displayed a median ARV amplitude of 129.00 µV (Q_1:93.90 ; Q_3:149.00 µV) which did not change significantly ($p = 0.86$) following the FP. Median ARV amplitudes of 133.00 µV (Q_1:77.90 ; Q_3:224.00 µV) were measured from the RF muscles during the post-FP landing. Prior to the FP on the synthetic surface, the RF muscles displayed a median ARV amplitude of 160.00 µV (Q_1: 123.00 ; Q_3: 189.00 µV). After the FP on the synthetic surface, median ARV amplitudes of 123.00 µV (Q_1: 86.40 ; Q_3: 211.00 µV) were displayed which were similar ($p = 0.68$) to the pre-FP measurements. When comparing the pre- and post-FP measurements from the concrete surfaces with the corresponding measurements from the synthetic surfaces, no significant differences were noted either in the pre-FP measurements ($p = 0.22$) or the post-FP measurements ($p = 0.93$) of the RF muscles during landing.

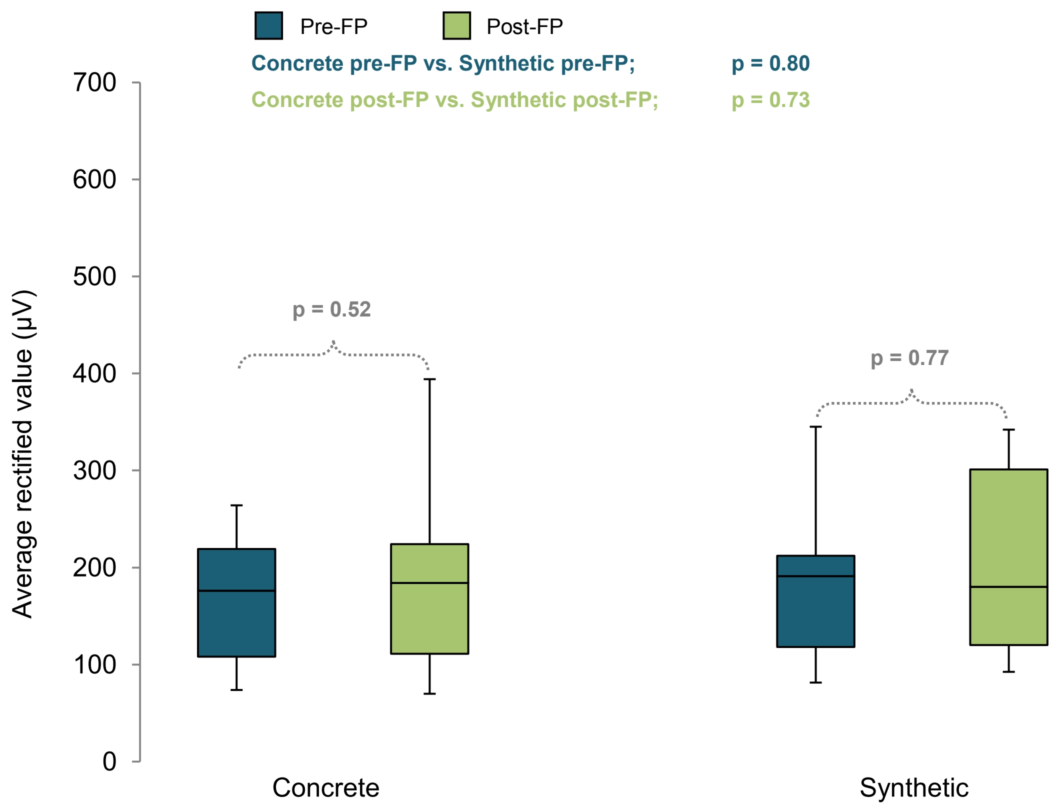

Figure 4.4.9 Average rectified value (ARV) of Vastus Medialis Oblique EMG amplitudes during the landing phase

During the landing phase of the vertical jump, prior to the FP on the concrete surface, the VMO muscles displayed a median ARV amplitude of 176.00 µV (Q_1:108.00 ; Q_3:219.00 µV) which did not change significantly ($p = 0.52$) following the FP. Median ARV amplitudes of 184.00 µV (Q_1:111.00 ; Q_3:224.00 µV) were measured from the VMO muscles during the post-FP landing. Prior to the FP on the synthetic surface, the VMO muscles displayed a median ARV amplitude of 191.00 µV (Q_1: 118.00 ; Q_3: 212.00 µV). After the FP on the synthetic surface, median ARV amplitudes of 180.00 µV (Q_1: 120.00 ; Q_3: 301.00 µV) were displayed which were similar ($p = 0.77$) to the pre-FP measurements. When comparing the pre- and post-FP measurements from the concrete surfaces with the corresponding measurements from the synthetic surfaces, no significant differences were noted either in the pre-FP measurements ($p = 0.80$) or the post-FP measurements ($p = 0.73$) of the VMO muscles during landing.

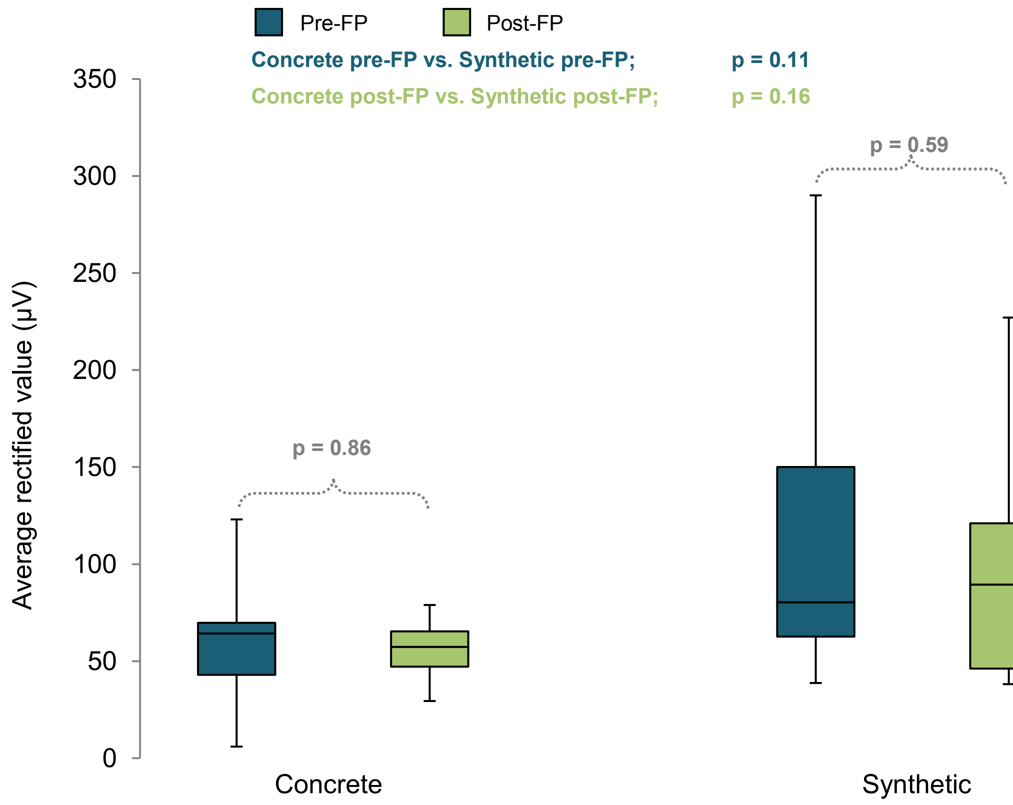

Figure 4.4.10 Average rectified value (ARV) of Tensor Fasciae Latae EMG amplitudes during the landing phase

During the landing phase of the vertical jump, prior to the FP on the concrete surface, the TFL muscles displayed a median ARV amplitude of 64.20 µV (Q_1:42.90 ; Q_3:69.70 µV) which did not change significantly (p = 0.86) following the FP. Median ARV amplitudes of 57.00 µV (Q_1:47.10 ; Q_3:65.30 µV) were measured from the TFL muscles during the post-FP landing. Prior to the FP on the synthetic surface, the TFL muscles displayed a median ARV amplitude of 80.30 µV (Q_1: 62.60 ; Q_3: 150.00 µV). After the FP on the synthetic surface, median ARV amplitudes of 89.40 µV (Q_1: 46.10 ; Q_3: 121.00 µV) were displayed which were similar (p = 0.59) to the pre-FP measurements. When comparing the pre- and post-FP measurements from the concrete surfaces with the corresponding measurements from the synthetic surfaces, no significant differences were noted either in the pre-FP measurements (p = 0.11) or the post-FP measurements (p = 0.16) of the TFL muscles during landing.

