Developing a prevention strategy for ankle injuries in soccer

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Abstract

The epidemiology and aetiology of ankle injuries in soccer has been widely established. Ankle injuries have been identified as a primary injury concern within soccer, highlighting the need for injury prevention programmes to be implemented in an attempt to reduce their incidence and severity. Injuries are multi-modal in occurrence thus indicating the need for a multi-modal battery of tests to further inform aetiology, whilst also allowing for greater informed rehabilitation and prehabilitation strategies. The purpose of study one was to determine whether relationships existed between aetiological risk factors associated with ankle sprain using a multi-modal battery of tests. In accordance with the multi-variate aetiology, a lack of commonality between task performance outcomes was demonstrated.

Studies two and three, utilising the same analysis parameters, investigated the effects of different brands of kinesiology tape (KT) and time of day effect on the same aetiological risk factors. Study two indicated that both brands of KT had some beneficial improvements in peformance for measures of postural stability and proprioception, whilst study three indicated a lack of time of day effect on task performance outcome measures.

Studies four and five attempted to provide greater ecological validity via assessing the effects of both KT and increased utlisation of interchanges (SAFT^{60}) on locomotive activity and measures of postural stability and mechanical variables in the form of GPS, Force Plate and Qualisys kinematics. Prior research has often failed to investigate the effects of sport specific fatigue on paramters of performance associated with aetiological risk factors. KT demonstrates improvement in both postural stability and locomotive mechanics in the form of GPS and Force Plate variables, compared to that of postural stability only for the SAFT^{60}. However, both the KT and SAFT^{60} intervention strategies failed to offset the effects of fatigue with regards to postural stability, indicating that other mechanisms such as different taping strategies need to be explored.

Study six, amalgamated the findings of the first five studies through designing a new six-week ankle injury prevention programme, which investigated the effects of training two groups of professional soccer players in either a non-fatigued or a fatigued state of performance, with measures of postural stability, GPS, Force Plate and Qualisys measured during the SAFT^{90}, pre and post intervention. Findings indicated that performing the new ankle injury prevention programme helps to improve performance parameters and mechanisms associated with postural stability and functional movement, whilst also highlighting improvements in movement efficiency. However, whether the ankle injury prevention programme was conducted pre or post training had no significant effect on measures of postural stability performance or mechanical responses associated with soccer match play.

The findings of these studies provide a novel insight into the aetiological mechanisms associated with ankle sprain injury in healthy male soccer players, adopting a multi-modal rather than univariate approach. This suggests that tasks used to screen athletes are discrete in nature, thus emphasising the need for a multi-modal battery of tests. Furthermore, they demonstrate that KT and the SAFT^{60} improve measures associated with injury risk. Additionally a new and novel multi-modal training programme over a six-week period can improve measures of postural stability and locomotive mechanics during soccer simulations, thus potentially reducing injury risk in healthy male soccer players.

Key Words: Aetiology, Ankle, Epidemiology, Fatigue, Injury, Kinesiology Tape, Prevention, Soccer, Sprain,

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Contents

List of Tables

List of Figures

Chapter 6: Influence of Therapeutic Tape on Measures of Ankle Function and Performance

Chapter 7: Influence of Therapeutic Tape on Measures of Ankle Function and Performance during Soccer-Specific Fatigue

Chapter 8: The effects of an interchange rule on ankle aetiological risk factors

Chapter 9: Warm Up or Cool Down? The Effect of Timing of an Ankle Injury Prevention Programme in Elite Male Soccer Players

List of Abbreviations, Acronyms and Symbols

A_D	Anterior Reach Direction
AJPS	Ankle Joint Position Sense
AP	Anterior/Posterior Deflection
ATFL	Anterior Talo-Fibular Ligament
BLa	Blood Lactate
BSS	Biodex Stability Systems
CAI	Chronic Ankle Instability
CFL	Calcaneofibular Ligament
CM	Centimetres
CNS	Central Nervous System
CoG	Centre of Gravity
CoM	Centre of Mass
Cool Down	Cool Down
CoP	Centre of Pressure
D	Indicates drop landing task performance indicator
DF	Dorsiflexion
EccH: conQ	Eccentric Hamstrings: Concentric Quadriceps Ratio
EMG	Electromyographic Activity
EMG_{Mean}	Mean Electromyographic Activity
EV.	Eversion
$\dot{F}$	Rate of Force Development
FA	Football Association
FAI	Functional Ankle Instability
FIFA	Federation Internationale de Football Association
F-MARC	FIFA Medical Assessment and Research Centre

Fx	Peak impact force in medio-lateral direction
$\dot{F}x$	Rate of force development medio-lateral
Fxy	Resultant rate of force development
Fy	Peak impact force in anterio-posterior direction
Fy	Rate of force development anterio-posterior
$\dot{F}z$	Rate of force development in vertical direction
Fz	Peak impact force in vertical direction
GLM	General Linear Model
GPS	Global Positioning Service
HR	Heart Rate
I-D	Duration between impact and initiation of drive phase
IE	Invertor: Evertor Ratio
IKD	Isokinetic Dynamometer
IN.	Inversion
JPS	Joint Position Sense
KG	Kilograms
KT	Kinesiology Tape
KT_1	Kinesio Tape
KT_2	RockTape
LG	Lateral Gastrocnemius
ML	Medio/Lateral Direction
NHE	Nordic Hamstring Exercises
NT	No Tape
OSI	Overall Stability Index
PF	Plantar Flexion
PL	Peroneus Longus

PL	Player Load
PL_{AP}	Player Load Anterio-Posterior
$PL_{AP\%}$	Player Load Anterio-Posterior Contribution
PL_D	Posterior Lateral Direction
PL_{ML}	Player Load Medio-Lateral
$PL_{ML\%}$	Player Load Medio-Lateral Percentage Contribution
PL_{Total}	Player Load Total
PL_V	Player Load Vertical
$PL_{V\%}$	Player Load Vertical Contribution
PM_D	Posterior Medial Direction
ROM	Range of Motion
RPE	Rate of Perceived Exertion
RT	RockTape
$SAFT^{60}$	Soccer Aerobic Field Test (Interchange)
$SAFT^{90}$	Soccer Aerobic Field Test
SEBT	Star Excursion Balance Test
$SEBT_T$	SEBT Total Distance
T	Time to complete task
t_{00-105}	Time point during $SAFT^{90}$/$SAFT^{60}$
TA	Tibialis Anterior
T_e	Evertor Peak Torque
T_i	Invertor Peak Torque
UEFA	Union of European Football Associations
VGRF	Vertical Ground Reaction Force
WU	Warm Up
θ	Angle of take off

θ_{15} 15 degrees of inversion

θ_{M} Maximal active inversion minus 5 degree

Chapter 1: Introduction

1.1 Overview

Soccer is the most popular sport throughout the world, with over 200,000 professional and 240 million amateur players (Junge and Dvorak, 2004). Injuries and a relatively high injury rate are a recognised problem within soccer (Aoki et al., 2012; Ekstrand et al., 1983; Ekstrand et al., 2011; Hawkins and Fuller, 1999; Woods et al., 2003), especially when compared to other industrial occupations which have been classified as high risk activity, with soccer players demonstrating an injury exposure of approximately 1000 times greater risk of an injury occurring (Hawkins and Fuller, 1999).

Injuries sustained by soccer players have a financial impact upon their club, with monetary losses seen in medical fees and increased insurance premiums (Gallo et al., 2006). Financial losses are also experienced by clubs of injured players (McCall et al., 2014), as they may not be able to present their best team, thus potentially reducing their income from lower gate attendances and a decrease in prize money as a result of their final league standings (Eirale et al., 2013; Hagglund et al., 2013). Perhaps more pertinent than financial losses is the health of the injured individuals, as injuries sustained through participating in training and match play can result in long standing health consequences (Faude et al., 2005), with 47% of professional soccer players forced to retire early due to injury and 32% medically diagnosed with osteoarthritis (Drawer et al., 2001). This, along with the fact that when considered on a whole, injuries do not appear to be reducing in elite European soccer (Ekstrand et al., 2013), has prompted the European Union of Football Associations (UEFA), the governing body which rules European soccer to express concerns regarding the physical and mental load placed upon modern players in relation to the number of injuries sustained (Ekstrand et al., 2011). Additionally, both UEFA and the Federation Internationale de Football Association (FIFA), the governing body of world soccer in collaboration with other national soccer associations, have commenced various research strategies in an attempt to increase the safety of its players and prevent/reduce the number of injuries sustained (Ekstrand, 2008).

Ankle sprains are a primary injury in soccer (Agel et al., 2007; Van den Berg and Jacob 2012) resulting in an average rehabilitation period of 14 – 28 days (Brito et al., 2012; Ekstrand and Gilquist; 1983; Woods et al., 2003) with a reoccurrence rate of 11-28% (Arnason et al., 2004; Cloke et al., 2011; Ekstrand et al., 2004; Jacobs and Van den Berg 2012). It is therefore pertinent that injury prevention strategies are implemented in an attempt to reduce this phenomenon, thus allowing players better health and their team's a greater number of players to select from.

Designing an intervention programme in an attempt to reduce the incidence of injuries sustained has been described as a four-step process, shown schematically in Figure 1.1 (van Mechelen, Hlobil and Kemper, 1992).

- Epidemiology - Firstly, the extent of the injury problem in question must be evaluated through injury surveillance.
- Aetiology – Injury risk factors and mechanisms are established.
- Preventative Strategies - Based upon the information gathered regarding risk factors, preventative strategies are implemented.
- Evaluation - Preventative strategies are evaluated through repeating the first step to determine the success rate of the implemented strategy.
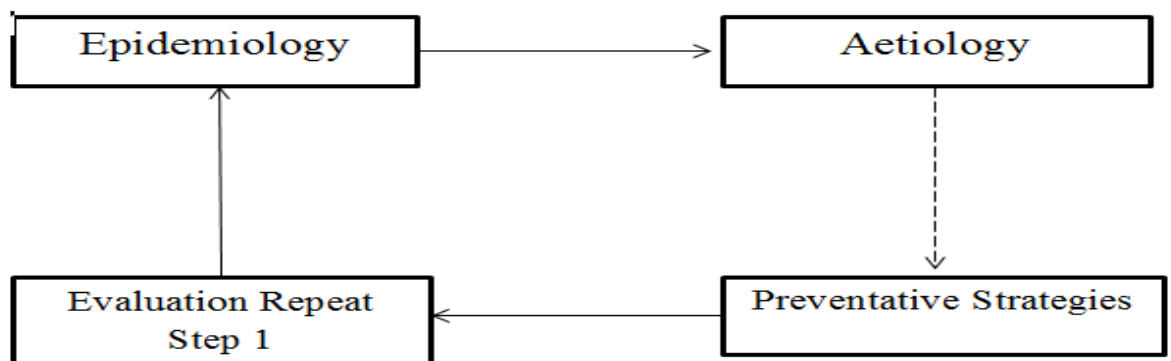
Figure 1.1 The injury prevention cycle (van Mechelen, Hlobil and Kemper, 1992)

The efficacy of such a model depends on the appropriate development of the preventative strategy, and thus the most appropriate battery of tests to reflect the multi-modal aetiology of injury. Current research is limited to the analysis of ankle injuries in a local rather than global perspective, with little research conducted on how these aetiological risk factors can combine to cause injury occurrence, with most studies choosing to focus on individual risk factors and their affects. For example, fatigue has been shown to increase injury risk (Aoki et al., 2012, Ekstrand et al., 2008; Woods et al., 2003), and the application of therapeutic tape has been shown to potentially reduce injury risk (Verhagen et al., 2000). Subsequently, it is pertinent to identify how taping strategies could potentially mediate fatigue, whilst also developing an understanding as to how training in a fatigued state could reduce injury risk

The results of this thesis could help to contribute to a better understanding as to why ankle injury incidence is so high within the game of soccer, whilst more importantly also attempting to reduce the amount of injuries sustained, via intervention strategies such as therapeutic tape and prehabilitation performed in a post exercise state. If this can be determined it will not only provide financial gains for clubs but also improved health for its participants which in turn will allow more players available for match day squad selection. In a more generic view, if the adapted version of the van Mechelen model (van Mechelen, Hlobil and Kemper, 1992) demonstrates significant results with regards to ankle sprains, then it could potentially be applied to a wider range of injuries in an attempt to reduce their incidence within a healthy male population.

Subsequent to a review of pertinent literature, the thesis comprises six experimental studies. The first three studies (1-3) consider factors influencing ankle injury and function: The first of which is to examine the commonality in performance, and mechanistic predictors of performance, across a battery of functional tasks considered to evaluate ankle joint function. The subsequent two studies utilised the same methodological approach as observed in study one, with the addition of circadian rhythm. Subsequently, study two aimed to determine the influence of time of day on performance tasks and their parameters associated with ankle aetiological risk factors. The third study within this first section aimed to investigate the

influence of different brands of kinesiology tape (KT) on performance tasks and their parameters associated with ankle aetiological risk factors.

Studies four and five place ankle injury incidence in a more ecologically valid context, moving away from discrete clinical measures of function and toward the demands imposed by soccer match play. In study four the aim was to investigate the effects of KT on aetiological risk factors associated with ankle sprain injury and measures of functional performance, with particular reference to soccer specific fatigue. This is in comparison to study five, which investigated the impact of an increased utilisation of interchanges, whereby the participants performed 15 minutes of soccer specific activity prior to 15 minutes of rest for the duration of the SAFT^{90} protocol. Subsequently the participants performed 45 minutes of soccer specific activity, with the study investigating the effects of a reduced workload on risk factors associated with ankle sprains in soccer players. Both studies attempted to assess whether fatigue could potentially be mediated, thus potentially reducing risk of injury.

Study six considers the third stage of the van Mechelen model (van Mechelen, Hlobil and Kemper, 1992), developing and implementing an injury prevention strategy, informed by the preceding chapters in this thesis. With the acknowledgement of fatigue as an aetiological risk factor within soccer, the thesis attempted to investigate the effects of performing the exercises during either a warm-up or cool-down of soccer training session on ankle injury risk factors during simulated soccer match play. The final stage of the injury prevention model is to quantify the effectiveness of such an intervention, which is beyond the remit of this thesis, but represents on-going work.

1.2 Aims and Objectives of Thesis

- Principal Thesis Aim: To develop an ankle injury prevention strategy for soccer players, considering a greater array of therapeutic, physiological and biomechanical measures
- To evaluate a range of clinical and functional tests to determine the nature of ankle joint function.
- To evaluate therapeutic taping methods as an injury prevention strategy.

- To quantify the influence of soccer-specific fatigue on injury risk.
- To evaluate the efficacy of prehabilitation training performed post-exercise.
- To develop an injury prevention strategy.

Chapter 2: Review of Literature

2.1 Introduction

The aims of the thesis are to investigate factors influencing ankle joint function and risk of sprain injury, and ultimately develop and implement a preventative strategy. The review first considers the epidemiology and aetiology of ankle sprain injury in soccer. Subsequently, aetiological risk factors and their associated assessments are discussed and considered

2.2 Ankle sprain epidemiology

Soccer is a team-based sport, which has been described as stochastic, acyclical and intermittent, with uniqueness in the sense of its unpredictability (Nicholas et al., 2000; Wragg et al., 2000) with movements being self-paced, irregular and multi-directional (Bangsbo, 1994). Soccer matches have been divided into different intensity zones, with approximately 80-90% of match play performance spent in the low to moderate zone, with the remaining `10-20% in the high intensity zone (Bangsbo, 1994; O'Donoghue, 1996; Reilly and Thomas 1976; Rienzi et al., 2000). The type and severity of injuries sustained and a relatively high injury rate have being recognised as a problem within the game of soccer (Aoki et al., 2012; Ekstrand et al., 1982; Ekstrand et al., 2011; Hawkins and Fuller, 1999; Woods et al., 2003), which has been related to the nature and intensity of performance.

In recognition of the van Mechelen model (van Mechelen, Hlobil and Kemper, 1992) and the nature of soccer, a vast amount of epidemiological research has been conducted (Agel et al., 2007; Aoki et al; 2012; Brito et al., 2012; Cloke et al., 2011; Ekstrand, 2008; Ekstrand et al., 2008; Ekstrand et al., 2011; Fong et al; 200; Gallo et al; 2006; Hawkins and Fuller, 1999; Jacobs and Van Den Berg; 2012; Le Gall, 2006; Tsiganos et al., 2007; Woods et al; 2003) in order to develop injury prevention programmes and to guide the rehabilitation process (Gallo et al; 2006). However, contentious issues surround many epidemiological studies concerning soccer injuries as the manner in which the word "injury" is defined and how the data is collected is often inconsistent (Dvorak and Junge, 2000; Inklaar, 1994; Ekstrand, 2008). Consequently, there are methodological differences in studies, which make

comparisons difficult. (Ekstrand and Karlsson, 2003; Hagglund et al., 2005). Meaningful comparisons of injury epidemiology and exposure should only be determined through studies with similar injury definitions, study design and methodology (Ekstrand and Karlsson, 2003). It is therefore necessary to carefully determine and ascertain information surrounding the nature, timing, severity and frequency of ankle injuries if the data is to be used correctly.

Frequency and Nature of Injuries

Studies have investigated the frequency and nature of injuries both in training and match play. Over a seven-season period, utilising 14 of the elite European soccer teams, Ekstrand et al., (2011) determined that in total 4483 injuries were registered. 1937 (43%) of these injuries occurred during training, compared to 2546 (57%) during match play. These findings are consistent with other epidemiological studies (Cloke et al., 2011; Jacobs and Van den Berg, 2012). The combined match play and training data suggests the incidence of injuries resulted in 8.0 injuries per 1000 hours (Ekstrand et al., 2011; Le Gall et al. 2006). Ekstrand et al. (2011) postulates that on average, an individual player would sustain two injuries per season. As identified earlier match play resulted in a significantly greater incidence of injuries compared to the training ($27.5\pm10.8/1000$h vs. $4.1\pm2.0/1000$h, $p<0.01$). The total injury incidence as well as match play and training injury incidence remained relatively stable over the 7-season period (Figure 2.1). Player to player contact was responsible for 59% of ankle injuries sustained, compared to that of 39% non-contact mechanisms (Woods et al., 2003). Within contact, tackling (36%) and being tackled (18%) were the most common mechanisms of sustaining an ankle sprain. Additionally Figure 2.2 provides information on the non-contact mechanisms of ankle sprains (Woods et al., 2003), identifying 77% of ankle sprains sustained during landing, twisting and turning and running activities.
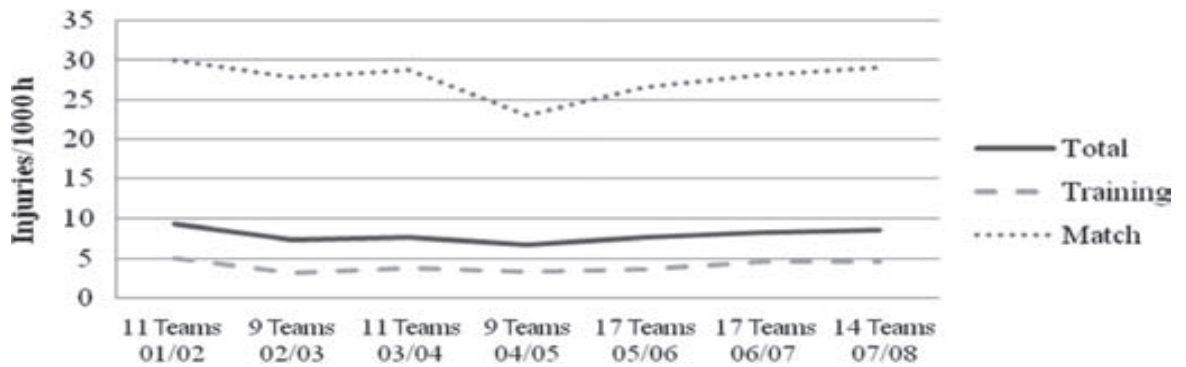
Figure 2.1: Incidence of injury per season across the seven-season study period (injuries/1000h) (Ekstrand et al., 2011)

Ankle sprains in professional football
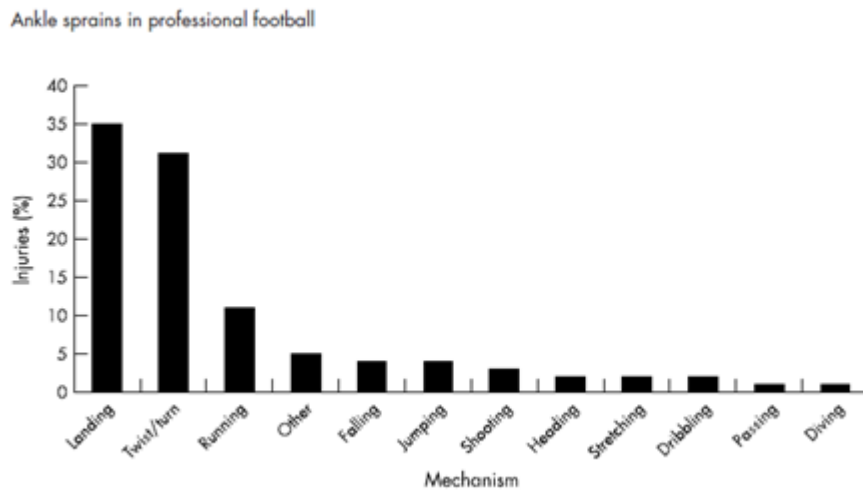
Figure 2.2: Non-contact ankle sprain mechanisms (Woods et al., 2003)

Injury Distribution

Between 80-90% of all soccer injuries sustained are to the lower extremities (Hagglund et al., 2003; Hawkins et al; 2001; Le Gall et al; 2006), with the most common sites of injury amongst professional and semi-professional players ranging from thigh (23%), knee (20%), ankle (13%) and hip/groin (12%). Table 2.1 indicates that ankle injuries range from the first (Agel et al., 2007; Van den Berg and Jacob 2012) to the third most common injury with the game of soccer (Ekstrand et al., 2011).

