UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA

UFS·UV
HEALTH SCIENCES
GESONDHEIDSWETENSKAPPE

LOWER LIMB MUSCLE FATIGUE ON GRASS AND ARTIFICIAL TURF PLAYING SURFACES AMONG ELITE SOCCER PLAYERS

J.A.T. Greyling

July 2016

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA

UFS·UV
HEALTH SCIENCES
GESONDHEIDSWETENSKAPPE

LOWER LIMB MUSCLE FATIGUE ON GRASS AND ARTIFICIAL TURF PLAYING SURFACES AMONG ELITE SOCCER PLAYERS

J.A.T. Greyling

Study leader: Dr C. Brandt

Co-study leader: Prof D. Coetzee

A dissertation submitted in fulfilment of the requirements of the ***Master of Science in Physiotherapy*** in the Faculty of Health Sciences, University of the Free State

July 2016

DEDICATION

This thesis is dedicated to my father, Prof J.P.C. Greyling, who has been my mentor and role model for 33 years and for always encouraging me to seek knowledge, new challenges and better myself in every way possible.

"Education is the most powerful weapon which you can use to change the world." - Nelson Mandela

ACKNOWLEDGEMENTS

- Dr C. Brandt, for her valuable time, mentoring, guidance, patience and encouragement. Without your help, this wouldn’t have been possible.
- Prof D. Coetzee for encouraging me to do this study, all the help, his enthusiasm and his co-supervision.
- Mr A. Vlok for his valuable time and help with the assessment and force plate measurements.
- Mr C. van Rooyen, for assisting with the statistical analysis.
- The field workers, for their voluntary participation in the study.
- Bloemfontein Celtic Football club, all its staff and players.
- All my family and friends for their support and motivation.

DECLARATION

I, Jantho Greyling, certify that the script hereby submitted by me for the M.Sc. (Physiotherapy) degree at the University of the Free State is my independent effort and had not previously been submitted for a degree at another university/ faculty. I furthermore waive copyright of the script in favour of the University of the Free State.

J.A.T. Greyling

July 2016

I, Corlia Brandt, approve submission of this dissertation as fulfilment for the M.Sc. (Physiotherapy) degree at the University of the Free State. I further declare that this dissertation has not been submitted as a whole or partially for examination before.

Corlia Brandt (Study leader)

July 2016

ABSTRACT

INTRODUCTION: Fatigue and hard playing surfaces have been indicated as risk factors for injury in soccer players. Recent literature, however, has found contradictory results on the prevalence of injuries on different playing surfaces, as well as regarding the interaction between fatigue and the type of playing surface. This raises the question as to the true mechanisms underlying the cause of injury on different playing surfaces.

AIM: The aim was therefore to compare lower limb muscle fatigue on grass and artificial surfaces in elite soccer players.

METHODS: Twenty two elite soccer players (mean age 24.8 years) were included in a cross-over study design. The players were randomly allocated to two conditions. It involved exposure to the same soccer-specific fatigue protocol on a grass and artificial surface respectively. A force plate was used for pre-test and post-fatigue measurements on force generation, force rates and jump height. The Pearson correlation coefficient was used to determine associations between baseline variables and interpreted by means of effect sizes and p-values. The Wilcoxon signed-ranks test was used to determine statistical significant changes from pre-test to post-test for each condition while the Chi-square test was used to compare the findings between the two conditions.

RESULTS: Statistical significant correlations were found at baseline between propulsion and concentric forces ($r=0.66$, $p<0.001$); propulsion force and body mass ($r=0.78$, $p<0.001$); propulsion force and BMI ($r=0.645$, $p<0.01$); landing force and body mass ($r=0.82$, $p<0.001$); landing and eccentric forces ($r=-0.75$, $p<0.001$); jump height and concentric force ($r=0.84$, $p<0.001$); and body mass and concentric force ($r=0.76$, $p<0.05$). Propulsion and concentric forces increased statistical significance after fatigue on the grass surface ($p=0.026$ and 0.005 respectively). On the artificial surface there was a statistical significant increase in propulsion force and propulsion force rate post-fatigue ($p=0.0001$ and 0.0153 respectively). Comparison of the changes from baseline to fatigue between the two conditions yielded no significant differences ($p>0.05$).

CONCLUSION: Limited significant differences were found comparing forces after fatigue on artificial and grass surfaces. The inconsistency in the behaviour of forces in response to fatigue indicate the possible variability in adaptation strategies to cope with a speculated fatigue state. Surface-specific training could therefore be recommended in order for muscle and sport/surface-specific adaptation to take place, thereby decreasing the risk for injury

INDEX

LIST OF FIGURES

LIST OF TABLES

LIST OF GRAPHS

LIST OF ADDENDA

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND/ RATIONALE

Soccer is one of the most widely played sports in the world with 265 million players globally and continuously growing (FIFA, 2006). Africa has 46 million players, the second largest population of football players, making up 17% of the global football playing population. According to Drawer and Fuller (2002:33) football is a sport associated with a high injury occurrence. The sport is characterized by short sprints, rapid acceleration or deceleration, turning, jumping, kicking, and tackling which makes the players vulnerable to injury. Risk assessments on European industries show that football players has a 1000 times higher risk of sustaining an acute injury compared to perceived high risk occupations, stressing the need for injury prevention, and support to minimalize the medical and socio-economic effects on the players (Drawer & Fuller, 2002:33).

It is generally assumed that through the years, the game of soccer has developed to become faster, with more intensity and aggressive play than seen previously. Elite soccer is a complex sport, and performance depends on a number of factors, such as physical fitness, psychological factors, player technique, and team tactics. Injuries and consequences from previous injuries, such as muscle weakness, joint stiffness, decreased muscle length, fatigue, and biomechanical dysfunction, can also affect the players' ability to perform (Arnason *et al*., 2004:6S-14S).

Soccer is a high-strategy, high intensity sport which requires the precise execution of technical motor skills with and without the ball. Soccer also requires the application of tactical knowledge when making decisions during many explosive sprints, abrupt stops, change of direction and landing movements. These high intensity, repetitive movements requires precise biomechanical functioning of the kinetic chain. Any imbalance due to fatigue, injury, or other reasons, may lead to overload and eventually failure and injury of the specific neuro-musculoskeletal structures (Bloomfield *et al.,* 2007:68). It is the interaction of these modifiable and unmodifiable risk factors that is the cause of lower extremity injuries that are common in the game of soccer (Dominguese *et al.,* 2012:306).

Greco et al. (2013) describes impairment related to the distance covered and high-intensity activities such as jumping and sprinting especially during the second half and directly after a soccer match. These impairments have been attributed to reduction in maximal strength and power due to fatigue (Greco *et al.,* 2013:18).

It is the conceptualisation of the modifiable and unmodifiable risk factors, such as fatigue, the frequency, intensity, technique and time of training in elite soccer players, which enables clinicians and researchers to understand and propose evidence-based interventions for injury prevention (Dominguese et al., 2012:306; Bloomfield *et al*., 2007:67-69).

Muscle fatigue is defined as an inability to sustain or maintain muscle contractions at a given force production and is accompanied by changes in muscle electrical activity (Dominguese *et al.,* 2012:306; Dimitrova & Dimitrov, 2003:13-14). Fatigue alters the shock-absorbing capacity of the muscle, the coordination of the locomotor system, as well as the neuromuscular input and output pathways which can predispose the athlete to injury (Stutzig & Siebert, 2015:379). These changes, however, become important factors in a sport such as soccer where coordinated eccentric muscle contractions are central in energy absorption and force dissipation during running, jumping, sprinting and direction changes (Otago, 2004:85-93).

The decreased ability to dissipate shock, resulting from muscle fatigue, could lead to an increase in injury risk as greater stress is placed on passive structures. Kristenson *et al.* (2013) found that there was a higher rate of acute training injuries and overexertion at clubs with artificial turf at their home venue when compared to clubs with natural grass (Kristenson *et al.,* 2013:776-780). The alteration between surfaces becomes a crucial factor in landing movements in a sport like soccer, as eccentric muscle contractions play a primary role in energy and shock absorption. Only a few studies have been done to determine the amount and difference in muscle fatigue between artificial turf and grass surfaces, while numerous studies have been done on the prevalence of injuries in relation to the type of playing surface.

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.,*1998:517-519). 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 (Voloshin *et al.,* 1998:517-519). The effect of the playing surface on muscle fatigue should therefore be taken into account when considering the nature of soccer and the fact that a soccer player have to contend with numerous sprints and jump landings with its associated ground reaction forces (GRFs). Certain ground conditions, including hardness and friction, have been associated with an increased injury risk (Pasanen *et al.,* 2008:194).

The process of analysing impact forces on different surfaces is often approached by measuring the force and time of the movement, such as during a countermovement jump (CMJ) or squat jump. Calculation of the impulse (in N.s) of the impact force is one example of analysis, while calculating rate of force production (N/s) is another. A shorter landing time, for example, may be associated with decreased range of motion of the lower limb (Haddas *et al.,* 2015:381). Impulse, on the other hand, has a direct relationship with momentum which is determined by a persons body mass and the velocity with which he or she collides with the ground. This implies that the impact force can be manipulated through an increase or decrease in the time in which the body has to attenuate the impact force (Robertson, 2013:86). 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. Assessment of exercise-induced reduction in the maximum capacity to generate force as a function of time, has been suggested to be the most exact way of exploring muscular fatigue (Verelst & Leivseth, 2004:145).

There are different factors that play a major role in muscle fatigue during training on a specific surface. The surface cannot be seen as the only external factor that causes muscle fatigue and injuries. Researchers have identified a number of risk factors for non-contact injuries. These include intrinsic factors such as proprioception, muscular strength, ligament properties, and biomechanics, as well as extrinsic factors such as the playing surface and other environmental conditions (Williams *et al.,* 2013:2-6).

Engstrom *et al.* (1991:373-375) found that 29% of lower extremity injuries in elite soccer players were overuse injuries due to muscle fatigue. The effect of play surfaces on injury potential have been illustrated through various studies, as seen in the association of harder play surfaces with overuse injuries (Brukner, 2012:127-128), and the association of high friction play surfaces with anterior cruciate ligament (ACL) injuries (Orchard *et al.*, 2005:420-431; Olsen *et al.*, 2003:449; Inklaar, 1994:55,72). Twofold increases in injury potential for elite male soccer have also been reported when playing on artificial turf compared to grass (Arnason *et al*., 2008:5S-6S). According to McLean & Samorezov (2009) it seems likely that play surfaces may have an effect on injury potential, however, conclusive evidence on the mechanisms through which the play surfaces affect the neuromuscular and musculoskeletal system's ability to prevent injuries, remains unclear. While muscle fatigue may be a contributing factor to injuries (McLean & Samorezov, 2009:1670-1672), limited research has been done to compare muscle fatigue on different play surfaces. Williams *et al.* (2013) stated that more research is needed regarding player movements, energy expenditure, and fatigue on artificial turf and natural grass surfaces (Williams *et al.,* 2013:5). The focus of this study was therefore structured around the concepts of fatigue and playing surfaces and is depicted in Figure 1 within the framework of injury prevention.

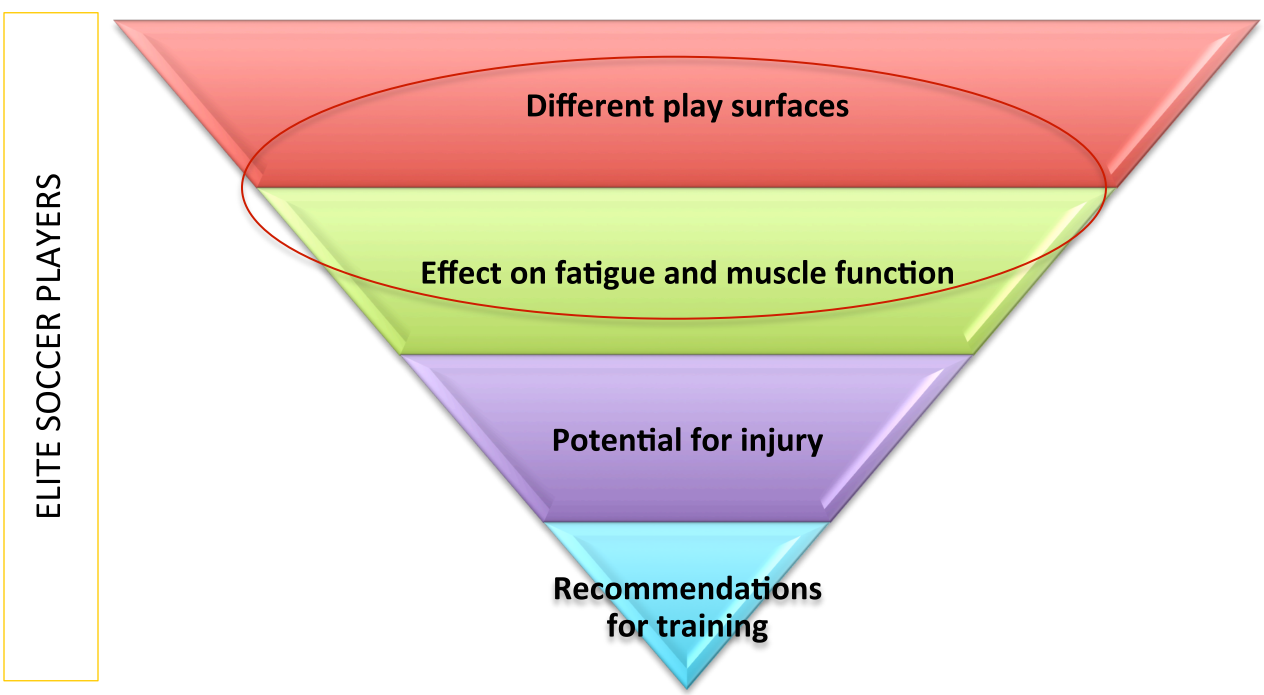


Figure 1. The focus and framework of the study.

1.2 AIM OF RESEARCH

The aim of this study was to compare lower limb muscle fatigue on grass and artificial turf in elite soccer players in Bloemfontein.

1.2.1 Research objectives

In order to achieve the aims, the following research objectives were stated:

1.2.1.1 To determine if there is a difference in squat jump performances, based on force plate measurements, following a soccer-simulated fatiguing protocol on artificial and grass playing surfaces.

1.2.1.2 To determine the change from baseline to post-fatiguing force plate measurements on grass and artificial training surfaces respectively.

1.2.1.3 To compare the change from baseline to post-fatiguing force plate measurements on grass and artificial surfaces.

1.2.1.4 To make recommendations regarding training programmes on a specific surface to prevent injuries, based on the findings of this study.

1.3 DISSERTATION SYNTHESIS

To achieve these objectives, a cross-over study was done which will be presented in this dissertation. The 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 of the research project which is followed by Chapter 5, discussing the findings relating 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 summarises the main findings and concludes with recommendations for further research.

The next chapter will explore the concepts of muscle fatigue, injuries, and playing surfaces as were raised in this chapter, within the context of elite soccer players and the aims of this study.

CHAPTER 2

SOCCER, INJURY, BIOMECHANICS AND FATIGUE – AN INTERRELATED OVERVIEW OF THE LITERATURE

This chapter will review the literature relevant to the research aims set out in Section 1.2. An overview of soccer with its sport-specific skills and associated risks will be explored. Thereafter, landing and associated factors in relation to soccer injuries will be investigated. The different surfaces and lower limb muscle fatigue will highlight what could typically be expected in a force plate analysis of this sport-specific skill (Figure 2). Finally, literature relevant to inform sound methodological approaches (Chapter 3) to achieve the aims of this research will also be reviewed.

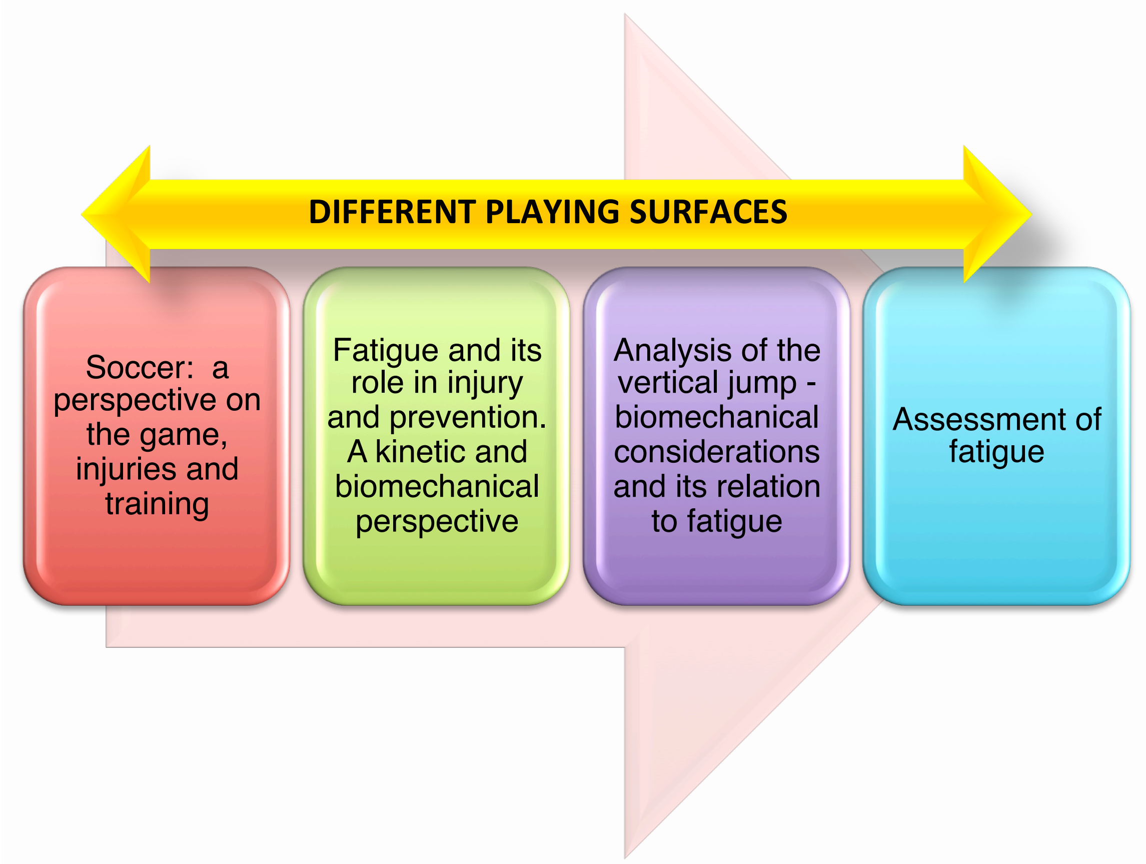


Figure 2. Outline of Chapter 2.

2.1 SOCCER: A PERSPECTIVE ON THE GAME, INJURIES, AND TRAINING

2.1.1 Soccer: an analysis of the game, skills, and training

Soccer is a dynamic, fast, skillful, male as well as female team sport. Soccer is the most popular sport in the world and is performed by men and women, children and adults with different levels of expertise. Soccer performance depends upon a myriad of factors such as technical/biomechanical, tactical, mental and physiological factors (Stolen *et al.,* 2005:502).

Soccer is a physically demanding game that requires a player to be well conditioned in high levels of endurance, strength, speed, power, agility and flexibility. Soccer is characterised as a high intensity, intermittent, and non-continuous exercise. Players cover approximately a distance of 10km per game, of which eight to eighteen percent (18%) is at the highest individual speed. In higher levels of competition there are a greater number of tackles and headings plus a greater percentage of the game is performed at maximum speed. The average aerobic energy yielded during a national level game is around 80% of the individual`s maximum capacity (Ekblom, 1986:50).