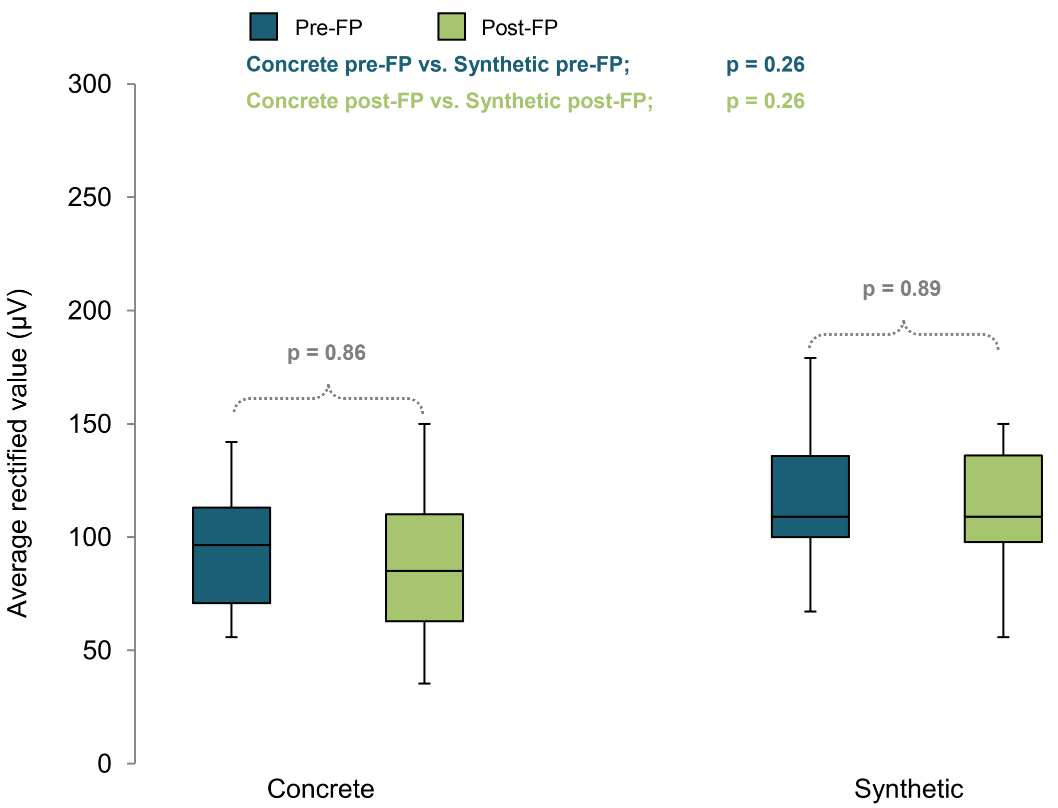

Figure 4.4.11 Average rectified value (ARV) of Bicep Femoris EMG amplitudes during the landing phase

During the landing phase of the vertical jump, prior to the FP on the concrete surface, the BF muscles displayed a median ARV amplitude of 96.50 µV (Q_1:70.80 ; Q_3:113.00 µV) which did not change significantly ($p = 0.86$) following the FP. Median ARV amplitudes of 85.10 µV (Q_1:62.80 ; Q_3:110.00 µV) were measured from the BF muscles during the post-FP landing. Prior to the FP on the synthetic surface, the BF muscles displayed a median ARV amplitude of 109.00 µV (Q_1: 99.93 ; Q_3: 135.75 µV). After the FP on the synthetic surface, median ARV amplitudes of 109.00 µV (Q_1: 97.80 ; Q_3: 136.00 µV) were displayed which were similar ($p = 0.89$) to the pre-FP measurements. When comparing the pre- and post-FP measurements from the concrete surfaces with the corresponding measurements from the synthetic surfaces, no significant differences were noted either in the pre- or post-FP measurements ($p = 0.26$) of the BF muscles during landing.

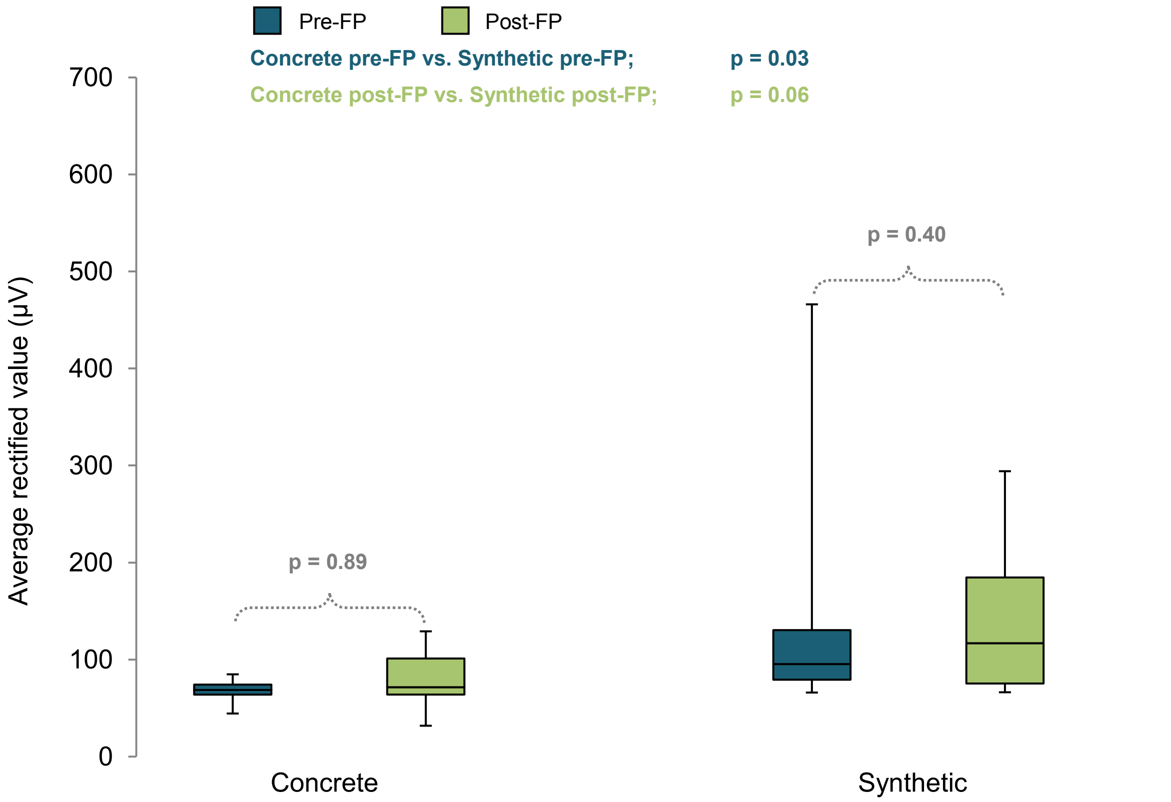

Figure 4.4.12 Average rectified value (ARV) of Semitendinosis EMG amplitudes during the landing phase

During the landing phase of the vertical jump, prior to the FP on the concrete surface, the ST muscles displayed a median ARV amplitude of 68.55 µV (Q_1:63.75 ; Q_3:74.08 µV) which did not change significantly ($p = 0.89$) following the FP. Median ARV amplitudes of 71.40 µV (Q_1:63.80 ; Q_3:101.00 µV) were measured from the ST muscles during the post-FP landing. Prior to the FP on the synthetic surface, the ST muscles displayed a median ARV amplitude of 95.25 µV (Q_1: 79.10 ; Q_3: 130.25 µV). After the FP on the synthetic surface, median ARV amplitudes of 116.75 µV (Q_1: 75.20 ; Q_3: 184.50 µV) were displayed which were similar ($p = 0.40$) to the pre-FP measurements. The ARV amplitudes were significantly higher ($p = 0.03$) on the synthetic surface prior to the FP and nearing significance ($p = 0.06$) with a tendency to be higher on the synthetic surface after the FP when compared to the corresponding measurements from the ST muscles during landing on concrete.