Table 2.1: Location of injuries sustained during training and competition (Hawkins et al., 1999)

LOCATION OF INJURY	ALL INJURIES		MATCH INJURIES		TRAINING INJURIES	
	No	%	No	%	No	%
THIGH	171	23	89	23	43	23
ANKLE	125	17	69	18	28	15
KNEE	103	14	59	15	27	14
LOWER LEG	95	13	47	12	33	18
GROIN	82	11	42	11	20	11

Regardless of the positioning of ankle injuries within the injury incidence table, they are still an extremely common injury with football, with previous studies demonstrating that they account for anywhere between 11 – 26% of all injuries sustained (Arnason et al., 2004; Cloke et al., 2011; Ekstrand et al., 2004; Jacobs and Van den Berg, 2012). It would therefore be of great benefit to attempt to reduce the number of ankle injuries sustained, thus allowing soccer teams to field their strongest teams and allow players to remain injury free for longer periods of time.

Nature of Ankle Sprains

Ankle sprains (67%) (See Table 2.2) have been reported to be the most common type of ankle injuries (Ekstrand et al., 2011; Woods et al., 2003) with between 67 and 77% of all ankle sprains involving the lateral ankle ligament complex (Lewin, 1989; Woods et al., 2003) (see Table 2.3). The potential reason for the lateral ankle ligament complex being compromised most frequently is the relative shortness of the medial malleolus and the natural tendency for the ankle to turn into inversion instead of eversion (Harris and Gilbart, 1995). Thus, the Anterior Talo-Fibular Ligament (ATFL) is the most frequently injured ligament in the ankle complex. Clanton and

Porter (1997), however, propose that another potential reason for the higher injury incidence rate to the ATFL could be that when compared to the Calcaneofibular ligament it has a lower load to failure, (138N and 345N respectively).

Table 2.2: Nature of ankle injuries (Woods et al., 2003)

NATURE	NUMBER	%
SPRAIN AND RUPTURE	677	67
TISSUE BRUISING	79	8
TENDONITIS AND PARATENDONITIS	65	6
INFLAMMATORY SYNOVITIS	31	3
FRACTURE	25	3
CAPSULE TEAR	21	2
STRAIN	21	2
OTHER	74	7
NOT SPECIFIED	18	2
TOTAL	1011	100

Table 2.3: Medical classification of ankle injuries (Woods et al., 2003)

NAME OF LIGAMENT	NUMBER	%
ANTERIOR TALOFIBULAR (ATFL)	493	73
MEDIAL	97	14
UNSPECIFIED	28	4
ANTERIOR TIBIOFIBULAR	23	3
CALCANEOFIBULAR	14	2
POSTERIOR TALOFIBULAR	13	2
OTHER	5	1
MISSING	4	1
TOTAL	677	100

Timing of Ankle Injuries

The incidence of ankle sprains through a soccer season remains relatively stable throughout the whole season (Figure 2.3), with a slight but insignificant peak seen towards the end of the soccer season (April – May), which could potentially indicate fatigue and overuse as a potential risk factor for ankle sprains (Ekstrand et al., 2011).
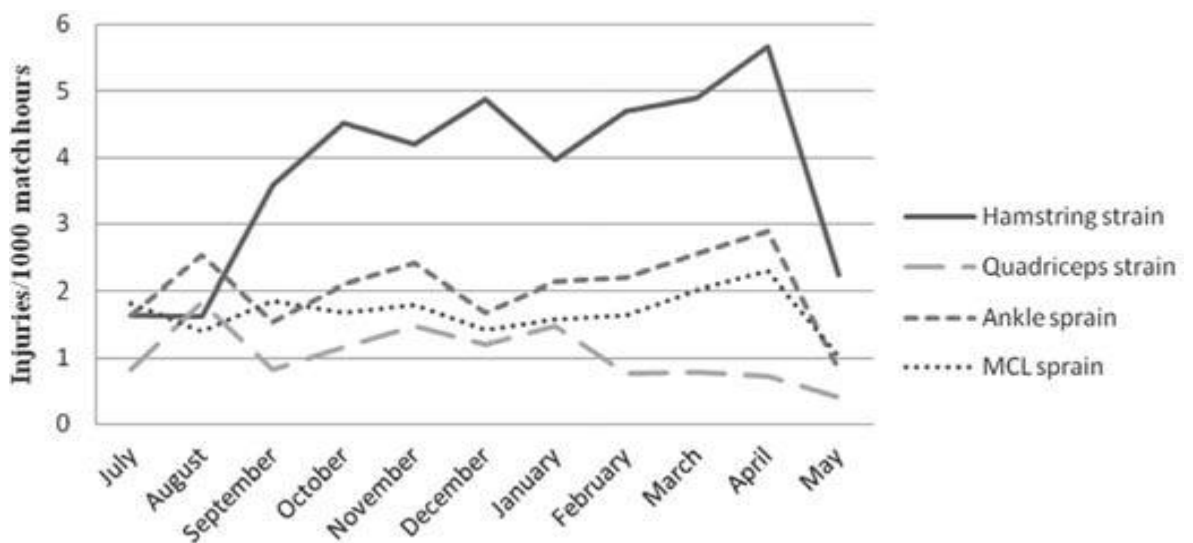
Figure 2.3: Distribution of the most common match play injuries over the football season (**Ekstrand et al., 2011**)

During a single soccer game, the amount of ankle injuries sustained has been shown to peak during the latter third of each half (30-45 and 75-90 minutes), with Hawkins et al., (1999) and Woods et al., (2003) reporting that up to 48% of ankle sprains (Figure 2.4) occur within these two periods of the game. It could be argued that fatigue may be a contributing factor for the greater incidence of injuries in this period. This notion is supported by a plethora of research which has demonstrated the manifestation of physical fatigue towards the end of each half, with a decrease in both the amount of high intensity running and technical performance evident (Bangsbo et al., 2007; Mohr et al., 2003; Rampinini et al; 2009). This information could emphasise the need to train endurance of the ankle to avoid fatigue at the end of each half (Woods et al., 2003), whilst also presenting the case for preventative training programmes in a fatigued rather than non-fatigued state.

Timing of ankle sprains sustained during match play.
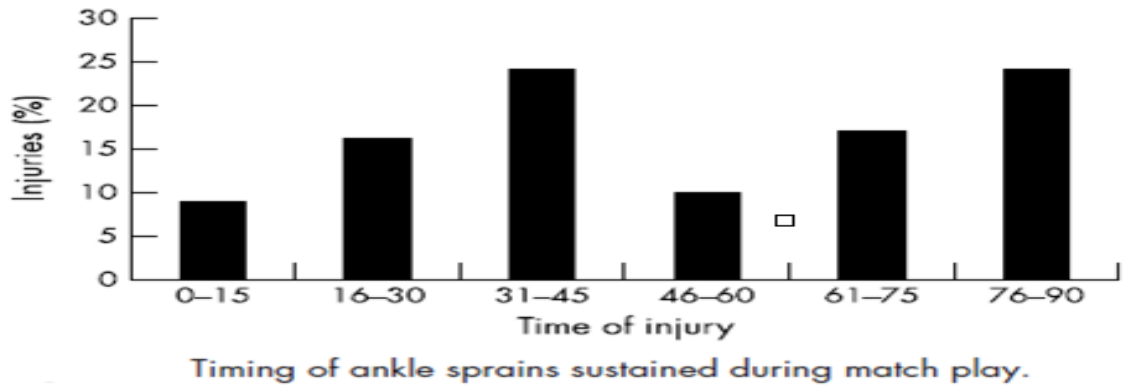
Figure 2.4: Timing of ankle sprains sustained during match play (Woods et al., 2003)

Severity of Ankle Sprains

Time lost from competition due to ankle sprains ranges from 14 - 28 days (Brito et al., 2012; Ekstrand and Gilquist; 1983; Woods et al., 2003). When the time lost from competition is taken into consideration, it suggests that the majority of ankle sprains are not defined as "severe", with the incidence of ankle sprains rather than the severity making them problematic injuries (Woods et al., 2003). With soccer players returning from injury relatively quickly in comparison to that of other injuries, it has been suggested that the rehabilitation period for ankle sprains is too short in duration. This could potentially help to explain why ankle sprain re-injury rate ranges between 9 – 24% (Aoki et al., 2012; Woods et al., 2003) compared to that of other injuries (7%), suggesting that the injury is not provided enough time to heal and recover, thus potentially causing reinjury and future complications such as chronic ankle instability (CAI).

Summary

In conclusion, it can be seen that ankle sprains, especially those involving the lateral ankle ligament complex are causing players to miss periods of play and incur potential decreases in their long term health. With ankle epidemiology thoroughly described, it is pertinent to gain a complete understanding regarding ankle aetiological mechanisms, which in turn will help to inform the design of injury prevention programs.

2.3 Ankle Sprain Aetiology

Due to the epidemiological nature of soccer, injury prevention and injury intervention strategies have become significant focal points for both researchers and clinicians alike (Murphy et al., 2003). However, before injury prevention/intervention strategies can be researched to determine their potential effectiveness, the risk factors for injury associated with the sport must be first identified and understood (Finch, 2006).

When discussing aetiological issues, risk factors can be separated into two different areas; intrinsic (those from within the body) and extrinsic (those from outside the body) (van Mechelen, Hlobil and Kemper, 1992); Williams, 1971). However, it is not enough to merely establish risk factors as intrinsic or extrinsic as it is important to thoroughly understand the mechanisms via which they occur, as sports injuries result from a complex interaction of various situations and risk factors, not all of which have yet to be identified (Bahr and Holme, 2003). These risk factors can be further sub divided into modifiable and non-modifiable factors (Bahr and Holme, 2003), with the latter being of some interest to certain studies. However, as a minimum it is imperative to research modifiable risk factors through training or behavioural approaches, such as previous injury history, joint strength, postural sway, joint position sense (JPS) and fatigue, all of which are intrinsic risk factors. Therefore, for the purpose of this literature review, modifiable intrinsic risk factors only will be discussed.

Intrinsic Risk Factors

Intrinsic risk factors have been defined as "predisposing factors that act from within, and that may be necessary, but seldom sufficient, to produce injury" (Meeuwisse, 1994). Numerous potential risk factors have been assessed and purported to determine potential intrinsic ankle risk factors; however there is limited soccer specific information (Engebertsen et al., 2010). These potential risk factors included previous injury history (Kofotolis et al., 2007; Willems et al., 2005), strength (Bennyon et al., 2002; Chomiak et al., 2000) postural sway (Murphy et al., 2003), JPS (Holme et al., 1999; Payne et al., 1997; Willems et al., 2005a and Willems 2005b) and fatigue (Aoki et al., 2012; Tsiagnos et al., 2007; Woods et al., 2003).

Despite the plethora of research regarding the detection of the intrinsic factors associated with ankle ligament injuries in various sports, very few studies have actually focused on the potential causes of ankle injuries within soccer, with their results being rather conflicting (Fousekis et al., 2012). It is therefore necessary to investigate and understand the mechanisms of the aforementioned risk factors in order to research this in a soccer specific context.

Previous Sprain

Previous ankle injury history, in particular a sprain of the lateral ankle ligament complex, has been long identified and researched as a risk factor for a subsequent ankle injury (Bennyon et al., 2002), with Agel et al., (2007) and Woods et al., (2003) reporting ankle sprain recurrence between 9 and 24%. This can potentially lead to further complications such as functional ankle instability (FAI), which is characterised by recurrent ankle sprains potentially causing mechanical instability and proprioceptive deficits (Yokoyama et al., 2008). The reasons which have been hypothesised for this are multiple in nature. However, the dominant theory is that previous ankle injury causes may cause future injury due to the lateral ankle ligaments, which act as biomechanical stabilisers, creating a partial deafferentation of the ankle (Bennyon et al., 2002). This deafferentation compromises a selection of the neuroreceptors that innervate the joint, thus potentially decreasing the level of proprioception available (Bennyon et al., 1999).

One of the first risk factor studies conducted was that of Ekstrand and Gilquist, (1983) who investigated 124 male soccer players, examining each player at the beginning of the year and documenting exposure to training and games for the duration of the season. The data demonstrated a significant relationship between those who had suffered previous ankle sprains and those players suffering subsequent ankle injuries. This notion has been subsequently supported by further researchers (Bahr et al., 2003; Ekstrand et al., 1990; Engebertsen 2010, Kofotolis et al., 2007; Murphy 2003. Conversely, (Barrett,1995; Baumhauer, 1995; Tropp, 1984) have reported no significant relationship between previous ankle sprains and subsequent ankle injuries. Various reasons have been proposed for these findings with one of the most popular reasons being inadequate rehabilitation or a premature return to play and/or inadequate rehabilitation. The latter reasoning may play a

significant role in the number of re injuries surrounding the ankle, with the demand to win and the monetary cost of doing so now being greater than ever (Gallo et al., 2006), players may be rushed to return to play before they are completely ready, thus suffering subsequent reinjury.

With regards to JPS, both persons with Functional Ankle Instability and persons with healthy ankles have been shown to underestimate ankle JPS (Robbins et al., 1995; Willems et al., 2002). Robbins et al. (1995) demonstrated that healthy volunteers, with no history of ankle injuries, demonstrated a greater underestimation of joint position in plantar flexion, which has been further supported by (Willems et al., 2002) who discovered similar findings in healthy ankles in the position of inversion.

Joint Position Sense (JPS)

JPS has been investigated as a mechanism of ankle injuries with four studies having investigated the predictive accuracy of proprioception in terms of JPS (Holme et al., 1999; Payne et al., 1997; Willems et al., 2005a and Willems 2005b) each with conflicting results and utilising different levels of participants and genders. Payne et al., (1999) demonstrated that only JPS in the left ankle predicted ankle injury, whereas JPS in the right ankle had no effect on right ankle whatsoever. The study also went further to suggest a similar pattern in the form of differences between the contralateral legs, suggesting that right dorsiflexion and right eversion predicted sprains, however the same movements in the left leg had no effect on left ankle sprains. De Noronha et al., (2006) suggested that these claims could not be deemed significant due to the nature of the findings, suggesting rather that the findings must be due to statistical error, thus bringing the (Payne et al., 1996) study results into question.

Willems et al., (2005a) investigated females and reported improved joint position sense in an uninjured group, proposing that those with an absolute error above 11° had 2.3 times greater risk of an ankle sprain when compared to the uninjured group. These results contradict the findings of Willems et al., (2005b) who investigated the effects of intrinsic risk factors on ankle inversion sprains in male Physical Education students, reporting no relationship between JPS and the risk of ankle sprains (Murphy et al., 2003). However, this finding could be attributed to the sample

utilised since the participants, whilst physically active, did not have the physical demands of soccer players.

Joint Strength

In soccer, strength asymmetries have been implicated as risk factors for injuries in the lower limb (Tsepis et al., 2004; 2006) as muscle strength is crucial for performance and injury prevention (Bangsbo, 1994). Ankle joint strength is supported by the evertor muscles, peroneus longus and brevis, which have been shown to provide extra support (Glick et al., 1976) to the lateral ankle ligament complex, which has been demonstrated to be the most frequently injured site of the ankle (Woods et al., 2003). The first studies to show the effect of decreased muscle evertor strength were Boisen et al. (1955) and Staples et al. (1972) on ankle inversion sprains using manual methods. The IKD was first utilised by Tropp et al., (1985) to measure the effects of muscle torque at the ankle, suggesting that weakness of the evertor muscles to be a significant component of CAI. However, research surrounding peroneal strength deficits is conflicting, with some studies identifying both concentric (Hartsell et al., 1999; Tropp, 1986; Willems et al., 2002) and eccentric eversion torque deficits, whereas other studies have failed to demonstrate that eversion deficits exist, regardless of speed of contraction or mode (Bernier et al., 1997;Kaminiski et al., 1999; Munn et al., 2003).

Although the evertor muscles help to combat a varus force, (Fox et al., 2008) whole ankle stabilisation can only be achieved via the surrounding muscles producing a coordinated effect (Kaminski et al., 2002). For this coordinated effort to occur, a combination of eccentric, concentric, isometric or kinetic motion of all muscle-tendon units surrounding the ankle joint would be required. Research involving the plantar flexor and dorsi flexor muscle is limited (Fox et al., 2008) and conflicting, with McKnight and Armstrong, (1997) demonstrating no effect of plantar flexion and dorsi flexion torque between FAI and control participants, compared to (Fox et al., 2008) who demonstrated a deficit in plantar flexion torque only. Given these discrepancies, further research is required into the effectiveness of inversion and eversion, and the potential influence they possess on ankle injuries sustained. However if it is proven that there are indeed deficits in joint strength surrounding the ankle, then these muscles which surround the ankle structure may not be providing

enough support to the lateral ligament complex, therefore placing the lateral ankle ligament under undue distress, thus causing potential afferent damage.

Postural Stability

Ability of athletes to control their centre of gravity has received a vast amount of attention with regards to being a risk factor for lower extremity injury (Murphy et al., 2003). It has been suggested that variation in postural control is associated with an altered neuromuscular control strategy, intersegmental joint forces and increased forces surrounding the ligamentous structures of the ankle, however the relationship between decreased levels of postural stability remain unclear (McKeon et al., 2008; Murphy et al., 2003). This is in part due to the variety of mechanisms used to test postural sway, whether this is via centre of gravity (Bennyon et al., 2002; Williams et al., 2005a; 2005b) or centre of pressure.

McGuine et al., (2000) demonstrated a sevenfold increase between those athletes who demonstrated an increase in postural stability and the incidence of ankle sprains, when compared to those subjects with normal balance in the sport of basketball. This is further supported by Tropp et al., (1984) who measured postural stability in soccer players and found an increase in postural stability leads to a higher incidence of ankle sprains when compared to those subjects with normal values. However, Beynnon et al., (2001) reported no relationship between ability to balance and those who sustained ankle injuries. However, when studies consider the risk of ankle injuries as multi modal, consistent results were not seen (Willems 2005a; 2005b). This could indicate that ankle risk factors cannot be examined in a singular sense, rather a combination of ankle injury predictor tests need to be utilised in a variety of conditions.

Fatigue

The most recent proposed risk factor within the game of soccer for injuries is fatigue, which is supported by the fact that there were an increased disproportionate number of ankle injuries, 48% occurring during the last third of each respective half (Aoki et al., 2012; Tsiagnos et al., 2007; Woods et al., 2003), with fatigue being cited as an underlying factor. This is possibly due to the fact that it may alter the neuromuscular

control of the ankle, therefore affecting a player's ability to dynamically stabilise the ankle joint (Woods et al., 2003). Due to the current nature of soccer, it is impossible to prevent the onset of fatigue and with greater levels of fatigue; there are increased deficits in postural control, which could potentially increases the risk of injury occurring. Gribble et al. (2003) proposed that a reduction in muscle force due to increased levels of fatigue causes an increase in the threshold of muscle spindle discharge, thus altering the afferent input, which could be the determining factor as to why so many ankle injuries occur during the final third of each half. This therefore suggests that an increase in fatigue may contribute to altering the ankles' neuromuscular control (Mohammadi and Roozdar, 2010), thus also affecting an individual's ability to stabilise the ankle joint (Woods et al., 2003). The evertor muscles of the ankle, Peroneus Longus and Brevis may help to prevent the onset of some inversion sprains (Willems et al., 2002), as they help to prevent sudden ankle inversion before the mechanical strain on the tissues surrounding the lateral ligament complex become too great. This valuable information has been extended further, as ankle JPS has been shown to decrease in patients who have suffered from recurrent ankle sprains (Glencross and Thornton, 1981; Mohammadi and Roozdar, 2010).

It has been generally hypothesised that muscle receptors have a greater influence on JPS when compared to joint receptors (Gandevia 1998; Lattanzio and Petrella 1998; Lofvenberg 1995), with further studies suggesting that fatigue would presumably affect muscle receptors to a greater level than joint receptors (Hiemsta et al., 2001). This suggests that reduced levels of JPS may be attenuated to a decreased level of muscle receptor input as this is affected by fatigue (Mohammadi and Roozdar, 2010) as the levels of afferent input of muscle receptors may cause changes in the neuromuscular control of the limb in question, therefore leading to a decreased level of control when the body attempts to control the limb. Consequently, it is proposed that the measurement of relevant muscle activity in the lower limb via electromyography would assist in determining whether it is a decrease in the activity of the muscle receptors or the joint receptors, which demonstrate a decrease in the level of JPS.

Mohammadi and Roozdar, (2010), identified a significant relationship between fatigue and JPS, whether this be via non- specific (evertor muscle exercised to fatigue using an IKD) or specific football mechanisms (45 minutes protocol). The elite soccer participants were asked to replicate 5° inversion and maximum inversion minus 5° after having the invertor muscles fatigued during IKD contraction of the invertor muscles or soccer specific fatigue. Whilst the exact mechanisms are still unknown it was proposed that fatigue may increase the laxity of joint ligaments (Nawata et al., 1999) with subjects who have lax ligaments being shown to have a decrease in ability to replicate JPS (Rozzi et al., 1999) which in turn could affect an individual's balance strategy.