During a soccer match it has been shown that professional or elite players cover an average distance of 11km per match, depending on the specific position of the player. Midfielders cover more ground on lower speeds than strikers/forwards and defenders. There is however no difference in the distances covered at high speed. High speed distances covered in the beginning and end of matches are the same. The physiological demands of a player during a match can only be measured to a certain extent by the distances covered during the match. There are many other energy demanding actions in soccer like tackling, turning, accelerating, and jumping which also affects the physiological demands. More precise physiological measurements are therefore needed to determine more accurate evaluations of energy consumption and demands in a game of soccer (Bangsbo, 1994:43-58).

Principles, such as frequency, intensity, time and type of exercise (FITT) are crucial factors in controlled conditioning of soccer players and prevention of overuse injuries. Training programmes should focus on specificity, overload, recovery, variation and progression (Martin, 2012:187). According to the demands of the sport, namely to be able to cover a distance of 10 km to 11km with high intensity speed, would indicate the need for endurance as well as strength training (Jull *et al*., 2015:69-70).

Should a training programme not adhere to these principles, a disturbance in the kinetic chain due to intrinsic or extrinsic risk factors, for example muscle fatigue, may lead to compensation and/or eventually failure of the neuro-musculoskeletal system.

In a study done by Eriksson *et al.* (1986:214-216), 40 senior male soccer players were tested by making a correlation between their VO2 max and injuries sustained. There were significantly more overuse injuries among subjects with high estimated VO2 max, and the incidence of distorsion injuries tended to be lower among subjects with high estimated VO2 max. This raised a concern regarding a possible correlation between fatigue in lower limbs and injuries thereof.

2.1.2 Injuries in soccer

According to Murphy *et al*. (2003:28) prevention and intervention of sport injuries have become focal points for researchers and clinicians. Many injury risk factors, both extrinsic and intrinsic, have been suggested. Extrinsic risk factors include level of competition, skill level, the type of shoe, the use of ankle tape or brace, and playing surface. Intrinsic risk factors include age, sex, previous injury, career duration and inadequate rehabilitation, aerobic fitness, body size, limb dominance, flexibility, limb girth, muscle strength, reaction time, postural stability, anatomical alignment, foot morphology, and other biomechanical factors (Taimela *et al.,* 1990:209). Some studies also indicate that mechanical instability in the ankle or knee, general joint laxity, or functional instability predispose players for new injuries in football (Arnison *et al*., 2004:5S-6S)

A study done by Engstrom *et al.* (1991:372-375) on two elite female soccer teams showed that 28% of all injuries occurred because of overuse. Another study done by Ekstrand (1983:824-832) on male elite soccer players in Sweden, found that out of 124 players with 256 injuries, most injuries were to the lower limbs (88%), of which 31% were overuse injuries.

Overuse injuries are frequent in the knee joint because of the numerous attachment sites for lower limb musculature and tendons surrounding the joint. A more recent study by O'Keeffe *et al*. (2009:725-739) found that overuse injuries are a common cause of morbidity in especially the knee. Repetitive microtrauma, abnormal joint alignment, and poor training technique without appropriate time to heal are some of the causing factors.

The above evidence is supported by epidemiological studies indicating that most soccer-related injuries occur to the lower extremities, predominantly to the ankles and knees as a result of tackling, running, being tackled, shooting, twisting and turning, jumping and landing (Wong, 2005:475). Fifty percent to 80% of soccer injuries affect the feet and legs. Forty percent to 45% of leg injuries involve ankle injuries and foot pain. These injuries include mostly ankle sprains while Sever`s disease may occur in younger players (Giza *et al.,* 2003:140-169).

Knee injuries, especially injury of the knee ligaments, account for 25% of leg injuries in soccer players. The anterior cruciate ligament (ACL) is a common structure affected by specific movements during soccer which is considered a common mechanism of these injuries, as stated above. In young football players, Osgood-Schlatter Disease may also be a common cause of knee pain (Brukner, 2012:708).

Considering the above statistics and type of injuries, correlational studies have also indicated that there is an association between surface-related injuries in athletes and the level of participation. Elite athletes seem to sustain surface-related injuries much more than athletes participating at a lower level. This may be due to increased torques, forces, and demands placed on these athlete`s neuromuscular system by the interaction with the surface (Taylor *et al.* 2012:4). Taylor *et al.* (2012:4) has emphasised the need for further investigation in this regard.

2.1.3 Injuries: the effect of different playing surfaces

Although previous studies have mainly indicated increased risk for injury on artificial surfaces, new literature seems to find contradicting results which raises a question as to the cause of increased injury rates on these surfaces. The increase of conflicting evidence may be due to confounding factors such as weather conditions, the mechanism of injury, the type of shoe worn by the athlete, and the field wear, which prevent definitive conclusions from being drawn (Taylor *et al.,* 2012:5).

A meta-analysis done on injury risk in soccer players, found no evidence that playing or training on artificial surfaces increase their risk for injury. In fact, they found that risk of injury may even be lower in certain populations when training or playing on artificial turf (Williams *et al.,* 2013:5). A recent case control study by Lawrence *et al.* (2016:8) supported these findings. They investigated extrinsic risk factors for injury in National Football League football players using the data from 960 matches. They found a small, but increased risk for shoulder injury when playing on grass surfaces, while no relationship was found between lower limb injuries and playing surface. Other studies on the incidence of injuries on different play-surfaces have shown that harder play surfaces are more associated with overuse injuries (Brukner, 2012:127) while play surfaces with higher friction have an increased risk for ACL injuries (Orchard *et al*., 2005:424; Olsen *et al*., 2003:449). Dragoo *et al.* (2013:194) concluded that the rate of ACL injuries are higher when playing on artificial surfaces, although it differs with playing position in American football.

Inklaar (1994:71-72) stated that the stiffness of artificial turf as well as the increased friction between the shoes and the surface may be the cause of a higher injury rate on artificial turf. Kristenson (2013:779-780) found that first-generation and second-generation artificial turfs were also associated with a higher injury rate and a different injury pattern compared with natural grass. In contrast to this Ekstrand *et al*. (2011:824-832) found no difference in the injury rates on artificial turf versus grass turf.

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*., 2002:419-432).

In summary, the playing surface is an extrinsic factor that can play a major role in injury rates (Pasanen *et al.,* 2008:4-6). 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*., 2008:4-6). Murphy *et al*. (2003:28) found that the hardness of the surface can influence the ground reaction forces and cause overloading of tissues, for example bone, ligaments, muscle and tendons.

Fabre *et al*. (2012:2183-2189) investigated the above concept of playing surfaces, injuries, fatigue and muscle responses in tennis. They measured the maximum voluntary contraction (MVC) force, maximum voluntary activation level, the maximal compound muscle characteristic, and the EMG activity of the lower leg muscles before and after tennis matches on hard and clay surfaces. Limited statistical differences were found when comparing the data on the different surfaces ($p < 0.05$). There was a non-significant reduction in the activation level, but a significant reduction of the H-reflex on the relaxed muscle state of the gastrocnemius and soleus muscles. No significant change in the reflex responses evoked during a MVC after the fatigue protocol was observed. The MVC itself was reduced after the fatigue protocol and associated with a change in the contractile properties of the plantar flexors. Based on these findings the authors concluded that the different surfaces did not affect the extent, nor the origin (namely central or peripheral) of the neuromuscular fatigue associated with a tennis match. They attributed the moderate force reduction that was observed to peripheral fatigue. This study, however, raised some significant concepts which will be further discussed in the following paragraphs.

It has to be acknowledged that the friction theory, as described in this section, is only a hypothesis and more research is needed to determine why play surfaces with different friction and absorbing qualities may cause a higher incidence of injuries and different responses of fatigue. 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 & Samorezov, 2009:1661-1672), there is a lack of research to compare muscle fatigue on different play-surfaces.

2.2 FATIGUE AND ITS ROLE IN INJURY AND PREVENTION. A KINETIC AND BIOMECHANICAL PERSPECTIVE

2.2.1 Defining fatigue in a neuromuscular and biomechanical context

Fatigue is a complex phenomenon with a lot of different aspects to it and different definitions, depending on the specific experiment at hand or the specific conditions (Halson, 2014:1). According to Halson (2014:1) and Fabre *et al*. (2012:2182) it is well known that the extent and origins of neuromuscular fatigue can be influenced by the type of stimulus, the type of muscle, the contraction and duration, frequency, and intensity of the exercise, 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 loss of maximal force generating capacity or the failure to maintain the required or expected force in a muscle (Vollestad, 1997:220) and is described as ‘‘any exercise-induced reduction in the capacity to generate force or power output’’. Fabre *et al*. (2012:2182) concluded that fatigue is usually described as a time-dependent, exercise-induced reduction in the maximal force generating capacity of the muscle. Haddas *et al.* (2015:379) described fatigue as a phenomenon which can alter muscle-burst activation, duration, intensity, and the ability of the lower extremity muscles to absorb repetitive shock or stress, thereby moderating the muscle-activation patterns of the lower limb during landing. This complex phenomenon can be the result of alterations at the central nervous system or at peripheral (muscular) level (Stutzig & Siebert, 2015:284).

More clarity is needed regarding the interrelationship between neuromuscular mechanisms and fatigue. Muscle fatigue can be divided into central and peripheral fatigue and arises from various areas in the body. A decrease in the discharge rate and number of recruited motor units, causes a decrease in the voluntary muscle activation and therefore relates to central fatigue factors. Peripheral factors relate more to a decrease in contractile strength of muscle fibers, or an increase in muscle action potential (Vollestad, 1988:219-223). However, landing mechanics may be affected by both central and peripheral fatigue which can alter muscle stiffness and the biomechanical execution of the landing due to insufficient force production (Dominguese *et al.*, 2012:306).

Once fatigued, most athletes alter their muscle recruitment patterns which lead to adaptation in the landing mechanics. This altered recruitment pattern, in turn, may alter the distribution of forces acting on the articular, ligamentous, and muscular structures such as during jumping and landing activities (Murphy *et al*., 2003:19). The change in the landing mechanics when fatigued, may therefore lead to and predispose players to musculoskeletal injuries of the lower limb (Dominguese *et al.*, 2012:306).

According to Voloshin *et al*. (1998:516,518-520) mechanical shock during landing from a height must be attenuated by the musculoskeletal system, and when the external loads become too great for the body to adequately attenuate, the probability of injury increases activity. Passively, soft tissues and bone achieve shock attenuation. Actively, shock attenuation is achieved through eccentric muscle action. This active mechanism is thought to be far more significant than the passive mechanism in attenuating shock, since muscles are thought to play a primary role in energy and shock absorption during landing. 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*., 1998:518-520). 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.*, 2006:1091).

The effects of fatigue during locomotor activities have demonstrated different responses in both GRF magnitudes and lower extremity control strategies in recent studies (James *et al.*, 2010:672-676). The reason for these different responses is unknown. Fatigue alters GRF magnitudes during the impact and eccentric braking phases of locomotor activities. This causes alterations in segmental control and joint and system stiffness could alter the load on passive structures.

Authors such as Haddas *et al.* (2015:381) and James *et al.* (2010:673-676) have suggested that GRF magnitudes increase during fatigued hopping, landing, and sub-maximum drop jumping. These findings have been accompanied by greater muscle premotor and reaction phases with fatigue, compromising their protective role (Haddas *et al.,* 2015:381). Increased pre-activation of stabilizing musculature may increase joint or system stiffness, and change the body geometry at initial contact (James *et al.*, 2010:673-676).

The study by James *et al*. (2010:667-675) found that fatigue increased GRF first peak magnitudes and decreased GRF second peak, second peak loading rate, and impulse values as measured by electromyography (EMG). They observed increases (large effect sizes) in the vastus medialis and gastrocnemius muscles. In addition, they found two different fatigue protocols affect neuromuscular and kinematic landing performance characteristics differently which could therefore also have an effect on the injury incidence profile. The difference in GRF feedback may indicate that the neuromuscular system is affected in different ways depending on the fatiguing protocol. It may also indicate that the neuromuscular system reacts differently depending on the neuromuscular dysfunction. Analysing such events and addressing these concepts in a rehabilitation programme could possibly enhance different performance factors. It could therefore be beneficial to establish under which circumstances players adapt to fatigue with less stiffness and reduced GRF, or increased stiffness and higher GRF. However, currently, there is very little research on the response of athletes regarding fatigue and the associated adaptations in the neuro-musculoskeletal system (James *et al.,* 2010:667-675).

Voloshin *et al*. (1998:519) studied 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. The biokinetics 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.

Bahr and Krosshaug (2005:325) related the mechanical properties of soft tissue, such as the stress-strain interaction, viscosity, and elasticity, to fatigue and physical loading. Mechanical properties in soft tissue are tissue specific and depends on a variety of factors. Some of these factors include the rate, nature, type, and frequency of load repetition, the magnitude of energy transfer, and intrinsic factors. The intrinsic factors comprise of the gender, age and physical condition of the individual. However, it is the relationship between the load tolerance and the implied load that determines the risk for sustaining an injury. There are mainly two factors to consider, namely how an event resulted in an excessive mechanical load, or how it reduced the tolerance level of the neuro-musculoskeletal system regarding the biomechanical load, leading to failure of the tissue at a level that would normally have been tolerated (Bahr & Krosshaug, 2005:325). These concepts are clarified in the following section where it is indicated how altered biomechanics may change the strain and strength of the surrounding soft tissue structures.

2.2.2 The effect of lower limb muscle fatigue on injury potential

Studies have shown that decision making and fatigue, factors which are synonymous with sports participation, promote high-risk lower limb joint neuromechanical adaptations. These adaptations may occur simultaneously with a present injury and create a worst case scenario for high-risk dynamic landing strategies. Considering that 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 planar deviations of hip and knee motions, as well as loads and sagittal plane ankle motions, are common postural outcomes when individuals are exposed to either factor during dynamic sports landings (Chappell *et al*., 2007:240).

Borotikar *et al.* (2008:90) investigated these altered biomechanics during neuromuscular fatigue in the execution of a dynamic single leg landing. He found significant decreases in initial contact hip flexion, while initial contact hip internal rotation, peak stance phase knee abduction, knee internal rotation and ankle supination positions increased significantly during the fatigued landing. Some of these changes were more pronounced during unanticipated compared to anticipated single leg standings. This could imply a degradation in the peripheral and the central processing mechanisms according to the authors. They also indicated that the changes in the lower limb kinematics, usually observed at 100% fatigue level, are already evident at only 50% of the fatigue level. This finding implied that a fatigued player could already be at risk for injury at only 50% of the maximum fatigue level.

2.2.3 The effect of lower limb muscle fatigue on vertical jump mechanics

Tamura *et al*. (2016: 1-7) concluded that fatigue decreases an athletes ability to reduce shock by increasing the angular velocity in the direction of knee flexion during single-leg drop jump landing. Haddas *et al*. (2015:378) has also found increased GRFs, reduced knee abduction with initial contact, increased maximum knee-flexion moment, and delayed activation of the semitendinosus, multifidus, gluteus maximus, and rectus femoris muscles with landing after a fatigue protocol. Their study was however done on participants with low back pain which may affect the response and activiation patterns of the kinetic chain post-fatigue.

Kellis (2009:63) concluded in a study that individuals with fatigued knee extensors landed with lower vertical ground reaction force (vGRFs) and a higher knee flexion angle. This was accompanied by an antagonist inhibition strategy around the knee and a quadriceps dominant strategy. In contrast, fatigue of the knee flexors had no effects on vGRFs but it was accompanied by increased activation of vastus medialis, biceps femoris and gastrocnemius muscles and an increased quadriceps: hamstring muscle ratio during the pre-activation phase. It is concluded that fatigue responses during landing are highly dependent on the muscle which is fatigued, therefore the discussion on the vertical jump kinetics in the following section (Kellis, 2009:63).

2.3 ANALYSIS OF THE VERTICAL JUMP: A KINETIC AND BIOMECHANICAL PERSPECTIVE

In a sport like soccer, transition from running to jumping or to a stance position requires well-controlled muscular activity by the athlete. During the stance phase of sports movements, the lower extremity undergoes the largest and most repetitious forces. Fatigue may promote altered biodynamical characteristics during the stance phase to enhance joint stability and protect inert internal tissues, such as ligaments. During the stance phase, shock absorption is achieved through muscle stiffness, bony deformation, joint motion, and cartilage compression (Nyland, 1994:132).

Common clinical measures of lower extremity power and performance include the squat jump, the countermovement jump (CMJ) and the drop jump (Padulo *et al*., 2013:520). During a squat jump, a concentric contraction of the knee and hip extensors help to propel the athlete upward. Landing after a jump requires eccentric contraction of the muscles of the lower extremities (Padulo *et al*., 2013:520). Movement patterns such as these, that terminate with passive vertical/braking ground reaction forces and eccentric muscle actions, may however demonstrate biodynamical characteristics that differ from more cyclical, continuous movement patterns, which present a succession of concentric-eccentric-concentric lower extremity muscle activation during physical activity (Nyland, 1994:136).

GRF is the resultant force vector of gravitational and reaction forces which act downward along the gravity line (Jull *et al.,* 2015:141; Neal & Sydney-Smith 1992:73-75). The magnitude of these forces, along with their repetitive nature, may contribute to the relatively high incidence of lower extremity injuries in soccer players. In a study done by Prapavessis and McNair (1999:355), it was evident that landing techniques play a big role in lowering GRF. Subjects who received instructions regarding jumping techniques had significantly lower GRF upon landing. Kellis (2009:63) found that fatigue responses during landing depended on the muscles fatigued and this had an effect on the GRF. Higher GRF is one of the contributing factors to injury (Seegmiller, 2003:314), and as discussed in 2.2.1, fatigue in the muscles of the lower limbs during jumping and landing, may cause higher GRF, which increases the risk of injury.

Given this association it is critical to look at factors which impinge on the landing technique. The technique a player uses to land after heading a ball or challenging in the air in soccer is influenced by several factors including the speed of the ball to be headed, the speed of the player’s approach to the ball, positioning of opposition players, movements required following the landing action, the material properties of the playing surface, and the footwear worn by the player.

2.3.1 The vertical jump

Slinde (2008:640) described jumping as a movement that requires complex motor coordination between upper- and lower-body segments. The vertical jump is widely used to study mechanics of muscle reaction. This can be done with or without countermovement and includes the countermovement jump (CMJ) and the squat jump (Kopper *et al.,* 2013:132). The drop vertical jump 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.

A CMJ is a jump where the athlete starts from an upright standing position and makes a downward movement before starting with an upward movement, where a squat jump starts from a semisquatted position without any counter-movement (Bobbart & Cassius, 2005:440). A CMJ thus involves movement that helps achieve extra height when jumping because of the stretch–shorten cycle. This is a pattern of muscle activation where the muscle stretch during the initiation phase leads to a shortening contraction (Enoka, 2008:248). Counter-movements are performed to lengthen the contact time with the ground, which increases the time the muscle gets to shorten and thereby increasing the jump height (Abernethy, 2013:116).

During a vertical jump, the jumper must overcome body weight, and the resultant force acting on the jumper's center of mass. Marcovic *et al*. (2014:209) concluded that both composition (in CMJ and squat jumps) 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 a CMJ or squat jump is recommended, while the peak power rather than the average power should be the variable of choice.