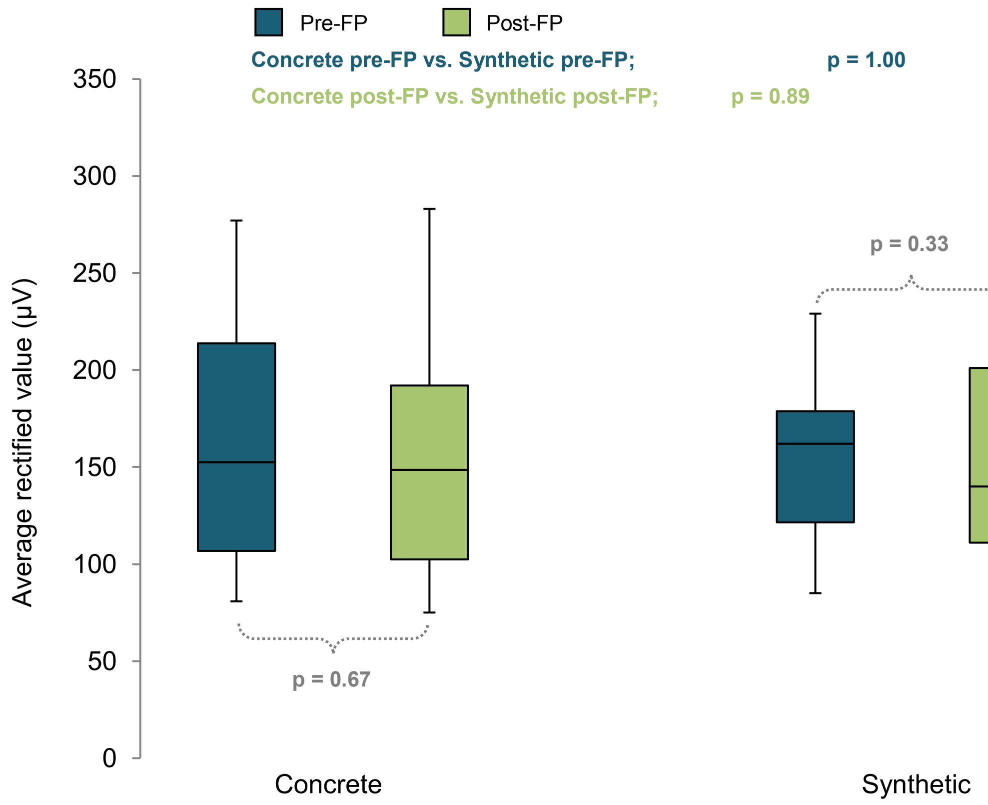

Figure 4.4.13 Average rectified value (ARV) of Tibialis Anterior EMG amplitudes during the landing phase

During the landing phase of the vertical jump, prior to the FP on the concrete surface, the TA muscles displayed a median ARV amplitude of 152.50 µV (Q_1:106.73 ; Q_3:213.75 µV) which did not change significantly ($p = 0.67$) following the FP. Median ARV amplitudes of 148.50 µV (Q_1:102.43 ; Q_3:192 µV) were measured from the TA muscles during the post-FP landing. Prior to the FP on the synthetic surface, the TA muscles displayed a median ARV amplitude of 162.00 µV (Q_1: 121.50 ; Q_3: 178.75 µV). After the FP on the synthetic surface, median ARV amplitudes of 140.00 µV (Q_1: 111.00 ; Q_3: 201.00 µV) were displayed which were similar ($p = 0.33$) to the pre-FP measurements. When comparing the pre- and post-FP measurements from the concrete surfaces with the corresponding measurements from the synthetic surfaces, no significant differences were noted either in the pre-FP measurements ($p = 1.00$) or the post-FP measurements ($p = 0.89$) of the TA muscles during landing.

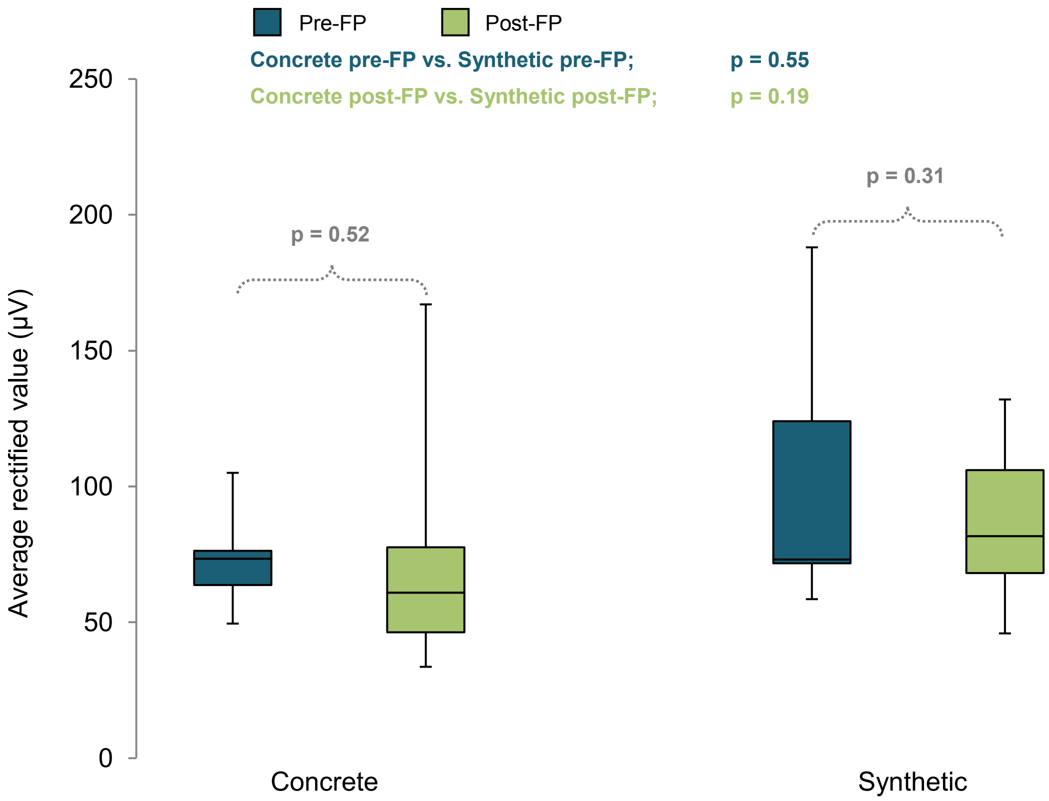

Figure 4.4.14 Average rectified value (ARV) of Gastrocnemius EMG amplitudes during the landing phase

During the landing phase of the vertical jump, prior to the FP on the concrete surface, the GN muscles displayed a median ARV amplitude of 74.40 µV (Q_1:63.70 ; Q_3:76.30 µV) which did not change significantly ($p = 0.52$) following the FP. Median ARV amplitudes of 60.90 µV (Q_1:46.30 ; Q_3:77.60 µV) were measured from the GN muscles during the post-FP landing. Prior to the FP on the synthetic surface, the GN muscles displayed a median ARV amplitude of 73.10 µV (Q_1: 71.70 ; Q_3: 124.00 µV). After the FP on the synthetic surface, median ARV amplitudes of 81.70 µV (Q_1: 68.10 ; Q_3: 106.80 µV) were displayed which were similar ($p = 0.31$) to the pre-FP measurements. When comparing the pre- and post-FP measurements from the concrete surfaces with the corresponding measurements from the synthetic surfaces, no significant differences were noted either in the pre-FP measurements ($p = 0.55$) or the post-FP measurements ($p = 0.19$) of the GN muscles during landing.