Alderton et al., (2003) hypothesised that within a fatigued state, a change in balance strategy may be produced due to increased muscular fatigue, specific to the locality of said fatigue. These compensatory strategies could increase the risk of either or both ligamentous and muscular structure particularly in dynamic movements, which are involved in soccer. In relation to ankle sprains, they are generally caused by stress being placed in the plantar-dorsi flexion and inversion-eversion ranges of movement (Hesari et al., 2006). Therefore, it is imperative that testing procedures are designed, which facilitate the ankle moving dynamically into these positions whilst under the influence of soccer specific fatigue. Greig et al., (2007) attempted to replicate the physical demands of soccer utilising a soccer specific protocol whilst testing every 15 minutes for dynamic balance, utilising a Biodex Stabilometer, allowing the ankle to be moved dynamically into the positions which potentially enhance the risk of injury. The results in this study differed to that of others conducted previously using localised fatigue procedures (Alderton et al., 2003). Greig et al. (2007) identified that although there were no significant changes in the overall stability index of postural control, a significant change was observed in the latter 15 minutes of each half of the soccer specific protocol in the anterior posterior direction, in favour of anterior displacement. This would seem to support the theory previous researchers (Aoki et al., 2012; Tsiagnos et al., 2007; Woods et al., 2003) who all observed an increase in the incidence of injuries in the latter third of each half of soccer. Greig et al. (2007) hypothesised that the increase in the anterior direction placed the ankle in greater plantar flexion, which has been purported to be indicative of ankle sprain occurrence (Palastanga et al., 2006). Increased plantar

flexion reduces the base of support, increasing the risk of injury, as there is a greater traverse and rotational movement allowed due to the more open packed nature of the ankle. This increase in plantar flexion could potentially be due to a change in postural control strategy (Greig et al., 2007) in favour of an increase in knee or hip flexion to move the centre of mass into a more anterior position, thus placing muscles which should not be as active under undue stress due to changes in muscular recruitment patterns. This notion is supported by Alderton et al., (2003) who reported similar findings using localised calf fatigue.

The potential causes of this change in balance strategy cannot be conclusively defined, with fatigued muscles having being shown to demonstrate electromechanical delay (Gleeson et al., 1998) thus a decrease in muscle reaction time therefore potentially affecting the ability of the evertor muscles to provide support in the form of strength. When fatigue is defined as drop of muscle force below 50% of torque, deficits in postural control occur, therefore increasing the risk of musculoskeletal injury (Gribble et al., 2004).

Summary

In conclusion, there are various intrinsic and extrinsic risk factors which can potentially influence ankle injuries, especially to the lateral ankle ligament complex, ranging from postural stability, strength, JPS and previous injury history). However, very few studies solely focussed upon the sport of soccer and its unique demands. More studies are warranted within the area of soccer, to determine why ankle sprains are the second most common injury within the game (Aoki et al., 2012; Woods et al., 2003) and if there is indeed a relationship between fatigue and injury incidence as the aforementioned studies suggest. Intrinsic risk factors have been defined as "predisposing factors that act from within, and that may be necessary, but seldom sufficient, to produce injury" (Meeuwisse, 1994), therefore suggesting that various factors interact and increase injury risk. This is further supported by Lohkamp et al., (2009) who suggested that future research should determine the interrelationship of factors affecting balance and attempt to determine respective risk factors relevant contribution to balance and their resistance to fatigue.

2.4 Preventative Strategies

Preventative interventions are commonly used in various sports to reduce the number of sports injuries (Janssen et al., 2015). Furthermore, injury prevention programmes generally focus on reducing all injuries within a particular sport (Ekstrand and Gilquist, 1983; Heidt et al., 2000; Junge et al., 2002) or a singular injury (Soderman et al., 2000; Surve et al., 1994; Tropp et al., 1985) that is extremely severe or has a high incidence rate (Dvorak et al., 2004). The potential chronic consequences and high incidence of ankle sprains, along with their associated economic burden (Thacker et al., 1999) provide a need for preventative measures to be implemented in order to prevent further ankle injuries (Verhagen and Bay, 2010).

Ekstrand and Gilquist, (1983) was the first study conducted into sports injury prevention in soccer, investigating the effects of multiple preventative measures such as correct training, correct equipment provision and controlled rehabilitation. Tropp et al., (1985) were the first researchers to investigate the effects of ankle disc training on ankle injury incidence over a 6-month period. However it was not until the mid-1990's that these prevention trials were conducted on a far greater scale. The contemporary preventative studies were of two types; studies designed to prevent a particular type of injury for example ankle sprains (Kofotolis et al., 2007; McGuine et al., 2006; Mohammadi et al., 2007; Tropp et al., 1985; Verhagen et al., 2004) and studies which were designed to prevent all injuries associated with a particular sport (Emery et al., 2005; Emery et al., 2007; Junge et al., 2011; Kirkendall et al., 2011). In this more injury specific focussed area, various preventative strategies have been implemented in an attempt to reduce ankle injury incidence, ranging from external support in the form of taping (Delahunt et al., 2010; Forbes et al., 2013; Halseth et al., 2004; Lohkamp et al., 2009; Refshague et al., 2009), bracing (Forbes et al., 2013; McGuine et al., 2012) and balance and neuromuscular training programmes (Arnason et al., 1996; Bahr et al., 1997; Olsen et al., 2005; McHugh et al., 2007).

Global Injury Prevention

For the purpose of this thesis those studies conducted to prevent or reduce all injuries associated with a sport will be termed global injury intervention strategies (Emery et al., 2005; Emery et al., 2007; Junge et al., 2011; Kirkendall et al., 2011), as they are

not focused on one particular injury, rather injuries associated with the sport per se or injuries with regards to the lower or upper extremity.

The Federation International de Football Association (FIFA) devised a medical intervention team known as the FIFA Medical Assessment and Research Centre (F-MARC). This aimed to reduce the frequency of injuries and their related symptoms for all players (Dvorak, 2009) as at the time it was estimated that by multiplying the number of registered players by the average estimated medical cost of an injury, $30billion US dollars were being spent annually on the primary care treatment of soccer-related injuries (Dvorak, 2009). Based upon this staggering amount of injury cost, a group of experts outlined a global injury prevention programme named the FMARC 11, which consisted of 10 simple exercises, plus fair play.

This programme was later expanded to include the progression of exercises over a season, with the new programme being named the FMARC 11+ (Dvorak, 2009). Both FMARC programmes have achieved success across various sports in reducing the number of injuries sustained when the programme has been implemented properly (Junge et al., 2011; Longo et al., 2012) with both studies concluding that the FMARC programmes reduced injury incidence in amateur soccer and elite male basketball players. The major benefit of the work conducted by Junge et al., (2011) was the fact that it was conducted on a nationwide (Switzerland) scale, whereas most previous literature had been conducted with singular teams or low participant numbers alone (Junge et al., 2011). One potential issue with this study is the fact that it relied on coaches to report the number of injuries sustained and commit to applying the FMARC programme consistently, which could potentially affect the results of the study. Junge et al., (2011) provided no detail as to which injuries were reduced, whereas Longo et al., (2012) produced a breakdown of injuries sustained specific to an area (e.g. leg, trunk etc.) when compared to a control group. Longo et al., (2012) discovered that overall injuries were reduced, however there was no significant effect in the reduction of ankle injuries during match play. It could therefore be hypothesised that in order to reduce the number of match day injuries as well as training injuries, a more localised, focused and specific injury prevention programme needs to be introduced.

Local Injury Prevention

Lower Limb/Lower Extremity Screening

It could be argued that the term "screening" could be misinterpreted to be a more global injury prevention method and this would be the case if the screening were to take place for the whole body. However, for the purpose of this thesis, the term screening refers to tests to be performed. These tests focus on the lower limb below the patella, with the main focus surrounding the ankle and its associated ligaments and musculature, therefore screening can be considered as local injury prevention strategy. The overall goal of ankle injury management is to firstly identify and detect proprioceptive, strength and functional deficits, which will then allow therapists the opportunity to construct and conduct appropriate rehabilitation programmes in order to return athletes to match play as quickly and as safely as possible (Yildiz et al., 2009). However, rather than being reactive and constructing rehabilitation programmes, prehabilitation programmes can be designed using similar principles in an attempt to prevent injuries from occurring. These effective prehabilitation programmes have often involved neuromuscular training, either on balance boards or balance mats in soccer (Tropp et al., 1985; Arnason et al., 1996) and in various other sports (Bahr et al., 1997; Olsen et al., 2005; McHugh et al., 2007). It is suggested, as described in the testing battery section, that a selection of tests are used to determine whether there are indeed any predisposing factors which either singularly predict or show a relationship with another injury risk factor. This would potentially allow a greater understanding of the risk factors which predispose an ankle sprain, thus allowing for a greater understanding as to what may potentially cause future ankle injury, thus allowing for further preventative measures to be implemented.

Proprioceptive and Balance Training

Proprioception is primarily related to the position sense of mechanoreceptors (Lephart et al., 1997; Olsson et al., 2004) involving both static and dynamic position sense (Postle et al., 2012). Dynamic position sense facilitates a neuromuscular feedback system related to the rate and direction of movement Olsson et al., (2004) involving both afferent and efferent feedback to maintain stability and orientation during activities such as soccer. However, when injury occurs, both proprioceptive

deficits and loss of JPS are associated with occurrence and re-occurrence of ankle ligament injuries (Willems et al., 2002; de Norohha et al., 2007). To rehabilitate persons with ankle ligament sprains, one of the main targets for improvement is that of proprioception, with studies targeting improvement in peroneal muscle reaction time and both kinaesthetic and postural stability deficits (Osborne et al., 2001; McKeon and Hertel, 2008). Studies are now using this rationale in an attempt to construct prehabilitation programmes in order to prevent ankle injuries from occurring.

The effectiveness of specific balance and proprioceptive training programmes has been researched and evaluated mainly using randomised controlled trials or laboratory based studies (Eils et al., 2001; Hupperets et al., 2009; Tropp et al., 1984; Verhagen et al., 2005; Verhagen et al., 2004). In the laboratory-based studies, different tests are performed before and after a training period in a pre and post-test design. With reference to randomised intervention studies, both a training and control group are utilised and monitored throughout a season, with the difference in the number of injuries sustained at the end of the season proving indicative of the effectiveness of the prevention programme. Both types of studies are insufficient to understand how ankle injuries are prevented as when investigating the effectiveness of training programmes, the reasons for reduced injury rates still remains unclear (Eils et al., 2011). When researching using a pre-post-test design, the test does not indicate that changes in neuromuscular parameters are responsible for a reduction in injury incidence, as no measures have been taken regarding neuromuscular performances throughout the seasons. Using a combination of both laboratory and prospective randomised controlled trials will help to increase the understanding of the relationship between neuromuscular performance and ankle injury prevention (Eils et al., 2011). Only one study has conducted this research design. Eils et al., (2011) tested neuromuscular properties throughout one basketball season, whilst injury incidence was monitored and a neuromuscular training programme was conducted once a week. Results demonstrated a significant relationship between a decreased ankle injury incidence rate and an increase in neuromuscular performance in biomechanical tests of proprioception and postural stability. It would therefore seem necessary to conduct a similar research design based upon the findings of the

proprioceptive testing battery to determine whether the results of Eils et al., (2011) would be applicable to soccer players.

Therapeutic Taping

Another mechanism, which has been used to potentially enhance functional performance and reduce the incidence of ankle sprains, is that of athletic tape (Verhagen et al., 2000). Taping has been used for the prevention and treatment of sports injuries for many years in order to provide the client with protection and support to muscle or joint during movement (Thelen et al., 2008). One particular brand of athletic tape, which has received much research attention (Halseth et al., 2004; Semple et al., 2012; Thelen et al., 2008), is that of Kinesio Tape (KT), a proprietary product that purports to offer a range of benefits in the treatment and prevention of various musculoskeletal conditions. Kinesio taping involves the application of elastic adhesive with a stretch up to 140% its original length to areas of pain, dysfunction or need of further support. The purported mechanisms as to how KT works are diverse, including reduction of pain through stimulation of sensory afferents (Thelen et al., 2008) and increased range of motion (ROM) due to enhanced local circulation (Yoshida et al., 2007), whilst also exerting a desired mechanical pulling force to the skin (Halseth et al., 2004). The mechanical benefits of KT are still not scientifically fully understood (Lohkamp et al., 2009) with many unambiguous conclusions drawn, however KT has been tested under specific guises, with reference to; ROM (Hsu et al., 2009; Thelen et al., 2008; Yoshida et al., 2011), strength (Fu et al., 2008; Halseth et al., 2004; Vitholuka et al., 2010) and proprioception (Cordova et al., 2002; Delahunt et al., 2010; Halseth et al., 2004; Wilkerson et al., 2002).

Considering there is not a vast amount of research for an injury-prevention effect of ankle tape (Lohkamp et al., 2009) and that it has cost and time implications (Olmsted et al., 2004), many clinicians have advocated the use of external ankle support in the forms of taping to help prevent acute ankle sprains. Furthermore, despite a recent increase in public profile due to use of kinesio taping by athletes at major sporting events, the clinical benefits of the intervention remain unclear (Semple. This increase in public profile has led to other manufacturers designing similar products to KT, with modification surrounding the elastic adhesive, cotton fibres and the degree of

stretch which the tape can maintain. Once such product is RockTape (KT$_2$), which claims to improve both rehabilitation and athletic performance via cutaneous stimulation through the body's integration of movement via multi-muscle contractions as a means of connecting the brain to the body's uninterrupted facial web in order to enhance both rehabilitation and athletic performance via cutaneous stimulation (Capobianco and Van Den Dries, 2009). Cutaneous skin stimulation is increased, RockTape claims, via a constant tissue shearing, vibration buffering, tactile and thermal effect, which facilitates muscle activation (Tsai et al., 2009).

The tapes contact with the skin appears to provide an increased ability to detect joint movement and respond to forces applied to the joints in question, therefore increasing the sensori-motor information to the brain, thus improving efferent feedback to the body to initiate appropriate responses. If true, this indicates that athletes, who wear the tape, will be provided with greater levels of feedback, therefore allowing them to initiate greater levels of feedback to the area of the body in question, thus decreasing the risk of potential injury. Other advantages when comparing KT and RT to conventional tape are that it is suggested that KT and RT allows for a greater ROM and can be worn for greater periods of time (up to 5 days) without the need for the tape to be removed and reapplied (Kase and Wallis, 2002; Capobianco and Van Den Dries, 2009). Refshague et al., (2009) suggested that the potential benefit of taping the ankle is due to the close contact between the tape and the skin causing a higher level of afferent nerve traffic to the site in question, arising from the cutaneous skin mechanoreceptors, with greater levels of proprioception having been shown to increase an individual's postural stability Corbeil et al., (2003), which in turn may help to reduce their injury incidence of ankle sprains (Lohkamp et al., 2009). Whether ankle taping has any proven benefit on the aforementioned areas is still debateable, (Delahunt et al., 2010; Halseth et al., 2004) observed no significant effect on dynamic stability when taping the ankle, whereas Wilkerson et al., (2002) and Cordova et al., (2002) indicated positive benefits of taping the ankle in terms of increased levels of proprioception.

Lohkamp et al., (2009) discovered that when testing zinc oxide at the ankle under a soccer specific protocol, the tape provided an initial benefit to the participants in terms of postural stability, however this effect was negated after a 15 minute period

of soccer specific exercise, therefore raising questions about its durability and its efficacy in games such as soccer which last for 90 minutes. Forbes et al., (2013) reported similar results, with a reduction in both ROM and proprioceptive benefits within the first fifteen minutes. However, both studies were conducted using zinc oxide tape rather than KT or RT, therefore further research is needed to investigate the effects of soccer specific exercise which causes fatigue on the proprioceptive capabilities of RT and KT.

Based on the growing epidemiological data with regards to fatigue being an aetiological risk factor for ankle injuries, more studies are needed to directly assess the effects of fatigue on neuromuscular function at the ankle, especially regarding JPS and dynamic balance (Mohammadi et al., 2010). With a greater abundance of performance tape now available to purchase and use, studies need to research whether these tapes have any greater benefits in the prevention of ankle sprains compared to their counterparts. Also for tape to be deemed scientifically significant or insignificant in terms of improving performance levels in soccer players it needs to be tested under demands which replicate professional soccer and soccer specific fatigue, to which there is a dearth of literature. This study aims to test the aforementioned areas, thus creating a niche area within published research.

Summary

According to the van Mechelen Model (van Mechelen, Hlobil and Kemper, 1992) model, a particular format needs to be followed if injury prevention programmes are to be implemented with great effect. This first requires the epidemiology of an injury to be determined, with ankle injury incidence shown to be the second most common injury within soccer (Agel et al., 2007; Van den Berg and Jacob 2012), thus highlighting its importance to be reduced further. The aetiology of ankle injuries has been shown to be multi-factorial with issues such as proprioception, postural stability, strength ratios and previous injury all being highlighted as factors which need to be investigated and injury prevention strategies implemented in an attempt to reduce the incidence of injury occurring. This therefore requires an adaptation to the van Mechelen model (van Mechelen, Hlobil and Kemper, 1992) with a multi modal battery of tests, which encompass the variety of aforementioned risk factors whilst also being made to a specific male semi-professional soccer population and their

functional requirements, such as semi-professional soccer players being added. This will therefore help to determine which tests and their associated risk factors influence the incidence of ankle sprains.

Ankle injuries have been shown to have a higher incidence during the latter third of each half, thus suggesting fatigue as potential aetiological risk factor (Aoki et al., 2012; Tsiagnos et al., 2007; Woods et al., 2003). Ekstrand et al., (2008) demonstrated that over a seven-year period that there were no significant increases in incidence of injuries sustained, however fatigue was still highlighted as having an effect on injury incidence. This therefore suggests that risk factors not only need to be tested under the influence of soccer specific fatigue, but also advocates the reasoning that injury prevention measures such as therapeutic tape need to be investigated in a fatigued state.

2.5 Testing Battery

Identification of athletes at risk of ankle injuries has been predominantly completed using balance and ankle control test measurements (Engebertsen et al., 2010). Various studies have investigated ankle injury risk factors often investigating using a univariate analysis, even though sports injuries are a multi risk phenomenon, with multiple risk factors occurring at different times. A singular measure of proprioception is inadequate to describe the proprioceptive ability of a patient after an ankle injury has been sustained (Noronha et al., 2007). Therefore, these risk factors need to be determined in a multivariate analysis within specific populations (Bahr et al., 2003; Willems et al., 2005b).

For this thesis the specific population relates to soccer players, and might be further developed to consider the physical demands of their sport. When combining these multi factorial risks with the combination of soccer specific fatigue, the risk is escalated further. This therefore requires a multifactorial intervention strategy; with a greater variety of functional soccer specific tasks (Greig et al., 2007) to be implemented in an attempt to reduce the incidence and severity of ankle injuries, developing a new ankle testing methodology with greater functionality and reliability (Engebertsen et al., 2010). Therefore, it is necessary to implement multi-modal battery of tests associated with ankle injury risk factors, from which regression

modelling can determine whether ankle joint function is a global measure, or whether performance on different tests are independent and represent local optima.

The tests selected will be based upon the aetiology literature, with these tests being divided into subsections;

- Clinical – Tests performed in a laboratory setting using specialised equipment such as the Isokinetic Dynamometer (IKD), requiring participants to perform movements
- Clinical/Functional – Tests, which are still controlled in the laboratory setting and may still utilise specialist equipment such as the Biodex Stabilometer and ground reaction force mats. Movements, which the subjects will be asked to perform, will be of greater function than those described in the clinical setting.

Clinical

Through the development of the IKD, clinicians are now able to examine a wider variety of factors surrounding injuries sustained to the ankle complex (Kaminski et al., 2003). These factors include joint strength (Inversion and Eversion and Plantar flexion and Dorsiflexion) ratios (Gribble and Robinson, 2009) and the proprioceptive capabilities of the ankle joint (Mohammadi and Roozdar, 2010).

Ankle Musculature Strength – Inversion and Eversion Ratios

Various studies have published results regarding the differences in ankle musculature strength ratios between inversion and eversion and plantar and dorsiflexion, in injured and uninjured groups (Baumhauer et al., 1995; Bennyon et al., 2001; Wang et al., 2006; Watson et al., 1999; Willems et al., 2005). The methodology for testing was similar for all studies, however different studies tested their participants at a range of different isokinetic speeds, ranging from 30°/s, (Baumhauer et al., 1995; Bennyon et al., 2001; Willems et al., 2005) 60°/s, (Wang et al., 2006) 120°/s Willems et al., (2006) and 180°/s (Wang et al., 2006). Witchalls et al., (2012) performed a meta-analysis on the aforementioned studies discovering an association between weaker eversion strength at testing speeds lower that 110°/s. At isokinetic

speeds faster than 110°/s, stronger concentric plantar flexion was discovered in the un-injured participants. Witchalls et al., (2012) hypothesised that this could potentially be not an elevated injury risk; rather that increased plantar flexion (PF) strength may be indicative of a higher level of sports participation and intensity workload with associated sports. However, an increased PF strength could potentially alter the DF/PF ratio, thus potentially causing athletes to be at an increased risk of injury.

The variability in testing speeds is due to the belief that slower speeds test muscular strength, whilst faster speeds test power (Arnold et al., 2009). The maximum isokinetic speed for testing for associations of inversion/eversion and PF/DF ratios in relation to a heightened risk of injury is 240°/s (Hartsell and Spaulding, 1999), suggesting that previous studies have only performed movements of up to 180°/s due to the fact that performing velocities of greater speeds could potentially induce injury. However, when the 240°/s isokinetic movements were performed, which is of greater functional relevance due to the high velocity at which ankle sprains occur, the ability of the evertor muscles to work eccentrically was reduced. This caused the functional muscle activity surrounding the ankle to be impaired under eccentric and high velocity conditions (Hartsell and Spaulding, 1999). This could potentially cause muscles surrounding the ankle complex to be recruited, even though their role is not to prevent the ankle from moving into positions of either eversion or plantar flexion

It is also recommended that fast slow ratios are determined as a functional measure. Rahnama et al., (2003) conducted a study, which aimed to determine the effects of soccer specific exercise on the strength of the knee extensors and flexors, discovering that their ability to produce force reduced with fatigue due to a decline in peak torque. A conclusion was drawn that the decline in strength had implications for the ability of the players to perform skills and functional movements towards the end of a game, leading to errors and increased risk of injury. Rahnama et al., (2003) noted that the decline in muscle strength in the knee extensors was influenced by the angular velocity of limb movements, with a greater decline in strength shown at low velocity speeds, which could affect the performance of explosive actions such as jumping, sprinting and changing direction, which require a high involvement of the ankle joint to produce movement. If there is a change in the dynamic strength control

of the invertor and evertor muscle groups of the ankle, this could affect the dynamic strength control ratio, which is thought to be an indicator of lower limb capability, where the bilateral muscles work against each other in an explosive movement such as PF and IN.