Research done by Kopper *et al*. (2013:138) investigating vertical jump in terms of range of movement of different joints in the lower limb, concluded that muscles, in a short range of motion, contract isometrically. Elastic components helps with the storage of elastic energy that provides increased potential to attain high acceleration at the beginning of joint extension. This may therefore contribute to considerably higher positive work with a CMJ when compared to jumps without countermovement.

2.3.2 Landing technique

Daneshjoo *et al*. (2015:2) states that most knee injuries in soccer involves planting, pivoting or landing. Landing with a smaller amount of knee-flexion joint angle (ranging between 10–30°), having a greater knee-valgus joint angle, as well as greater vertical and posterior ground reaction forces, increase the load on the knee joint and therefore the risk for injury.

Brazen *et al*. (2010) concluded that athletes had greater knee and ankle flexion angles with initial contact with the ground when they were fatigued. They also had greater peak ground reaction forces, and took longer to stabilize the body after landing. Fatigue therefore clearly affected lower body biomechanics during single-leg landings as was investigated by their study (Brazen, 2010:286-292).

Landing with incorrect knee alignment and single leg support therefore stresses the ligamentous structures of the knee and the surrounding musculature. This is a predisposing factor to lower extremity overuse injuries (see 2.2). This supports the literature on the epidemiology on soccer injuries of the lower limb in 2.1, and the consequence of muscle fatigue on landing strategies. As stated previously, the body may react with less or more movement and stability which may affect normal alignment in order to compensate for the loss of power due to fatigue.

Few studies are available that examined the relationship between anatomical alignment and injuries, but Söderman *et al*. (2001:317-320) found with a univariate analysis, that hyperextended knees in female football players was related to a higher risk of traumatic lower leg injuries. Beynnon *et al*. (2001:219) also found an association between the phenomenon of tibial varum among female football players and an increased risk of ankle ligament injuries.

Anterior Cruciate Ligament (ACL) injuries are mostly non-contact injuries with a predisposing injury mechanism such as cutting movements or one legged landings after a jump (Myklebust, 2015:1357-1367). Certain studies have suggested that ACL injuries are because of the valgus load which increases the ACL force where an anterior tibial force is applied (Koga, 2015:110). Mazur (2016:72) stated that a more extended knee on the plant leg has been shown to be one factor that is associated with knee injuries in soccer.

The influence of other risk factors for injury, such as height, weight, BMI, player position and somatotype, has not been significantly associated with poor landing technique in literature. However, one study of adolescents found that tall and muscularly weak boys incurred significantly more injuries than short and weak or tall and strong boys (Arnason, 2004:7S-8S). These findings therefore further motivates for the investigation of and emphasis on neuromuscular aspects affecting kinetics and biomechanics during fatigue.

2.4 ASSESSMENT OF MUSCLE FATIGUE ON DIFFERENT PLAYING SURFACES – METHODOLOGICAL CONSIDERATIONS

The discussion in 2.1 to 2.3 indicated the association between muscle fatigue, injury, muscle force generation during a vertical jump and the possible effect of different playing surfaces on force generation. These considerations were related closely to the choice of measuring instrument and technique for this study (see Chapter 3).

Force plates are commonly used in biomechanics laboratories to measure ground reaction forces involved in the motion of human or animal subjects, such as a vertical jump. The gravitational and reaction forces acting on the subject is represented by a resultant force vector along the line of gravity and applied to the center of gravity. This reaction resultant load is measured by a dynamometer such as the force plate (Jull *et al.,* 2015:141) (Figure 3).

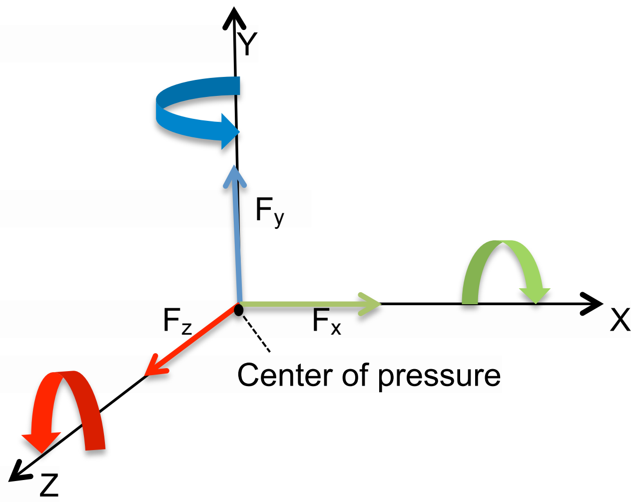


Figure 3. The resultant reaction force and couple components relative to a force plate (Jull *et al*., 2015:141).

Other than measuring GRFs, it can also give information regarding rate of force development upon which explosive muscle strength is highly dependent. These explosive-type movements are important to measure due to its importance for jumping, sprints and tackles which are decisive events for scoring in a soccer game (Greco *et al*., 2013:19). With the use of a force plate, it is possible to display and measure the force wave form directly. By means of this technique qualitative or quantitative relations between force, acceleration and displacement can be calculated and analysed (Cross, 1999:304).

A force plate is a metal plate with one or more sensors attached to give an electrical output proportional to the force on the plate. The sensor can either be a strain gauge or a piezoelectric element. Changes in forces, for example due to muscle fatigue, can therefore be easily detected by means of accurate measurement and a small margin of error before and after a fatigue protocol (Bobbert *et al*., 1990:442-443).

Measurement of the GRF with a force plate, can give information regarding the first and second peak of the force, the average loading rate from the instant of ground contact to the instant of the first peak, or the average loading rate from the instant of minimum force between the first and second peak, to the instant of the second peak. Figure 4 indicates this accuracy of the measurement of the GRF that can be deducted from the dynamic and kinematic curve for a counter-movement jump as measured by an AccuPower 2.0™ force plate (Linthorne, 2001:1199-1200).

CHAPTER 3
RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter describes the protocol that was designed to investigate the objectives stated in Chapter 1. A description of the subjects, instruments and methods that were used as well as the technique for every measurement will be discussed. In preparation for this study, literature was collected from electronic databases such as Kovsiekat, Pubmed, EbscoHost (Academic Search Elite and Medline), academic journals, and textbooks to inform methodological approaches and the choice of study design.

3.2 THE RESEARCH PROCESS AND STUDY DESIGN

Research has to be a methodical and organised process in order for the information obtained to be relevant and of any use in initiating advances or even change. There are many different forms of research but ultimately research is designed to improve knowledge on a topic and to enhance reasoning and development in the field of interest (Oxford, 2015: online; Maree, 2013: 51-52). Broadly, research can be divided into quantitative and qualitative research. The quantitative research process is characterised by three basic concepts, namely that it is systematic and objective, and use numerical data from a selected subgroup in order to generalise the findings to similar populations (Maree, 2013:145). When compared to the qualitative research process quantitative research focuses more on establishing cause and effect, than trying to understand and explore social and cultural contexts underlying behavioural patterns (Maree, 2013:51). The quantitative research process was therefore most suitable to answer the research question on what the effect of lower limb muscle fatigue on two different playing surfaces would be on force generation. The research process that was followed in this study is depicted in Figure 5.

Figure 5.The quantitative research process.

The ideal situation was to control the environment and include the largest possible number of respondents to limit confounding factors and increase the validity of the findings. The quantitative research process made it possible to introduce factors such as blinding of the researcher and assessors, thereby increasing the objectivity of the findings.

An experimental crossover study, also sometimes referred to as a related-/within- or same-subject design, was therefore chosen as the most appropriate design, mainly due to the restricted population of elite soccer players. This design would allow for one group to be exposed to two different conditions, while at the same time limiting individual differences at baseline and allowing for randomisation to the first condition. The latter would also introduce counterbalance into the study design, thereby limiting effects such as the testing effect and the Hathorne effect (Maree, 2013:151-152; Hicks, 1999:78).

The study design also posed the opportunity to include different levels of measurement, e.g. nominal (demographic information), equal interval and ratio scale (demographic data and force) measurement (De Vos *et al.,* 2005:165-166). Different methods of data collection (De Vos *et al*., 2005:166-191), namely subjective and objective methods, were utilised. Questionnaires (demographic) as well as more objective measures such as the Force Plate™ were used.

The whole group was pre-tested, whereafter the group was randomised and exposed to the independent variable (namely the fatigue protocols on the different surfaces). After the intervention time, the group underwent the post-test to determine the outcome (Leedy & Ormrod, 2010:231; De Vos *et al.,* 2005:141). This process was repeated with the groups being exposed to the second condition. Figure 6 demonstrates how the crossover experimental design was applied to investigate the research problem in this study.

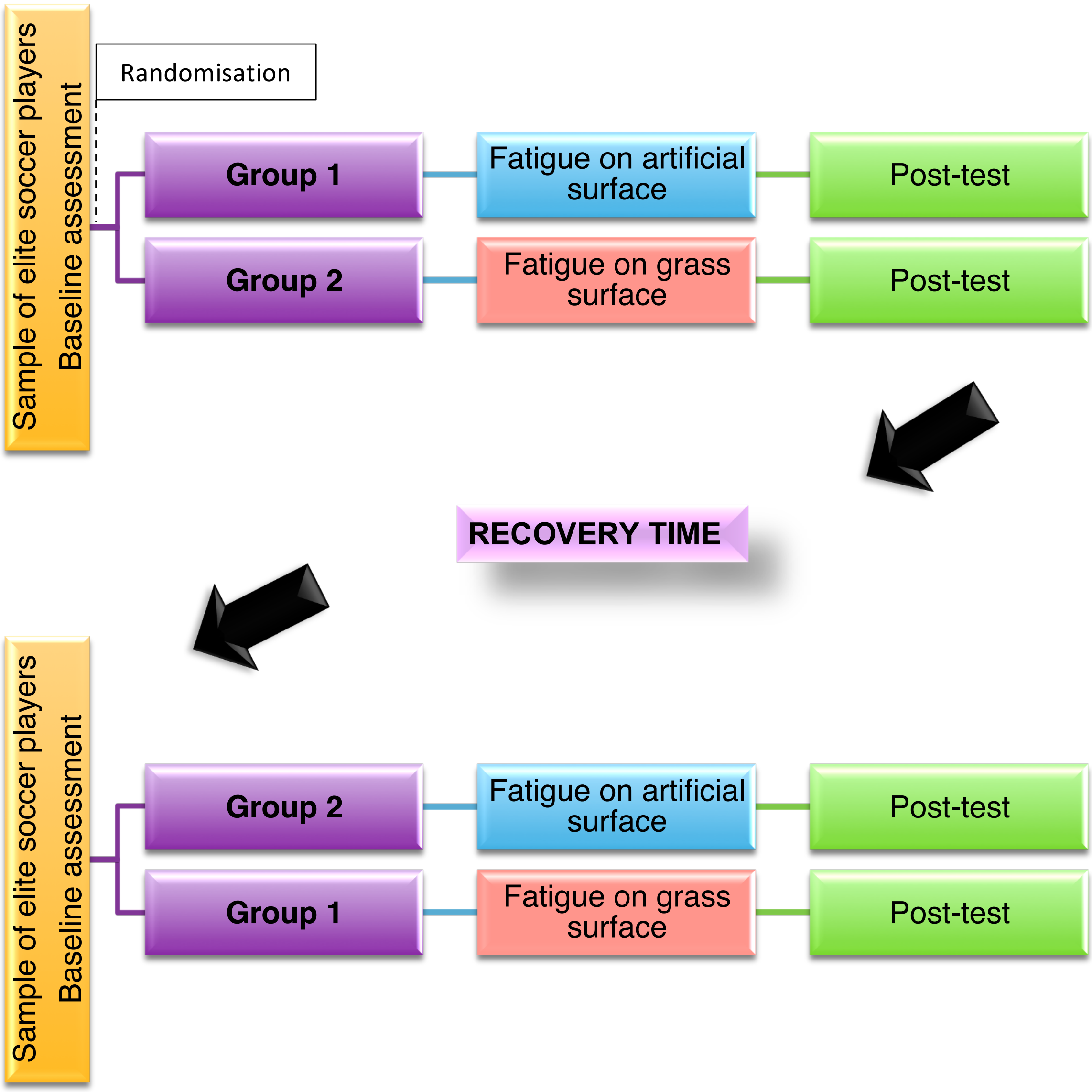


Figure 6.The crossover study design.

Although the crossover experimental design limited confounding factors, it did not eliminate them. An example of a confounding variable that is not necessarily underpinned by an experimental design is researcher and participant bias. This aspect was for example dealt with by introducing blinding of researchers into the research design (Maree, 2013:151). These and other aspects to improve validity and reliability, are discussed further in the following sections.

Following on the protocol development, the second phase of the research process involved ethical clearance in order to commence the study (see Figure 5).

3.3 ETHICAL ASPECTS

This study was approved by the Ethics Committee, Faculty of Health Sciences, University of the Free State (Ecufs 68/2015) (Addendum 1). Permission from Bloemfontein Celtic's chief executive officer (CEO) and head coach was obtained to approach the soccer players as participants (Addendum 3).

After obtaining permission from the above authorities, an information sheet was handed to the participants on the first day of measurement to describe the motivation and the nature of the research. The information sheet and demographic questionnaires (Addendum 2) were available in English to offer the participants the opportunity to make an informed decision to take part in the research study. The information sheet ensured that all participants received the same information. Emphasis was placed on the fact that their participation would be completely voluntary and all information was to be treated confidentially.

Participating in the study was voluntary and refusal to take part did not lead to any penalty or loss of benefits the participant was entitled to. Each participant had the right to withdraw from the study at any time. Informed, written consent was obtained from all study participants (Addendum 4) before inclusion in the study sample.

3.4 STUDY POPULATION AND SAMPLING

The sample can be defined as the elements of the population which is considered for inclusion in the study, or the subset of measurements drawn from the population for inclusion. In other words, the sample is the means of understanding the population from which it was drawn (De Vos *et al.,* 2005:194).

The main reason for sampling is feasibility. Time, money, and effort can be concentrated to produce better quality research when sampling is done, compared to including a large population. Better instruments, more in-depth information, and better trained fieldworkers and assessors can be used to execute the research. On the other hand the researcher may have to deal with a small population size as was the case with this study, especially when the phenomenon occurs on a relatively small scale. In such cases it would be preferable to involve the whole population in the study due to already compromised statistical findings and generalisability based on a small sample (De Vos *et al.,* 2005:194,195).

3.4.1 Population

The target population for this study was elite soccer players. The sample frame consisted of soccer players who played for Bloemfontein Celtic in the South African Premier Soccer League (PSL). It therefore included 25 players who were part of this squad at the time of the study.

3.4.2 Sample selection

Due to the relatively small population (see 3.4.1), the whole population, fulfilling the eligibility criteria, was targeted for inclusion. The players had to be part of the Bloemfontein Celtic/ Bloemfontein Celtic Colts squad during the 2015/16 season; had to be healthy and free of illness or any disease which could affect his performance, or put his health at risk; free of any lower limb injuries or injuries that could prevent him from doing the fatigue protocol effectively; and had to be able and willing to give consent in English, being the spoken language in the team.

If a potential participant displayed any of the exclusion criteria, the person was excluded from the study. These included players who were not included in the Bloemfontein Celtic/Colts squad for the 2015/16 season; who were rehabilitating from an injury involving the lower limbs or an area that would directly affect his performance during testing; who were suffering from an illness such as common flu or any disease which might put the participant at risk, and players who were unwilling or unable to give consent in English.

After signing informed consent, participants were randomly assigned, by means of simple random allocation, to one of the two conditions by means of a computerised list. This meant that all possible allocation of participants to one of the two conditions initially, would have the same probability (De Vos *et al.,* 2005:196-197). The process of allocation was done by an independent researcher to limit bias.

Participants were however closely monitored during the course of the study. In the event of a participant sustaining an injury during either of the two measurements, becoming ill or admitting to being sleep deprived, the participant was withdrawn from the study and referred for appropriate management. This was done to ensure accurate and valid measurement of the forces on the Force Plate^{TM} in response to the conditions being exposed to.

3.5 MEASURING INSTRUMENTS

An AMTI AccuPower^{TM} force plate was used for the measurement of forces during the vertical jump. The AccuPower^{TM} is a portable six component force plate designed for athletic performance evaluation during jumping, lifting and power analysis. It utilises Hall Effect sensors to accurately measure the ground reaction forces, while allowing for internal amplification and high overload protection on all axes. The AccuPower^{TM} then interfaces directly with a computer via USB or RS-232 connection for data analysis, by using AccuPower Software (Figure 7).

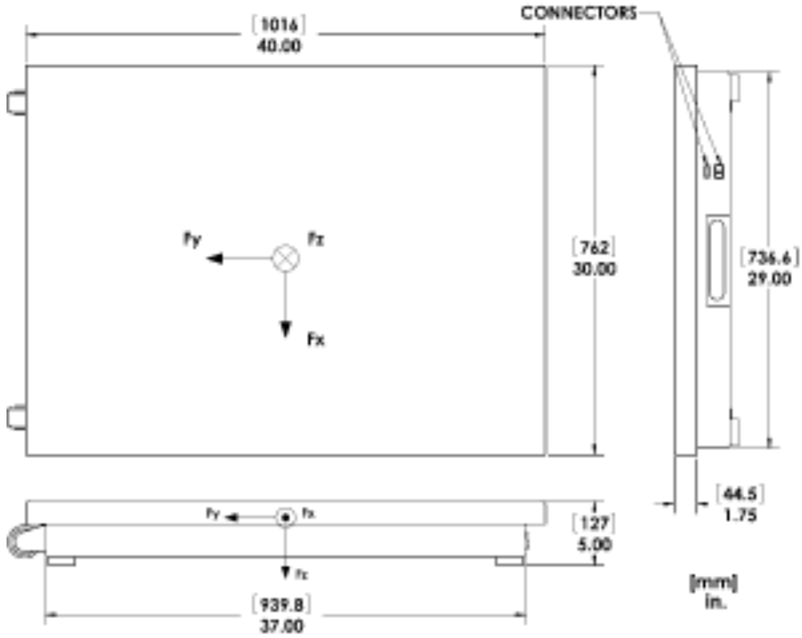


Figure 7. AccuPower force plate footprint (amti.biz).

The jump height, propulsion force, landing force (GRF), propulsion force rate, landing force rate, maximum concentric and eccentric forces were recorded from the markers on each participants graph. These recordings are demonstrated in Figure 8.

CHAPTER 4

RESULTS

The main purpose of this chapter is to present the results for the discussion (in the following chapter) on the objectives identified in the first two chapters (see 1.1, Figure 1).

It starts with a presentation of the demographic data and training history of the soccer players. This is followed by a summary of results on correlations that were drawn on baseline data in order to guide the interpretation and consequent recommendations from the cross-over trial. For the purpose of continuity and to relate the results to the context of the study, the results are presented according to the objectives of the study.

Under each results section, the specific statistical formulas used for calculation are noted, followed by the analysis of the results of each variable. Results are interpreted and compared to normal values where applicable, to help with clinical interpretation.

4.1 DATA VERIFICATION

Prior to analysis, all data was checked for errors in coding and by investigating reasons for missing data. Missing information was gathered directly after the completion of the questionnaire where applicable.

Coding was done twice by two different researchers and typing errors were checked for by reading data in twice. Spot checks were also done by the biostatistician.

Firstly, logical checks were done to confirm that all participants fulfilled the eligibility criteria by checking the demographic data for inclusion. Categorical variables were checked for plausible values, while the ranges of the continuous data were checked for out of range minimum and maximum values. This was firstly done by a basic Excel analysis of the data - also to detect patterns and relationships to be explored further by formal statistical methods (De Vos *et al.,* 2005:222). The Excel analysis was followed by a formal statistical analysis by a biostatistician using SAS software to compare findings.