Chapter 5
DISCUSSION

5.1 INTRODUCTION

The aim of this study was to assess lower limb muscle fatigue on different netball playing surfaces by investigating the response of lower limb muscles during the vertical jump following a sport-specific fatiguing protocol (FP) on concrete and synthetic surfaces. Nine female elite netball players participated in this cross-sectional study. A linear transducer and electromyography (EMG) system were used to address the following research questions:

1) Is there a significant difference in jump performances following a netball simulated fatiguing protocol on different play surfaces?
2) Is there a significant difference in lower limb surface EMG activity following a netball simulated fatiguing protocol on different play surfaces?

5.2 DISCUSSION

5.2.1 Anthropometric results

The anthropometric profiles of the netball players participating in this research project were similar to literature using comparable population groups (Hopper, 1997; Ziv, 2009). Average body masses of 68.8 ± 6.0 kg, heights of 1.76 ± 0.05 cm and fat percentages of 19.8 ± 3.3 % were measured. Even though the relatively small standard deviations found for these anthropometric measures suggest homogeneity of the sample group, which was favourable for this research, it is contradictory to other studies suggesting significantly different anthropometric profiles of netball players from different player positions (Geithner *et al*., 2006; McManus and Stevenson, 2005). Senior goal defence players usually present with tall, ectomorphic characteristics compared to the goal attack and midfield players who display mesomorphic characteristics (Hopper, 1997). However, Hopper (1997) also found no significant differences in somatotyping between the different players from the under 21 year group, which is also true in this study which consisted mainly of under 21 year netball players.

5.2.2 Outcome measures

Success of the vertical jump is portrayed in the jump height achieved and is determined by the vertical velocity at the point of take-off and amount of muscular power produced during propulsion. Vertical velocity typically peaks slightly earlier than take-off and declines somewhat during the last 0.15 sec of the propulsion phase (Bobbert and Van Ingen Schenau, 1988). Although the vertical velocity at take-off would have been a more accurate and conventional outcome measure to assess, it was impossible to accurately determine the point of take-off with the available equipment. As a consequence, peak velocities were measured and reached values ranging from 2.31 ± 0.16 $m.s^{-1}$ to 2.39 ± 0.14 $m.s^{-1}$ on average which was less than that reported by Kirby *et al*. (2011). Due to the fact that literature mostly report the vertical velocities at the point of take-off, it was difficult to directly compare these findings to literature. Considering that the peak vertical velocity during a typical countermovement jump decreases by approximately 6% to the point of take-off (Harman *et al*., 1990), the results from this study suggest that estimated take-off velocities reached approximately 2.17 to 2.25 $m.s^{-1}$ on average. This is considerably less than the average take-off velocities reported in literature which is in the region of 2.67 $m.s^{-1}$ (Bobbert *et al*., 1987; Bobbert and Van Ingen Schenau, 1988; Feltner *et al*., 1999; Moran and Wallace, 2007; Vanrenterghem *et al*., 2004; Voight *et al*., 1995). A possible explanation for this discrepancy could be the resistance from the linear transducer of the Tendo device which did not allow the opportunity for uninhibited force and vertical velocity production as is the case with force plate measurements.

A related study (Schmitz *et al*., 2014) also had similar findings where the countermovement jump (CMJ) height was maintained regardless of the change in biomechanics brought on by fatigue.

Despite the decreased vertical velocities displayed by the participants from this study compared to literature, jump heights greater than that reported in literature (in the range of 0.36 m; Bobbert *et al*., 1987; Bobbert and Van Ingen Schenau, 1988; Feltner *et al*., 1999; Moran and Wallace, 2007; Vanrenterghem *et al*., 2004; Voight *et al*., 1995) were achieved. On the concrete surface, the post-FP jump heights of 0.42 ± 0.04 m were slightly higher ($p = 0.07$) than the pre-FP jump heights of 0.39 ± 0.13 m, while the jump heights before (0.41 ± 0.04 m) and after (0.42 ± 0.05 m) the FP on the synthetic surface were similar to each other ($p = 0.40$), both of which were contrary to expectation. A study by (Pupo *et al*., 2013) found that fatigue causes reduction in jump performance. However, in this study, the opposite was found. Despite the fact that the participants could not keep up with the required pace dictated by the Yo-Yo test and met the criteria for termination of the test, superficial observations of the results seem to imply that fatigue had not been reached. However, considering that the efficacy of the Yo-Yo test to induce muscle fatigue has been established (Crockett, 2011) and attention was given to collect the post-FP data before recovery could set in (Kenney *et al.*, 2011), alternative explanations should be considered.

The modification of the Yo-Yo test to include countermovement jumps between the shuttle runs may potentially explain this unexpected phenomenon. The stretch-shortening cycle present within the countermovement jump brings about a transient increase in contractile performance after previous eccentric-concentric activity (Sale, 2002) and is known as the post-activation potentiation (PAP). An increase in the recruitment of Type 2 muscle fibres during the explosive countermovement jumps may potentially have enhanced the lower limb muscular performance through three possible mechanisms (Tillin and Bishop, 2009):

1) *Phosphorylation of myosin regulatory light chains*

A myosin molecule is composed of two heavy chains. At the end of each chain a myosin head is formed, containing two regulatory light chains (RLC). Each RLC has a specific binding site for a phosphate molecule. The RLC phosphorylation process is catalyzed by the enzyme myosin light chain kinase, which is activated when Ca2+ molecules, released from the sarcoplasmic reticulum during muscular contraction, bind to the calcium regulatory protein calmodulin. This phosphorylation is thought to potentiate subsequent contractions by altering the structure of the myosin head as well as adjust the actin-myosin interaction to be more sensitive to myoplasmic Ca.

2) *Increased recruitment of higher order motor units*

An induced tetanic isometric contraction caused by stimulating specific afferent neural fibres, which in turn activate adjacent motor neurons via an afferent neural pathway, elevates the conduction of excitation potentials across synaptic junctions at spinal cord level. As a result there is an increase in post-synaptic potentials, for the same pre-synaptic potential during subsequent activity.

3) Change in muscle pennation angles

The pennation angle of a muscle is the angle formed by the fascicles and the central aponeurosis. It is a reflection of the orientation of muscle fibres in relation to connective tissue/ tendon. The pennation angle will affect the force vector transmission to the tendons and bones. A smaller pennation angle will have a mechanical advantage with respect to force transmission to the tendon. Studies found a small decrease in pennation angles 3-6 minutes after a voluntary muscle contraction that can be contributed to the PAP phenomenon.

The first two proposed mechanisms might be explanatory to the result found in this study as the post-FP data was obtained during the time span of 8-12 minutes when PAP is active (Gouvêa *et al*., 2013; Kilduff *et al*., 2008). Considering the fact that the participant performances should (theoretically) have declined while being fatigued, yet their performances remained the same or even increased following the FP on the concrete surface, the PAP seemingly had a positive effect on the post-FP performances. The increased concrete performances suggest that the PAP effect was greater on the concrete compared to the synthetic surfaces.

Based on motion equations ($v^2 = u^2 + 2as$) which implies that that velocity at take off will determine the displacement at a constant deceleration attributed to gravity, the miscommunication between the decreased velocities with increased jump heights from this study is not possible. Despite the fact that other researchers have reported the Tendo to be a reliable measuring tool (Gernacho-Gestano *et al*., 2015), a feasible explanation for the discrepancy found in these results tends to bring the reliability of the measuring tool into question. However, it has to be acknowledged that the comparison to literature is based on the estimated take-off velocity derived from the actual measured peak velocity from the Tendo which would lead to unsubstantiated conclusions if too much emphasis were placed on this discrepancy. Furthermore, within the aim of this research project, the speculative systematic error brought about by the Tendo measurements would not have influenced inferences made from the pre-post analyses.

The fact that there was no difference in the pre-post peak power on both surfaces, but a trend towards an increase in jump height on the concrete surface post fatigue implies that other factors than peak power contributed to the slightly higher jump height seen on the concrete surface and should be investigated in future research.