To determine the IE, peak torque angles must first be generated. With specific reference to ankle injury risk factors, less attention has been afforded to the angle at which peak torque occurs. Studies regarding the hamstring musculature (Coratella et al., 2015), demonstrated that under the influence of fatigue, peak torque angle increases in the hamstrings but is not apparent in the quadriceps, the antagonistic partner, subsequently impairing hamstring lengthening capacity (Coratella et al., 2015). Therefore, in order to compensate for the lack of in quadriceps, the hamstring will become overstretched, enhancing the risk of injury (Coratella et al., 2015). Furthermore, previous literature has reported that repeated eccentric contractions induce a shift of peak torque towards a longer muscle, which is now commonly used as a marker or muscle damage (Brughelli and Cronin, 2007; Chen et al., 2007). Although this concept may be of interest to ankle injury research, the reduced range of motion at the ankle compared to the knee joint, could potentially decrease the sensitivity of the angle of peak torque measure to determine differences between subjects.

Proprioception - Joint Position Sense (JPS)

Academic literature has reported a variety of mechanisms for investigating proprioception, ranging from sensory evoked potentials (Courtney et al., 2005), gait analysis adaptations following injury (Devita et al., 1998), EMG activity of the lower extremity (Wikstrom et al., 2006) and ligament protective reflexes (Beard et al., 1993). However, the three most frequently used protocols in a clinical setting are threshold to detect passive motion (TTDPM) joint position sense (JPS) and active movement extent discrimination assessment (Han et al., 2015; Reimann et al., 2002). The three tests originate from differing concepts, are conducted under different testing conditions, and assess different aspects of proprioceptive modalities (71, Elganovan, Hermann and Konczak, 2014).

The TTDPM method has been utilised at various joints throughout the human body, involving the researcher controlled machine moving an isolated body segment in pre-determined direction at varying speeds (Cordo et al., 2011;Refshague et al., 1995;). During TTDPM tests involving the ankle joint, participants are placed in a seated position, with peripheral information limited utilising blindfolds and headphones. The body segment in question is then passively moved in a pre-determined direction, with participants instructed to press a stop button when they detect both the movement and direction (Han et al., 2015). Subsequently, TTDPM utilises dynamic proprioception, as the participant must indicate when they believe their specified body segment to be moving. TTDPM methods will not be investigated within the current thesis as previous literature has shown them to be lacking in ecological validity (Elangovan, Herrmann and Konczak, 2014).

AMEDA tests utilise active movements, with participants informed that they will experience differing movement displacements. The participants are allowed one practice trial, thereafter utilising their memory of the movement extents from the familiarisation and practice trials to enable them to identify the various degrees of movement (Han et al., 2015). AMEDA trials represent the greatest level of ecological validity as it seeks to explore proprioception functions under natural conditions utilising normal function and movement (Han et al., 2015) rather than attempting to move a limb in isolation, as seen in TTDPM and JPS. However, with the current thesis aiming to determine ankle function solely, it is speculated that too much proprioceptive contribution will be derived from joints more proximal in the kinetic chain (Han et al., 2015).

In contrast to TTDPM, JPS utilises both passive and active movements, involving either ipsilateral or contralateral limb movements. For ipsilateral JPS, a predetermined target position is passively or actively presented to participant for a period of five seconds. The participant is then required to reproduce the target angle experienced previously, actively moving their limb to what they perceive to be the target position, subsequently measuring static proprioception (Han et al., 2015). Although JPS may not possess the same levels of ecological validity and applicability as the AMEDA tests, it does allow for isolation of the ankle joint when used in conjunction with the IKD. Subsequently, as this thesis aims to investigate

ankle joint function, tests which describe JPS rather than AMEDA and TTDPM will be utilised and discussed further

Proprioception includes the sensations of position and movement of the joints, including sensations related to muscle force, effort and tension, heaviness and stiffness Gandevia, (1996), with JPS being the most frequent proprioceptive test utilised (Refshague, 2003). A reliable clinical test is utilising the IKD Willems et al., (2002) whilst attempting to determine ankle JPS (AJPS), which has been described as the ability of an individual to replicate a pre-determined position (Mohammadi and Roozdar, 2010). Previous literature (Mohammadi and Roozdar, 2010) has reported high levels of reliability ICC = 0.91) for AJPS, thus demonstrating that the results achieved are repeatable and can be interpreted with confidence

The healthy public has been the main population when measuring JPS at the ankle (Hua Lin et al., 2008; Forrestier et al., 2002; South et al., 2007) with only one study, to current knowledge, being conducted using soccer players of an unspecified standard (Mohammadi and Roozdar, 2010). These studies asked their subjects to actively replicate AJPS angles of varying measures from 15° inversion to maximum inversion minus 5° (Mohammadi and Roozdar, 2010), 10 and 20° inversion and 10° eversion (Hua Lin et al., 2008), and 90 and 20% inversion and 90% eversion movements (South et al., 2007). Plantar and dorsiflexion movements were only measured by Forrestier et al. (2002), with measures of -20° and -10° dorsiflexion and 10 and 20° plantar flexion. The aforementioned studies conducted their testing post-localised muscular fatigue (Forrestier et al., 2002; Hua Lin et al., 2008; Mohammadi and Roozdar, 2010; South et al., 2008) whilst (Mohammadi and Roozdar 2010) also conducted a 45-minute soccer specific fatigue protocol. Both protocols induced significant differences for AJPS in the inversion range of motion.

AJPS is important to maintain dynamic joint stability; therefore functional joint stability is the product of proprioception (Glencross and Thornton, 1981). The ability to detect AJPS and make according postural adjustments is thought to be crucial in the prevention of ankle sprains (Willems et al., 2002). Fatigue, whether induced (Forrestier et al., 2002; Hua Lin et al., 2008; Mohammadi and Roozdar, 2010; South et al., 2008) or soccer specific (Mohammadi and Roozdar, 2010) could potentially increase the incidence of ankle sprains in a sport such as soccer, which has shown

that there is disproportionate number of injuries sustained during the latter third of each half (Aoki et al., 2012; Woods et al., 2003).

Clinical/Functional Tests

Star Excursion Balance Test (SEBT)

The SEBT offers a low cost alternative, simple, valid and reliable measure (Olmsted et al., 2002) of dynamic postural control and stability (Hertel et al., 2000). Participants perform a variety of single limb squats, using the free standing limb to maximally reach along a pre designated direction in each of 8 lines at 45° angles to one another (Gribble et al., 2003). Hertel et al. (2006) reported similar scores to the original SEBT when reduced to three directions (anterior, posteromedial and posterolateral), therefore potentially making the 8 movements SEBT redundant. Movements of ankle dorsiflexion, knee flexion and hip flexion range of motion and adequate, proprioception, strength and neuromuscular control are required from the stance leg (Olmsted et al., 2002).

Musculoskeletal pathological conditions, which are typically associated with deficits in postural and neuromuscular control (Gribble et al., 2012), extensively use the SEBT to research an individual's level of dynamic postural control. Chronic ankle instability (CAI) is a lower extremity injury, which has been commonly associated with the SEBT (Arnold et al., 2010; Delahunt et al., 2010; Gribble et al., 2004; Gribble et al., 2007; Olmsted et al., 2002). Impaired SEBT performance indicates a deficiency in dynamic postural control that could be associated with the pathological condition associated in the injured limb (Gribble et al., 2012). Throughout the literature, participants with CAI perform worse on the SEBT than persons with uninjured limbs (Gribble et al., 2004; Hertel et al., 2006; Olmsted et al., 2002). However, although performing the SEBT determines deficits, which are present in subjects with CAI, it does not provide any insight into the mechanisms of ankle sprain occurrence, but rather a link between participant performance and potential injury risk. Therefore it is necessary to understand how the SEBT is linked to healthy individuals and a link to injury.

Plisky et al., (2006) researched the ability of the SEBT to predict lower extremity injuries in male and female high school basketball players. Lower extremity injury incidence was documented throughout the season and compared to SEBT performance. Those athletes with an anterior right to left leg reach differences of > 4 cm were 2.5 times more likely to sustain lower extremity injuries, with Plisky et al., (2006), hypothesising multiple reasons as to why this could potentially be a risk factor for injury. Firstly, reduced distance in one limb potentially could alter the mechanics of how a participant reacts to certain situations, thus causing increased stress to the more adept lower extremity. Secondly, the less adept lower extremity may not provide a stable base for the athlete to land or pivot (Plisky et al., 2006). Having a greater SEBT reach in one direction compared to the contralateral limb could cause muscular imbalances when participating in sports, which require persons to balance and perform sports specific actions on a singular limb. This would produce greater levels of stress, possibly producing greater postural stability, decreased levels of dynamic stability and joint laxity, all of which have been shown to be indicators of ankle injuries.

Biodex Stability Systems (BSS)

The ability of athletes to control their centre of gravity has received a great deal of research attention with regards to being a risk factor for lower extremity injury (Murphy et al., 2003). It has been suggested that variation in postural control is associated with an altered neuromuscular control strategy, intersegmental joint forces and increased forces surrounding the ligamentous structures of the ankle, however the relationship between decreased levels of postural stability and injury remain unclear (McKeon et al., 2008; Murphy et al., 2003). This is in part due to the variety of mechanisms used to test postural stability, whether this is via centre of gravity (Bennyon et al., 2002; Williams et al., 2005a; 2005b) or centre of pressure.

The Biodex Stability System (BSS) is a reliable measure (ICC 0.77) of postural balance (Schmitz and Arnold, 1998; Cachupe et al., 2001) using a multi axial circular platform that is able to move freely around an anterior-posterior (AP) and media-lateral (ML) axes simultaneously (Akhbari et al., 2007), ranging from levels 1 (least stable) to level 8 (most stable) and allowing up to 20° of foot platform tilt, permitting the ankle joint mechanoreceptors to be stimulated maximally (Biodex

Medical Systems, 1999). The BSS objectively measures and records a subject's ability to stabilise the weight-bearing limb (usually dominant) which is placed under dynamic stress, producing measures of overall stability index (OSI), anterior-posterior stability index (APSI) and a medial lateral stability index (MLSI) (Cachupe et al., 2001). The stability index scoring system is quantified as a function of the variance of platform displacement from a flat level (Greig and Walker-Johnson, 2007). Various studies have utilised the BSS using a variety of different levels ranging from levels 2 – 4 (Cachupe et al., 2001; Greig and Walker Johnson, 2007; Rein et al., 201l; Schmitz and Arnold 1998) to investigate injured (Akhbari et al., 2007) and healthy subjects (Greig and Walker Johnson, 2007; Rein et al., 2011) in fatigued (Gioftsidou et al., 2011; Greig and Walker Johnson, 2007) and non-fatigued states. (Cachupe et al., 2001; Schmitz and Arnold, 1998). Postural stability studies have also utilised localised fatigue, in order to isolate specific musculature. Alderton et al., (2003) demonstrated impaired levels of postural control after participants underwent a localised calf fatigue protocol. Similar deteriorations were observed in sedentary individuals after repeated ankle musculature contractions, producing complete exhaustion and/or joint movement reduction by 50% (Lundin et al., 1993; Johnston et al., 1998; Nardrone et al., 1997; Yaggie and McGregor, 2002). However, as previously stated, increased ankle injury incidence is observed in the final third of each half (Hawkins et al., 2001; Ekstrand et al., 2011; Woods et al., 2003), suggesting soccer-specific protocols should be utilised to investigate the effects of fatigue on postural stability.

With a greater injury incidence observed droning the final 15 minutes of each soccer match (Hawkins et al., 2011; Ekstrand et al., 2011; Woods et al., 2003), it is suggested that fatigue must be investigated when discussing postural stability. Additionally, fatigue must be investigated utilising ecologically valid protocols, which can better replicate the demands of soccer match play. Gioftsidou et al., (2011), investigated the effects of soccer training fatigue on measures of postural stability, discovering no fatigue effect between pre and post training. However, it is suggested that the demands of soccer training may not be sufficient enough to evoke a fatigue effect in its participants due to the stop-start nature of soccer training. Additionally, (Gioftsidou et al., 2011) failed to state the level at which the BSS was set to assess postural stability, making it difficult to truly assess the results of this

study. Furthermore, not attempt was made to standardise the physical demands of the soccer training session, with no physiological data reported to infer how difficult the participants found the training sessions. Subsequently, it is suggested that using soccer-specific protocols such as the SAFT[90] will provide ecological validity, whilst also providing a standardised protocol to elicit fatigue.

Greig and Walker Johnson (2007) discovered no relationship between balance and fatigue, contradicting the proposition of fatigue as a risk factor for injury incidence. This is potentially due to the intermittent soccer specific treadmill protocol (Greig et al., 2006) utilised within the study. Participants were required to perform a 90 minute intermittent soccer-specific treadmill tests, which was designed to replicate the demands of soccer match play. However, rather than clustering sprints to elicit a fatigue response as per intermittent team sports (Spencer et al., 2004), sprints occurred on an ad-hoc basis, thus not representing the true profile of soccer. It is also suggested, that using a treadmill to perform soccer-specific activities does not represent the true profile of soccer match play, as all actions on a treadmill occur in a linear direction, whereas soccer is multi-directional in nature in combination with utility movements. Subsequently, the linear direction of the intermittent soccer-specific treadmill protocol utilised (Greig and Walker-Johnson), may not sufficiently fatigue ankle stabilisers such as the peroneal muscles, due to no changes in direction. The lack of ecological validity within the intermittent soccer-specific treadmill protocol (Greig et al., 2006), may potentially explain the lack of fatigue effect observed during the Greig and Walker-Johnson (2007), study. Furthermore, Greig and Walker-Johnson, (2007) set their BSS level at 4 for 30 seconds. Asking participants to stand on a single limb for up to periods of 30 seconds will potentially begin to induce its own levels of fatigue, subsequently detracting from the fatigue sustained during soccer specific protocols. It is therefore suggested that to remove this factor, single leg stance should be maintained for a maximum period of 10 seconds, allowing for a BSS score to be obtained, whilst also preventing fatigue from standing on one limb for a prolonged period. Additionally, it is suggested that if the true effects of fatigue are to be felt by the dynamic stabilisers of the ankle, then a BSS level, which is going to evoke the demands of the game of soccer is required This refers to a level, which is going to cause excessive movements associated with ankle sprains, plantar flexion and supination of the ankle. Literature has

demonstrated soccer players to possess balance levels, which are only inferior to those of dancers and gymnasts (Bressel et al., 2007; Davlin, 2004; Gerbino et al., 2007; Matsuda et al., 2008). This suggests that studies which employ greater levels of stability (Greig and Walker-Johnson, 2007) may not provide sufficient stimuli to effectively test soccer players true balance capabilities. Therefore, it could be proposed that the BSS level needs to be decreased to a level 2 to induce such movements. Both Gioftsidou et al., (2011) and Greig and Walker-Johnson (2007) induced fatigue via soccer specific mechanisms, however Gioftsidou et al., (2011) used a soccer training session to fatigue their athletes and thus may not be standardised.

Drop Landing

Holmes and Delahunt (2009) suggested that studies should investigate the effects of dynamic neuromuscular protocols on established ankle joint injury risk factors and sensorimotor control. Quantifying biomechanical variables of vertical ground reaction force (VGRF) and the degree of maximal ankle inversion are well established methods of determining loads attenuated by the body, whilst also quantifying the amount of ankle joint perturbation, defined as an unconscious reaction to a sudden outside force or movement (Cortes et al., 2011), experienced by the ankle during the dynamic landing test. One such test which will produce these functional movements is the drop landing and drop to jump tests O'Driscoll et al., (2011), which require subjects to step off a platform from a pre-determined height, ranging from 20 to 60cm (Cortes et al., 2011; Dicus and Seegmiller, 2012; Kernozek et al., 2005; Mache et al., 2013; O'Driscoll et al., 2011; Weinhadel et al., 2011) to measure multiple ranging from kinematic (joint positions and movements), kinetic (ground reaction forces) (Cortes et al., 2011; Dicus and Seegmiller, 2012; Kernozek et al., 2005; Mache et al., 2013; O'Driscoll et al., 2011; Weinhadel et al., 2011) and EMG activity in the form of muscle latency Dicus and Seegmiller, (2012), with the aforementioned studies using subjects ranging from healthy adults, recreational athletes and female collegiate soccer players. These variables can be measured in the form of static balance from landing (Dicus and Seegmiller 2012; Kernozek et al., 2005; Mache et al., 2013) to landing into vertical jump height (Cortes et al., 2011; Weinhadel et al., 2011) or in a dynamic direction Cortes et al., (2011).

When landing a jump in soccer or during a drop jump test, effective attenuation of the biomechanical loads experienced when landing, requires ankle plantar flexion and usually ankle inversion, which have been shown to be movements which precede an ankle injury (Gribble and Robinson, 2009). During the stabilisation period after landing, both dorsiflexor and evertor muscles, which include the peroneal muscles activate to stabilise the joint (Dicus et al., 2011). The period between joint perturbations and muscle activation is known as the latency period and is a reliable indicator to sudden inversion stress (Kernozeck et al., 2008), which may be extended in sudden eversion events, which typically result in ankle injury (Dicus and Seegmiller, 2012). In movements, which produce unanticipated landing, the time from surface contact to muscle activation increases (Dicus and Seegmiller, 2012). Subsequently, to design more functional and valid drop landing tests, an unanticipated component must be included to greater mimic the demands of soccer.

Understanding how the lower extremities respond to single limb dynamic balance such as the SEBT or Biodex Stabilometer is extremely useful. However, when playing a sport such as soccer, single limb stance does not always occur from a standing position. Soccer is a stochastic, acyclical sport, which is made up of a variety of movements such as sprinting, twisting, turning, cutting and landing (Nicholas et al., 2000; Wragg et al., 2000). One of the widely accepted mechanisms of an ankle sprain is that of the aberrant nature of ankle joint positioning upon initial contact with the surface during the transition period from a unloaded to loaded state, for example, those seen in activities such as jumping or running in soccer (Wright et al., 2000). Therefore, it is important that postural stability, JPS and reaction time are tested from a position that does not start in a standing balanced position. Additionally, it is vital to ensure that the drop landing tests are reactive rather than prescriptive to provide more functionality to the tests. As stated earlier, many drop landing tests performed have been done so in a static or vertical finishing position, which only accounts for a small proportion of soccer specific movements (Bloomfield et al., 2007). Therefore, it is necessary to test high ability soccer players, whilst providing them with stimuli which they will need to react to, in an attempt to mimic both decision-making and soccer specific actions such as cutting and changes

of direction. This will place the ankle into greater lateral eversion and supination (Wright et al., 2000), which are more likely to mimic positions that cause ankle injuries, therefore providing more pertinent information on potential mechanisms.

Current research has focused mainly on landing test protocols, which assess time to stabilisation or angular joint displacement after stepping or jumping down as an outcome of postural control (Eeachaute et al., 2009). However, kinematical studies require a laboratory setting, which often uses expensive equipment requiring detailed analysis, with the method of analysis differing between studies (Eeachaute et al., 2009). Therefore it is of great use to be able to assess dynamic postural control using cheaper and less sophisticated tests, which are still valid and reliable.

Many tests have attempted to investigate the relationship between ankle injury risk factors and the incidence of injury. However, various tests have been conducted in a manner which does not replicate the demands of soccer, with tests either being conducted at too low a speed, a platform that is too stable to replicate postural stability or tests which do not have a real functional relevance to soccer and the injuries which it sustains. It is, therefore, necessary to implement a multi modal testing battery, which better replicates the demands of soccer, thus adapting some pre-existing protocols. Relevant tests then need to be tested under the influence of soccer specific fatigue.

2.6 Summary

The epidemiology and aetiology of ankle sprains has been previously well described, demonstrating a multi-modal aetiology. Subsequently, many forms of functional assessment claiming to measure ankle joint function have been devised in an attempt to reduce injury incidence. When considered in a univariate manner, individual tests such as the BSS, JPS and IE vary in their ability to highlight potential injury risk factors as they are discriminative in nature, investigating singular functions of ankle joint function such as postural stability and proprioception. However, when combined with a multitude of tests, informed by ankle aetiological risk factors, these tests may combine to provide a greater holistic insight into ankle joint function, potentially highlighting correlations between tests and their mechanistic determinants.

Furthermore, intervention strategies have been developed specific to a function, or are multi-modal in nature, to better replicate mechanisms of injury.

This thesis aims to observe the van Mechelen model (van Mechelen, Hlobil and Kemper, 1992), using the already well established epidemiology data regarding ankle injuries, whilst attempting to determine whether commonality in performance exists across a multi-modal battery of tests, thus considering injuries in a multi rather than univariate manner. In addition to this, with fatigue now commonly accepted as an aetiological risk factor due to the increase in injury incidence observed in soccer match play, the thesis aims to provide a greater level of ecological validity to the field, through investigating aetiological risk factors under soccer-specific fatigue. The aforementioned research will help to arrive at the ultimate aim of the thesis, which considers the final stage of the injury prevention model (van Mechelen, Hlobil and Kemper, 1992), producing a research-informed, evidence-based, ankle injury intervention programme utilising an appropriate setting and population.

Chapter 3: General Methodology

Identification of Research Participants

Semi-professional and professional level soccer players volunteered to participate in the studies contained within this thesis. Participant's eligibility was determined using stringent inclusion and exclusion criteria. Inclusion criteria required players to have no previous injury history in the lower limb for the previous six months, neurologic or balance disorder or chronic ankle instability as determined by the Cumberland Ankle Instability Tool. In addition to weekly match-play, participants were also required to participate in soccer-specific training volumes equating to > 4 hours per week during the season. Participants were also excluded from the studies if their medical history indicated that they possessed any cardiovascular and/or pulmonary disease.

Retrospectively, professional training history was also implemented for inclusion/exclusion criteria, due to two participants in studies 1-3 being removed from the thesis as they were identified as outliers upon data analysis.