4.2 DEMOGRAPHIC DATA AND TRAINING HISTORY (duration, frequency, and intensity)

The results start with a presentation of independent variables, which can also be interpreted as the external/internal (as applicable) or confounding factors which could influence the effect of fatigue on a participant. However, the cross-over design accounted for the limitation of confounding factors. The factors that are presented in this section are thus only the most applicable results for interpretation and recommendation purposes.

4.2.1 Statistical methods

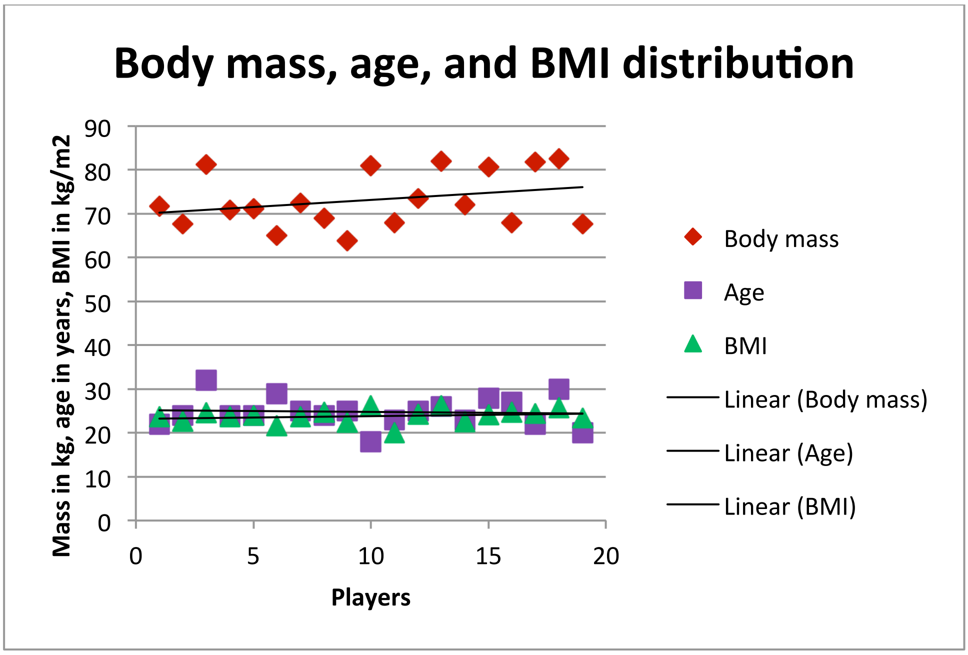
A univariate analysis was done to describe the independent variables in a sample of 25 elite soccer players (De Vos *et al.,* 2005:222). Only two players were lost to follow-up, while missing data was responsible for further deviations in n-values. The aim of the analysis was to explore the distribution of the data in the whole sample, in order to challenge the hypotheses and to help explain and compare the outcomes of fatigue on the two different playing surfaces they were exposed to.

Descriptive statistics were used to describe the data. This included calculation of the mean, standard deviation (s), minimum and maximum values in the case of a symmetric distribution of the variable. Where data was skewed positively or negatively, the median, 25^{th} percentile and 75^{th} percentile were also included for interpretation.

The distribution of the data was interpreted as skew where the value of the skewness was larger or smaller than 1 or -1 respectively. The distribution was confirmed by checking if the mean and median were lying close together, as well as if the *mean-2*SD* was larger than zero. If the latter two estimates were not true, the question was raised as to the parametric distribution of the data. Box-plots were then drawn to observe and interpret the skewness of the data (Maree, 2013:189,190; De Vos *et al.,* 2005:236,237).

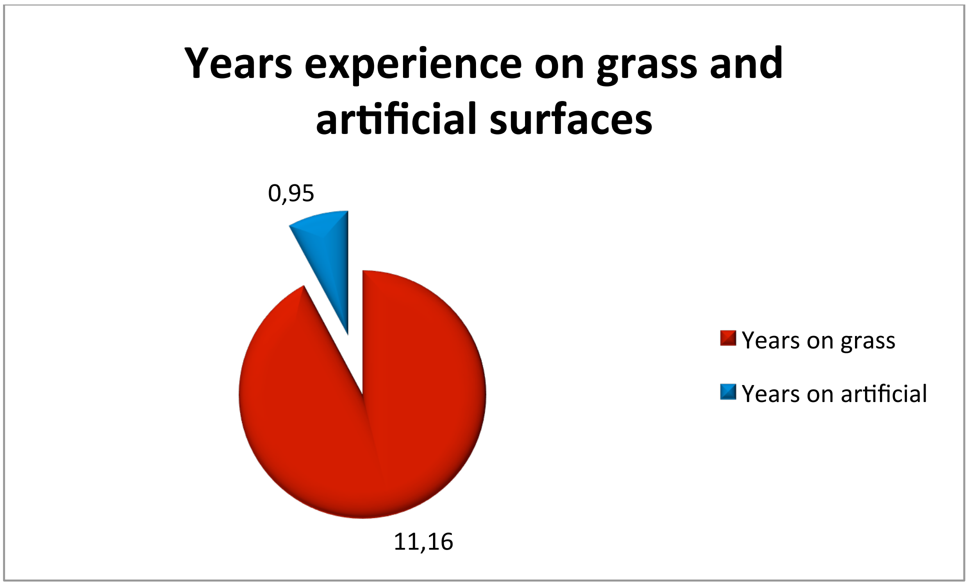
4.2.2 Data analysis

Most variables yielded a parametric distribution within the sample at baseline (Graph 1). The players were relatively young with a mean age of 24.8 years (SD = 3.39). Their mean BMI (23.82kg/m^2) was within normal range (19-24.9kg/m^2) expected for an athlete (Table 1). It would therefore not be expected that these variables would have a confounding effect on the outcomes of the fatigue measurement.



Graph 1. Distribution of body mass, age, and BMI (n=19).

Training history yielded interesting findings regarding exposure to the different playing surfaces. No training were done on artificial surfaces, while only six players (32% of the team, n=19) had previously played on artificial surfaces. The mean amount of years regarding exposure to each surface, are depicted in Graph 2.



Graph 2. Mean number of years exposed to artificial and grass surfaces (n=19).

Very limited time was also spent on specific aerobic (one hour per week) and strength training (two hours per week). Based on these findings, specific attention would be given to notice any differences regarding muscle behaviour and force generation when fatiguing the participants specifically on the artificial surface which might be speculated to require different demands regarding muscle behaviour and response (see 4.4.2).

Table 1. Demographic data and results on training history (n=22).

VARIABLE	MEAN	SD*	MIN*	MAX*
Age (years)	24.78947	3.392458	18	32
BMI (kg/m^2)	23.81684	1.51	20.09	26.15
Amount of sessions per week on grass	6.1	0.458831	6	8
Amount of sessions per week on artificial	0	0	0	0
Amount of time per week on grass (hours)	8.05	0.229416	8	9
Amount of time per week on artificial (hours)	0	0	0	0
Amount of years played on grass	11.15	4.462973	0	18
Amount of years played on artificial	0.95	2.320768	0	10
Amount of time per week aerobic training (hours)	2	0	2	2
Amount of time per week strength training (hours)	1	0	1	1

*Min = minimum; Max = maximum; SD = standard deviation

Muscle behaviour and force generation were further defined by correlating baseline data on two different occasions.

4.3 CORRELATIONS ON BASELINE DATA

Correlations were done on baseline data from the two different testing occasions to enhance validity of the findings. These correlations were used to detect patterns in data and to guide the interpretation of the comparison of the different testing occasions from the cross-over trial. The correlations would also help with the compilation of training programmes by addressing variables and components that could interact with one another.

4.3.1 Statistical methods

Bivariate analyses included calculation of correlations by means of the Pearson correlation coefficient (r) for parametric continuous data and by means of the Spearman correlation coefficient (r_s) for non-parametric continuous and ordinal variables. A correlation coefficient of $-1<r<0$ indicated a negative correlation, while $0<r<1$ indicated a positive correlation, where $r=0$ indicated no correlation (Leedy & Ormrod, 2010:279). For categorical data, cross-tabulations were done to indicate a descriptive degree of association (De Vos *et al.*, 2005:239). Statistical significance for correlation coefficients was calculated by means of the critical values of r at various levels of probability. The critical value for a 5% significance level, two-tailed test, and rejection of the null hypothesis was taken as the minimum level of probability. Any p-value greater than 0.05, was therefore interpreted as statistically insignificant (Hicks, 1999:194-198). Practical significance was indicated by means of effect size, based on the r-value (Table 2).

Table 2. Interpretation of effect size (Maree, 2013:211).

d or r	Meaning
0.2	Small effect
0.5	Medium effect
0.8	Large effect

4.3.2 Data analysis

Due to the symmetric distribution of data, the Pearson correlation coefficient was used to determine the r-value. Clinically, most correlations yielded medium to large effect sizes. The clinical findings were also supported by statistical significant values indicated in Table 3.

Body mass, being closely related to the forces that must be overcome with propulsion and landing, showed strong positive correlations with both landing and propulsion forces on both testing occasions (Table 3). Body mass was also positively correlated with the mean maximum concentric force generation ($r=0.52$ and $r=0.76$, $p<0.05$ and $p<0.001$ respectively). However, the only difference in findings between the two testing occasions were regarding the correlation between body mass and mean maximum eccentric force generation. One testing occasion revealed no statistical significant correlation ($r=-0.22$, $p>0.05$) while the other revealed a strong correlation ($r=-0.68$, $p<0.01$). Repeating this correlation with the BMI instead of body mass, yielded no correlations on both testing occasions ($r=-0.106$ and $r=-0.22$ respectively, $p>0.05$).

Contrary to theoretical belief, no correlations were found between jump height and propulsion force on both testing occasions ($r=0.042$ and $r=0.179$ respectively, $p>0.05$). However, jump height were correlated with the mean maximum concentric force of contraction ($r=0.72$ and $r=0.84$ respectively, $p<0.001$). Complicating the interpretation of these findings, is the fact that the mean maximum concentric force was however positively correlated with the mean propulsion force ($r=0.64$ and $r=0.66$, $p<0.01$ and $p<0.001$ respectively).

Table 3. Correlations between baseline variables at two different occasions.

Variable 1	Variable 2	BASELINE OCCASION 1				BASELINE OCCASION 2			
		Pearson CC (r)	p-value	df=n-2	Effect size	Pearson CC (r)	p-value	df=n-2	Effect size
Jump height	**Propulsion force**	0.042	>0.05	19	Small	0.179	>0.05	17	Small
Propulsion force	**Concentric force**	0.64	<0.01*	20	Medium	0.66	<0.001*	18	Medium
Propulsion force	**Body mass**	0.60	<0.01*	16	Medium	0.78	<0.001*	15	Large
Propulsion force	**BMI**	0.45	<0.02*	17	Medium	0.645	<0.01*	15	Medium
Landing force	**Body mass**	0.63	<0.01*	17	Medium	0.82	<0.001*	15	Large
Landing force	**Eccentric force**	-0.39	<0.01*	17	Medium	-0.75	<0.001*	18	Large
Jump height	**Concentric force**	0.72	<0.001*	19	Large	0.84	<0.001*	17	Large
Jump height	**Eccentric force**	0.032	>0.05	17	Small	-0.11	>0.05	17	Small
Body mass	**Concentric force**	0.52	<0.05*	17	Medium	0.76	<0.001*	15	Large
Body mass	**Eccentric force**	-0.22	>0.05	16	Small	-0.68	<0.01*	15	Large
BMI	**Eccentric force**	-0.106	>0.05	16	Small	-0.22	>0.05	15	Small
Landing force rate	**Eccentric force**	-0.361	>0.05	17	Small	-0.763	<0.001*	18	Large
Propulsion force rate	**Concentric force**	0.238	>0.05	20	Small	0.029	>0.05	18	Small

CC: correlation coefficient

*statistical significant p<0.05

Speed of contraction, and therefore maybe force rate, has been speculated to be closely related to force of contraction. A correlation between landing and propulsion force rates, yielded a statistical significant negative correlation between landing force rate and maximum eccentric force production (r=-0.763, p<0.001). However, this was only found on one of the four occasions of correlating force rates and forces.

To answer some of the concerns and discrepancies raised in this section on correlations, the data was again observed (under different circumstances) to observe for similar patterns during comparison of the different conditions of fatiguing.

4.4 RESULTS FOR MEASUREMENT OF MUSCLE FATIGUE ON TWO DIFFERENT PLAYING SURFACES

The change in variables as a response to fatigue was observed during two testing occasions. The same participants, randomised during the first session, were exposed to both playing surfaces, on a separate occasion.

4.4.1 Statistical methods

The two different intervention groups were firstly described by a univariate analysis on each occasion to determine the distribution of the baseline characteristics within each group. This analysis was done similar as was described in 4.2 above.

As the study progressed through the different stages, participants were lost to follow-up (n=2) mostly due to not being assigned a contract. However, as players (participants) were lost, new players (participants) were recruited and included for measurement at baseline (see 4.2). Therefore the deviation seen in the n-values ranging from 19 to 25 (see 4.4.2, Tables 4a and b).

The within-subject differences were reduced to a one sample problem for comparison of the group`s performance in each condition. Non-parametric tests were used to determine the p-value. The Wilcoxon signed-ranks test was used to determine statistical significance from pre-test to post-test for each condition. A p-value of less than 0.05 was again taken as an indication of statistical significance. Comparison of the changes regarding exposure to each condition was determined by the Kruskal-Wallis test.

The changes from baseline to fatigue were calculated by subtracting the fatigue value from the baseline value. A negative value therefore indicated an increase in value. This however did not apply to the eccentric force values. Eccentric forces were coded as negative to differentiate it from the concentric force values. A negative change regarding the eccentric force therefore indicated a decrease from baseline to fatigue.

4.4.2 Data analysis: lower limb muscle fatigue before and after a sport specific fatigue protocol on a grass and artificial playing surface.

As a general introduction to this section a summary is given of some observations and trends regarding the calculated correlations and the changes that took place from baseline to post-fatigue measurements (see 4.3; Tables 4a and 4b).

If we refer back to Table 3 (see 4.3), the positive correlation that was found between the propulsion force and the concentric force, are reflected in the changes yielded on both surfaces. Both testing conditions led to a decrease in both of these variables.

The positive correlation between the concentric force and the jump height, however, was only reflected in the results yielded by fatigue on the grass surface where both variables increased during the post-test. Fatigue on the artificial surface, led to a decrease in the jump height, and a very small increase in the concentric force, which could partially have contributed to the decrease in the median jump height (1.9cm, p=0.495).

The negative correlation that was found between the landing force and the eccentric force in Table 3, are only reflected in the results of the changes that was found with fatigue on the artificial surface, where an increase in the landing force was accompanied by a decrease in the eccentric force (see Tables 4a and 6).

Specific analysis of the changes under each condition can be described as follows. Tables 4a and 4b are a summary of the mean values at baseline and after fatigue on both surfaces, upon which the analysis of the change in values were based.

Table 4a. Mean values for the baseline and post-fatigue measurements on the artificial surface.

VARIABLE	n	MEAN	MEDIAN	SD*	MIN*	MAX*
BASELINE						
Jump height (cm)	19	31.77	33.70	9.25	10.20	51.60
Propulsion force (N)	20	1732.34	1640.05	249.61	1444.92	2355.83
Propulsion force rate (N/s)	20	3584.11	3896.58	1519.46	1246.89	7914.38
Landing force (N)	20	2222.89	2132.44	418.40	1518.79	3019.33
Landing force rate (N/s)	20	27024.82	27091.80	6792.45	11237.13	41798.21
Concentric force (N)	20	3731.70	3781.50	825.22	1872.00	5709.00
Eccentric force (N)	20	-4676.50	-4415.50	1127.39	-7324.00	-2948.00
FATIGUE						
Jump height (cm)	20	30.05	30.85	8.45	6.30	41.80
Propulsion force (N)	20	1875.65	1772.66	294.82	1524.57	2408.34
Propulsion force rate (N/s)	20	4900.14	4749.43	1891.29	2578.90	8646.31
Landing force (N)	20	2240.80	2196.08	400.16	1559.73	3272.09
Landing force rate (N/s)	20	26443.26	26117.33	5556.18	16728.37	35735.00
Concentric force (N)	20	3822.05	3767.50	848.50	2167.00	5246.00
Eccentric force (N)	20	-4518.85	-4529.00	2437.04	-9245.00	4126.00

*Min = minimum; Max = maximum; SD = standard deviation

Table 4b. Mean values for the baseline and post-fatigue measurements on the grass surface.

VARIABLE	n	MEAN	MEDIAN	SD*	MIN*	MAX*
BASELINE						
Jump height (cm)	21	30.45	29.70	8.08	14.50	45.30
Propulsion force (N)	22	1745.48	1723.04	231.65	1401.31	2270.39
Propulsion force rate (N/s)	22	4007.02	3766.85	2070.66	1298.28	10727.39
Landing force (N)	22	2146.66	2242.80	284.33	1550.83	2597.47
Landing force rate (N/s)	22	23902.43	24183.94	5007.65	13879.76	33321.86
Concentric force (N)	22	3591.23	3475.50	690.68	2371.00	4738.00
Eccentric force (N)	21	-4401.57	-4270.00	607.21	-5671.00	-3461.00
FATIGUE						
Jump height (cm)	21	31.60	29.60	5.97	21.00	41.50
Propulsion force (N)	20	1860.92	1838.96	257.28	1478.74	2556.53
Propulsion force rate (N/s)	20	4440.39	4368.19	2068.80	2142.62	10124.74
Landing force (N)	21	2308.42	2296.20	420.40	1678.10	3250.20
Landing force rate (N/s)	21	25381.03	24223.48	8712.46	2137.73	43262.53
Concentric force (N)	21	3926.00	3724.00	596.71	3216.00	5038.00
Eccentric force (N)	19	-4723.21	-4378.00	1033.01	-7422.00	-3123.00

*Min = minimum; Max = maximum; SD = standard deviation

Exposure to fatigue on the grass surface yielded statistical significant findings regarding the change in the two variables measured. This included a statistical significant increase in the propulsion force after fatigue (-112.246N, p=0.0258) as well as in the concentric force (-324.75N, p=0.0049). The jump height, propulsion force rate, landing force, landing force rate, as well as the eccentric force produced, all increased with the induction of fatigue (Table 5). However, these variables did not change statistical significantly.

Table 5. Values for the change from baseline to fatigue on grass surface.