Bobbert (Bobbert and van Ingen Schenau, 1988) found that in order to obtain maximum jump height the angular velocity of body segments must reach their peaks in a sequence. The sequence is from upper body, upper legs, lower legs to the feet. In a more recent similar study (Kirby *et al.*, 2011) it was found that the jump with the maximum peak power was not always the jump with the maximum height, but the jump where the participant were instructed to squat to a depth lower than the self-selected depth. It can be argued that while the peak power remained the same, the participants managed to optimize the sequence of the angular velocities, during a fatiguing state, to a more effective way as described above to reach an increased height.

Research (Eloranta, 2003) also suggest that prolonged training in a specific sport will cause the central nervous system (CNS) to program muscle coordination according to the demands of that sport. That learned skill-reflex of the CNS seems to affect the performance of another task. It could therefore be postulated that the conditioned skill-reflexes the participants already obtained from playing netball, predominantly on a concrete surfaces, contributed to a greater jump height even in a fatigued state.

The countermovement depth is another highly debatable contributing factor to vertical jump performance. In literature there seems to be an optimal value of countermovement depth, but have a small contributing role in maximal jump height (Mandic *et al*, 2014). A study done my Markovic also concluded that both body size and countermovement depth (in CMJ) had no effect on the muscle power output or the performance of maximum vertical jumps (Markovic *et al*, 2014). Due to the limitations in available equipment, the effect of the countermovement depth could not be assessed, but should be considered for future research.

5.3 ELECTORMYOGRAPHY

The generally large standard deviations (SD) seen for most averaged rectified value (ARV) distributions suggest that varied motor unit recruitment strategies were followed by the participants, despite the fact that a homogenous group with similar exposure to jump training participated in this group. Although it is generally believed that fatigue causes a general reduction in muscle force, fatigue and the amount of muscle strength are not always proportional (Smilios, 1998), bringing about the concept of central and peripheral fatigue. Central fatigue is associated with a reduced ability to fire voluntary contractions of the muscle, while peripheral fatigue is the reduction in the muscle force itself (Boerio *et al.*, 2005). Based on the results from this study which did not indicate peripheral fatigue, it is necessary to look at the EMG results for signs of central fatigue. It is important to note that Taylor and Gandeva (2008) found it very hard to determine whether central fatigue occurred during submaximal tasks without a disproportionate increase in the participants' rates of perceived exertions.

5.3.1 Electromyography of the upper leg muscles

This particular study could not found any significant change in the muscle groups of the upper leg muscles activation during landing phase of the vertical jump on either surface comparing pre- and post-FP values, but interestingly there was a significant difference in ST activation during the landing phase prior to the FP on the synthetic surface compared to the concrete surface. There was also a greater activation of semitendinosis (ST) after the FP on the synthetic surface, however not significantly so. The fact that there was such a difference in activation prior the fatiguing protocol implies that ST activation is not a repeatable and therefore reliable measure to assess pre-post effects from different surfaces. However, the fact that the ST ARV displayed a very high upper range value following the FP on the synthetic surface could possibly suggest that some of the participants experienced peripheral fatigue of the knee flexors which had to be counteracted by an increased recruitment of muscle fibres.

Studies found that antagonist hamstring activity is needed to counteract the quadriceps muscle forces during landing (Kellis and Kouvelioti, 2009). Research also found that the neuromuscular system adapts to compensate for fatigued muscles by alternating joint kinematics and the activation of muscles in order to minimize knee joint loading and anterior cruciate ligament (ACL) straining (Kellis and Kouvelioti, 2009). In the study mentioned it was proposed that the hamstring antagonist activity adapted according the activity of the quadriceps, regardless the state of fatigue, to always maintain the optimal quadriceps to hamstring ratio. To consider this theory within the scope of this research project, isokinetic testing would have been useful. Except for the slight increase in Bicep femoris (BF) activity during the propulsion phase after the FP on the concrete surface, the activity of neither Rectus Femoris (RF) nor vastus lateralis (VL) increased parallel with ST during the landing phase, regardless the incorporation of the FP, which is contradictory to the reasoning of Kellis and Kouvelioti (2009).

In a related study (Hassani *et al.*, 2006) that used a dynamometer to produce fatigue it was found that agonist and antagonist activity patterns depends on the intensity of the isokinetic fatiguing test. During continued sub-maximal concentric contractions the agonist activity increased and antagonist activity initially increased and decreased as the FP continued (Hassani *et al.*, 2006). It could be argued that there was continues concentric muscle contractions during the vertical jump and FP in this particular study.

A similar study (Chappell *et al*, 2007) found a unexpected increase in activation of the hamstrings in preparation of landing. This increase was greater in female athletes compared to males, but the activation stayed the same during landing. The study did not include a fatiguing protocol and made use of a stop-jump task, but the results could however clarify the greater ST activation found in this study. An increase in BF activation should however also have been expected to rectify the theory.

Research (Mullany *et al*, 2002) also suggest that a common neural pathway may exist to the knee extensors and the antagonist BF during knee extension which could lead to a more pronounced fatigue in the lateral than medial hamstring muscle. This could have a potential negative impact on the neuromuscular control of rotational knee stability and valgus control. In this study however, greater activation was found in the medial ST hamstring muscle which was also comparable to findings in a related study (Thorlund *et al*, 2008), but the theory of a common neural pathway to the knee extensors and hamstrings could be explanatory to the greater activation of ST found in this study. An increased quadriceps activation should however been expected to confirm the theory.

The activation of Tensor Faciae Latae (TFL) during propulsion and landing was somewhat higher before the FP on the synthetic surface than on the concrete surface, however not significantly. A comparison of activation pre- and prior the FP will therefore be challenging, but there was however an increased activation after the FP on the synthetic surface during the landing - and the propulsion phase. In a similar study (Pinnington *et al*, 2005) that compared muscle activation while running on soft sand surface and a hard firm surface found greater activation of TFL as well as in the hamstring and quadriceps muscle groups when running on a soft sand surface due to a wider range of joint motion and a need for greater joint stability. As TFL is a prominent hip and knee stabilizer (Palastanga and Soames, 2012), it could be argued that additional hip and knee stability was needed during the FP on the softer synthetic surface regardless the state of muscle fatigue. The synthetic surface used in this particular study, however was not nearly as soft as sand used in the study mentioned and the fact that the hamstring – and quadriceps muscle groups activation did not follow the same pattern challenges the theory.

Perhaps the most noteworthy finding from the EMG results is the pronounced consistency in EMG activity from the ST muscles for all participants, both during propulsion and landing on the concrete surface. The fact that the distribution patterns are extremely centred around ARV measurements in the region of 100 µV (Figures 4.4.6 and 4.4.12) for EMG values which is usually quite varied, suggest that the recruitment requirement for this specific muscle is fairly constant for this homogenous participant group, and more so following the FP on the concrete surface compared to the synthetic surface which gives a wide distribution pattern.

5.3.2. Electromyography of the lower leg muscles

The average activation of the lower leg muscle did not change comparing the post FP values on the separate surfaces during the propulsion and landing phase of the jump. The activation of Tibialis Anterior (TA) however did show a significant decrease after the FP on the concrete surface during the propulsion phase, but did not show a significant change compared to the synthetic surface. The fact that the pre-FP values were comparable and that the decrease in activation only took place after the FP on the concrete surface, suggests that the concrete surface had a significant effect on the decrease in activation especially during the propulsion phase of the vertical jump. It could be further argued that TA is the muscle that displays the first evidence of muscle fatigue compared to the other muscle groups. Interestingly to note that the activation of Gastrocnemius (GN) decreased, however not significantly, in a similar fashion after the FP on the concrete surface compared to the synthetic surface, also during the propulsion phase of the jump. This would suggest central fatigue for the lower leg muscles following the FP on the concrete surface.

For optimal jumping performance the joint angular velocities need to peak in a sequence (Bobbert and van Ingen Schenau, 1988) and that the sequence becomes more relevant during fatigue to maintain optimal jumping performance (Pupo *et al*., 2013; Schmitz *et al*., 2014). It could be argued, that the TA and GN that controls the most distal ankle joint was not optimally activated at the time the rest of the more proximal muscle groups revealed optimal activation. Due to the slower nature of the jump after the FP, the delayed activation was more profound, and could therefore be explanatory to the result found in this study.