Removal of Outliers

The removal of outliers from studies creates much academic debate (Osborne and Overbay, 2004). An outlier is defined as a data point that is far outside the norm for a variable or population (Jarrell, 1994). Hawkins (1980) further expanded on this statement, identifying an outlier as deviating so much from other observations as to arouse suspicions that it was generated by a different mechanism. Subsequently, the presence of outliers can produced inflated error rates and substantial distortions when using parametric tests (Zimmerman, 1998). Additionally, outliers can have deleterious effects on statistical tests through increasing error variance and reducing the power of statistical tests. Furthermore, if non-randomly-distributed, outliers can decrease levels of normality, altering the chances of creating both type I and II errors. It has been argued that if the outlier is a legitimate part of the data or the cause creating the outlier is unclear, choosing whether to remove or include outliers become less transparent (Osborne and Overbay, 2004). Judd and McClelland (1989), argue that outliers should be removed in all cases, so to produce amore honest

reflection of the population and parameters. However, Orr Sackett and DuBois (1994) disagree, stating that outliers should remain within the analysis, as it is more likely to provide a greater representation of the population.

Osborne and Overbay (2004) state that researchers must use their academic training, intuition and reasoned arguments when deciding whether to remove outliers. Within studies 1-3, two participants were removed from the studies due to data analysis demonstrating their results to violate the assumptions of normality. The reason for this could potentially be due to the fact that the two participants who were removed from the studies did not possess the same level of professional soccer training during their youth football careers compared to the remaining participants. Subsequently, reduced training history may create anomalous scores, thus providing the author with a reasoned argument to remove the participants from the study (Osborne and Overbay, 2004). Although it could be argued that removing the outliers from the study decreases the overall representation of the population (Orr, Sackett and DuBois, 1994), it has been demonstrated that by doing so errors of inference are significantly reduced, thus providing a strong rationale for the removal of outliers

Ethical Considerations

All participants were informed of the testing procedures and risks involved with participating in physical testing prior to the commencement of any of the studies. Participants were then provided with written informed consent in accordance with university ethical procedures and following the principles outlined in the Declaration of Helsinki. All equipment utilised within the studies was risk assessed and calibrated in accordance with the specific manufacturer guidelines prior to data collection.

Statistical Power

Determining an optimal sample size before commencing research is an important ethical consideration (Sedgwick, 2013), as trials need to be adequately powered. If the sample size is too small it will not possess sufficient power and may fail to detect the smallest effect of clinical interest, if it existed within the given population (Sedgwick, 2013). Underpowered studies are deemed to be unethical as it suggests

that time, effort and resources may be wasted in performing a trial that has the potential to show clinical significance (Sedgwick, 2013). Conversely, if too large a sample size is recruited, the trial would be overpowered to demonstrate the smallest effect of clinical interest (Sedgwick, 2013). Subsequently, a target value of 0.80 is conventionally determined for statistical power, demonstrating a likelihood that four times out of five, a null hypothesis will be correctly rejected (Fox and Mathers, 1997).

A range of values will be determined from pilot testing data, to demonstrate that each study within the thesis possessed adequate statistical power

Pre-Exercise Measurements

To further determine participant suitability for all studies, participants were required to complete a thorough and comprehensive health screening procedure. This procedure implemented tests concerning both heart and blood pressure (Omron. Mx3 plus, Netherlands), with values of > 90 b·min^{-1} and > 140 mmHg/ 90 mmHg respectively, indicating a contraindication to exercise. Prior to the commencement of each individual study, each participant's age (yrs), height (cm) and mass (kg) were recorded using a wall-mounted stadiometer (Holtain, Harpenden HSK-BI, UK) and top pan scales (Seca, Germany) respectively.

Experimental Design and Controls

To account for circadian variation (Klein et al., 2007), all experimental trials with the exception of study 2, were conducted between the hours of 19:00 – 22:00 in accordance with participants regular training and match-play times (Rae et al., 2015). All data collection was conducted in ambient controlled laboratory settings, with both temperature and humidity maintained at 21.5 °C and 35 ± 1.5% respectively. For each study, participants were asked to consume 500ml of water 2 hours prior to testing and refraining from consuming caffeine 24 hours prior to exercise commencement. Additionally, participants were required to attend testing sessions in a 3 hour post-absorptive state, following a period of 48 hours abstinence from all types of vigorous exercise and alcohol. For all studies, participants were required to wear their club training shorts, t-shirts and trainers in an attempt to standardise

clothing worn. Prior to the completion of each testing session, participants undertook a ten-minute standardised warm up protocol, consisting of light jogging and self-directed stretching

During the completion of the exercise trials, where the exercise protocol and equipment allowed, participants were allowed to consume water only ad libitum. No additional drinks or food were allowed to be consumed during the completion of any of the trials. For all experimental trials, only one male researcher and the participant were present, as previous research has identified that physiological response, perceptions of effort and performance may be influenced by both the gender (Winchester et al., 2008) and the number (Rhea et al., 2003) of researchers/observers. Additionally, no visual or verbal feedback was provided during any of the experimental trails, in an attempt to reduce the potential performance enhancing benefits (Andreacci et al., 2002) may possess.

Reliability

General reliability is defined as the consistency and/or the reproducibility of a measure (Atkinson and Nevill, 1998), with Hopkins (2000) stating test-retest reliability to be one of the most imperative aspects of research, critical to the understanding of measurement error. Assessment of test-retest reliability was conducted in all studies using intra-class correlation coefficients, with 95% Confidence Intervals (CI) and Standard Error Mean (SEM) (calculated as standard deviation x $\sqrt{1 - ICC}$) (Weir, 2005). SEM suggests absolute reliability, as it measures real changes in the context of measurement error (Battrham and George, 2000). ICC analysis was chosen as the predominant measure of reliability, as the more traditional Pearson's product moment coefficients are potentially biased to smaller sample sizes (Hopkins, 2000), subsequently being discredited in academic literature (Atkinson and Nevill, 1998). Furthermore, ICCs have the potential to differentiate amongst individuals and state the extent as to which the participants maintain their position in the sample across repeated measures trials (Batterham and George, 2000). To determine the ICC scores, measures of each variable were recorded once the participants were completely familiarised during the familiarisation session, then once again after the practice trials on the first testing

session. ICC values were interpreted according to the following criteria (Coppieters et al., 2002)

- Poor = < 0.40
- Fair = 0.40 - 0.70
- Good = 0.70 – 0.90
- Excellent = > 0.90

Isokinetic Dynamometer (IKD) Inversion and Eversion Ratio (Studies 1 – 3 only)

Calibration of the IKD (System 3, Biodex Medical Systems, New York) occurred before each testing session to ensure valid and reliable results, with participants positioned according to manufacturer guidelines. In accordance with Hartsell and Spaulding, (1999) four submaximal trials (50% effort) were followed by five maximal effort concentric/eccentric reciprocal contractions at a velocity of 60°/s for both IN and EV. Isokinetic data were analysed during the isokinetic (constant angular velocity) phase of the movement, which was determined by the velocity signal. At 60°/s, the maximum isokinetic torque output was identified for both IN. and EV movements. Mean peak torque values were then calculated from the second, third and fourth repetition, with the IE ratio derived from this. A two minute rest period was permitted between tests for IN and EV to prevent accumulation of fatigue (Hertsel and Spaulding, 1999). Reliability analysis stated the ICCs value for IE, T_e and T_I to be 0.85, 0.92 and 0.91 respectively for the current thesis, thus demonstrating good to excellent levels of reliability for the IE test (Coppieters et al., 2002). These results correlate well with ICC results observed in academic literature, with Ozyemisci et al., (2013) demonstrating test-retest reliability scores ranging between 0.86 and 0.92 for isokinetic measures of ankle strength using the IKD (Ozyemisci et al., 2013). Furthermore SEM results provided absolute reliability scores for the current thesis ranging between 1.31 – 1.38, producing lower scores than the 1.23 – 6.12 observed in academic literature (Kaminski and Dover, 2003).

Results reported for this procedure are the invertor/evertor ratio (IE).

Ankle Joint Position Sense (Studies 1 – 3 only)

Measurement of JPS was assessed using an Isokinetic Dynamometer, which has been reported as a valid tool (Willems *et al.,* 2002). All participants were positioned in accordance with manufacturer guidelines. To reduce cutaneous receptor input, the barefoot of the dominant foot of the participant was aligned with axis of the dynamometer and attached to the footplate by a small wrap (Mohammadi and Roozdar, 2010). The talocrural joint was then placed into 15 degrees of plantar flexion, with the lower leg secured using hooks and loops. Two target positions were tested, 15 degrees of IN (θ_{15}) and maximal active IN minus 5 degrees (θ_M). To eliminate any visual feedback, the subjects were blindfolded to offset any other feedback other than internal proprioception. All participants were afforded a chance to familiarise themselves with the procedure, with the subjects being allowed three experimental trials (Mohammadi and Roozdar, 2010). Participants were initially passively moved into the desired target position and held there for a period of 5 seconds, with instructions provided to concentrate on the position of the foot, which was then passively returned to the starting position at a speed of 5 °/s. Once returned to the starting position (anatomical neutral), the participant was instructed to actively move their dominant foot to what they perceived to be the desired testing position and push a stop button when they believed they had found this. The participant's foot was then passively taken back to the anatomical neutral position, at which point the procedure was then repeated a further two times (three in total per set), with participants provided 30 seconds of rest between each set. ICC scores of 0.87 and 0.89 were recorded for θ_{15} and θ_M respectively, correlating with the reliability scores of 0.86 – 0.92 observed in current academic literature (Mohammadi and Roozdar, 2010). Subsequently, tests of JPS have been shown to demonstrate good to excellent levels of reliability for AE scores. Strimpakos et al., (2006), demonstrated cervical spine SEM scores ranging between 1.20 – 3.00, indicating a higher level of error in their scores when compared to the current thesis (0.16 – 0.21). Subsequently both Θ_{15} and Θ_M, demonstrate high levels of reliability, both in terms of ICC and SEM, indicating absolute reliability amongst the results.

Absolute error results were taken from the participant's scores, this being the difference between the actual position the subject is asked to achieve and the position they actively move their ankle too, to replicate the original position. Results reported for this procedure are JPS at 15° (θ_{15}) and (θ_M).

Biodex Stability Systems (All Studies)

Postural stability was assessed using the Biodex Stability Systems (BSS) (Biodex Medical Systems, Shirley, NT, USA). Participants were required to step onto a circular platform with their dominant foot, in a position which felt comfortable whilst being able to centre a visual stimulus on an electronic screen directly in front of them. At this point, the participant's foot co-ordinates (vertical and horizontal) were recorded and inputted into the BSS. The BSS was set to an unstable level 2 setting with participants required to maintain their balance by attempting to maintain a visual cursor on a screen as close as possible to the centre of a specific marker for 10 seconds. Participants were provided 2 familiarisation trials, followed by 2 practice trials (Capuche et al., 2001) with one minute between each trial. The BSS was utilised to objectively record and evaluate dynamic (degree of axis tilt from the level platform) conditions, with task performance being quantified as according to the deviation of the platform during the task. Measurements were recorded for the Overall Stability Index (OSI), which is a function of the variance of platform displacement, whilst stability was also quantified in both the A/P and M/L planes of movement. High levels of reliability have been demonstrated with the BSS, with test-retest intraclass correlation coefficients ranging between 0.65 and 0.77 for indices OSI, AP and ML (Arifin et al., 2014). For the same test and level, the current thesis demonstrated ICC reliability scores ranging from 0.76 – 0.87 for measures of AP, ML and OSI, thus demonstrating good levels of reliability (Coppieters et al., 2002). Arifin et al., (2014), demonstrated good SEM scores (0.22 – 0.39) using the BSS to measure dynamic balance. However, these results are slightly higher than those observed in the current thesis (0.07 – 0.11) for the same measures, indicating high levels of reliability for the BSS using both ICC and SEM.

Results reported for this procedure are Overall Stability Index (OSI), anterior/posterior (AP) and medio-lateral (ML) deflection.

Star Excursion Balance Test (All studies)

The SEBT was performed barefoot, using the modified three directions (anterior, posteromedial and posterolateral) recommended (Hertel et al., 2006). Participants placed their hands on hips and maintained contact between the ground and the heel of the standing foot, reaching as far as possible along each of the three directional components to touch with the distal portion of the non-dominant foot. Participants performed four practice trials for familiarisation, followed by three test trials (Robinson and Gribble, 2008). The trials began when the participant left a double-footed stance and finished upon return to the original bipedal position (Delahunt et al., 2010). The reaching distance was recorded from the centre of the grid to the marked point of maximum reach for each direction. The sum of the three directional distances ($SEBT_T$) was recorded as the outcome measure of this task. Anterior (A_D), posterior-lateral (PL_D) and posterior-medial (PM_D) reach distances were recorded as performance predictors. Good to excellent levels of reliability were observed for measures of A_D, PL_D, PM_D and $SEBT_T$, with scores ranging from $0.85 - 0.93$, similar to the ICC scores of $0.83 - 0.94$ observed in current academic literature (Hyong et al., 2014). Munro and Herrington (2010) produced SEM scores ranging from $2.2 - 2.9\%$ of the mean, when measuring SEBT raw distances. These scores are in direct correlation with those observed in the current study ($2.5 - 2.96\%$), thus indicating high levels of reliability in terms of ICC and SEM, suggesting that an individual participant's true score would lie within this range.

Electromyographic Analysis (EMG) (Studies 1 – 5 only)

During performance of the postural stability tasks, participant's electromyographic (EMG) Surface EMG was applied to the dominant leg, Tibialis Anterior (TA), Peroneus Longus (PL) and Lateral Gastrocnemius (LG). Prior to this application, the participant's skin was shaved, abraded and cleansed with 70% isopropyl alcohol before pairs of disposable silver chloride passive wet gel surface electrodes (inter-electrode distance 2cm) (Noraxon, Noraxon USA inc, Arizona, USA) were placed on the skin of the muscles in accordance with SENIAM (Surface Electromyography for

the Non-Invasive Assessment of Muscles) guidelines, in accordance with muscle fibre alignment. A two snap lead was used to connect the electrode to a small telemetric module, which have a small built in reference module, transmitting EMG data telemetrically to a personal computer.

Due to the fact that the peroneus longus is long, thin muscle, the surface EMG signal was checked for crosstalk. Crosstalk is defined as signal contamination due to the close proximity of other muscles (Basamajian and De Luca, 1985). To help reduce the possibility of crosstalk occurring during all studies, the participant's EMG signal for both PL and TA were checked prior to test performance. This method of crosstalk verification required the participant to lie supine on a plinth with the EMG electrodes already applied using the previously mentioned techniques. Participants were then asked to actively place their foot into a position of plantar flexion and eversion, in order to produce a response from the peroneus longus muscle. The EMG trace for both PL and TA was then visually inspected to determine whether the shape of the signal was similar, as this would be indicative of crosstalk occurrence. The same process was then repeated for the TA muscle, with subjects asked to place their foot into dorsiflexion, with the EMG signal again visually inspected for similarities. If similarities were detected, the electrodes were removed and re-applied according to Seniam guidelines. In addition to this small inter-electrode distances were selected to reduce the prospect of cross talk occurrence (Kondrad, 2006).

Often within EMG research, a normalisation method is employed to allow participant comparison in addition to allowing data to be compared over a period of time (Sinclair et al., 2012). The EMG signal during dynamic activity is normalised in relation to reference amplitude, most commonly a maximal voluntary contraction (MVC) (Burden and Bartlett, 1999), allowing for the raw EMG amplitude to be rescaled as a percentage of the reference value (Burden and Bartlett, 1999). However, MVCs are often performed using an isometric contraction, subsequently questioning their relevance and ecological validity when using tasks, which require dynamic movements involving isotonic contractions. Sinclair et al., (2012), demonstrated low levels of reliability when utilising MVCs as a reference point in trained male cyclists, raising questions with regards to the suitability of MVCs during dynamic tasks. Furthermore, as the studies utilising EMG in this thesis

employed a repeat measures design, it was deemed that an MVC would be made redundant as the participants were being compared against their own data. Subsequently, normalisation methods were not performed for EMG analysis for all studies in this thesis, due to their lack of ecological validity in tasks, which require dynamic movements such as sprinting and postural stability

During experimental trials, EMG activity for each 10 second period of the BSS task and the full the duration of the SEBT was recorded in addition to the time taken to perform the cutting maneuverer onto the force plate during the sprint task. EMG signals demonstrate an interference pattern of a random nature, due to the fact that the recruited motor units constantly change throughout movement (Kondrad, 2006). Subsequently, a raw EMG signal cannot be reproduced with the exact same shape a second time, requiring the non-reproducible part of the signal to be reduced using applied digital algorithms, which outline the mean trend of a signal. (Kondrad, 2006). Within the Noraxon software, there are two main smoothing algorithms, Moving Average (MOVAG) and RMS. RMS reflects the mean power of the EMG signal and is the preferred recommendation for smoothing (Basmajian and de Luca, 1985). Once the RMS algorithm is applied, it defined for a defined epoch, which is recommended to be between 50 and 100ms (Konrad, 2006), to account for dynamic human movement.

Collected EMG data was saved and analysed using the Noraxon software (MyoResearch XP, Noraxon USA Inc, Arizona, USA). Upon completion of a sensitivity analysis, a high pass filter of 20 Hz was implemented to process the raw EMG data in an attempt to remove movement artefacts, whilst data was smoothed using root mean square (RMS) of a 75ms time constant. Once smoothed, the rectified EMG signal was then analysed to determine the EMG_{Mean} value, as this best describes the gross innervation of a selected muscles for a given task and works best for competition analysis (Renshaw et al., 2010). EMG_{Mean} is a standard amplitude parameter similar to EMG_{Peak}, subsequently it produces a data reduction of a given portion to one value. Furthermore, the amplitude mean value of as selected analysis is probably the most important EMG calculation, as it is less sensitive to duration differences of analysis intervals (Renshaw et al., 2010). Moreover, EMG_{Mean} is a robust enough measure to both movement artefact and time, thus providing a reliable

average of EMG activity over the entire movement. Good to excellent ICC scores were observed for the LG (0.77), PL (0.92) and TA (0.96), indicating the methods used for EMG to be reliable and consistent in nature. These results are similar to those observed in current academic literature (Murley et al., 2010), who demonstrated ICC scores ranging from 0.93 – 0.96. EMG as a measure demonstrates varying absolute reliability ranging between 1 and 35%, due to the fact that the same identical signal cannot be reproduced (Oskouei et al., 2013). The current thesis produces SEM scores ranging between 8.65 and 18.35% of the EMG_{Mean} signal, thus occurring within the limits suggested as acceptable (Oskouei et al., 2013).

Drop Landing (Studies 1 – 3 only)

During performance of the drop and drive-landing test, participants were required to step off a 35cm high platform (O'Driscoll et al., 2011) positioned to ensure landing was centred on the force platform (Bertec, Columbus, USA). Participants were required to step off the platform onto their dominant limb using a heel-to-toe landing technique. Before performing the landing, the participants passed through a set of timing gates (SmartSpeed, Fusion Sport, Australia), automatically stimulating a light response in one of three directions. Upon landing, participants were required to react to the light stimulus, thus producing a self-determined drive phase, accelerating through a set of timing gates positioned at a 45° cutting angle from the mid-line of the force platform, at a distance of 4m. IN and EV trials were counter-balanced, with five minutes passive recovery between trials. Data presented here were measured during the inversion trial, given the relevance to the mechanism of ankle injury. The eversion trial was included to ensure a reactive task.

Performance was quantified as the time taken to complete the task. Kinetic measures at a sampling frequency of 1000 Hz were obtained in the medio-lateral (Fx), anterio-posterior (Fy) and vertical (Fz) movement planes. All drop landing force plate data collected were transferred into an individual subject specific Excel work spread sheet (Microsoft Office Excel 2013). Microsoft Excel was used to crop the data, produce force overtime graphs and highlight the times at which peak forces were obtained (Figure 3.1). Analysis of the ground reaction force data enabled the measurement of peak impact force in each direction (vertical (Fz), medio-lateral (Fx) and anterio-posterior (Fy), the duration between impact and initiation of the drive phase (I-D),

peak forces and rate of force development in each direction for the drive phase ($\dot{F}$), angle of take-off (θ) towards the timing gate and time to complete the task. The resultant of the medio-lateral and anterio-posterior forces (Fxy) was used to calculate the rate of force development along the angle of take-off. Equations (Figure 3.2) were then used to calculate θ and Fxy respectively.

The drop and drive task, is a novel test, subsequently no previous reliability scores are available to compare the results of this thesis too. However, good to excellent ICC scores were recorded ranging between 0.86 and 0.97, for measures of Fz, Fy, Fx, I-D, θ AND T, indicating the drop and drive test to produce extremely reliable and consistent results. When measuring $\dot{F}$, it has been suggested that SEM scores < 10% are arbitrary and considered small, indicating high levels of agreement (Casartelli, Lepers and Maffiuletti, 2014). Results of the current thesis suggest $\dot{F}$ SEM scores to occur within 2.94 − 7.16%, indicating high levels of agreement for both ICC and SEM.