VARIABLE	MEAN (SD)	MINIMUM AND MAXIMUM	P-VALUE (Signed rank)
Jump height (cm)	-1.642 (7.798)	[-18 – 10.5]	0.495
Propulsion force (N)	-112.246 (212.688)	[-738.7 – 213.6]	0.0258*
Propulsion force rate (N/s)	-404.777 (2988.873)	[-8826.46 – 5264.420]	0.4900
Landing force (N)	-138.480 (330.315)	[-926.855 – 334.195]	0.114
Landing force rate (N/s)	-1094.3238 (6474.862)	[-16197.23 - 15542.31]	0.3683
Concentric force (N)	-324.75 (419.964)	[-1045 – 547]	0.0049*
Eccentric force (N)	356.667 (1145.876)	[-1453 – 3528]	0.3301

*statistical significant difference p<0.05

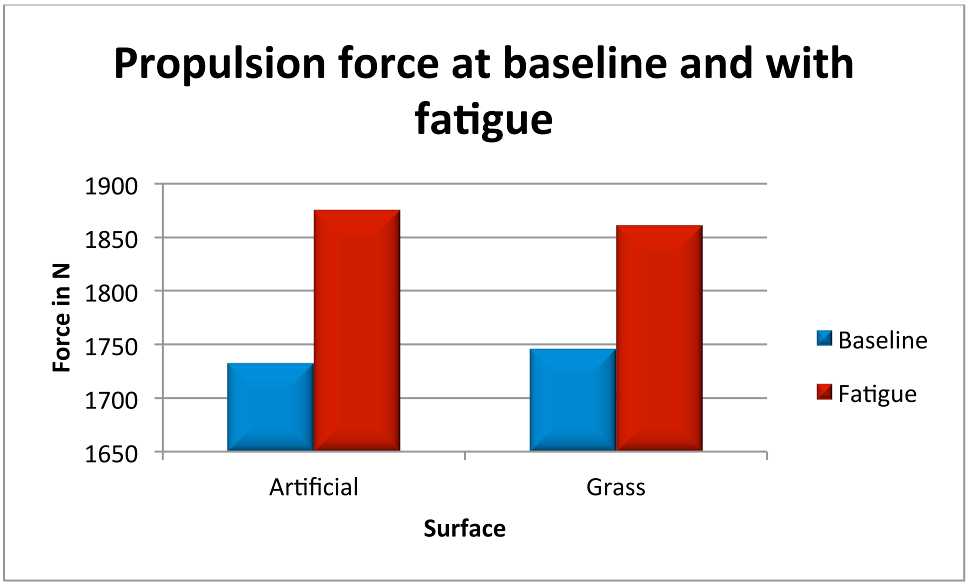
The fatigue protocol on the artificial surface yielded a different trend in findings (Table 6).

Table 6. Values for the change from baseline to fatigue on artificial surface.

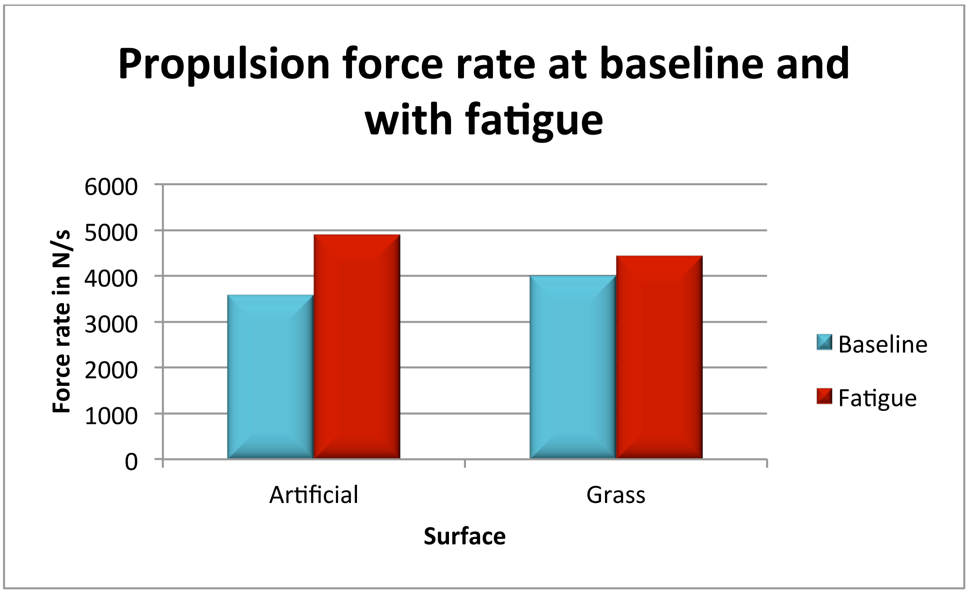
VARIABLE	MEAN (SD)	MINIMUM AND MAXIMUM	P-VALUE (Signed rank)
Jump height (cm)	1.895 (9.138)	[-14.9 – 21.5]	0.447
Propulsion force (N)	-143.312 (131.868)	[-488.610 – 69.420]	<0.0001*
Propulsion force rate (N/s)	-1316.0302 (2069.238)	[-5769.03 – 1407.590]	0.0153*
Landing force (N)	-17.911 (324.218)	[-736.475 – 492.170]	0.8983
Landing force rate (N/s)	581.556 (6772.295)	[-9160.76 – 16269.48]	0.9854
Concentric force (N)	-90.35 (700.336)	[-1001 – 1952]	0.2815
Eccentric force (N)	-157.65 (2382.445)	[-8666 – 4321]	0.7562

*statistical significant difference p<0.05

However, similar to the fatigue induced on the grass surface, the propulsion force (Graph 3) increased statistical significantly after fatigue on the artificial surface (-143.312N, p<0.0001). Different from the findings from fatiguing on the grass surface, the propulsion force rate (Graph 4) increased statistical significantly after fatigue on the artificial surface (-1316.0302N/s, p=0.0153) (see Table 6).

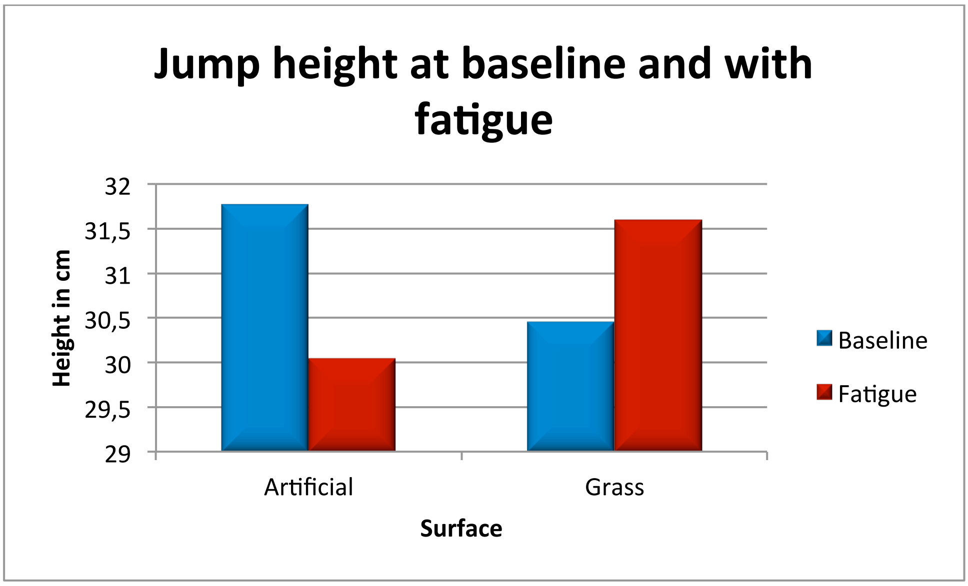


Graph 3. Mean propulsion force at baseline and after fatigue (n=20).

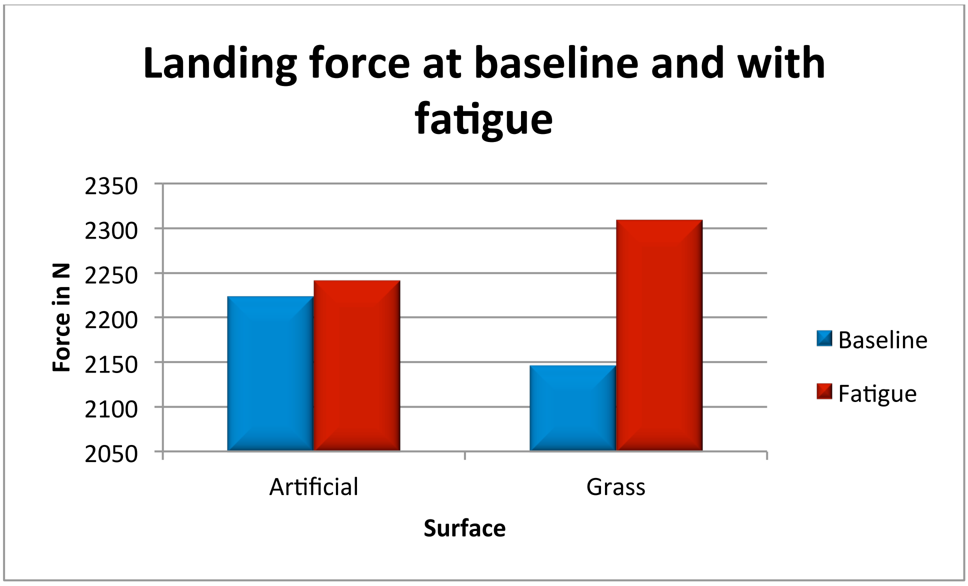


Graph 4. Mean propulsion force rate at baseline and after fatigue (n=20).

Fatigue on the artificial surface led to a decrease in jumping height (Graph 5) and an increase in the landing force (Graph 6), though the latter was much smaller when relating it to the value found after fatigue on the grass surface (-17.911N compared to -138.480N on grass) (Tables 5 and 6). It must however be noted that for both of these variables, the baseline measurements seem to differ for the two testing occasions, although not statistically significant (p=0.616 for jumping height and p=0.821 for landing force).

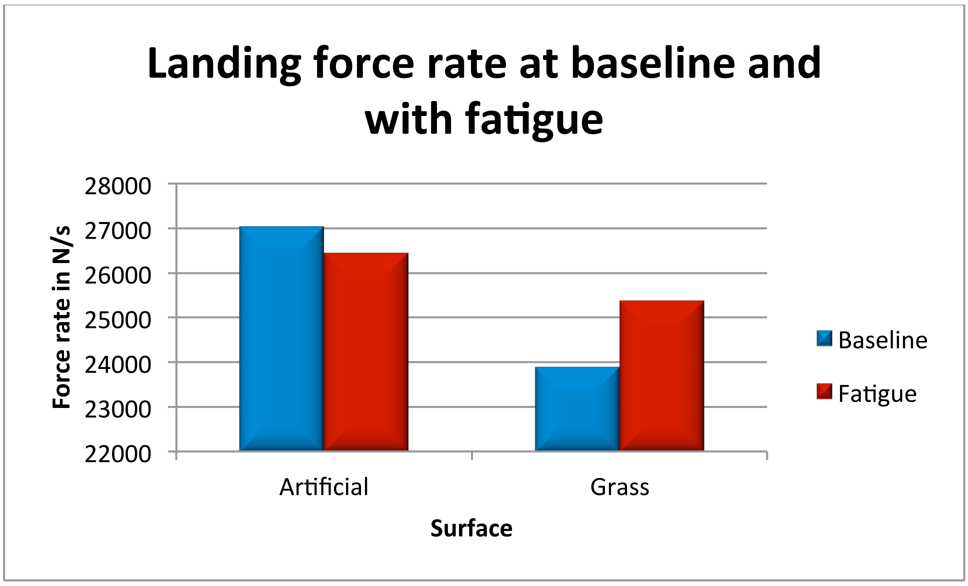


Graph 5. Jump height at baseline and after fatigue (n=20).

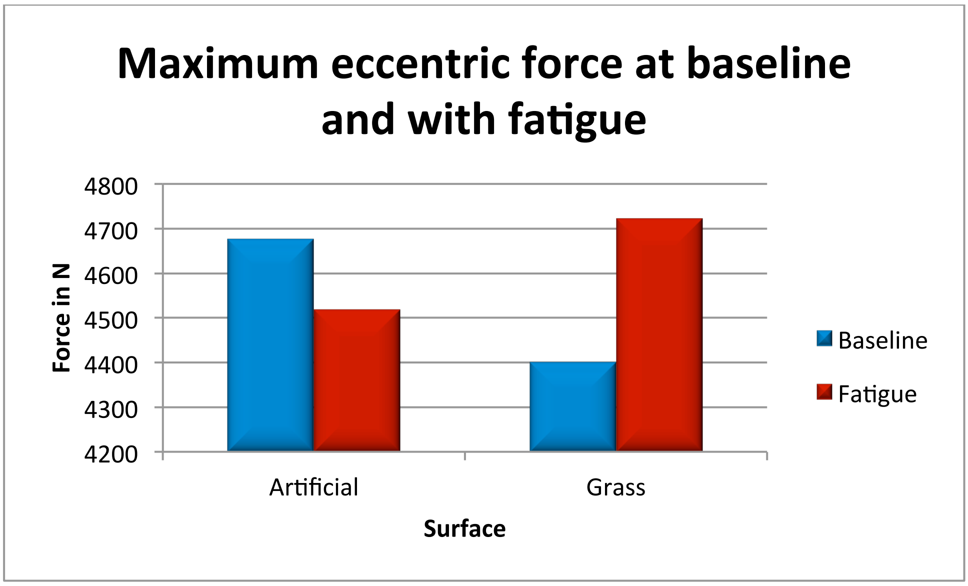


Graph 6. Landing force at baseline and after fatigue (n=20).

The landing force rate (Graph 7) as well as the eccentric force (Graph 8) produced decreased from baseline to fatigue. Relating it to the measurements after fatigue on the grass surface, it could again be noticed that the baseline measurements for the two occasions differed, but not significantly (p=0.0525 and p=0.449 respectively).

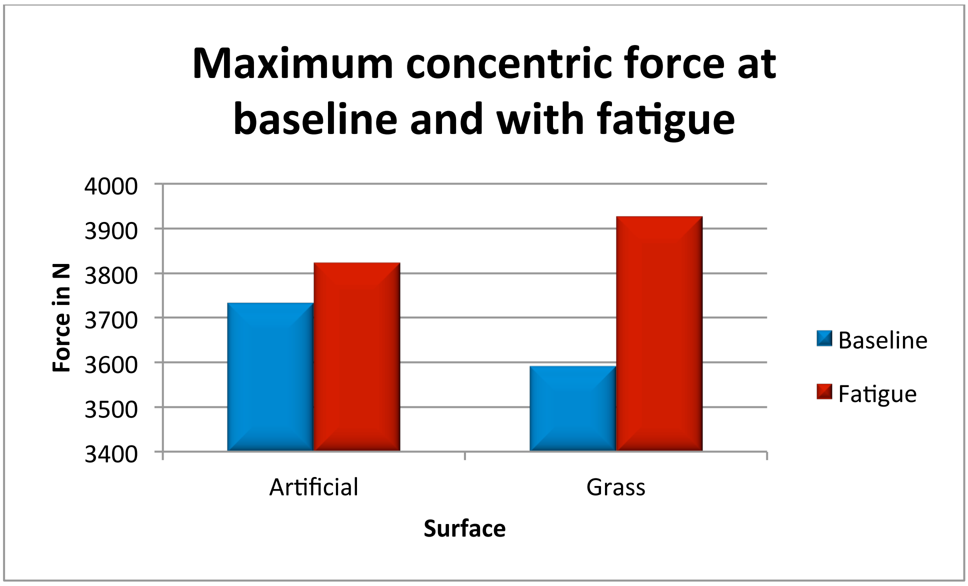


Graph 7. **Landing force rate at baseline and after fatigue (n=20).**



Graph 8. **Maximum eccentric force at baseline and after fatigue (n=20).**

Although the concentric force increased after fatigue on the artificial surface, it was with a much smaller value when relating it to the value obtained with fatigue on the grass surface (-90.35N compared to the increase of -324.75N on the grass surface) (Graph 9; see Tables 5 and 6). Baseline measurements again seemed to differ on the two occasions, but again it was found to be insignificant (p=0.650).



**Graph 9.	Maximum concentric force at baseline and after fatigue (n=20).**

4.4.3 Data analysis: comparison of data from the two different testing occasions

Although the different surfaces yielded different trends in their results post-fatigue as was seen in 4.4.2, statistical comparison of the changes between the two conditions, namely fatiguing on grass and fatiguing on the artificial surface, did not reveal any statistical significant differences between these two conditions (Table 7).

Table 7. Comparison of the changes from baseline to fatigue between the two conditions.

VARIABLE	P-VALUE (Kruskal-Wallis)
Jump height (cm)	0.373
Propulsion force (N)	0.311
Propulsion force rate (N/s)	0.227
Landing force (N)	0.267
Landing force rate (N/s)	0.646
Concentric force (N)	0.372
Eccentric force (N)	0.907

4.5 SUMMARY

No statistical significant differences were found in the change in variables when compared after a fatigue protocol on a grass surface and a fatigue protocol on an artificial surface. Jump height decreased after fatigue on an artificial surface, while it increased after fatigue on the grass surface. Propulsion force and propulsion force rate increased on both occasions after fatigue, but statistically significant after fatigue on the artificial surface. Landing force also increased on both occasions after fatigue, although it was more observed after fatigue on grass. The landing force rate as well as the eccentric force decreased with fatigue on an artificial surface, while it increased with fatigue on the grass surface. Concentric force increased on both occasions after fatigue, but statistically significant after fatigue on the grass surface.

Some differences were however observed at baseline, which must be taken into account with the interpretation of the findings, as will be discussed in the next chapter. Other findings that were observed at baseline included some statistical significant correlations between the propulsion force with the concentric force, body mass, and BMI. The concentric force was also significantly correlated with the body mass and jump height. The same accounted for the landing force and the body mass, as well as for a negative correlation between landing force and eccentric force production.

The discussion on the findings follows in the next chapter, where reasons were sought for the observed trends and significant results, by relating it to existing literature and evidence on the topic.

CHAPTER 5

DISCUSSION

Chapter 1 and 2 introduced the reader to the themes of muscle fatigue, playing surfaces and overuse injury, as well as how biomechanics and exercise intensity may relate to these aspects. It indicated how these concepts were integrated into the development of the aims and objectives of this research.

The aim of this chapter is to provide a discussion of the findings of this study and how it can be integrated into a model of injury prevention and recommendations for exercise intensity and training on different playing surfaces. This is based on current and new evidence and set within a framework of elite sport participation. The discussion will be based on the outline of themes and hypotheses identified in Chapter 1 and 2 and integrate the findings regarding the comparison on the different surfaces and the correlations that were drawn. It also critically reflects on the process that was followed to answer the research question, current literature, raises new questions and problems, and gives an indication of the clinical value of the research.

5.1 INTRINSIC AND EXTRINSIC FACTORS (DEMOGRAPHIC VARIABLES) RELATING TO MUSCLE FATIGUE

A variety of intrinsic and extrinsic factors, as discussed in section 2.1.2, are closely related to fatigue and injury. The study design chosen for this research, however, was of such a nature to limit the effect of within group variables on the chosen outcome, namely force and rate of force generation. A few variables are discussed which are important when considering exercise prescription, conditioning, and injury prevention in a specific population such as elite athletes (see 5.3.2).

Literature has indicated that there is a correlation between increased age and the risk of injury, because of the increased exposure over time in older athletes (Murphy *et al.*, 2003:15). An average age of 24.8 (SD 3.392) years of the participants in our study would therefore not seem to be a risk factor for injury and fatigue in our population, according to the above statement by Murphy *et al.* (2003).

Closely related to ageing, is changes in body composition with increasing age. However, other factors during the season such as diet, exercise and habitual activity also determine body composition (Ostojic, 2003:13). Body mass index (BMI) can be defined as a tool for indicating the weight status in adults. This is a measure which indicates weight for height (Ferrera, 2005:168) and the normal value for males are between 18.5kg/m^2 and 24.9kg/m^2 (Hoffman, 2006:87). The body mass index (BMI) of the participants in this study were an average of 23.8kg/m^2 (SD 1.602) which can therefore be classified as acceptable for a population of elite athletes. The BMI was calculated from their mean body mass (73.18kg) and mean length (175.27cm).