A study (Wikstrom *et al*, 2008) found that for a successful jump landing, muscles need to have earlier preparatory activation, accept for TA. In this study however the decrease in TA activation was not during the landing phase as expected, but during the propulsion phase.

5.4. LIMITATIONS

Skinfolds were determined with a skinfold caliper, but it should be noted that the accuracy of the test is dependent on the measurer and his/her skill level.

The study sample was small. The reason for that was that the size of the available candidates was limited and subsequently limited the statistical power. This was addressed through a stringent alpha value despite the small sample size and the use of robust statistical tests such as the Mann-Whitney U, which limited the possibility for Type 1 errors to occur. However, given the small sample size together with the high variability inherent to EMG data, it has to be acknowledged that Type 2 errors could have occurred and therefore it is recommended that future research in this field aim to use considerably larger sample groups.

In this study surface EMG data and jump performance was each used in its own capacity to measure the extent of muscle fatigue. As described in literature surface EMG data cannot be used in isolation to evaluate muscle fatigue and should be analyzed in conjunction with accessory biomechanical data (González-izal *et al*, 2012). The only associated biomechanical data that could have been used in correlation with the surface EMG data in this particular study was peak power, jump height and peak vertical velocity during propulsion.

The surface EMG data was not normalized between each participant. It would have been a difficult due to the nature of the functional movement of a CMJ. The fact that the countermovement during propulsion and landing was not standardized; the joint range of movement as well as the time span of movement were not consequent, increased the variability between the participants.

Data were collected two days after each other. It could be postulated that the exertion on day one had an effect on the results of the next day. It could be argued that a longer period of rest in between the days of data collection was needed to rectify the results.

There was no proving that the participants did a maximal jump effort or a pre-collected value which against to measure it. That opens up another door for variability among the participants and subsequent results.

Chapter 6
CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the Yo-Yo test which has been validated to induce fatigue in other studies, did not lead to a decrease in jump performance as expected. The addition of vertical jumps within the Yo-Yo test to simulate a netball-specific scenario (running with intermittent jumps) seemingly led to a post-activation potentiation of the lower limb muscles which enabled the participants to maintain their jump performances despite the fact that fatigue has seemingly been reached. Whether the conclusion can be made that a concrete surface causes a more pronounced effect on muscle fatigue, which can lead to an increase incidence of injuries, remains debatable and could not be determined in this study.

The result revealed

1) The fatiguing protocol (FP) on the concrete surface possibly had a more prominent effect on post activation potentation (PAP) and jumping performance than the synthetic surface, however not significantly.

2) A non-specific difference in hamstring activation before and after the FP on the synthetic surface during landing from a vertical jump (VJ). The difference may potentially be attributed to a change in biomechanics during landing. Whether the change is brought on by fatigue, specific to a particular surface, could not be determined.

3) A significantly change in activation in lower leg muscles after the FP on the concrete - compared to the synthetic surface. Whether the change is brought on by of fatigue is questionable.

A fact that should also be taken in consideration is that the participants mostly trained and played on a synthetic surface. It could be argued that the FP on the concrete surface had a more prominent effect on the participants as discussed because the participants' muscles were not conditioned to that surface. It could be postulated that when an athlete plays on a surface that the muscles is not conditioned to, there be changes in muscle activation and jumping performance. What the changes are, and whether the changes is brought on by an earlier onset of fatigue compared to the surface the player usually played on, and whether those changes will lead to an increased incidence of injuries, still need to be determined by further research with an improved protocol.

Recommendations to further research will include a longer and more extensive FP that will simulate a training session or a game rather than a short FP used in this particular study that was more focused on anaerobic cardio-vascular fitness. A FP that includes sport specific drills for an extensive period of time or an simulated game as seen in a related studies (Thorlund *et al*, 2008; Schmitz *et al*, 2014) will have a more significantly effect on muscle fatigue. The challenge will be to take measurements when muscles are still in a fatigued state after the extensive FP but to eliminate the possible effects of PAP that is still manifest 8-12 min after explosive movements. To synchronize a schedule between an extensive FP on a desired surface and then taking the necessary measurements in a narrow time span will certainly be a formidable task, although an analogue scale to measure a perceived rate of exertion may potentially help.

In this study the vertical jump height, peak velocity and peak power was determined with a Tendo device as the Force plate, as initially planned in the protocol, was not available at the time of data collection. The results from a Tendo device could be misleading due to the possibility of artefacts when the belt attached to the waist shift during the VJ. It is recommended that in further research a Force plate, which is a more accurate measuring device, should be used (Nicholas, 2001). The use of a forceplate not only gives more accurate reading regards the vertical ground reaction forces (vGRF), vertical velocity and subsequent jump height, but also opens up new possibilities including comparison between fore-foot, mid-foot, hind-foot landing and actual changes of the forces on different areas on foot at play after a FP. The focus of future research should be on the change in muscle activation during landing in a fatigue state. A possibility that could be incorporated into future protocols is different landing techniques specific to the sport of netball, for instance one leg landing onto a forceplate in a fatigued state.

The protocols used during electromyography (EMG) analysis to determine the state of muscle fatigue is still a debatable perception (González-izal *et al*, 2012). An effective comparable model still needs to be found. Further research should also attempt to distinguish between the two concepts weather the friction quality or the absorbing quality of the surface mostly contributes to the extent of muscle fatigue. One of the above-mentioned variables should be normalized in future research to make that distinction.

Chapter 7
LESSONS LEARNED: REFLECTING ON THE RESEARCH PROCESS

"There is only one thing more painful than learning from experience, and that is not learning from experience."

Archibald MacLeish

7.1 INTRODUCTION

The journey leading up to this reflection did not start with the research itself. Instead, it started years ago. Being a keen sportsman myself, I have had a particular interest in sports injuries for as long as I can remember. This interest guided me to pursue a career in Orthopaedic Surgery, but after some exposure as a Medical Officer, I realised that I had a greater interest in injury prevention, biomechanics and rehabilitation than surgery. So, I chose to go down another route and enrolled in a Masters in Sports Medicine at the University of the Free State. Naturally, I was eager to absorb the wealth of theoretical and practical knowledge, but I soon realised that it was impossible to ignore the elephant in the room; no research, no degree! Besides a minor undergraduate project, I have never been involved with research and to say that the unfamiliar task which lay ahead was daunting would be a gross understatement.

Choosing a topic with appropriate and relevant research questions proved to be a major challenge and certainly not a very encouraging starting point considering that the actual research (as I saw it at that point) had not even begun yet. As several topics were added to the list of no-goes, a general concept of the thought process which should go into the search for worthwhile research questions started to take shape. Clothed with this new addition to my knowledge attire, I eventually arrived at the first major milestone of identifying my research topic. The idea to look at netball injuries evolved from a broad biomechanical analysis to an assessment of fatigue on different play surfaces to narrow down the research questions. Even though I thought the research had only begun at that stage, I now realise that the research had begun the day I enrolled for the degree and coming to a research topic with specific aims were already some way along the research path that would lead me through various phases and emotions.

7.2 GOING THROUGH THE PACES

My experience of research echoed the description by Phillips and Derek (2005) of the combined psychological and intellectual components resulting in various emotional phases which are part and parcel of research. Excitement and enthusiasm during the initial stages of the research project were underpinned by the opportunity to engage in the academic degree as a whole and a desire to excel in this new endeavour. This was, however, short lived. Feel-good-emotions disappeared into a crevasse of limited knowledge and unfamiliarity on electromyography which dragged me into isolation to read, read and read some more. Spending numerous hours scouring through literature did not lead to the enlightenment I expected. Instead, the more I learned, the more I learned how little I knew. Reading an academic paper without an idea of what you have actually read and how to make sense of it were extremely frustrating. Even communications with study leaders seemed to be hit and miss due to unfamiliar terminologies and concepts hanging in the air. The vastness of the mountain of work and knowledge I had to conquer before I could really engage in the research project was often overwhelming. Sometimes I found myself wishing I had my own personal expert on EMG sitting next to me, eager to explain unfamiliar concepts during unsociable hours while saving me the time and brainpower to figure it out myself. However, as snippets of revelation and understanding started to unfold, I finally ascended out of the big black hole and into a place where I could experience a genuine interest in the work ahead of me. Looking back, I realise that this process of self-directed learning was not only characteristic of post-graduate studies, but also guided my time and focus towards information I did not possess and possibly would not have mastered during passive observations.