Results reported for this procedure are D T (time taken to complete the task), D θ (angle of cut from the force plate) and D Fxy (resultant force at the point of leaving the force plate).
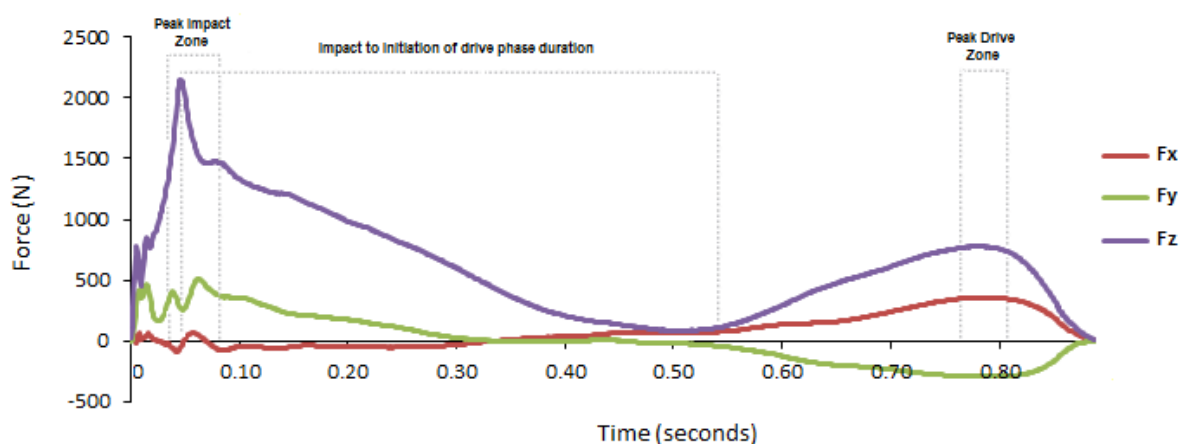
Figure 3.1 Example of force plate trace with superimposed data collection periods

$$Tan^{-1} = \frac{Fy}{Fx}$$

$$R = \sqrt{Fx^2} + Fy^2$$

Eq 3.1 Equations used to determine angle of take-off and resultant forces respectively

Qualisys (Studies 4 – 5 only)

Three dimensional kinematic analysis was carried out using Proreflex infrared cameras (Qualisys, Inc. Sweden; 658×500 pixels) with the sample frequency set at 200 Hz. Along with two wall mounted cameras, three additional cameras on 1.5 m tripods were strategically positioned around the BSS and SEBT measurement area to ensure each marker could be visible by at least two cameras at all times throughout each movement. Three reflective markers (25 mm spheres) were placed on selected dominant lower limb landmarks (Fifth metatarsal, lateral malleolus and the head of the fibula) to calculate the motion and angle of the ankle join in the sagittal plane. To ensure the markers remained in position, the skin was first cleansed and dried, before the markers were applied to the skin using double-sided adhesive tape. Prior to data collection, the capture volume was calibrated according to Qualisys (Qualisys, Inc. Sweden) guidelines. To do so, a dynamic method was used whereby a two-marker wand of known length (749.9 mm) was moved around the whole capture volume while a stationary reference object, a L-frame (dimensions: 850×650 mm) containing four markers of known locations to the system, was used to define a right-handed coordinate system for motion capture. Marker information, which was lost due to a marker falling off the model or due to marker occlusion (Federolf, 2015), resulted in data gaps, which compromised the accuracy of the recorded data (Chiari et al., 2005). To counter this, the Qualisys Track Manager software (Qualisys AB, Gothenburg, Sweden), includes a basic gap filling method for missing marker points, utilising a spline interpolation or reconstruction of markers in a local segment coordinate system. Utilising both underwrap and a portable and static camera set up allowed for maker data capture to occur seamlessly. Underwrap help to better secure the reflective markers to the participants, whilst utilising both a portable and static camera set up allowed the markers to remain in view for the vast majority of data

collection. In situations where marker drop out occurred for less than 200 ms (Howarth and Callaghan, 2010), reconstruction of the markers provided a satisfactory solution to the problem (Federolf, 2015), thus allowing for gap fill trajectory to occur.

The Qualisys Track Manager (QTM) software ® was used to record the trials. BSS kinematic measures were recorded for the full 10 seconds of the trial, with measures angle change determined via subtracting the final from the start position. Kinematic measures of SEBT were determined using the same formulas and can be found using the prefix SEBT instead of BSS. Reliability analysis of Qualisys measures for both the BSS and SEBT, demonstrated good to excellent levels of reliability, with scores of 0.84 – 0.93 observed for all tasks.

KT Application (Studies 3 and 4 only)

Before tape application, the lower shank of the dominant leg was cleaned using alcohol gel, before being thoroughly dried using a clean towel in order to allow the glue's acrylic ability to adhere to the skin (Kase, Wallis and Kase, 2003). The tape was applied to the dominant limb using a corrective application technique in accordance with the KT® application guidelines, shown in Figure 2.3**.** The participant lay on a plinth in a supine position with the foot placed in relaxed position. The first strip of tape was placed from the anterior mid foot, stretched approximately to 115-120% of its maximal length and attached just below the anterior tibial tuberosity over the tibialis anterior muscle. The second strip began just above the medial malleolus and wrapped around the heel like a stirrup, attaching just lateral to the first strip of tape. The third strip stretched across the anterior ankle, covering both the medial and lateral malleolus. Finally, the fourth strip originated at the arch and stretched slightly, measuring 4-6 inches above both the medial and lateral malleolus. All KT was applied by the same qualified practitioner, so as to increase both consistency and reliability of application.

Figure 3.2 Application of KT$_1$ and KT$_2$

Heart Rate (Studies 4 – 6 only)

Heart rate was continuously monitored throughout the SAFT[90] trial using short-range radio telemetry (Polar Team System, Polar Electro; Kempele, Finland), sampled every five seconds. Mean heart rate was calculated for each 15-minute period of the protocol, with extra measurements taken at rest (HR$_{00}$) and at the end of half-time (HR$_{60}$). Good levels of reliability were observed for HR, with an ICC score of 0.88 recorded and SEM scores of 2.06% of the mean, similar to those observed (2.00 – 9.00%) when studying the effects of submaximal exercise and HR (Lamberts et al., 2004)

Blood Lactate (Studies 4 – 6 only)

Blood lactate (BLa) concentration was measured at rest (BLa$_{00}$), the beginning of the half time period (BLa$_{45}$) and immediately once the trial had finished (BLa$_{105}$). Prior to taking a capillary finger-tip blood sample, the area was cleansed with an alcohol wipe, with the skin punctured using a disposable automated lancet device (Accu - Check Safe-T-Pro, Indianapolis, USA). The first blood drawn to the area was wiped, with pressure then applied to the finger in order to fill a 5-µl capillary blood sample Lactate Pro reagent strip directly from the fingertip site. The Lactate Pro reagent strip was then placed into a Lactate Pro 2 analyser (Lactate Pro, LT-1710, Arkray KDK, Japan), providing an immediate measurement of the BLa value. This device is a reliable measurement for the assessment of whole blood lactate (Pyne, Boston,

Martin and Logan, 2000). Reliability analysis stated an ICC score of 0.77 for BLa, indicating good levels of reliability for this method.

Accelerometry (Studies 4 – 6 only)

Tri-axial accelerometer data was sampled at 100 Hz, and located within a GPS unit (MinimaxX, S4, Catapult Innovations, Scoresby, Australia). The GPS device was placed in a pouch located at cervical spine C7 in neoprene vest worn by the participant, to standardise the position of the device and prevent any unnecessary movements. PlayerLoad™ was calculated as the square root of the squared instantaneous rate of change in acceleration in each of the three movement planes (Boyd, Ball and Aughey, 2011). Accumulated load over each 15min bout of exercise was quantified in the medio-lateral (PL_{ML}), anterio-posterior (PL_{AP}), and vertical planes (PL_V), which comprise to produce a total score (PL_{Total}). The relative contribution of each individual vector to total load was also quantified. Barrett et al., (2014), identified moderate to high (0.80 – 0.93) interclass correlation coefficients, for test re-test reliability during treadmill running for measures, PL_{Total}, PL_V, PL_{AP} and PL_{ML}. These results are lower than those observed within the current thesis, with ICC scores ranging from 0.95 – 0.98 for measures of PL_{AP}, PL_{ML}, PL_V and PL_{Total}, indicating excellent levels of reliability for all accelerometry measures. Furthermore, when determining PL SEM scores as a percentage of the mean value, the current study thesis indicated results ranging between 0.64 – 1.22%. These SEM values are below the 5% suggested in the literature (Jennings et al., 2010) as an acceptable level of reliability for sports analysis technology, thus indicating high levels of reliability.

Soccer Aerobic Field Test (SAFT90) Exercise Protocol (Studies 4 – 6 only)

The SAFT[90] is a free running protocol designed to replicate the physiological and biomechanical demands of soccer performance, designed using contemporary time-motion analysis data from English Championship level matches, 2007 to develop a 15 minute audio activity profile, which is repeated six time to total 90 minutes. The protocol incorporates frequent acceleration, decelerations and utility movements over a 20m course, with four poles positioned which the participants are required to navigate, performing either forwards, backwards or sideways running around the first pole, followed by cutting through the middle three poles
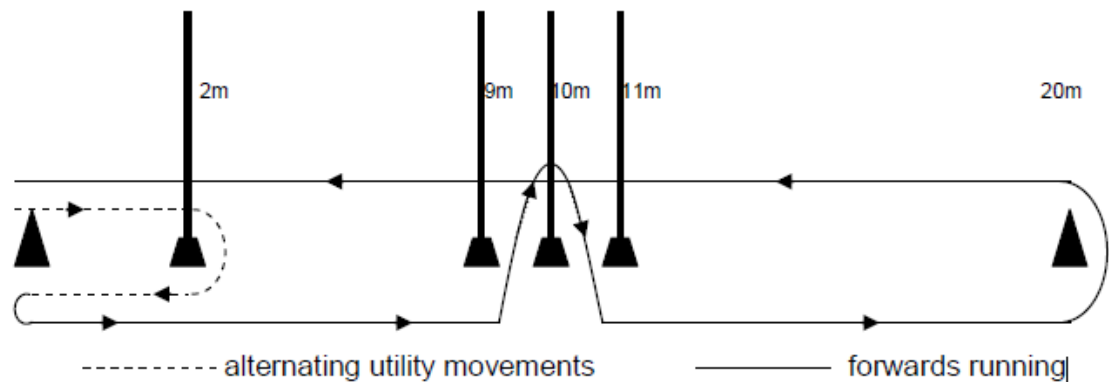
Figure 3.3: A diagrammatic representation of the SAFT^{90} field course

The activity profile is performed in an intermittent and randomised manner, using command signals from the audio CD which the participants need to respond to, incorporating 1269 changes in speed, approximately every 4.3 seconds and 1350 changes in direction over the 90 minute duration, which concurs with the 1250 activities involved in soccer match play (Mohr et al., 2003).

Physiological measures of HR and BLa were recorded at T_0, T_{45} and T_{105}, with measures of dynamic balance, postural stability, EMG (studies 4 – 5) and kinematic analysis (studies 4 – 5) recorded at the end of each 15 minute cycle of the SAFT^{90} (T_{00}- T_{105}), whilst GPS was recorded continuously throughout the trial. Load rates were quantified by dividing the change in force by the change in time.

Force Plate (Studies 4 – 5 only)

During one of the sprint phases of the SAFT^{90}, participant were asked to run at the speed required and perform a cut onto the force plate (Bertec, Columbus, USA) between poles two and three of the course (Figure 2.4). Performance was quantified as the time taken to complete the task. Kinetic measures at a sampling frequency of 1000 Hz were obtained in the medio-lateral (Fx), anterio-posterior (Fy) and vertical (Fz) movement planes. Ground reaction force data was calibrated to body weight for each player. Analysis of the ground reaction force data enabled the measurement of peak impact force in each direction (PFz, PFy and PFx), load rate upon impact ($\dot{F}z$, $\dot{F}y$ and $\dot{F}x$) the

duration between impact and initiation of the drive phase (I-D), the rate of force development during the propulsion phase ($\dot{F}z_D$, $\dot{F}y_D$ and $\dot{F}x_D$), the angle of the cut (θ) toward the next pole in the course and the time taken for the participant to be completely removed from the force plate (T). Good to excellent ICC score were demonstrated for all previously aforementioned variables, with results ranging from 0.76 – 0.91.

Chapter 4, Study 1: The global nature of ankle joint function

4.1 Introduction

The ankle joint complex is a passive mechanical system, connecting the lower leg with the foot, comprising of both passive and active interactions with the mid and forefoot (Kleipool, and Blankevoort, 2010). Passive interactions occur as a result of articular contacts and ligaments, whereas active interactions are a result of tendons crossing the ankle joint complex (Kleipool and Blankevoort, 2010). Good ankle function has been proven to be crucial to professional soccer activity (Rein et al., 2011). As a weight-bearing joint, the ankle must concern itself with a wide range of forces in multiple directions, from activities as benign as walking to more complex responses of significant forces such as turning and changing direction in running gait, to landing on uneven and sometime unstable surfaces, whilst also providing the correct sporting technique required for success (Kolt, 2013). Subsequently due to its high involvement in sporting activity, the ankle joint is one of the most commonly injured sites within soccer (Ekstrand et al., 2011, Woods et al., 2003).

As a result of high injury incidence and its importance to sporting activity, various functional tests have been designed in an attempt to investigate ankle joint function and how assessment of these tests may correlate with injury risk. A multitude of intrinsic risk factors have been identified, with previous ankle sprain injury being highlighted as the greatest indicator of future injury risk (Bahr et al., 2003; Ekstrand et al., 1990; Engebertsen 2010, Kofotolis et al., 2007; Murphy 2003). However, previous injury is non-modifiable, therefore other modifiable injury risk factors such as deficits in isokinetic strength (Fousekis et al., 2012; Hadzic et al., 2009; Hartsell and Spaulding, 1999; Wang et al., 2006), flexibility (Arnason et al., 2004; Baumhauer et al., 1995; Ekstrand and Gilquist, 1983), JPS (Mohammadi et al., 2013; Mohammadi and Roozdar, 2010; Willems et al., 2005), postural stability (Hiller et al., 2008; McGuine et al., 2000; Troijan and McKeag, 2006; Semple et al., 2012; Wang et al., 2006), gait mechanics (Willems et al., 2005) and limb dominance (Barker et al., 1997) have all being identified. Each of these risk factors now has appropriate assessments designed, either clinical or functional, ranging from isokinetic dynamometry for strength asymmetries to Biodex stability systems for postural stability, to determine whether an athlete is at potential risk of injury.

However, in screening athletes for injury risks, the traditional assessment of isolated joints and muscles is no longer considered adequate practice (Mottram and Comerford, 2008), with an evaluation of movement quality during closed kinetic chain exercises more functionally linked to performance and injury risk (Whatman et al., 2011).

Current research using functional tests is limited to the analysis of ankle injuries in a univariate manner, in contrast to the multivariate nature of risk factors. Studies investigating the aetiology of sports injuries require a dynamic model, which accounts for the multi-factorial nature of sports injuries (Bahr and Holme, 2003). The efficacy of injury prevention depends on the appropriate development of a preventative strategy, and thus only a battery of tests can reflect the multi-modal aetiology of injury (Bahr and Holme, 2003). Therefore, this study aims to analyse tests of ankle function, predictive factors and their associated risks in a multivariate analysis within a specific population (semi-professional soccer players) (Bahr et al., 2003; Willems et al., 2005b), to determine whether any inter and/or intra-test correlations occur between injury prevention tests. Inter-test correlation is quantified to consider the 'global' nature of ankle function. The factors underpinning each test are also considered in relation to the test battery, to investigate the commonality in predictors of ankle function.

Moreover, investigating whether performance predictors of various injury tests help to contribute to successful/unsuccessful completion of other injury predictor tasks, thus suggesting that these factors may be more important to test and train rather than specific injury predictor tasks themselves. Therefore, the aim of this study was to consider the multifactorial nature of ankle joint injuries, whilst investigating whether relationships exist between ankle aetiological risk factors and the mechanisms, which facilitate ankle function. It is hypothesised that a level of commonality will exist between some of the predictors of performance, thus allowing for a greater understanding and insight into aetiological mechanisms associated with ankle sprain injuries.

4.2 Methodology

Participants

Participants were recruited from a semi-professional male soccer team. In total, seven players were ineligible to participate in the current study, and eleven players (age = 25.5 ± 5.0 years, height 1.75 ± 0.12 m, body mass = 74 .50 ± 8.25 kg) completed the present study. Participant eligibility was determined from the inclusion and exclusion criteria described in the general methodology (Chapter 3). Preliminary health screening procedures and anthropometric measures were also completed as per the description in Chapter 3.

Experimental Design

Participants attended the university laboratory on two occasions to complete a familiarisation trial and a multi modal testing battery session, which contained six different functional and clinical tests consisting of strength, proprioception, postural stability and dynamic balance.

Experimental Procedures and Measures

The experimental design and controls are described in greater detail in Chapter 3. Measures of IE, JPS, BSS, SEBT, EMG and the Drop and Drive test were recorded as per the test descriptions in Chapter 3. All tests were conducted in a random and counter-balanced order

Data Analysis

All results are reported as adjusted R^2 values, with significance set at $P \leq .05$. Single, multiple and stepwise regressions were used to investigate the influence of the different taping conditions for each variable. All statistical analysis was completed using Minitab (Version 15).

Inter-test single linear regressions were performed for the outcome measure of each task. A high correlative strength between task outcome measures would be indicative that good performance was transferable across tasks. Multiple linear

regression models were then used to quantify the correlative strength of those predictive measures defined for each task. This was completed using a forward stepwise modelling approach, thereby determining the hierarchical order of predictors for each test. A forward stepwise approach was also applied between tests, so that for each task outcome measure the correlative strength and hierarchical order of non-task specific predictors could be determined. This approach was used to investigate commonality in task predictors; i.e. to investigate whether any predictors are consistent across multiple tasks.

Inter-test single linear regressions were performed for the outcome measure of each task. A high ($R^2 \geq 0.36$) correlative strength between task outcome measures would be indicative that good performance was transferable across tasks. Pearson product moment correlations were examined between the explanatory and criterion variables to reduce the number of explanatory variable for each model (Gabriner et al., 2015). For each category (i.e., postural stability, proprioception, strength, dynamic movement and electromyography) the explanatory variable with the greatest correlation coefficient was entered into the respective regression model. Multiple linear regression models were then used to quantify the correlative strength of those predictive measures defined for each task. This was completed using a forward stepwise modelling approach, thereby determining the hierarchical order of predictors for each test. A forward stepwise approach was also applied between tests, so that for each task outcome measure the correlative strength and hierarchical order of non-task specific predictors could be determined. This approach was used to investigate commonality in task predictors; i.e. to investigate whether any predictors are consistent across multiple tasks.

4.3 Results

Inter-test predictive correlations

Linear regressions analysis was used to determine which within task performance measure contributed most significantly to either successful or unsuccessful performance (see table 4.1).

Table 4.1

Ankle Performance Predictor Results

Task Outcome Measure	Mean and Standard Deviation
OSI	0.95 ± 0.28
$SEBT_T$ (cm)	241.45 ± 19.10
IE	1.06 ± 0.12
Θ_{15} (Absolute Error °)	2.8 ± 0.53
Θ_M (Absolute Error °)	2.92 ± 0.51
t (Seconds)	1.62 ± 0.16

Table 4.2 summarises the performance on each task, with the linear regression equations between each task outcome measure detailed in Table 4.2. Generally the regression coefficients were low as each test measures particular components of ankle joint function. The greatest predictive strength (R^2 = .37, p = .05) between the Overall Stability Index from the unstable balance task and the isokinetic invertor: evertor strength ratio.

Table 4.2

Outcome Measure Intra – Test Correlations

OUTCOME MEASURE	$SEBT_T$	IE	Θ_{15}	Θ_M	OSI	T
$SEBT_T$	-	= 200 + 38.3 IE	= 190 + 18.0 θ_{15}	= 227 + 5.5 Θ_M	= 214 + 23.3 OSI	= 279 - 23.4 t
IE	$R^2 = .14$ $p = .26$	-	= 0.82 + 0.09 θ_{15}	= 1.00 + 0.03 Θ_M	= 0.80 + 0.23 OSI	= 0.35 + 0.45 t
Θ_{15}	$R^2 = .36$ $p = .05$	$R^2 = .10$ $p = .35$	-	= 2.53 + 0.12 θ_M	= 2.36 + 0.42 OSI	= 3.55 − 0.43 t
Θ_M	$R^2 = .06$ $p = .48$	$R^2 = .02$ $p = .71$	$R^2 = .03$ $p = .65$	-	= 1.55 + 0.96 OSI	= 6.74 − 2.51 t
OSI	$R^2 = .36$ $p = .05$	$R^2 = .37$ $p = .05$	$R^2 = .10$ $p = .34$	$R^2 = .31$ $p = .08$	-	= 1.94 − 0.47 t
T	$R^2 = .06$ $p = .46$	$R^2 = .24$ $p = .12$	$R^2 = .02$ $p = .69$	$R^2 = .37$ $p = .05$	$R^2 = .04$ $p = .57$	-

Table 4.3 summarises the correlative strength of predictor measures on each task. The multiple linear regression model is structured so that the hierarchical ordering of task predictors is evident. In the case of the SEBT, since task outcome measure is simply a sum of the three directional indices the linear fit is perfect. Similarly a strong regression coefficient is observed for OSI (R^2 = .82, p < .01), which is calculated as a function of AP and ML stability indices. The lowest regression coefficients were observed for the JPS tasks.

Table 4.3

Inter-test predictive correlative strength of within task predictor measures.

Outcome Measure	Hierarchical order of predictors		
	(1)	(2)	(3)

$SEBT_T$ $=$ $0.00 + 1.00\ A_D + 1.00\ PL_D + PMD$

$R^2 = 1.00;\ P < .01$

IE $=$ $0.66 + 0.02\ T_i$

$R^2 = .38;\ P = .04$

θ_{15} $=$ $1.70 + 1.07\ IE$

$R^2 = .10;\ P = .35$

θ_M $=$ $1.17 + 0.06\ T_i$

$R^2 = .25;\ P = .12$

OSI $= -0.20 + 1.03\ AP + 0.86\ ML$

$R^2 = .82;\ P < .01$

t $=$ $1.36 + 0.32\ Fz - 0.10\ \dot{F}y$

$R^2 = .54;\ P = .04$

The inter-test regression equations are summarised in Table 4.4, with the hierarchical ordering of non-task specific predictors highlighted. The highest regression coefficient ($R^2 = .91$, $p < .01$) was observed for the SEBT, with the lowest coefficient ($R^2 = .20$, $p = .17$) for the inversion sprint. The vertical force generated

in the inversion sprint was the most consistent predictor across tests, evident in the stepwise model for all tasks aside from the angle-specific JPS (and excluding the inversion sprint from which it was derived).