BMI has been associated with increased risk of injury. A review by Murphy *et al.* (2003:19) found inconclusive evidence regarding the association between body size and injury risk in the lower extremity. This was mostly contributed to the heterogeneity in methodology of the different studies included in the review. It seemed however that the majority of the studies did not find an association between risk of injury in the lower limb and body size. Two studies that were included involved a soccer playing population. Only one of these two studies indicated an association between increased heights in male soccer players with an increased risk of injury (Murphy *et al.,* 2003:24). However, the concern regarding body size and fatigue/GRF/injury risk relates to the fact that both increased body size and fatigue leads to a proportional increase in forces that the articular, ligamentous, and muscular system must resist. Overload may lead to failure of the tissue with consequent injury.

Although the BMI gives a better indication of relative body composition and its relation to injury, the body mass itself is important when considering GRF. GRF can be defined as the product of the mass and acceleration due to gravity which interacts with the reaction forces through the surface of contact (Haddas *et al.,* 2015:381). An increased body mass may therefore affect the resultant GRF and therefore alter the impact on the neuro-musculoskeletal system.

An interesting finding by the study of Vaverka *et al.* (2013:195) found a decrease in force of impact at landing as additional load was added to the body weight during the vertical jump, although it was not statistically significant. It could be speculated that the change in the duration of the jump due to the added weight changed the force impulse as well as the reaction forces exhibited by the contact area (Vaverka *et al.,* 2013:197).

Contradicting the above speculation, a positive correlation was found in this study correlating the landing force with the body mass ($p<0.01$ and $p<0.001$). It might therefore be speculated that the BMI of the participants in this study, which were normal, would not be the main reason for poor performance when measuring landing forces and GRF. The reaction of and control provided by the surrounding musculature however, could determine the loading of specific structures proximal in the kinetic chain. Delays in activation of muscles such as the multifidus and gluteus maximus which are important stabilisers have also been associated with lower limb muscle fatigue (Haddas *et al.,* 2015:382). Proper training and conditioning would therefore be of importance in order for the musculature to be able to absorb and dissipate the imposed load efficiently.

Compared to the literature, the one hour of strength training per week in-season which our sample was exposed to was within the norms to maintain strength gains during the pre-season phase (Rønnestad *et al*., 2011:11). A weekly strength training session in-season is also necessary to maintain vertical jump ability which relates to the force generation and absorption of forces of the lower limb, and therefore fatigue (Rønnestad *et al*., 2011:15). Fatigue has been defined as the failure in the ability of the muscle to maintain the required or expected force (Vollestad, 1997:220) (see 2.2.1).

Aerobic fitness is also an important component to optimise muscle behavior and prevent fatigue and injury (Jull *et al*., 2015:69; Murphy *et al*., 2003:19). The participants spent an average of two hours per week on aerobic training. Whether this would be efficient to prevent fatigue as indicated by force generation according to the demands of the sport and surface, are further discussed in 5.2.

The question, however, was if different surfaces would have a significant effect on fatigue of the lower limb, despite training programmes to increase fitness and prevent injuries. Training sessions on grass per week was an average of 6.1 sessions per week, while time spent on grass turf per week was an average of 8.05 hours per week. There was no sessions on artificial turf noted, although some players had a history of previous training on artificial surfaces. This exposure, however, was also quite low (a mean of 0.95 years). In a study done by Steffen *et al*. (2007:34), the players spent far more time on artificial turf than in this particular study, with 45% on grass and 30% on artificial turf. In another study done by Ekstrand *et al*. (2006:9), where the risk of injury between artificial and grass turf were studied, the exposure of soccer players training on artificial turf was much higher (51266 hours) and much lower on grass (18355 hours). This data should also be considered when the findings of these studies are interpreted regarding the prevalence of injury on different training surfaces.

The finding in this study regarding training time on grass surfaces, could imply that the participants` muscles were adapted for reactions and function on a grass surface. Playing on an unfamiliar artificial surface, might therefore have led to increased movement variability trying to adapt to the changing demands which it could place on the muscles and kinetic chain. The mechanical properties of the playing surface also influence the kinematics and kinetics of running. This also leads to changes in metabolic and physiological responses. A different playing surface may also change the nature of the game regarding fatigue levels, sprinting speeds and the time the ball is in play (Williams, 2016:106). The implication would thus be that the performance of the players might be expected to be poorer when tested on the artificial surface.

Different surfaces can demand different kinetics and biomechanics from the kinetic chain (see 2.1.3). If players are therefore not exposed to an artificial surface, it can be speculated that it might have led to inadequate muscle responses and kinetics and, together with induced fatigue, what could be interpreted as poor performance.

The next section will discuss this speculation, focusing on the results of the forces measured during the testing on the force plate before and after training and fatiguing on the two different surfaces.

5.2 MUSCLE FATIGUE ON GRASS AND ARTIFICIAL PLAYING SURFACES

Muscle fatigue is seen as a time-dependent and exercise-induced reduction of the maximal capacity of force which a muscle can produce during exercise (Fabre *et al.*, 2012:2182). Measurement of different aspects of forces and force generation during a vertical jump post-fatigue in this study, however, yielded limited significant differences in and between the changes in these variables when comparing exposure to the different surfaces (see 4.4.3).

However, when looking at the changes that took place with each testing occasion on the different surfaces, some tendencies were noted. Taking into account the training history of this sample, it would be expected that their performance on the grass surface might be superior to their performance after fatigue on an artificial surface due to the effects of muscle adaptation and specificity of training (see 5.1).

This assumption was noted only in the improvement of the concentric force and the jump height which was more after fatigue on the grass surface (see Tables 5 and 6). Jump height after fatigue on the artificial surface, decreased, although there was an increase in the concentric force. The latter finding therefore did not reflect the positive correlation which was found at baseline between the jump height and the concentric force ($p<0.001$). It also suggested that other factors could have an influence when correlating these two variables during a vertical jump. Subtle changes in for example the technique of the squat jump may cause a difference in the shortening and lengthening cycle of the muscles, leading to a different force generation and therefore jump height (Abernethy, 2013:116). Graph 5 and 9 reflected the latter statement by indicating that the baseline measurements of the group differed at the two separate occasions with the measurement of both of these variables, although not statistically significant. This difference was noted despite efforts to control other variables which might limit validity (see 3.7). This finding might therefore have been partially responsible for the observed difference in the changes between the two testing occasions from pre- to post-fatigue.

It was interesting to note that on both occasions the propulsion force improved statistically significantly post-fatigue, although the change in concentric force did not show the same significant findings, as well as the change in the jump height as explained above (see Tables 5 and 6). Other factors than improved muscle contraction might therefore have contributed to the improved propulsion force, such as changes in the force rate. Force rate has been closely related to explosive muscle action (Greco *et al.,* 2013:19). This was depicted by the increase in loading rate which was also observed post-fatigue on both occasions (see Tables 5 and 6). However, these findings differ from the findings of Greco *et al.* (2013:20) who found a significant decrease in rate of force development in the hamstring and quadriceps muscles after a soccer-specific fatigue protocol. Their study, however, measured force variables by means of a Biodex isokinetic dynamometer which implied the measurement of different, isolated muscle action when compared to a functional movement such as the squat jump as measured with a force plate in this study.

Other factors, such as joint range of motion, muscle length and technique of the vertical jump, could be some of the main internal factors to consider which might also have differed on the two occasions (Stutzig & Siebert, 2015:284).

As mentioned in 5.1, muscle force/strength depends on the age of the patient, the type and number of motor units recruited, the initial length of the muscle, and the nature of the neural stimulation of the motor unit. The proportionality of the muscle strength to resting muscle length, must however be differentiated from its proportionality from the length of the fiber itself. Muscle force has been found to be independent of fiber length. It may therefore be speculated that muscle stiffness may not necessarily have had a confounding effect on force production, but rather the length of the muscle which could be affected by slight variability in the technique of the vertical jump (Petty & Moore, 2008:160). It could partially explain why the changes were not to the same extent on both occasions, although it did reflect the positive correlation between the concentric force and propulsion force at baseline ($p<0.001$ and $p<0.01$).

The change in propulsion force rate however tended to be much more post-fatigue after training on the artificial surface. This can be interpreted as the participants being able to generate more force in a shorter period of time after fatigue on the artificial surface.

The rate of force production may however be the consequence of several factors. Firstly, for a given force, muscles with a greater amount of fast-twitch fibers will produce a greater speed of movement when compared to muscles with a larger percentage of slow-twitch muscle fibers (Petty & Moore, 2008:161). Although the speed of contraction was not measured directly, and can be suggested for future research, the rate of loading may reflect to some extent the speed at which the muscle functioned to absorb or produce the load. It may therefore be speculated that a quicker rate of force production might have been associated with contraction of muscles such as the gastrocnemius, which has more fast-twitch type of fibers when compared to the soleus muscle. It must also be considered that muscles with more fast-twitch type of fibers can produce a greater force at a faster speed. It is therefore important to consider the muscles involved with the squat jump to determine the interpretation of the findings. If we refer back to 2.3 where the squat jump was described, it is clear that the muscles and movement involved are mainly the mobiliser muscles with a larger amount of fast-twitch fibers. A slower rate of force production such as with the propulsion force, may therefore indicate inadequate behaviour of these muscles.

A second argument could be raised for the change in the landing force rate after fatigue on the artificial surface when compared to the grass surface. The landing force rate decreased after fatigue on the artificial surface, while it increased after fatigue on the grass surface. This meant that more force needed to be absorbed in one second after fatigue on the grass surface. This could again imply that much more muscle action would be needed to absorb these forces with landing in one second, which could lead to increased loading of the kinetic chain, making it more prone to injury and overload (Haddas *et al.,* 2015:381). The possibility of increased adaptation strategies after fatigue on the artificial surface in this sample, must however also be considered when relating it to their training history on mostly grass surfaces. An increase in joint range of motion as an adaptation strategy would for example result in a decreased loading rate and increased eccentric muscle contraction which would accompany the control of movement in the increased range of motion (Brazen, 2010:286-292).

As mentioned in 2.2.1, the neuro-musculoskeletal system may react in different manners to compensate for loss of muscle force/absorption of muscle force due to fatigue. It has been mentioned that in the presence of fatigue or pain the muscle may redistribute its` activity to an adjacent region. Fatigued muscles respond by recruiting smaller motor neurons and recruiting different muscles, thereby influencing neuronal synaptic transmission, firing rate and frequency, conduction velocity, and sequence of muscle contraction (Dominguese *et al.,* 2012:310). A recent study by Stutzig and Siebert (2105:285) has also indicated by means of EMG assessment of the lower limb muscles that the activity in specifically the synergistic muscles to the fatigued muscle, increase post-fatigue. This attempt to compensate for the fatigued muscle, led to no observed change in the total muscle torque observed post-fatigue. These findings correlate with the limited changes found in our study, as well as for slight increases in muscle force that was observed occasionally post-fatigue (see Tables 5 and 6).

However, in the presence of pain or dysfunction, muscles may not react in this manner and lead to overuse and fatigue of the specific muscle region (Jull *et al*., 2015:172). This may manifest in the form of adaptation strategies such as increased movement variability, re-distributing the forces, or in the form of rigidity, trying to stabilise the joints (Figure 10). Increased movement with landing may be hypothesised to lead to a slower force rate with landing in an attempt to redistribute the forces/allow for increased range of movement (Haddas *et al.,* 2015:381). Taking into account the discussion in the previous paragraph, a slower force rate with landing might result in a decreased eccentric force production protecting the (fatigued) muscle from overload by distributing the force in other musculature. The opposite argument would be raised for landing with a rigid lower limb. According to this discussion, it would seem appropriate to include and optimise movement variability in a training programme to help limit the consequences of muscle fatigue (see 5.4).

Figure 10. Circle of muscle dysfunction and compensation (Comerford *et al.*, 2005:2-7).

The latter speculation could also have been reflected in the increased eccentric forces that were generated with landing after fatigue on the grass surface. The eccentric forces decreased after fatigue on the artificial surface, possibly indicating less need for force absorption or re-distribution of forces due to fatigue (see Table 6). This reasoning is based on the statement by Voloshin *et al*. (1998:518-520) that eccentric muscle force is mainly responsible for shock attenuation. The opposite reasoning must however also be considered, namely that the fatigue could have resulted in less eccentric force production and therefore less ability to act as global stabilisers more cephalad post-fatigue, thereby increasing risk for injury on the passive structures (James *et al*., 2010:671-674).

It must be noted, that the same tendency that was observed regarding differences in baseline measurements for jump height and concentric force measurement, was also observed regarding the baseline data for landing force, landing force rate, and eccentric force measurement with the comparison of the different exposures in this study. These differences were however not statistically significant (see 4.4.2).

The change in landing force rate and eccentric force production after fatigue on the artificial surface may also be reflected in the change in landing force that was observed. The general increase in landing force that was found post-fatigue is similar to the findings of other studies such as by Haddas *et al. (*2015:381) who investigated lower limb fatigue by means of a drop vertical-jump landing in patients with low back pain. Although the landing force increased on both occasions post-fatigue in our study, the change was much less after fatigue on the artificial surface (18N versus the change of 138N after fatigue on the grass surface). This could imply that participants would generate less GRF after fatigue on an artificial surface and therefore needed less muscle response to absorb these forces, decreasing the risk for injury and overload. However, the study by Kellis referred to in 2.2.3, found that individuals with fatigued knee extensors landed with lower vertical ground reaction force (GRFs) and a higher knee flexion angle which could also explain the concomitant decrease in loading rate and eccentric force production in the current study.

The correlation that was calculated between landing force and eccentric force production at baseline however, indicated a statistically significant negative correlation between these two variables ($p<0.01$ and $p<0.001$). The same accounted for the correlation between the landing force rate and eccentric force production on one occasion ($p<0.001$). This could emphasise the adaptation and variability in muscle responses that is speculated to be present during muscle fatigue, namely that increased loading with landing may lead to failure of muscle response and therefore redistribution of muscle activity/adaptation strategies.

Another interesting factor to consider with interpretation of the correlation between force rate and maximum concentric or eccentric force generation, is the fact that increased speed of eccentric contraction, such as with a landing, may lead to an increased force generation. The opposite is true for concentric contraction, such as with propulsion, where an increased speed of contraction may lead to a reduction in force generation (Petty & Moore, 2008:161). We could thus expect lower concentric forces with an increased force rate with propulsion, while higher eccentric forces would be expected with increased landing force rates according to this theory.

However, correlations done on baseline data yielded a contrary statistical significant finding when correlating landing force rate with the maximum eccentric force production on one occasion (Table 3). There was a negative correlation ($r=-0.762$, $p<0.001$) indicating that an increased force rate was associated with a decreased maximum eccentric force. Other explanations, as stated above, therefore had to be considered to explain the difference in associations.

In summary: although the tendencies leaned towards less force that needed to be absorbed after fatigue on the artificial surface, and therefore less demands on the eccentric muscle force generation, no significant differences were found for the changes that occurred comparing the two exposures. Intrinsic factors due to slight variations in technique and differences at baseline could have contributed to these findings.

The limited differences in change regarding the landing force in this study, also correlates with the limited findings of Fabre *et al*. (2012:2188) who investigated the effect of different playing surfaces on neuromuscular fatigue in tennis players (see 2.1.3). However, differences in internal and external factors contributing to the studies` findings must be considered. Tennis players use different foot wear and have different sport-specific muscle activation patterns and training programmes. Different measuring instruments were also used namely, EMG versus the force plate which was used in the current study.

The tendency of increased landing forces (GRF) that was found after fatigue on both surfaces in this study, concurs with the findings of studies such as done by James *et al*. (2010:672-676). Similar to the findings in this study, they also found an increase in landing forces, but at the same time a decrease in the landing force rate (see 2.2.1). They also found different responses in the GRF when measured after two different fatigue protocols. This concurs with the opinion of the researcher and other authors (Vollestad, 1988) that differences in neuro-musculoskeletal adaptation strategies may be a reason for discrepancies in responses and therefore limited significant findings.

Dominguese *et al.* (2012:310) attributed the significant increased landing forces they observed in their study after a fatigue protocol, to increased landing stiffness. The increased landing stiffness was a result of decreased trunk and knee flexion which was an effort by the neuro-musculoskeletal system to allow for landing even when the fatigued muscles were not able to produce or withstand the imposed demand of the landing.

Relating the landing forces to specific surfaces and injury potential, the tendencies found in this study regarding less landing forces and eccentric force generation on an artificial surface, could relate to the findings of a meta-analysis done by Williams *et al.* (2013). The analysis was done on eight different studies involving soccer players playing on artificial versus grass turf, regarding prevalence of injury. It was suggested that there is a lower risk of injury on artificial surfaces (Williams *et al.,* 2013:4-5). These findings however, contradicts the findings by numerous previous studies (Brukner, 2012:127; Orchard *et al.,* 2005:424; Olsen *et al.,* 2003:449) which found increased injury rates in soccer players on artificial surfaces, speculated to be mainly due to the higher friction and stiffness of artificial surfaces (see 2.1.3). The discrepancies in findings may be an indication that it might not be the surface itself being responsible for the adverse effects, but that the neuro-muscular response to training/playing on different surfaces should rather be the focus of analysis to detect dysfunction and causes of injury.

5.3 LIMITATIONS

The question remains whether the lack of consensus and limited results found in research regarding training on different surfaces, are due to confounding factors influencing the results or due to insufficient quality of evidence. These two aspects are however interrelated. The choice of study design in this study contributed to the limitation of some methodological errors regarding between group differences (see 3.2 and 3.7). However, methodological limitations were still identified throughout the research process and must be considered in order to draw valid conclusions and make recommendations.

5.3.1 Limitations regarding the study sample and population

Reflecting upon the whole research process, a critical discussion of the sample follows first. The inclusion of only one group exposed to two different conditions, may have yielded strengths as well as limitations. It helped to ensure similarity at baseline regarding the demographic variables limiting the problem of between group differences and selection bias. On the other hand could the testing effect have had an influence on the outcomes, although the cross-over design should account for such confounding factors (Leedy & Ormrod, 2010:244).

The advantage of using the cross-over design was partially to help overcome the problem with the small population size. The group size (and population) were limited to approximately 20 to 25 participants due to the inclusion of only elite soccer players in a restricted area. The small sample size was therefore not caused by poor recruitment rates, but rather due to the eligibility criteria. Despite the reason for the small sample size, it must be considered how it may affect the generalisability of the results. Although the sample size fell within the suggested power calculations of previous studies (Greco *et al.,* 2013:19; Dominguese *et al.,* 2012:307) and also correlated with the sample sizes of similar previous research, larger samples may yield more statistical and clinical significant results and provide for the loss to follow-up.

Participants were lost for similar reasons across the two testing conditions and the missing data regarding physical assessments were balanced in numbers across the testing under the two conditions. It can be noted that there was only a deviation of three participants between the two testing occasions. ITT helped to address the relative small sample size and the lost to follow-up testing on the other surface. Missing data was handled with an intention-to-treat analysis (ITT) to lower the risk of bias. ITT reflects the practical and clinical scenario, preserves the sample size, and limits inferences based on ad hoc or arbitrary subgroups of participants in the trial. ITT therefore helps to limit type I errors and allows for the greatest generalisability and external validity (Gupta, 2011:110-111).

5.3.2 Limitations regarding the intervention

Certain decisions were made during the planning of this study to ensure clinical relevance and therefore external validity. Some of these decisions included for example to fatigue and take measurements with the participants` wearing their foot wear in order to get a true reflection of the imposed forces. It was ensured that the foot wear remained the same for measurement on both occasions.