Research lessons learned

- Going through various emotions is not only normal, but part and parcel of the research process.
- Struggling through important concepts on your own not only equips you with insight and understanding for data analysis, but is also fundamental in your development as a novice researcher.

7.3 DEALING WITH THE UNEXPECTED

Another major milestone in my personal development was when I learned to accept that unexpected events and outcomes were inherent to the research process. Participants arriving with unsuitable clothing for data collection, rippling effects on the data collection schedule, laptops with processed data being stolen, reprocessing the data again, falling behind on the research schedule … all of these were unexpected setbacks. While it would be imprudent to expect no setbacks whatsoever, I never could have been prepared for the unexpected turn of events around data collection and analysis.

Initially, the research project was going to focus on assessing the landing mechanics in a fatigued state using a Kistler piezoelectric force platform in combination with the surface EMG since lower limb netball injuries usually occur during the landing phase (Hopper, 1986; Benjaminse *et al*., 2008; Bates *et al*., 2013). Unfortunately the force platform had an unexpected technical fault very close to the scheduled data collection with inadequate time to fix it. This, in combination with a very busy netball season allowing no room to manoeuvre around the agreed dates for data collection called for an urgent rethink of the protocol and the eventual inclusion of the Tendo. Considering the nature of the linear transducer, a substantial shift in focus towards assessment of the propulsion phase had to be made which also carried into the analysis.

The inclusion of the propulsion phase in the analysis (albeit forcefully) turned out to be a positive event since it provided insight into the, once again, unexpected results. When an initial screening of the results did not point towards pronounced fatigue following the fatiguing protocol, let alone different levels of fatigue between the different surfaces, it was impossible to hide my utter disappointment. Even though I now know that this is true within the framework of research, I was not impressed to hear my study leaders say that "not finding anything is a finding in itself" and I should simply continue to analyse the data as planned. In the end, this proved to be the best approach to the unexpected results since closer examination of the outcome variables from the Tendo and propulsion EMG results provided a plausible explanation for the findings.

Research lesson(s) learned

- An unexpected finding is also a finding and not a failure of the research project in itself.
- Expect the unexpected and make the most with what you have to your disposal.

7.4 METHODOLOGICAL FULCRUM

Learning how to ask 'what and why' questions (Phillips and Derek, 2005) while reading the literature was one of the most pronounced learning curves as a novice researcher. My study leaders constantly played devil's advocate whenever I proposed methods for data collection, which made me realise that the success of the research project pivots on methodological considerations. It would be unwise to rush the planning phase.

Writing a protocol proved to be a maze-like venture. Not always understanding if and how what I was reading were useful and relevant to my study proved to be very frustrating at times. However, as I learned to understand the importance of reading the methods used by other researchers and interpreting their findings in relation to my envisaged research project, not only did my understanding of how to approach my research take shape, but also how not to approach it.

From the literature it was evident that the use of surface EMG to measure the extent of muscle fatigue was not a straight-forward science (Gonzalez-izal *et al.*, 2012; Kim *et al.*, 2012). Considering that there are so many possibilities to analyse surface EMG data, figuring out which method would be appropriate to assess muscle fatigue during a dynamic movement was certainly one of the most difficult and formidable tasks of this project. The use of root mean square (Rahnama *et al.*, 2006; James *et al.*, 2010) average rectified values (Thorlund *et al.*, 2008; Kellis and Kouvelioti, 2009; Kopper *et al.*, 2013) and spectral analyses (Rainoldi *et al.*, 2004) were evenly dispersed between related studies. In the end, the aim of my research project drove the decision for using the average rectified value since I wanted to look at clear time intervals (the propulsion and landing phases respectively) and needed a suitable measure to describe the gross innervations of selected muscles (Konrad, 2006).

Research lessons learned:

- Do not rush the planning phase; failing to plan is planning to fail.
- The success of a research project and appropriateness of the collected data for the envisaged analyses rest on the methodological considerations. If your methods are inappropriate, your data would be unsuitable to help achieve your research aims.

7.5 PEARLS OF WISDOM

The Webster Dictionary defines research as being a laborious or continued search after truth. From my personal experience, it was laborious indeed and I was thankful for being prepared that it would most likely be a lengthy process. However, research does not come with a manual and I learned a couple of lessons which would have made the journey less treacherous had I known it beforehand. So, for my future colleagues, here are some pointers.

Make peace with the fact that you are a novice researcher. Listen to your study leaders, they have been through the process more than once and really do have your best interest at heart. What may feel like a "let's nail the student" session are actually priceless attempts to facilitate your development as researcher and shape the thought processes needed for conducting sound research. Also, when you feel every word is going over your head and you cannot see how on earth you'll ever be able to function on your own, do not be disheartened - your skills and knowledge will eventually gain ground and you will gain confidence to put some pen to paper independent of your study leaders. The euphoria of finishing your dissertation really is worth the effort and what may seem like suffering during many long, lonely hours late at night. As my study leader once said, when you go through hell, keep going!

Do not attempt to eat the elephant all at once. It is a process of slow, steady and hard work. Keep doing a little bit as often as possible to avoid overwhelming volumes of work in limited amounts of time. Being in private practice doesn't always allow the opportunity to sit down with dedicated time to spend on your research. Always have something to read or do at hand since unexpected snippets of time may just be your only opportunity to spend on your research for a couple of days amidst overflowing patient lists and hectic on-calls.

Effective communication with your study leaders is the foundation of research. Being a distance learner required the development of new skills and considerations which never would have crossed my mind had I not engaged in this research project. A couple of emails went unnoticed (causing confusion, frustration and delays) since I did not open a new email thread for a new email topic, but simply went into an old thread, clicked replied and started a new conversation under the same heading. What I didn't know was that internet based emails such as Gmail would just file it under the old thread in my study leader's inbox and not flag it as a new conversation in her inbox if the email heading did not change. If you are replying to an email sent by them, sure, just reply. But when you are communicating something new from your side, start a new email with a new heading to avoid it getting lost within old threads.

Stolen or crashing computers are a real possibility. Despite numerous attempts to make back-ups, these were made on the computer in question. This can cause major time delays trying to retrieve documents, data and latest versions of chapters from various sources. Use the marvellous technology available to us in this day and age. Save your work on a cloud-based data storage facility such as Dropbox or Google Drive to dissociate your work from a specific computer, it may just be your saving grace amidst major technological setbacks.

7.6 CLOSING REMARKS

In many ways it was both a challenging and fulfilling journey rollercoasting through many emotions. I have learned so much, not only through reading heaps of literature, but through the research process itself. Believing that I was doing the best I could with my admittedly limited knowledge and equipment available was the fuel to my perseverance. The fact that this research project did not conclude where I thought it would at the start of the journey has sparked my curiosity. I will keep an eye out for any new contributions to this field of knowledge and most certainly will embrace research-based literature with new respect and insight.