Table 4.4

Hierarchical ordering of non-task specific outcome measures.

Outcome Measure	Hierarchical order of predictors		
	(1)	*(2)*	*(3)*
SEBT$_T$	$= 170 + 21.00$ Fz $- 41.70$ Fxy $+ 25.70$ Ḟxy		
	$r^2 = .91; p < .01$		
IE	$= 0.20 + 0.62$ AP $+ 0.29$ Fz		
	$r^2 = .82; p < .01$		
θ_{15}	$= 1.21 - 1.60$ Fy $+ 0.03$ PL$_D$		
	$r^2 = .50; p = .06$		
θ_M	$= 2.62 + 0.13$ Ti $- 2.07$ Fz		
	$r^2 = .47; p = .08$		
t	$= 2.09 - 0.02$ Te		
	$r^2 = .20; p = .17$		
OSI	$= 0.04 + 0.04$ Ti $+ 0.03$ Ḟz		
	$r^2 = .64; p = .02$		

4.5 Discussion

The aim of the study was to examine the commonality in performance, and mechanistic predictors of performance, across a battery of functional tasks considered to evaluate ankle joint function. Direct comparison with previous studies is limited, with tasks such as these typically considered in relation to the efficacy of an intervention or reducing injury incidence (Dallinga et al., 2012). The literature is also far from equivocal in the potential for such measures to predict injury occurrence, with Bauhaumer et al., (1995) opposed in their observations of whether muscle strength imbalances can predict inversion ankle sprains. The multi-modal nature of ankle joint sprain aetiology is reflected in preliminary observations, with low magnitudes observed in all intra-test correlation coefficients.

Each test within the battery is therefore discrete, good performance on one test not indicative of good performance on another test. Both the BSS and SEBT are tasks, which require maintenance of postural control via a stable base of support and centre of gravity (CoG) (Schmitz and Arnold, 1998). However, the low correlation between tests suggests that participants may perform differently on tasks (BSS and SEBT), which are considered to measure similar attributes in the form of postural stability (Capuche et al., 2001). This difference may occur due to the BSS producing an unstable base of support, whereas the SEBT allows a static surface for the participant to stand, thus, the underlying control mechanisms for the two tasks differ. The complexity and variety of mechanisms underpinning balance is reflected in the weak intra-test correlations.

The outcome measures were used to develop a hierarchical ordering of parameters measured within each task. The success of this modelling ranged from absolute ($R^2 = 1.00$, $p < 0.01$) in the star excursion balance test (where the outcome measure is simply the sum of the three directional measures) to only 10% of variance accounted for in the Θ_{15} test. The JPS measure in mid-range inversion was most influenced by the inversion: eversion strength ratio, whereas the JPS measure closer to maximal inversion was influenced primarily by the peak inversion torque. It has been reported (Willems et al., 2002) that both decreased JPS near maximum inversion and

eversion muscle strength in a cohort with ankle instability, although these parameters were not correlated with each other. Greater strength at end range is likely to benefit the participant in recreating the target joint angle, and the inversion: eversion strength ratio was influenced greater by inversion strength than eversion strength.

Overall stability index was more strongly predicted by AP than ML balance, potentially as a result of training adaptations and previous motor experiences (Vuillerme et al., 2002) in this group of elite soccer players. It has been suggested (Golomer et al., 1999) that ballet dancer's specific training could shift the sensorimotor dominance from visual to proprioception, whilst Palliard and Noe (2006) reported that soccer players are more adapted to rely on proprioceptive mechanisms, rather than visual feedback to maintain postural stability. This observation might also be reflected in the typical ankle sprain epidemiology of soccer players, where lateral ankle sprains are prevalent (Woods et al., 2003).

The task predictor measures were shown to account for 20-91% of the variance across tasks, with the reactive inversion sprint the most difficult to predict. Only 20% of the variance in sprint time (t) was accounted for, with the primary predictor being peak eversion torque. Whilst eversion strength offers a functional benefit to the player in developing this cutting technique, there are many other factors likely to contribute to overall performance. This task is arguably the most functionally relevant, and the least clinically controlled. Landing from height manoeuvres are key tasks within many high intensity sports (Marshall et al., 2014) as they involve key lower extremity joint muscle actions such as hip, knee and ankle extensors that help to dissipate kinetic energy more evenly in an attempt to reduce injury risk (Zhang et al., 2000). In this respect there are many factors beyond even the scope of the ankle joint complex, which will contribute to performance. Furthermore, the second component of the drop landing task, requires players to translate the force towards a 45° cut. In the field, cutting mechanics have been shown to be determined by both vertical jump peak power and various anthropometric measures, (Chaouachi et al., 2012), whereas in a more laboratory controlled environment Marshall et al., (2014) identified five biomechanical factors which influenced cutting time performance, most pertinently, peak ankle power, peak ankle plantar flexor moment, range of pelvis lateral tilt, maximum thorax lateral rotation angle and total ground

contact time. With the exception of the latter, none of the aforementioned variables were measured, again possibly highlighting the unexplained variance within this sprint task.

Negating the functional sprint task, the inter-test predictive measures were able to account for 47-91% of variance in task outcome measures. The most prominent of these was the SEBT, a task which requires the player to destabilise the ankle joint in order to maximise their displacement, thus potentially highlighting either a weakness in IE or a maladaptation due to soccer specific condition, where the overriding safety mechanism is ignored in order to enhance performance. The hierarchical modelling of the SEBT comprised measures from the functional sprint, with magnitude and rate of development of force along the take-off vector included. The ability to absorb a landing and subsequently generate force along the inversion cutting angle is naturally indicative of the capability to create, and maintain, the ankle instability required to enhance SEBT performance. The musculature surrounding the ankle joint plays an integral role in stabilisation (Holmes and Delahunt, 2010). Subsequently, to achieve this enhanced force generation, either an imbalance exists in the IE muscular co-contraction due to strength deficits possibly leaving the ankle unstable, thus allowing the movement to occur, or soccer players due to prior sport specific conditioning to override this safety mechanism in order to achieve optimal results. The inclusion of vertical force development possibly reflects the functionally demanding drop landing that precedes the inversion sprint, the player having to first arrest, absorb and distribute ground reaction forces including vertical (McNitt-Gray et al., 2001) and control the landing before generating the subsequent phase of movement, which is often required in sport.

Vertical force rate of development was also evident but not the key predictor in both the predictive regression equation for OSI and IE. The key predictor of OSI was peak inversion strength. Since the OSI outcome measure was more influenced by the AP index than the ML index of balance, the inversion strength enables a balance strategy characterised by movement of the system in the AP plane. The strong ankle invertor muscles are able to lock the ankle in the ML plane, such that an AP strategy might be used to balance. The primary predictor for IE was anterio-posterior index of stability on the BSS. The correlation is positive, suggesting a higher AP balance

index results in a higher strength ratio. With the platform free to move in this task, a high AP balance index reflects worse performance, i.e. greater deviation of the balance platform. A high strength ratio is indicative of imbalance in the Medio-lateral plane, which might result in a selected AP strategy during tests of dynamic balance. Lateral ankle sprains are the most common form of ankle sprain (Woods, et al., 2003) and have traditionally been considered to be at highest risk with the ankle both plantar flexed and inverted (Verhagen and Bay, 2010). However recent investigations of ankle sprain injuries has suggested that plantar flexion alone was not associated with great risk of injury, whereas injury could occur in an inverted ankle even without plantar flexion (Fong et al., 2012). An AP strategy in the dynamic balance tests might therefore be preferable for injury prevention. It has been suggested (Fong et al., 2007) that prehabilitation focus should be on reducing inversion, landing with a neutral ankle orientation to prevent lateral shift of the centre of pressure, and thereby reduce the risk of inversion sprain injury.

The JPS tasks both showed a negative correlation to force generated in the sprint task. In this respect greater force generation is reflected by a lower score, i.e. better JPS. Thus, the capacity to develop force in the sprint task is positively correlated with JPS. The additional contributing parameter to end-range JPS was inversion strength, and posterior-lateral reach on the SEBT for mid-range JPS. Successful completion of the SEBT, requires ROM, flexibility, neuromuscular control and strength (Hertel, Miller, and Denegar, 2000). The positive relationship with posterior lateral reach can be explained as difficulty is enhanced due to it being more difficult to maintain a stable base of support, (Hardy, Huxel, Brucker, and Nesser, 2008) therefore in order to obtain a high displacement the ankle must be made unstable. This ability to create an unstable ankle is enhanced as visual input is removed when performing the PL_D, thus requiring the body to rely increasingly on somatosensory feedback strategies (Coughlan et al., 2012). Thus, creating a large displacement in the PL_D requires negating the proprioceptive input, whose role is to keep the system stable and reduce risk of injury. This notion is supported by Nagai et al. (2013) who stated that individuals with enhanced levels of proprioception, process information in dangerous movements more effectively, thus using safer positions to prevent injury.

The ability to work in this unstable position effectively is likely to be indicative of high error scores in joint positioning. The musculature surrounding the ankle joint plays a pivotal role in dynamic stabilisation (Holmes and Delahunt, 2010) requiring an effective balance between the invertor and evertor muscles (Lin, Liu, Hsieh, and Lee, 2009). However, an imbalance between these sets of muscles is not uncommon, with the invertor muscles generally producing greater levels of strength than the evertor muscles (Hazdic et al., 2009). This subsequently leaves the ankle joint susceptible to instability (Holmes and Delahunt, 2010), which has been associated with poor proprioception as it is essential for neuromuscular control involving dynamic restraints (Reimann and Lephart, 2002). Thus, a linear correlation between inversion strength and greater error during a proprioceptive task demonstrates a potential compensation between strength and position sense. This is further apparent in sport activities such as badminton, where the long serve requires gross motor skills for power, compared to the short serve, which utilises fine motor skills to emphasise accuracy (Bottoms et al., 2012).

Vertical force generated in the sprint task was the most global predictor across the battery of ankle function tasks, where 47-91% of variance in the outcome measure could be accounted for. Vertical force in the sprint task was a key performance indicator in all but the mid-range JPS score, and this parameter reflects the capacity of the player to generate vertical force during a reactive cutting task following a drop landing. In terms of performance and time to complete a task, movement in the vertical plane is deemed inefficient and unnecessary (Dayakidis and Boudolos, 2006), which supports the positive correlation determined between the two variables in this study. Enhanced vertical forces imposed on the body during landing activities, have been demonstrated to be determinants of injury (Kellis et al., 2004), especially if landings are repeated with high forces. However, an alternative trade of thought suggests that enhanced levels of Fz could be a compensating mechanism employed in an attempt to reduce forces experienced in the medio-lateral direction. Although this would be detrimental to performance via wasted energy, it would allow for a more effective and efficient dissipation of loads experienced at the ankle joint (Dayakidis and Boudolos, 2006). This more efficient energy dissipating mechanism is feasibly a result of a neuromuscular response (Dayakidis and Boudolos, 2006), which this sport specific training group have developed over enhanced training and

match play exposure. This allows for a more stable ankle joint which is able to manage excessive levels of inversion shown to enhance risk of injury (Fong et al., 2007). Whether the drop element was a factor in highlighting vertical force is unclear, but the capacity to generate force subsequent to and in preparation for challenging functional events appeared to be the most 'global' issue for ankle joint function.

4.6 Conclusion

It has been stated (Bahr and Holme, 2003) that it is not acceptable to consider injury risk factors in a singular manner; rather they need to be considered using a multivariate mode. The results of this study show that screening and evaluation of the ankle joint should also be multi-factorial, with weak intra-test correlation across a battery of tests. This finding suggests a lack of 'global' ankle function, and that performance on one test is not predictive of performance on a discrete test, supporting the complexity of injury aetiology.

The most 'global' predictor of task performance was the capacity to generate vertical ground reaction force following a drop landing and in reaction to a visual stimulus to initiate an inversion sprint. This mechanistic relationship requires greater scrutiny, but it might be hypothesised that this reflects an ability to absorb force and stabilise the ankle joint in a way as to protect both the plantar flexion and inversion typically associated with ankle sprain incidence (Dayakidis and Boudolos, 2006).

The findings suggest that it is not acceptable to only measure individual tasks of performance and aetiological risk factors. Furthermore, if a participant is identified as having performance deficits in certain screening tasks, the mechanisms, which enhance that task, should be trained for improvements rather than the task itself for optimal (p)rehabilitation. Further research is required regarding how aetiological risk factors associated with ankle sprain injury can be mediated, whilst also investigating the effects of circadian rhythm on functional performance tests which are commonly used to assess and screen for athletic performance, injury risk and rehabilitation.

The multi-modal testing battery reflects the aetiological mechanisms of ankle injury occurrence, with results highlighting a lack of inter-test correlation across a battery of tests designed to assess ankle function. The results further suggest, that elite male soccer players do not display "global" ankle joint function performance, as there is a lack of commonality amongst the key predictors of these tests.

The results of this study highlight the need for evaluation, screening and (p)rehabilitation to be multi-modal in nature, thus further supporting the complexity of ankle aetiology, whilst also highlighting key performance predictors which can be trained to improve both athletic performance and reduce injury incidence in healthy male soccer players.

Chapter 5, Study 2: Influence of Circadian Rhythm on Measures of Ankle Function and Performance

5.1 Introduction

The assessment utilised during study one requires performance parameters such as optimal postural control, proprioception, strength and neuromuscular function, all of which are fundamental components needed for successful movement during physical activity (Kwon et al., 2014), whilst also being demonstrated to be associated with aetiological mechanisms of ankle injury occurrence. These aforementioned components have been commonly used in laboratory and clinical settings as a method of assessing functional movement in non-injured and more commonly, injured groups of personnel (Gribble et al., 2007). However, little research has been conducted to determine how the time of day may affect human performance during these tasks. Therefore, precise and reliable measures of aetiological risk factors in clinical and scientific settings is essential in order to greater inform and potentially reduce ankle injury incidence occurrence.

It is well established that many physiological and performance variables display a circadian rhythm (Atkinson and Reilly, 1996; Drust et al., 2005) for example core temperature displays a nocturnal decline and peak temperatures are observed between 17:00 h and 18:00 h (Reilly et al., 2007). This relationship is inverse to that of melatonin, which is deemed to be one of the key markers of the endogenous rhythm. Whilst the endogenous rhythm is robust, exogenous factors such as environmental temperature, social interaction and daylight may also influence physiological processes (Hoyer and Clairambault, 2007). Time of day has been shown to influence physical activities involving aerobic fitness, with fine and gross motor skills also being shown to display a clear circadian rhythm (Bessot et al., 2007, Kline et al., 2007; Reilly et al., 2007). Complex activities involving a greater cognitive element are optimal in the early morning (Folkard and Rosen, 1990). However, there is limited research on the effects of time of day on injury predictive measures such as postural control and proprioception

Gribble et al. (2007) demonstrated a time of day effect for dynamic postural control, observing greater normalised reach distances in the Star Excursion Balance Test

(SEBT), at 10:00 h compared to both 15:00 h and 20:00 h, thus concluding that postural control was enhanced in early morning activities. These results are further confirmed by Kwon et al., (2014), who demonstrated improved performance of postural stability during the morning compared to the afternoon and evening. However, both studies only measured circadian rhythm effects using measures of postural control and healthy subjects. Nevertheless, little attention has been afforded to diurnal variation in factors which have been shown to predict injuries, even though soccer matches, training and rehabilitation can occur at various times across a day.

With injuries being such a pertinent and perennial issue within soccer (Ekstrand et al., 2011) the aim of this study was to investigate the influence of time of day on aetiological risk factors associated with ankle injury incidence using semi-professional soccer players. If the results of these assessment demonstrate a common time of day effect, clinicians and researchers may need to consider circadian rhythms when assessing soccer players and/or other athletes during screening and/or (p)rehabilitation.

The aim of this study was to determine whether the time of day affected the performance outcome of tests used to assess athletic performance and/or rehabilitation. It is hypothesised that certain measures such as the BSS and SEBT will be influenced by the time of day, with participants demonstrating poorer results in the evening when compared to the morning.

5.2 Methodology

The participants used during study two were the same as those that completed study one (please see section 4.2 for further details). All participants were moderate or intermediate chronotyopes according to the questionnaire of Waterhouse et al. (2001) based on the work of Smith et al. (1989) which is a composite scale of previous items developed (Horne and Osberg, 1976).

Experimental Design

The experimental design was also equivalent, participants completed the same battery of functional tests, with a specific methodological insertion of circadian rhythm, with testing occurring at 3 different times of day, 07:00h, 12:00h and 19:00h to investigate the effects of circadian rhythm on physical performance. All trials were conducted in a randomised and counter-balanced order.

Experimental Measures

Additional detail in relation to each measure is provided in Chapter 3.

Data Analysis

All results are reported as mean $\pm$ SD, with significance set at $P \leq .05$. Prior to parametric analysis, the assumptions of normality were verified using the Shapiro-Wilk test. A 3x1 repeated measure ANOVA was used to investigate the influence of the different times of day for each variable. Assumptions associated with a repeated measures general linear model (GLM) were assessed and verified to ensure model adequacy. Q-Q plots were generated using stacked standardised residuals to assess residual normality for each dependent variable. Additionally, using standardised and unstandardised residuals, scatterplots were generated to assess the error of variance associated with residuals. Furthermore, Mauchly's test of Sphericity was also completed for all dependent variables, with a Greenhouse Geisser correction applied if the test was deemed significant. If any variables violated the assumptions of normality for one variable, they were immediately checked to determine whether they violated any additional assumptions of normality. If this was deemed to be the case, the participant was subsequently removed from the study

Where significant main effects were observed, post hoc pairwise comparisons with a Bonferonni correction factor were applied. All statistical analysis was completed using PASW Statistics Editor 18.0 for windows (SPSS Inc., Chicago, USA). For all significant interactions, 95% confidence intervals (CI) are reported in conjunction with the traditional statistical approach, Cohen's d effect sizes (< 0.50 = small, 0.50 $- 0.80$ = small to moderate, > 0.8 = large) will be calculated to further assess

differences in measures. All results are reported as mean $\pm$ SD, with significance set at $P \leq .05$, unless otherwise stated.

5.3 Results

Table 5.1 demonstrates results for all measures taken at three different times of day.

Table 5.1 Ankle performance predictor results at different times of day

Predictor of Performance	07:00 Mean and Standard Deviation	12:00 Mean and Standard Deviation	19:00 Mean and Standard Deviation
OSI (au)	1.11 ± 0.4	1.07 ± 0.42	1.17 ± 0.5
AP (au)	0.88 ± 0.25	0.67 ± 0.17*	0.89 ± 0.25
ML (au)	0.77 ± 0.29	0.62 ± 0.22	0.76 ± 0.24
θ_{I5} (AE°)	2.22 ± 0.79	2.72 ± 0.70	2.1 ± 0.78
θ_M (AE°)	2.06 ± 0.74	2.8 ± 0.8	2.1 ± 0.71
IE	1.15 ± 0.23	1.06 ± 0.12	1.08 ± 0.22
T_i (Nm)	23.41 ± 4.83	24.28 ± 4.83	22.79 ± 5.15
T_e (Nm)	21.66 ± 4.55	22.07 ± 4.88	21.47 ± 4.27
D T (S)	1.50 ± 0.13	1.53 ± 0.14	1.47 ± 0.15*
D I-D	0.65 ± .21	0.63 ± 0.2	0.53 ± .018*
D Θ (°)	47.03 ± 10.38	48.94 ± 7.99	48.21 ± 13.11
D $\dot{F}_{xy}$	2.29 ± 0.68	2.35 ± 0.62	2.42 ± 0.69
$SEBT_T$ (cm)	242.55 ± 17.49	241.45 ± 19.73	246 ± 18.59

*Denotes a significant difference (P < .05)

Circadian rhythm demonstrated a significant time of day effect on AP (figure 5.1) (P = .02) with post hoc tests with Bonferonni adjustments identifying significantly increased values at 12:00 h (0.88 ± 0.25 au; P = .02; 95% CI = 0.04 to 0.31au; d = 0.77) and 19:00 h (0.93 ± 0.35 au; P = .04; 95% CI = 0.01, to 0.43; d = 0.80) when compared to 07:00 h (0.71 ± 0.17 au). In contrast, the GLM failed to identify any significant trial differences for either ML (0.73 ± 0.28 au; P = .10) nor OSI (1.17 ± 0.37 au; P = .51).
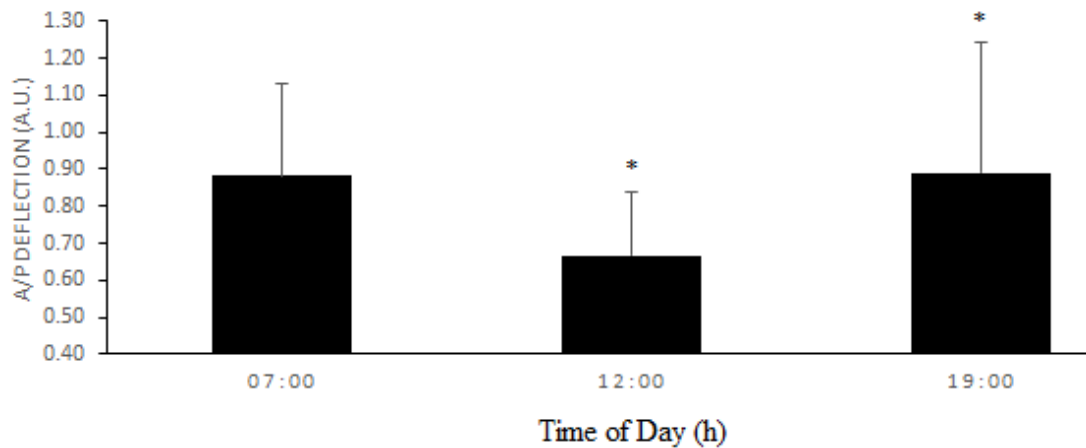
Figure 5.1 Effects of circadian rhythm on AP (* denotes significant difference (P < .05) with 07:00 h)