Another example was to design the fatigue protocol not only according to standardised testing, but also to make it sport specific to truely reflect the effect it may have on the lower limb. For this experiment, fatigue was seen as the muscles` failure to maintain the expected force after a fatigue protocol that simulated 90 minutes of playing football. However, it must be acknowledged that these decisions might have lead to some degree of loss of internal validity, due to the addition of factors that may result in different outcomes. The major limitation of a jumping and running protocol is that it introduces variability due to the individual skill that is necessary for performing the tasks. Establishing fatigue criteria is also a challenge regardless of the protocol, and as indicated by literature, it has not been agreed upon. Therefore, in all literature up to now, including this study, observed changes have been attributed to the effects of fatigue. In all studies on fatigue the question whether the protocol effectively introduced fatigue therefore remains open for interpretation, due to many other factors that may also affect performance (Dominguese *et al.,* 2012:310). However, Borotikar *et al.* (2008:90) has reported that fatigue-induced modifications in lower limb kinematics are already evident at 50% of the fatigue level (see 2.2.2), adding to the validity of observations during studies investigating fatigue.

Internal validity during the intervention of this study was however accounted for by controlling factors such as the environment (temperature and time of day), the effect of nutrition and sleep deprivation, correct technique of executing the vertical jump and fatigue protocol, ensuring fatigue, blinding of the field workers and participants (the latter regarding expected outcomes), randomisation of the participants to the first exposure, ensuring recovery between the different test occasions on the different surfaces while limiting maturation, and executing the same warm-up procedure (see 3.6.3). Historical factors, such as asymptomatic illness or psychological factors that could have affected the participant between the different occasions, must however not be neglected (Maree, 2013:151-152).

5.3.3 Limitations regarding the measuring instruments

Further efforts were made with the measuring procedures to increase internal validity and reliability (see 3.7). The assessors were blind as to which condition the participant was exposed to while the participants received proper training on each occasion as to the correct execution of the vertical jump. These efforts together with the use of the same instrument, field workers and assessor for every measurement, limited the possibility of instrumentation affecting reliability (Maree, 2013:152).

It must however be considered that subtle, involuntary differences might have existed with the execution of the vertical jump on the different occasions. Although participants were requested to repeat a measurement if a poor technique was observed, this possibility cannot be ignored due to the sensitivity in the measurement by the force plate. Authors have also reported instances where participants (on that occasion physiotherapists), despite proper instruction and training, were still unable to execute a correct exercise (Bo, 2004:454).

Effects such as the Hawthorne effect, sensitisation to the experimental conditions, or the demand effect should be considered here (Maree, 2013:152). Presence of these effects may lead to change in the behaviour of the participants which could again affect their motor response (Jull *et al.,* 2015:466). Attempts to address this limitation was however made by introducing counterbalancing into the study design (Hicks, 1999:78).

It would therefore be a suggestion to include a variety of measuring instruments which would be able to detect different aspects of fatigue which would require different responses from the participant. Examples could include EMG measurement and measurement of endurance (Jull *et al*., 2015:300). A limitation of measuring the muscle force production with the force plate, is that the observed change is not muscle specific. As suggested by Padulo *et al*. (2013:520), eccentric force production was associated with the landing phase of the lower limb in this study. This problem of non-specificity can however be overcome by adding EMG measurement of specific muscles to the outcome measures. These suggestions together with an increased sample size may yield higher quality results.

5.4 RECOMMENDATIONS: A PROPOSED MODEL FOR TRAINING ON DIFFERENT PLAYING SURFACES FOR ELITE SOCCER PLAYERS – INTEGRATING THE EVIDENCE

Other than some methodological suggestions that have emanated from the limitations in 5.3, recommendations can also be made for implementation. These recommendations must however be considered in the context of the tendencies and statistical significant findings from this study, but also in the context of the limitations outlined in 5.3.

Based on the findings of this study, it seemed as if training on artificial surfaces may have some beneficial effects reducing landing forces and force rates, and therefore the amount of eccentric muscle force needed to absorb these forces. The outcome of such effects might be a reduction in overload and therefore injury prevention. However, the findings did pose certain limitations (see 5.2 and 5.3) which should make interpretation and recommendations cautious.

Based on the correlations drawn in this study, the findings on the muscle force responses to fatigue, and the literature on the musculature involved with vertical jumps, certain recommendations could be made.

Firstly, although some training surfaces may pose beneficial effects regarding loading and force generation when fatigued, the principles of specificity and overload must be considered. Muscles adapt to the environment they are exposed to and the demands placed on them. Different surfaces may place different demands on the kinetic chain and the movement variability required by the motor control system. Taking this into account, it would be beneficial to train on the surface which will be mostly used for match playing. During a match the demands placed on the muscles and performance required is much higher than during training (Taylor *et al.,* 2012:4). Therefore the need for match-specific (surface) training and the consequent prevention of injuries (Jull *et al*., 2015:69-70). It also seems from the findings of this study that if playing on a grass surface, more emphasis should be placed on eccentric muscle control in order to absorb a possible increased load during landing. However, such decisions must be made in the context of a full neuro-muscular assessment of the player, due to technique and range of motion, amongst other factors, that could also affect the muscle response (Taylor *et al.* 2012:5).

The latter would therefore imply a second suggestion of muscle-specific training. Looking at the muscles involved during a vertical jump and landing specifically (which has also been related to functional movements in soccer), emphasis should be placed on the conditioning of these specific muscles (see 2.3.1) and also on endurance. The aim would be to prevent fatigue and overload during landing in order to absorb the GRF sufficiently. From the findings of the current study, it could imply emphasis on concentric training of the lower limb when training on artificial surfaces, due to poorer performance which was observed when compared to concentric contraction after training on the grass surface. According to available evidence and the finding of an increased landing force with a concomittant decreased eccentric force production in this study, it could imply poor performance of eccentric muscle function post-fatigue on the artificial surface, or indicate a redistribution of muscle activity for adaptation. However, the importance of eccentric muscle force for shock attenuation and global stability must be the main considerations for inclusion in a training programme (see 2.2.1). The question whether it would be more important for a specific surface, remains to be answered. Therefore it could be suggested at this stage, that training be on the specific surface demanded by the sport/competition, in order for muscle specific adaptations to take place (Jull *et al.,* 2015:69-70).

Thirdly, the conditioning should also emphasise movement variability and strengthening of the whole kinetic chain in order to absorb and redistribute the imposed forces and lack of force generation due to fatigue. This would involve motor control training, sufficient joint range of motion, muscle length, and proprioception in addition to the above suggestions of strengthening and endurance training (Haddas *et al.,* 2015). It could be speculated to be more important when training on grass surfaces in order to be able to absorb the increased GRF sufficiently (as found in this study), or to account for the increased movement which is usually associated with softer surfaces. It can also be suggested that these exercise components be investigated in follow-up studies to determine their association with fatigue responses on different surfaces.

The associations that were established on baseline variables in this study, could also implicate some suggestions for training programmes. Significant positive correlations could suggest the use of propulsion activities in a training programme to improve concentric force production and jump height, together with a well-executed technique (see 4.3.2). A decreased body mass may lead to a decreased landing force and an increased eccentric force production. This also suggest that factors such as nutrition, amongst others, may indirectly play an important role in effective training.

Factors such as BMI, technique, and foot wear could also affect the response to landing and force absorption and should be appropriately addressed (Hardin, 2004:838; Beutler, 2009:666). This suggestion also implies the interdisciplinary and holistic approach that should be part of elite sport participation (Brukner, 2012:8; Körner, 2010:745-755).

Lastly, other than the physical components, but also part of the holistic approach, training should include player education and assessment of their belief system, perceptions and attitudes regarding training on different surfaces. Recent literature has found professional soccer players to perceive artificial turf as posing a higher risk to overuse injury, although evidence seems to be controversial regarding these findings. It was however found that these players had a history of injury on these surfaces, possibly affecting their perceptions (Poulos *et al.,* 2014:4). The concern is that the belief system and cognitive behaviour can influence the motor control system adversely, thereby increasing the risk to injury (Jull *et al.,* 2015:466).

In summary, the recommendation would be to implement surface-specific training with the training of movement variability and stability to accommodate any imposed demands on the neuro-musculoskeletal system. This should be implemented with consideration of other factors that could also affect fatigue and injury risk, such as nutrition, foot wear, skill and player education.

Future research should include bigger populations of elite soccer players. Maybe differences in gender could also be looked at. The difference in results between African based players and European based players that are exposed to artificial surfaces on a regular basis can also be considered.

5.5 CONCLUSION

This chapter was an interpretation and integration of the findings outlined in Chapter 4. Considering the findings, literature, strengths and limitations of the study, a model for training on grass and artificial surfaces for elite soccer players were suggested and recommendations made for further research.

The next chapter (Chapter 6) summarises this discussion and research process in the contextual framework of elite sport participation as outlined in Chapter 1.

CHAPTER 6

CONCLUSION

Literature has indicated that different play surfaces may have an effect on injury potential. It has also been indicated that muscle fatigue may contribute to the sustaining of injuries. The biomechanical and neuro-musculoskeletal reasons underlying these phenomena remain unclear.

This study therefore investigated the effect of muscle fatigue on artificial and grass playing surfaces by determining the changes in muscle and impact forces on the lower limb. It was done on a population of elite soccer players who, due to the demands placed on their neuro-musculoskeletal system by their training programmes, may be especially prone to overuse injuries.

The players were exposed to a sport-specific fatigue protocol on two different surfaces, on two different occasions. Significant attempts were made to control internal and external confounding factors which could affect the outcome of the results.

It seemed as if the fatigue protocol on the artificial surface led to less increase in landing forces and force rates, as well as less maximum eccentric forces produced by the muscles when compared to the fatigue protocol on the grass surface. These findings were however not statistically significant, although they could have a clinical implication for training. Fatigue on both surfaces however, led to a statistical significant increase in the propulsion force, concentric force as well as propulsion force rates on the different surfaces.

The tendencies that were shown by the results were further explored by calculating correlations between different variables from the baseline measurements. The findings indicated some statistical significant correlations which were integrated into the discussion on the comparison of the effect of the two different surfaces on the force production. Significant positive correlations were found specifically regarding jump height, concentric and propulsion forces, as well as with BMI and body mass.

Based on the findings of this study and previous literature, recommendations were made regarding training on different surfaces in order to ensure surface-specific muscle adaptation and therefore possible prevention of injuries. These recommendations were accompanied by suggestions of using specific muscle force components, derived from the findings of the correlations, to achieve the outcome of the proposed training. The importance of an interdisciplinary approach towards training programmes was also emphasised by the findings of this study.

The proposed model for training however, provides an opportunity for further investigation, based on the limitations identified by this and other studies. Components such as joint range of motion, muscle length, motor control, movement variability and proprioception amongst others, should be investigated to determine their role in force production and muscle training on different surfaces. The different and patient-specific responses/adaptation of the neuro-musculoskeletal system to fatigue, however, makes this a challenging topic to investigate.

The latter statement is substantiated by comparing the findings to those of similar previous studies. There seems to be contradicting results and findings depending on population size, gender, age and level of participation, as well as other intrinsic/extrinsic confounding factors, when determining the effects of fatigue on different playing surfaces. Recent literature and the findings of this study therefore raises the question as to the true causes of previously reported increased risk of injury on artificial surfaces, as well as the interpretation of increased GRFs which had been found in response to fatigue on artificial surfaces. The exposure of players, for example, to a specific surface might also influence the outcome of the study results. There is a lack of studies being done on elite professional soccer players, fatigue, and different playing surfaces, and together with the controversy in results on this specific topic, it emphasises the need for further investigation.

REFERENCES

Abernethy, B., 2013. Biophysical foundations of human movement. Human Kinetics.

Arnason, A., Sigurdsson, S.B., Gudmundsson, A., Holme, I., Engebretsen, L. and Bahr, R., 2004. Risk factors for injuries in football. *The American journal of sports medicine*, *32*(1 suppl), pp.5S-16S.

Bahr, R. and Krosshaug, T., 2005. Understanding injury mechanisms: a key component of preventing injuries in sport. British Journal of Sports Medicine, 39(6), pp.324-329.

Bangsbo, J., 1994. Physiological demands. In: Handbook of Sports Medicine and Science Football (soccer). Blackwell Publishing Ltd. p. 43-58.

Beynnon, B.D., Renström, P.A., Alosa, D.M., Baumhauer, J.F. and Vacek, P.M., 2001. Ankle ligament injury risk factors: a prospective study of college athletes. Journal of Orthopaedic Research, 19(2), pp.213-220.

Bisiaux, M. and Moretto, P., 2008. The effects of fatigue on plantar pressure distribution in walking. Gait and Posture, 28, pp.693–8.

Bobbert, M.F. and Casius, L.J., 2005. Is the effect of a countermovement on jump height due to active state development?. Medicine and Science in Sports and Exercise, 37(3), pp.440-446.

Bobbert, M.F. and Schamhardt, H.C., 1990. Accuracy of determining the point of force application with piezoelectric force plates. Journal of

Biomechanics, 23(7), pp.705-710.

Borotikar, B.S., Newcomer, R., Koppes, R. and McLean, S.G., 2008. Combined effects of fatigue and decision making on female lower limb landing postures: central and peripheral contributions to ACL injury risk. Clinical Biomechanics, 23(1), pp.81-92.

Brazen, D.M., Todd, M.K., Ambegaonkar, J.P., Wunderlich, R. and Peterson, C., 2010. The effect of fatigue on landing biomechanics in single-leg drop landings. Clinical Journal of Sport Medicine, 20(4), pp.286-292.

Brukner, P., 2012. Brukner & Khan's Clinical Sports Medicine. North Ryde: McGraw-Hill.

Chappell, J.D., Herman, D.C., Knight, B.S., Kirkendall, D.T., Garrett, W.E. and Yu, B., 2005. Effect of fatigue on knee kinetics and kinematics in stop-jump tasks. The American Journal of Sports Medicine, 33(7), pp.1022-1029.

Coventry, E., O'Connor, K.M., Hart, B.A., Earl, J.E. and Ebersole, K.T., 2006. The effect of lower extremity fatigue on shock attenuation during single-leg landing. Clinical Biomechanics, 21(10), pp.1090-1097.

Cross, R., 1999. Standing, walking, running, and jumping on a force plate. American Journal of Physics, 67(4), pp.304-309.

Daneshjoo, A., Osman, N.A.A., Sahebozamani, M. and Yusof, A., 2015. Analysis of jumping-landing manoeuvers after different speed performances in soccer players. PloS One, 10(11), p.e0143323.

Dominguese, D.J., Seegmiller, J. and Krause, B.A., 2012. Alterations in peak ground-reaction force during 60cm drop landings caused by a single session of repeated wingate anaerobic tests. Journal of Sport Rehabilitation, 21, pp.306-312.

Dragoo, J.L., Braun, H.J. and Harris, A.H., 2013. The effect of playing surface on the incidence of ACL injuries in National Collegiate Athletic Association American Football. The Knee, 20(3), pp.191-195.

Engström, B., Johansson, C. and Tornkvist, H., 1991. Soccer injuries among elite female players. The American Journal of Sports Medicine, 19(4), pp.372-375.

Ekblom, B., 1986. Applied physiology of soccer. Sports Medicine, 3(1), pp.50-60.

Ekstrand, J., Hägglund, M. and Fuller, C.W., 2011. Comparison of injuries sustained on artificial turf and grass by male and female elite football players. Scandinavian Journal of Medicine and Science in Sports, 21(6), pp.824-832.

Ekstrand, J Gillquist - Med Sci Sports Exerc, 1983 - udel.edu

Enoka, R.M., 2008. Neuromechanics of human movement. Human Kinetics.

Eriksson, L.I., Jorfeldt, L. and Ekstrand, J., 1986. Overuse and distorsion soccer injuries related to the player's estimated maximal aerobic work capacity. International Journal of Sports Medicine, 7(4), pp.214-216.

Fabre, J-B., Martin, V, Gondin, J., Cottin, F., and Grelot., L., 2012. Effect of playing surface properties on neuromuscular fatigue in tennis. Medicine and Science in Sport and Exercise, pp.2182-2189.

Gerlach, K.E., White, S.C., Burton, H.W., Dorn, J.M., Leddy, J.J., Horvath, P.J., 2005. Changes with fatigue and relationship to injury in female runners. Medicine and Science in Sports and Exercise, 37(4), pp.657-663.

Giza, E., Fuller, C., Junge, A. and Dvorak, J., 2003. Mechanisms of foot and ankle injuries in soccer. The American Journal of Sports Medicine, 31(4), pp.550-554.

Greco, C.C., Silva, W.L., Camarda, S.R. and Denadai, B.S., 2013. Fatigue and rapid hamstring/quadriceps force capacity in professional soccer players. Clinical Physiology and Functional Imaging, 33(1), pp.18-23.

Haddas, R., James, R. and Hooper, T.L., 2015. Lower extremity fatigue, sex, and landing performance in a population with recurrent low back pain. Journal of Athletic Training, 50(4), pp.378-384.

Inklaar, H., 1994. Soccer injuries. Sports Medicine, 18(1), pp.55-73.

James, C.R., Scheuermann, B.W. and Smith, M.P., 2010. Effects of two neuromuscular fatigue protocols on landing performance. Journal of Electromyography and Kinesiology, 20(4), pp.667-675.

Kellis, E. and Kouvelioti, V., 2009. Agonist versus antagonist muscle fatigue effects on thigh muscle activity and vertical ground reaction during drop landing. Journal of Electromyography and Kinesiology, 19(1), pp.55-64.

Kernozek, T.W., Torry, M.R. and Iwasaki, M., 2008. Gender differences in lower extremity landing mechanics caused by neuromuscular fatigue. The American Journal of Sports Medicine, 36(3), pp.554-565.

Kibele, A., 1998. Possibilities and limitations in the biomechanical analysis of countermovement jumps: A methodological study. Journal of Applied Biomechanics, 14, pp.105-117.

Koga, H., Muneta, T., Bahr, R., Engebretsen, L. and Krosshaug, T., 2015. Video Analysis of ACL injury mechanisms using a model-based image-matching technique. In: Sports Injuries and Prevention. Springer: Japan, pp. 109-120.

Kopper, B., Csende, Z., Sáfár, S., Hortobágyi, T. and Tihanyi, J., 2013. Muscle activation history at different vertical jumps and its influence on vertical velocity. Journal of Electromyography and Kinesiology, 23(1), pp.132-139.

Körner, M., 2010. Interprofessional teamwork in medical rehabilitation: a comparison of multidisciplinary and interdisciplinary team approach. Clinical rehabilitation, 24(8), pp.745-755.

Kristenson, K., Bjørneboe, J., Waldén, M., Andersen, T.E., Ekstrand, J. and Hägglund, M., 2013. The Nordic Football Injury Audit: higher injury rates for professional football clubs with third-generation artificial turf at their home venue. British Journal of Sports Medicine, 47(12), pp.775-781.

Lawrence, D.W., Comper, P. and Hutchison, M.G., 2016. Influence of extrinsic risk factors on National Football League injury rates. The Orthopaedic Journal of Sports Medicine, 4(3), pp.1-9.

Linthorne, N.P., 2001. Analysis of standing vertical jumps using a force platform. American Journal of Physics, 69(11), pp.1198-1204.

Markovic, S., Mirkov, D.M., Nedeljkovic, A., and Jaric, S., 2014. Body size and countermovement depth confound relationship between muscle power output and jumping performance. Human Movement Science, 33, pp.203-210.

Martin, J., 2012. The Best of Soccer Journal: An NSCAA Guide to Soccer Coaching Excellence. Meyer and Meyer Sport (UK) Ltd. p.187.