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APPENDICES

Appendix A.1	Ethical approval letter
Appendix A.2	Information sheet
Appendix A.3	Written consent
Appendix A.4	Data collection sheet

APPENDIX A.1

Ethical approval letter

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2012-11-08

REC Reference nr 230408-011
IRB nr 00006240

DR GJ VAN JAARSVELD
c/o DR M SCHOEMAN
DEPT OF SPORT AND EXERCISE MEDICINE
MULLER POTGIETER BUILDING
FACULTY OF HEALTH SCIENCES
UFS

Dear Dr Van Jaarsveld

ECUFS NR 188/2012
PROJECT TITLE: THE EFFECT OF CONCRETE AND ARTIFICIAL TURF SURFACES ON LOWER LIMB MUSCLE FATIGUE AMONG UFS NETBALL PLAYERS

- You are hereby kindly informed that the Ethics Committee approved the above project at the meeting held on 6 November 2012.
- Committee guidance documents: Declaration of Helsinki, ICH, GCP and MRC Guidelines on Bio Medical Research. Clinical Trial Guidelines 2000 Department of Health RSA; Ethics in Health Research: Principles Structure and Processes Department of Health RSA 2004; Guidelines for Good Practice in the Conduct of Clinical Trials with Human Participants in South Africa, Second Edition (2006); the Constitution of the Ethics Committee of the Faculty of Health Sciences and the Guidelines of the SA Medicines Control Council as well as Laws and Regulations with regard to the Control of Medicines.
- Any amendment, extension or other modifications to the protocol must be submitted to the Ethics Committee for approval.
- The Committee must be informed of any serious adverse event and/or termination of the study.
- A progress report should be submitted within one year of approval of long term studies and a final report at completion of both short term and long term studies.
- Kindly refer to the ECUFS reference number in correspondence to the Ethics Committee secretariat.

Yours faithfully

....
PROF WH KRUGER
CHAIR: ETHICS COMMITTEE

cc. **Dr M Schoeman**

205 Nelson Mandela Drive/Rylaan, Park West/Parkwes, Bloemfontein 9301, South Africa/Suid-Afrika
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INFORMATION DOCUMENT

THE EFFECT OF CONCRETE AND ARTIFICIAL TURF SURFACES ON LOWER LIMB MUSCLE FATIGUE AMONG UFS NETBALL PLAYERS

Dear Ms

I, Gawie van Jaarsveld, a Masters student in Sports Medicine from the UFS, is doing research on the effect different netball play-surfaces have on muscle fatigue. Research is the process to learn the answer to a specific question. In this study we want to learn more about the biomechanics of injuries among netball players.

We are asking you to participate in a research study that involves 10 netball players affiliated with the senior netball teams of the UFS.

In the study the extent of muscle fatigue after a netball fatiguing protocol on two separate surfaces will be measured and compared. The two different play-surfaces used are artificial turf and concrete. The two measurements sessions will take place in May 2013 (dates to be confirmed). Muscles from the thigh and two muscles from the lower leg will be used during the measurement protocol.

The magnitude of muscle fatigue will be measured using electromyography (EMG) and a Tendo linear transducer. The EMG device will measure the electric current generated during muscle contraction. The devise consists of two separate electrodes (metal-head surrounded by a gel) stuck a distance apart onto the skin overlying the muscle that is measured. The skin where electrodes are attached is prepared by cleaning and abrading it with an alcohol wipe to secure attachment and sterility. The electrodes will be taped with transpore tape to the skin and a soft cotton tubigrip sock will be worn over the whole leg to keep the electrodes from falling off and minimise movement. The Tendo device is basically a belt that you'll be wearing around your waist which is connected to a measurement apparatus to the ground through a thin wire. The Tendo will measure the vertical velocity, power and jump height achieved during three maximum effort vertical jump trials.

If you agree to participate in this study, your age, height, weight and body fat percentage will be measured. You will perform three maximum effort vertical jumps with your arms on your hips after which you will perform a shuttle run test between demarcation cones, 20 meters apart, for as long as you can until you are too fatigued to complete the shuttle runs within the designated time. Between each shuttle run you will also perform a vertical jump. After you have completed the shuttle run test to the point of fatigue, you will again perform three maximum effort vertical jumps.

The measurement procedure is pain free and non-invasive and will have no effect on your sporting performance. There is a chance that an allergic skin reaction from the attached electrodes develops. In such an unfortunate event a hydrocortisone cream, that is available from any local pharmacy, must be applied on the affected skin as treatment. If any further advice or help is needed you may contact me on the contact information supplied.

As a lack of sleep and calorie intake have an effect on fatigue you are kindly requested to take the necessary precautions before the measurement take place.

In the unfortunate event that you sustain an injury or became ill during the two days measurement take place; you will be excluded from the study. This is a precaution towards your own health and the quality of the data attained.

Participation is voluntary, and refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled; you may discontinue participation at any time without penalty or loss of benefits to which the subject is otherwise entitled.

Efforts will be made to keep personal information confidential. Absolute confidentiality cannot be guaranteed. Personal information may be disclosed if required by law. Organizations that may inspect and/or copy your research records for quality assurance and data analysis include groups such as the Ethics Committee for Medical Research and the Medicines Control Council. Results from the study may be published.

Thank you
Dr Gawie van Jaarsveld (0828309223)
engel-pyp@hotmail.com

For reporting of complaints or problems, please contact the Secretariat of the Ethics Committee of the Faculty of Health Sciences at UFS: 051 405 2812.

Written consent

CONSENT TO PARTICIPATE IN A RESEARCH STUDY

THE EFFECT OF CONCRETE AND ARTIFICIAL TURF SURFACES ON LOWER LIMB MUSCLE FATIGUE AMONG UFS NETBALL PLAYERS

You have been asked to participate in a research study.

You have been informed about the study by Dr. Gawie van Jaarsveld and UFS Netball.

You have been informed about medical treatment if injury occurs as a result of study-related procedures;

You may contact Doctor Gawie van Jaarsveld at 0828309223 any time if you have questions about the research or if you are injured as a result of the research.

You may contact the Secretariat of the Ethics Committee of the Faculty of Health Sciences, UFS at telephone number (051) 4052812 if you have questions about your rights as a research subject.

Your participation in this research is voluntary, and you will not be penalized or lose benefits if you refuse to participate or decide to terminate participation.

If you agree to participate, you will be given a signed copy of this document as well as the participant information sheet, which is a written summary of the research.

The research study, including the above information has been verbally described to me. I understand what my involvement in the study means and I voluntarily agree to participate.

____________________ ____________________

Signature of Participant Date

______________________ ____________________

Signature of Witness Date

(Where applicable)

APPENDIX A.4

Data collection sheet

DATA SHEET

Participant number:		_____________	/10
Age:		_____________	years
Body mass:		_____________	kg
Length:		_____________	m
Skinfolds:	Bicep	_____________	mm
	Tricep	_____________	mm
	Subscapularis	_____________	mm
	Abdomen	_____________	mm
	Thigh	_____________	mm
	Calf	_____________	mm

*** **Day:** **1 / 2 (circle appropriate)**

*** **Surface:** **Concrete / Synthetic (circle appropriate)**

*** **Yo-Yo test level reached** _____________

PRE-FATIGUE TENDO RESULTS

Jump 1	Jump height	____________	cm
	Peak velocity	____________	$m.s^{-1}$
	Peak power	____________	Watt
Jump 2	Jump height	____________	cm
	Peak velocity	____________	$m.s^{-1}$
	Peak power	____________	Watt
Jump 3	Jump height	____________	cm
	Peak velocity	____________	$m.s^{-1}$
	Peak power	____________	Watt

POST-FATIGUE TENDO RESULTS

Jump 1	Jump height	____________	cm
	Peak velocity	____________	$m.s^{-1}$
	Peak power	____________	Watt
Jump 2	Jump height	____________	cm
	Peak velocity	____________	$m.s^{-1}$
	Peak power	____________	Watt
Jump 3	Jump height	____________	cm
	Peak velocity	____________	$m.s^{-1}$
	Peak power	____________	Watt

PRE-FATIGUE EMG RESULTS (ARV, µV)

***** Jump trial analysed 1 / 2 / 3 (circle appropriate)**

	Propulsion	**Landing**
Bicep Femoris		
Rectus Femoris		
Tensor Fasciae Latae		
Semitendinosis		
Vastus Medialis Oblique		
Tibialis Anterior		
Gastrocnemius		

POST-FATIGUE EMG RESULTS (ARV, µV)

***** Jump trial analysed 1 / 2 / 3 (circle appropriate)**

	Propulsion	**Landing**
Bicep Femoris		
Rectus Femoris		
Tensor Fasciae Latae		
Semitendinosis		
Vastus Medialis Oblique		
Tibialis Anterior		
Gastrocnemius		