Mazur, K., Moulder, A., McLean, S.P. and Smith, J., 2016. The effects of playing surface on plant leg knee kinematics of men and women collegiate soccer players. International Journal of Exercise Science: Conference Proceedings, 2(8), p.72.

McLean, S.G. and Samorezov, J.E., 2009. Fatigue-induced ACL injury risk stems from a degradation in central control. Medicine and Science in Sports and Exercise, 41(8), pp.1661-1672.

Murphy, D.F., Connolly, D.A.J. and Beynnon, B.D., 2003. Risk factors for lower extremity injury: a review of the literature. British Journal of Sports Medicine, 37(1), pp.13-29.

Myklebust, G. and Steffen, K., 2015. Anterior cruciate ligament injuries: prevention strategies. In: Sports Injuries. Springer: Berlin Heidelberg, pp. 1357-1367.

Neal, R.J. and Sydney-Smith, M., 1992. The effects of footfall pattern and passing height on ground reaction forces in netball. Australian Journal of Science and Medicine in Sport, 24, p.73

Nyland, J.A., Shapiro, R., Stine, R.L., Horn, T.S. and Ireland, M.L., 1994. Relationship of fatigued run and rapid stop to ground reaction forces, lower extremity kinematics, and muscle activation. Journal of Orthopaedic and Sports Physical Therapy, 20(3), pp.132-137.

O'Keeffe, S.A., Hogan, B.A., Eustace, S.J. and Kavanagh, E.C., 2009. Overuse injuries of the knee. Magnetic Resonance Imaging Clinics of North America, 17(4), pp.725-739.

Olsen, O.E., Myklebust, G., Engebretsen, L., Holme, I. and Bahr, R., 2005. Exercises to prevent lower limb injuries in youth sports: cluster randomised controlled trial. British Medical Journal, 330(7489), p.449.

Orchard, J., 2002. Is there a relationship between ground and climatic conditions and injuries in football?. Sports Medicine, 32(7), pp.419-432.

Padulo, J., Tiloca, A., Powell, D., Granatelli, G., Bianco, A. and Paoli, A., 2013. EMG amplitude of the biceps femoris during jumping compared to landing movements. Springerplus, 2(1), p.520.

Poulos, C.C.N., Galucci, J., Gage, W.H., Baker, J., Buitrago, S. & Macpherson, A.K., 2014. The perceptions of professional soccer players on the risk of injury from competition and training on natural grass and 3rd generation artificial turf. Sports Science, Medicine and Rehabilitation, 6(11):4.

Prapavessis, H., and McNair, P. J., 1999. Effects of instruction in jumping technique and experience jumping on ground reaction forces. The Journal of Orthopaedic and Sports Physical Therapy, 29(6), pp352–356.

Rahnama, N., Lees, A. and Reilly, T., 2006. Electromyography of selected lower-limb muscles fatigued by exercise at the intensity of soccer match-play. Journal of Electromyography and Kinesiology, 16(3), pp.257-263.

Robertson, G., Caldwell, G., Hamill, J., Kamen, G. and Whittlesey, S., 2013. Research methods in biomechanics, 2E. Human Kinetics. p.86.

Rogan, S., Radlinger, L., Imhasly, C., Kneubuehler, A. & Hilfiker, R., 2015. Validity study of a jump mat compared to the reference standard force plate. Asian Journal of Sports Medicine, 6(4), pp.e25561.

Sarabon, N., (2011). Development of software for comprehensive analyses of force plate measurements: technical note. Kinesiology, 43(2), pp.204-212.

Seegmiller, J.G. and McCaw, S.T., 2003. Ground reaction forces among gymnasts and recreational athletes in drop landings. Journal of Athletic Training, 38(4), p.311.

Slinde, F., Suber, C., Suber, L., Edwén, C.E. and Svantesson, U., 2008. Test-retest reliability of three different countermovement jumping tests. The Journal of Strength and Conditioning Research, 22(2), pp.640-644.

Schmitz, R.J., Cone, J.C., Copple, T.J., Henson, R.A., Shultz, S.J., 2014. Lower-extremity biomechanics and maintenance of vertical jump height during prolonged intermittent exercise. Journal of Sport Rehabilitation, 23, pp.319-29.

Söderman, K., Alfredson, H., Pietilä, T. and Werner, S., 2001. Risk factors for leg injuries in female soccer players: a prospective investigation during one out-door season. Knee Surgery, Sports Traumatology, Arthroscopy, 9(5), pp.313-321.

Spägele, T., Kistner, A. and Gollhofer, A., 1999. Modelling, simulation and optimisation of a human vertical jump. Journal of biomechanics, 32(5), pp.521-530.

Stølen, T., Chamari, K., Castagna, C. and Wisløff, U., 2005. Physiology of soccer. Sports Medicine, 35(6), pp.501-536.

Stutzig, N. and Siebert, T., 2015. Influence of joint position on synergistic muscle activity after fatigue of a single muscle head. Muscle and Nerve, 51(2), pp.259-267.

Taimela, S., Kujala, U.M. and Osterman, K., 1990. Intrinsic risk factors and athletic injuries. Sports Medicine, 9(4), pp.205-215.

Tamura, A., Akasaka, K., Otsudo, T., Sawada, Y., Okubo, Y., Shiozawa, J., Toda, Y. and Yamada, K., 2016. Fatigue alters landing shock attenuation during a single-leg vertical drop jump. Orthopaedic Journal of Sports Medicine, 4(1), pp.1-7.

Taylor, S.A., Fabricant, P.D., Khair, M.M., Haleem, A.M. and Drakos, M.C., 2012. A review of synthetic playing surfaces, the shoe-surface interface, and lower extremity injuries in athletes. The Physician and Sportsmedicine, 40(4), pp.1-7.

Thorlund, J.B., Michalsik, L.B., Madsen, K., Aagaard, P., 2008. Acute fatigue-induced changes in muscle mechanical properties and neuromuscular activity in elite handball players following a handball match. Scandinavian Journal of Medicine and Science in Sports, 18(4), pp.462–72.

Umberger, B.R., 1998. Mechanics of the Vertical Jump and Two-Joint Muscles: Implications for Training. Strength & Conditioning Journal, 20(5), pp.70-74.

Vøllestad, N.K. and Sejersted, O.M., 1988. Biochemical correlates of fatigue. European journal of applied physiology and occupational physiology, 57(3), pp.336-347.

Vøllestad, N.K., 1997. Measurement of human muscle fatigue. Journal of neuroscience methods, 74(2), pp.219-227.

Voloshin, A.S., Mizrahi, J., Verbitsky, O. and Isakov, E., 1998. Dynamic loading on the human musculoskeletal system—effect of fatigue. Clinical Biomechanics, 13(7), pp.515-520.

Williams, J.H., Akogyrem, E. and Williams, J.R., 2013. A meta-analysis of soccer injuries on artificial turf and natural grass. Journal of Sports Medicine, 2013, pp1-6.

Williams, S., Trewartha, G., Kemp, S.P.T., Michell, R. and Stokes, K.A., 2016. The influence of an artificial playing surface on injury risk and perceptions of muscle soreness in elite Rugby Union. Scandinavian journal of medicine & science in sports, 26(1), pp.101-108.

Wong, P. and Hong, Y., 2005. Soccer injury in the lower extremities. British journal of Sports Medicine, 39(8), pp.473-482.

ADDENDUM 1

Ethics committee letter

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA

UFS·UV
HEALTH SCIENCES
GESONDHEIDSWETENSKAPPE

IRB nr 00006240
REC Reference nr 230408-011
IORG0005187
FWA00012784

22 July 2015

Mr JAT Greyling
Department of Physiotherapy
UFS

Dear Mr JAT Greyling

ECUFS 68/2015
PROJECT TITLE: LOWER LIMB MUSCLE FATIGUE ON GRASS AND ARTIFICIAL TURF PLAYING SURFACES AMONG ELITE SOCCER PLAYERS

1. You are hereby kindly informed that, at the meeting held on 21 July 2015, the Ethics Committee approved the above project after all conditions were met.

2. Any amendment, extension or other modifications to the protocol must be submitted to the Ethics Committee for approval.

3. 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.

4. Kindly use the ECUFS NR as reference in correspondence to the Ethics Committee Secretariat.

5. The Ethics Committee functions in compliance with, but not limited to, the following documents and guidelines: The SA National Health Act. No. 61 of 2003; Ethics in Health Research: Principles, Structures and Processes (2015); SA GCP(2006); Declaration of Helsinki; The Belmont Report; The US Office of Human Research Protections 45 CFR 461 (for non-exempt research with human participants conducted or supported by the US Department of Health and Human Services- (HHS), 21 CFR 50, 21 CFR 56; CIOMS; ICH-GCP-E6 Sections 1-4; The International Conference on Harmonization and Technical Requirements for Registration of Pharmaceuticals for Human Use (ICH Tripartite), Guidelines of the SA Medicines Control Council as well as Laws and Regulations with regard to the Control of Medicines, Constitution of the Ethics Committee of the Faculty of Health Sciences.

Yours faithfully

....
DR SM LE GRANGE
CHAIR: ETHICS COMMITTEE

Ethics Committee
Office of the Dean: Health Sciences
T: +27 (0)51 401 7795/7794 | F: +27 (0)51 444 4359 | E: ethicsfhs@ufs.ac.za
Block D, Dean's Division, Room D104 | P.O. Box/Posbus 339 (Internal Post Box G40) | Bloemfontein 9300 | South Africa
www.ufs.ac.za

ADDENDUM 2

Information document

INFORMATION DOCUMENT

Study title: **Lower limb muscle fatigue on grass and artificial turf playing surfaces among elite soccer players**

Dear Mr……………………………………..

I, Jantho Greyling, a Masters student at the Department of Physiotherapy, is doing research on the effect different soccer play-surfaces have on muscle fatigue. Research is the process to learn the answer to a specific question. In this study the Department want to learn more about the biomechanics of injuries among soccer players.

The study leaders and student are asking you to participate in a research study that involves 30 soccer players affiliated with the Bloemfontein Celtic Football Club.

In the study the extent of muscle fatigue after a soccer fatiguing protocol on two separate surfaces will be measured and compared. The two different play-surfaces used are artificial turf and grass. The two measurements sessions will take place in May 2015 (dates to be confirmed) one week apart.

The magnitude of muscle fatigue will be measured by a device known as a force platform. The force platform is a device, flushed with the ground, which measures the force produced during a vertical jump. From that information we can calculate the height achieved during the jump.

This procedure will take more or less an hour of your time and we will have two sessions one week apart.

The measurement procedure is pain free and non-invasive and will have no effect on your sporting performance. If any further advice or help is needed you may contact the student on the contact information supplied.

As lack of sleep and kilojoule 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 become ill during the two days measurement is taking 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 our research records for quality assurance and data analysis include groups such as the Ethics Committee of the Faculty of Health Sciences, UFS.

Contact details of researcher(s)

Jantho Greyling
0827732466
janthogreyling@outlook.com

For reporting of complaints or problems, please contact the Secretariat of the Ethics Committee of the Faculty Health Sciences at UFS at 410 2.

ADDENDUM 3

Permission letter

Siwelele Park, 40 Ryk Tulbach Street,
Bayswater, Bloemfontein, 9301

Tel. 051 433 1387 - Fax. 051 433 1658

Email: info@celticfc.co.za

Web: www.bloemfonteincelticfc.co.za

02 July 2015

University of Free State
Health Studies
Bloemfontein

To whom it may concern

We hereby confirm and endorse Johannes Greyling for his studies in Master's degree to do some testing on our players regarding the effect of artificial turf and grass turf on muscle fatigue on the lower limbs

We also confirm that our facilities has the artificial grass as well as the rye grass for testing

Feel free to contact us for any other enquiries

Hope you find this in order

Yours in Sports

Khumbulani Konco
CEO
BFN Celtic
0827740339

ADDENDUM 4

Written consent form

CONSENT TO PARTICIPATE IN RESEARCH

Project Title: **Lower limb muscle fatigue on grass and artificial turf playing surfaces among elite soccer players**

You have been asked to participate in a research study.

You have been informed about the study by Mr Jantho Greyling and Bloemfontein Celtic Football Club.

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

You may contact Jantho Greyling at 0827732466 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)

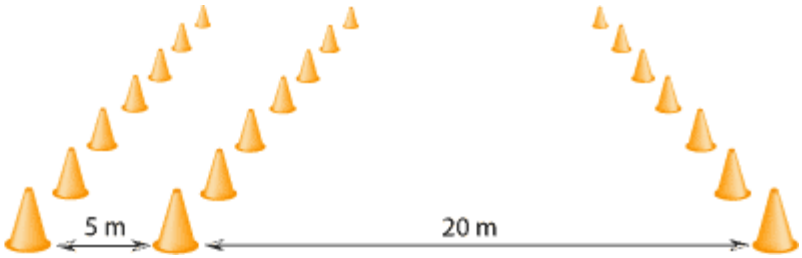
ADDENDUM 5

Fatigue protocol

Yo-Yo Intermittent Test

The Yo-Yo Intermittent Tests are similar to the Yo-Yo Endurance Test (a variation of the beep test), except in the intermittent tests the participants have a short active break (5 and 10 seconds for the *intermittent endurance* and *intermittent recovery* test, respectively). There are two versions of each Yo-Yo Intermittent Test, A Beginners Level 1 and Advanced Level 2 (see details of the speeds and levels for the Yo-Yo Intermittent Recovery Test and Yo-Yo Intermittent Endurance Test). A Yo-Yo test recording can be replicated using the Team BeepTest software.

- **purpose:** The test evaluates an individual's ability to repeatedly perform intervals over a prolonged period of time, particularly for athletes from sports such as tennis, team handball, basketball and soccer or similar sports.



- **equipment required:** Flat, non-slip surface, marking cones, measuring tape, pre-recorded audio cd or mp3 (buy or make your own), cd player, recording sheets.

- **procedure:** Use cones to mark out three lines as per the diagram above; 20m and 2.5 (endurance test) or 5m (recovery test) apart. The subject starts on or behind the middle line, and begins running 20 m when instructed by the cd. This subject turns and returns to the starting point when signaled by the recorded beep. There is an active recovery period (5 and 10 seconds, respectively for the endurance and recovery versions of the test) interjected between every 20m (out and back) shuttle, during which the subject must walk or jog around the other cone and return to the starting point. A warning is given when the subject does not complete a successful out and back shuttle in the allocated time, the subject is removed the next time they do not complete a successful shuttle.

- **variations:** There are two test levels: the Yo-Yo Intermittent Recovery Level 1 (Yo-Yo IR1) test (designed for lesser trained individuals) and the Yo-Yo Intermittent Recovery Level 2 (Yo-Yo IR2) test (aimed at well trained and elite athletes) starting at a faster speed. Both test variations have increasing speeds throughout the test. See the Yo-Yo Intermittent Test Table for more details.

- **scoring:** The athlete's score is the total distance covered before they were unable to keep up with the recording. The Yo-Yo intermittent test usually takes between 6-20 minutes for level 1 and between 2-10 minutes for level 2. For more details see the speeds and distances for the Yo-Yo Intermittent Recovery Test and Yo-Yo Intermittent Endurance Test).

A formula for estimating VO2 max (ml/min/kg) from the Yo-Yo IR2 test result (Bangsbo *et al.,* 2008): *VO2max = IR2 distance in meter x 0.0136 + 45.3*

- **target population:** The yo-yo intermittent test was developed specifically for soccer players, though it is suitable for similar sports teams which are intermittent in nature. The level 1 test is designed for recreational level players, while the level 2 test is for elite soccer players. The test is not suitable for populations in which a maximal exercise test would be contraindicated.

- **reliability:** Test reliability would depend on how strictly the test is run, and the previous practice allowed for the subjects.

- **advantages:** Large groups can perform this test all at once for minimal costs.

- **disadvantages:** Practice and motivation levels can influence the score attained, and the scoring of when a person is out of the test can be subjective. As the test is usually conducted outside, the environmental conditions can also affect the results. The test cd must be purchased.

- **other considerations:** This test is a maximal test, which requires a reasonable level of fitness. It is not recommended for recreational athletes or people with health problems, injuries or low fitness levels. You may not have power where you want to conduct this test. If so, you need to ensure that the batteries of the audio player are fully charged.

- **comments:** This test was developed by the Danish soccer physiologist Jens Bangsbo and his colleagues.

ADDENDUM 6

Data collection form

DATA FORM

			For office use
Name:			
Participant number:			1-2

	MEASUREMENT 1	MEASUREMENT 2	For office use
	GRASS	ARTIFICIAL	
Pre-fatigue vertical jump			
Height 1	cm	cm	3-5
Height 2	cm	cm	6-8
Height 3	cm	cm	9-11
Force with propulsion	N	N	12-14
Force with landing	N	N	15-17
Post-fatigue vertical jump			
Height 1	cm	cm	18-20
Height 2	cm	cm	21-23
Height 3	cm	cm	24-26
Force with propulsion	N	N	27-29
Force with landing	N	N	30-32

Somatotyping		For office use
Biceps	mm	33-34
Triceps	mm	35-36
Subscapularis	mm	37-38
Abdomen	mm	39-40
Thigh	mm	41-42
Calf	mm	43-44

		For office use
Age:	years	45-46
Body mass:	kg	47-49
Length:	cm	50-52
Playing position:		53-54
Amount of sessions on grass per week:	sessions	55-56
Amount of sessions on artificial turf per week:	sessions	57-58
Amount of time playing on grass per week:	hours	59-60
Amount of time playing on turf per week:	hours	61-62
Amount of time spent on aerobic fitness per week:	hours	63-64
Amount of time spent on strength training per week:	hours	65-66
Amount of years playing on artificial turf:	years	67-68
Amount of years playing on grass surfaces:	years	69-70

ADDENDUM 7

Standing vertical jump

The vertical jump most commonly used for testing purposes are the countermovement jump (CMJ) or the squat jump (Padulo *et al*., 2013:520).

Both the CMJ and squat jump requires predominantly hip and knee movement (Sarabon (2011:206).
The jumper first stands upright and stationary for the purposes of the force plate to calibrate. To make sure that the jump is primarily performed by the leg extensor muscles, subjects has to keep their hands in their sides (Kibele,1998:106).

The jump starts in a squat position with hands in the sides. The jumper relaxes the leg and hip muscles, thus allowing the knees and hips to flex under the effect of gravity.

The jump is divided into three phases. The first part of the jump known as the preparatory phase, where there is flexion of the hip and knee and dorsiflexion at the ankle(Umberger,1998:71). The take-off phase of the vertical jump is characterized by hip extension, which is followed directly by knee extension (Umberger,1998:71). The gluteus and hamstring muscle groups produce extension of the thigh. The hamstrings and the biceps femoris muscles counteract the required motion of the shank. There is plantar movement of the foot and this accelerates the body in a vertical direction. This movement is produced by the gastrocnemius muscle and the soleus muscle (Spägele,1998:526). The take-off phase ends when the jumper's toes leaves contact with the ground.

The tibialis anterior muscle counteracts the plantar movement of the foot. The tibialis anterior muscle is not activated in the first part of the jump. During vertical acceleration, extension of the shank is produced by concurrent contraction of the rectus femoris muscle and the vastus muscle group (Spägele,1998:526).

These muscles are uncontrolled during the jumping movement. The biggest amount of load and torque acts in the knee joint at the beginning of the landing phase. At this stage there is intense activation of the rectus femoris and the vastus muscle groups to help with deceleration during landing (Spägele,1998:526).