Figure 5.2 illustrates the time of day effect on T, demonstrating a significant difference (P = .01) with post hoc pairwise comparisons with a Bonferonni adjustment identifying significantly lower times to complete the task at 19:00 (1.47 ± 0.15 s; P = .04; 95% CI = -0.12 to 0.09 s; d = 0.43) compared to 12:00. A contributing factor of T is the ID component of the test. Figure 5.3 illustrates the time of day effect on ID, identifying a significant difference (P = .04) with post hoc pairwise comparisons demonstrating significantly decreased times at 19:00 (0.53 ± 0.18 s; P = .02; 95% CI = -0.12 to -.017 s; d = 0.61) compared to 07:00 (0.65 ± 0.21 s). Insignificant results for Θ and Fxy are depicted in Table 4.1.
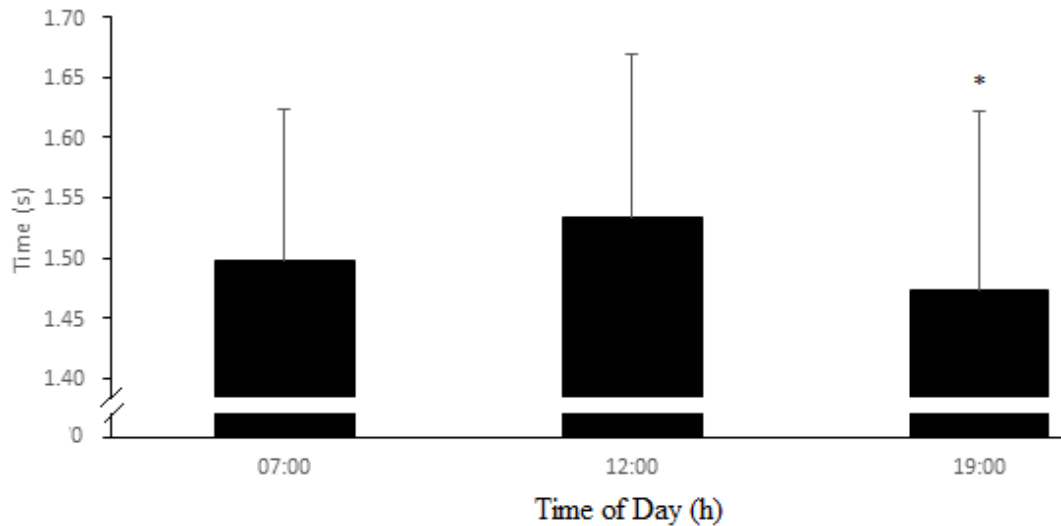
Figure 5.2 Effects of circadian rhythm on D T (* denotes significant difference ($P < .05$) with 12:00 h)
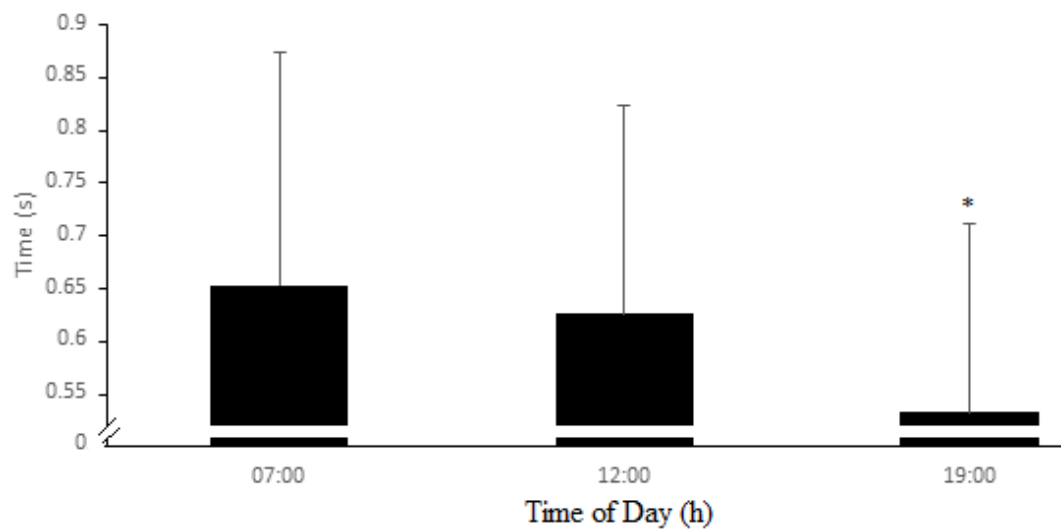
Figure 5.3 Effect of circadian rhythm on D ID (* denotes significant difference ($P < .05$) with 07:00 h)

Figure 5.4 illustrates the time of day effect on BSS LG EMG_{Mean}, demonstrating significantly increased EMG_{Mean} activity at 07:00 (45.81 ± 21.37 µV: $P = .02$; 95% CI = 4.42 to 34.15 µV; $d = 1.20$), when compared to 12:00 (26.53 ± 7.95 µV). Contrasting results were observed for BSS TA EMG_{Mean} (62.41 ± 28.29 µ: $P = .36$) and BSS PL EMG_{Mean} (132.91 ± 50.38 µV: $P = .36$) with the GLM failing to identify any significant differences across the three time points (62.41 ± 28.29 µV: $P = .66$).

Furthermore, during the SEBT Trial, EMG$_{Mean}$, failed to display any significant interactions for muscles TA (226.06 ± 107.46 µV: P = .75), PL (150.03 ± 68.32 µV: P = .43) nor LG (53.83 ± 24.36 µV: P = .09).
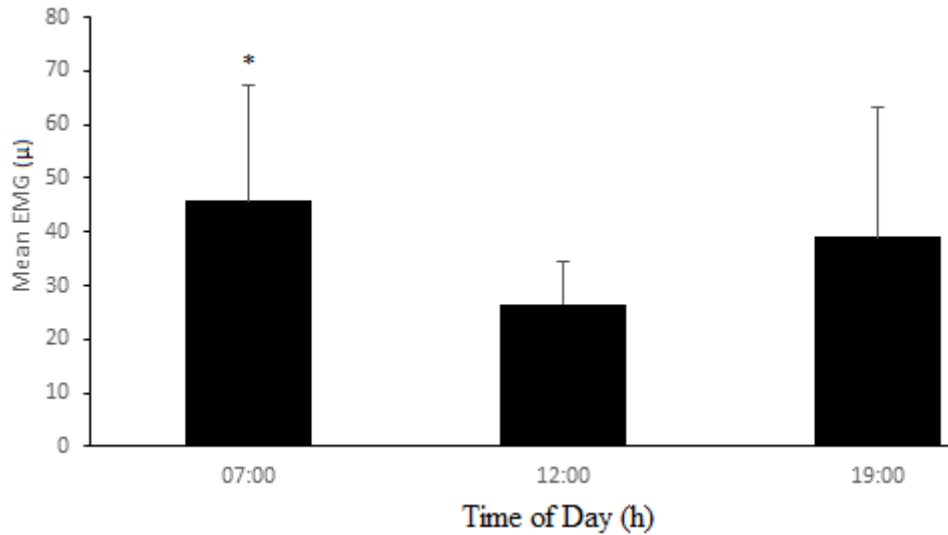
Figure 5.4 Time of day effect on LG EMG$_{Mean}$ Biodex performance (* denotes significant difference (P < .05) with 12:00)

5.5 Discussion

The aim of this study was to determine whether tests used to predict ankle injury and the performance predictors within these tasks are affected by time of day. This study performed a multi-modal battery of tests involving intrinsic injury risk factors such as proprioception (Mohammadi et al., 2013; Mohammadi and Roozdar, 2010; Willems et al., 2005), strength asymmetries (Fousekis et al., 2012; Hadzic et al., 2009; Hartsell and Spaulding, 1999; Wang et al., 2006), balance and postural stability (Hiller et al., 2008; McGuine et al., 2000; Semple et al., 2012) and the drop and drive test, which produced a culmination of the aforementioned variables (Reiman and Manske, 2009) in order to determine whether a circadian rhythm effect existed in semi-professional soccer players.

Time to complete (D T) the drop and drive task was shown to be significantly decreased in the evening compared to both the morning and afternoon. Further analysis of the drop and drive task identified that this could be potentially due to another performance predictor within the same test in the form of the impact to drive

period (I-D). The same pattern was observed I-D as T, with a decreased time to complete the action observed in the evening compared to both that of the morning and afternoon. Literature surrounding speed supports these findings (Reilly et al., 2007), who demonstrated a reduction in dribbling speed during the evening when compared to that of the morning and afternoon. Although dribbling speed is not directly related to that of the drop and drive task, some of the fundamental processes are similar, such as both tasks involving an agility component and the prerequisite of completing the task as quickly as possible. This observed reduction in speed is further supported by Reilly et al., (2007) who reported improved performance in the evening compared to other times of day, potentially due to increased power output being observed in the evening following the increase in body temperature (Reilly et al., 2007).

Explosive movements which require speed and/or time to complete a task are derived from other predictive measures such as rate of force development ($\dot{F}$). Beretic et al. (2013) identified a significant correlation between early stage $\dot{F}$ and faster 10m start times of swimmers. No significant differences were observed for drop and drive performance at the three different times of day, however a trend towards significance was observed, with D F_{xy} demonstrating an increase in force as the day progresses. This is in accordance with Pereria et al., (2011) who investigated the effects of $\dot{F}$ using the knee extensors of healthy volunteers at three separate times of day (morning, afternoon and evening), identifying that there was a significant increase in $\dot{F}$ in the evening compared to that of both the morning and afternoon, with a steady rise in $\dot{F}$ throughout the day. Pereria et al., (2011), hypothesised that the ability to produce increased explosive force as the day progressed, was not due to an increase in muscle recruitment in the form of EMG, rather that peripheral mechanisms, such as an increase in body temperature (Reilly, Atkinson and Waterhouse, 2000) were responsible for this variation. The results of the current study further support this notion, as no time of day effect was identified in EMG activity, other than the LG_{Mean}, which decreased in the afternoon rather than the evening. This, therefore, suggests that the improvement in time to complete a task is in greater alignment with diurnal variation rather than that of central mechanisms such as EMG activity.

During completion of the BSS task, participants wore EMG equipment on the TA, PL and LG to determine EMG_{Mean}. The BSS task demonstrated a time of day effect in form of decreased AP deflection in the afternoon when compared to both the morning and evening (see Figure 5.2), thus indicating more efficient balance in this plane of motion. The finding of decreased AP deflection could potentially be explained due to decreased EMG activity in the afternoon in the LG_{Mean} signal. The LG helps to stabilise the ankle joint during balance tasks with its main role to produce plantar-flexion at the ankle joint (Reimann et al., 2011), which would place the participant into a more open pack position with a greater AP deflection (Wright et al., 2000). Therefore, if the EMG activity in the LG is reduced, one can assume less AP deflection will occur, with greater emphasis on other stabilising musculature such as the TA and PL to reduce postural stability. This could potentially explain why although a decrease in AP deflection was observed during the afternoon, no improvement in the overall measure of performance OSI was detected (see Figure 5.1), as the remaining structure had to complete more work, thus potentially fatiguing the muscles at a greater rate and not improving overall performance.

Limited research has been conducted into the effects of circadian rhythm on balance and postural stability performance. However, Gribble et al. (2007) and Kwon et al. (2014) both demonstrated an improvement in postural stability whilst performing dynamic balance tasks in the morning, when compared to the same task performed in the evening, thus indicating a diurnal effect for postural stability. Both studies used different methods of dynamic balance assessment and participants. Gribble et al., (2007) used the SEBT and university students, whereas Kwon et al., (2014) used a Good Balance system with participants only defined as healthy. This current study apart from reduced AP deflection in the afternoon, demonstrated no significant improvement in performance in either of its measures of dynamic balance in the form of the BSS or SEBT. This could potentially be due to the difference in the nature of the participants observed. Semi-professional soccer players were used as participants in this study, compared to that of either healthy or university students. Soccer matches have various kick off times throughout the day, ranging from late morning to evening starts, with training in semi-professional soccer players in season generally occurring during the evening. Both Chtourou et al. (2012) and Souissi et al. (2002) discovered that adaptation to strength and resistance training is greater at

the times of day at which training is conducted for an extended period, when compared to that of other times of day. Although these findings concern that of strength and resistance training, it would seem reasonable to suggest that the participants involved in this study, who will have trained in the evening, whilst also playing competitive matches at this time plus the afternoon for considerable years, may also have improved their levels of balance and postural stability at the aforementioned times. The explanation of the potential specificity of time of training could be due to an effect of the body clock and/or habituation, subsequently giving participants a competitive edge at these times (Reilly and Waterhouse, 2009). This could therefore infer, that soccer players who have been demonstrated to have balance levels which, are only inferior to that of dancers and gymnasts (Bressel et al., 2007; Davlin, 2004; Gerbino et al., 2007; Matsuda et al., 2008), could potentially improve their balance and postural stability ability in both the afternoon and evening due to the sheer volume of activity they conduct at these times of day.

The training effect described by previous research (Chtorou et al., 2012; Soussi et al., 2002) indicates that increases in strength are observed at the times at which they the participants are used to regular training. However, this study demonstrated no significant improvement in performance in accordance with diurnal variation for IE, $T_{i \text{ or }} T_{e,}$ even though the participants used in this study either train or play in the evening or afternoon. Further evidence would suggest that increases in strength are observed according to diurnal variation and an increase in body temperature, with greatest levels of strength usually demonstrated in the evening (Reilly et al., 2000), with (Callard et al., 2000) demonstrating improvement in quadriceps strength in the evening compared to other times of day. A popular way to measure the effect of diurnal variation on strength is the IKD, with a time of day effect in variables such a peak torque and angular velocity being noted at speeds ranging from $1.05 - 5.24$ rads.s^{-1}, with peak values shown to occur in the evening (Chtorou et al., 2012; Gauthier et al., 2001; Soussi et al., 2002). However, Deschenes et al., (1998) contradicts this claim, stating that measurement such as peak torque can only be observed at velocities greater than 3.14 rads.s^{-1}. This could potentially be a result of speed-specific circadian variations in muscle strength, due to muscle fibre type recruitment patterns (Deschenes et al., 1998). This study chose to perform ankle inversion/eversion movements at 60°/s to ensure that an isokinetic period was

ascertained; however this may not have allowed a quick enough speed to detect diurnal variation of ankle strength. It is this author's belief that an isokinetic period for ankle inversion/eversion would not be achieved at speeds greater than 3.14 rads.s^{-1}, due to the reduced range of motion the movement occurs, when compared to that of another antagonistic group such as the hamstrings and quadriceps. The author also wishes to highlight that no studies have been conducted investigating effects of diurnal variation on ankle strength; therefore it is difficult to make a direct comparison for the ankle musculature to that of larger muscle groups such as the quadriceps.

Another ankle injury predictive test, which uses the IKD, is that of JPS (Mohammadi and Roozdar, 2010). Limited research has been conducted into the effects of diurnal variation and proprioception, with no research conducted in this area surrounding the ankle joint. This study demonstrated no time of day effect for improvements in JPS in either the θ_{15} or θ_M tasks. Both θ_{15} and θ_M demonstrated a trend towards significance, with less absolute error achieved in the morning and evening compared to that of the afternoon, which could potentially be attributed to a transient post lunch dip in circadian rhythm (Edwards et al., 2007). Edwards et al., (2007) investigated the effects of circadian rhythm on dart throwing accuracy at two different distances (normal distance and normal distance + 50%), discovering improvements in accuracy for both distances as the day progressed. Both distances require muscular contraction and hand eye-co-ordination, however the improvement in accuracy for the increased distance was far greater than that of the normal distance. Edwards et al., (2007) hypothesised that this greater improvement in accuracy could be attributed to the fact that the increased throwing distance would require greater contraction of the surrounding musculature, thus increased strength, which has a parallelism with core temperature (Reilly et al., 2000). In contrast, the shorter distance throws would place greater emphasis on control mechanisms, which are affected by factors that are more susceptible to fatigue (Edwards et al., 2007). Therefore any improvement in performance due to a rise in body temperature would be counteracted by an increasing amount of time spent awake, thus the improvements in performance are not as pronounced (Carrier and Monk 2000; Waterhouse et al., 2001). The darts study draws parallelisms with this current piece of work due to the fact that the θ_{15} and θ_M tasks both rely on more finite muscular

control, accuracy and proprioception. However, the aforementioned variables are more dominant than strength when compared to darts throwing. Therefore, in a similar manner to which the normal distance throwing tasks accuracy was offset by levels of subjective fatigue, it is hypothesised that the same mechanisms occur for both θ_{15} and θ_M, as strength is not required in this task, therefore core temperature does not affect performance. This would indicate that tasks, which require such finite control, proprioception and accuracy such as JPS, are not affected by diurnal variation.

5.6 Conclusion

The results of this study would suggest that although some measures of ankle injury predictive tasks have been shown to be affected by diurnal variation, the vast majority of measures performed within this battery of tests are diurnal independent. This therefore indicates that when conducting injury predictive or rehabilitative tests which focus on the ankle joint of healthy/uninjured soccer players, these tests can be performed at various times of the day without the risk of unreliable results with regards to diurnal variation. This information allows practitioners greater scope and time to conduct testing, without the concern that the results may be affect by external mechanisms such as diurnal variation.

Future research needs to be conducted to determine how ankle function performs using the multi-modal battery of tests used within this study under the influence of soccer specific fatigue. The results of this study help to inform future research as the multi-modal battery of tests can be performed at various times of the day without the effect of diurnal variation. Therefore it is suggested that future testing should mirror that of the regular training or match play routine conducted by semi-professional soccer players, with testing either to take place in either the late afternoon or early evening.

Chapter 6, Study 3: Influence of Therapeutic Tape on Measures of Ankle Function and Performance

6.1 Introduction

The previous two studies demonstrated a lack of commonality between performance indicators across assessments used to determine ankle function, whilst also indicating that time of day had limited detrimental effect on performance in a healthy soccer specific population. Thus far, the first two studies have attempted to determine improved performance through intrinsic methods, however extrinsic tools can also be utilised in an attempt to improve ankle joint function.

Various factors have been shown to influence ankle function (Verhagen et al., 2010), with taping proving to be a popular and commonly used method for the prevention and treatment of sports injuries, as they provide the athlete's muscles and/or joints with both protection and support during movement (Thelen et al., 2008; Verhagen et al., 2010). However, traditional "white" tapes, whilst having been shown to be effective in both injury prevention and management, have also demonstrated range of motion (ROM) restriction which can negatively affect athletic performance (Bicci et al., 2012), thus potentially enhancing injury risk at anatomical positions proximal in the kinetic chain (Stoffel et al., 2010). A recent development in sports medicine and rehabilitation is kinesiology tape (KT). KT has gained worldwide popularity in recent years (Semple et al., 2012), as a method of athletic taping, which is believed to provide protection to weak and/or injured muscles and joint complexes. KT differs from other athletic tapes as KT_1 (Kinesio^{TM}) can stretch up to 140% of its original length, whereas KT_2 (RockTape^{TM}) is made from a different cotton fibre, has a different acrylic and can stretch up to 180% of its original length. This increase in stretch is proposed to allow the tape to exert a pulling force to the skin (Halseth et al., 2004), offering greater mechanical support and proprioceptive ability via stimulating mechanoreceptors and muscle activation patterns (Semple et al., 2012) without restricting ROM (Kase and Wallis, 2002). Further to this, it is purported that the benefits of KT application can last up to 96 hours (Kase, Wallis and Kase, 2003), with various studies claiming to produce findings which support the effects of KT application to exist beyond the day which it was applied (Fayson et al., 2013; Simon, Garcia and Docherty, 2014).

Although there are many substantial claims made via manufactures of KT, the mechanical benefits of these tapes are still not scientifically fully understood (Lohkamp et al., 2009). A plethora of literature exists, investigating the effects of KT on various injury risk factors such as strength (Mohammadi et al., 2014; Vithoulka et al., 2010), flexibility (Chen et al., 2013), postural stability (Fayson et al., 2013; Semple et al., 2012; Shields et al., 2013) and proprioception (Mohammadi et al., 2014; Simon, Garcia and Docherty, 2014) with ambiguous conclusions being drawn due to the conflicting nature of the results of the studies. In terms of ROM the proposed benefits are that the tape restricts the ROM of the ankle joint, especially during inversion and dorsiflexion, whilst also providing greater levels of stability (Cordova et al., 2002). The ankle is at great risk of a lateral ligament complex sprain when then ankle is positioned into movements of inversion and plantar flexion (Wright et al., 2000). Therefore, if the ankle can be prevented from moving too far into those positions it could potentially reduce the number of injuries sustained, via decreased levels of postural stability, thus providing a rationale for therapeutic tape to be utilised.

With regards to KT and proprioception, Refshague et al., (2009) suggested that the potential benefit of taping the ankle is due to the close contact between the tape and the skin, causing a higher level of afferent nerve traffic to the site in question, arising from the cutaneous skin mechanoreceptors. Subsequently, greater levels of proprioception have been demonstrated to increase an individual's postural stability. This in turn, may help to reduce their injury incidence of ankle sprains (Lohkamp et al., 2009). Whether ankle taping has any proven benefit on the aforementioned mechanism is debatable, (Delahunt et al., 2010; Halseth et al., 2004; Miralles et al., 2014) observed no significant effect on dynamic stability when taping the ankle, whereas Chang et al. (2010) indicated positive benefits of taping the ankle in terms of increased levels of proprioception. A recent study (Semple et al., 2012) investigated the effects of the application of KT on dynamic balance in a group of male semi-professional rugby union players, discovering a significantly lower overall stability index (OSI) using KT when compared to NT. Semple et al., (2012) hypothesised that this improvement in OSI could be attributed to KT being designed to stretch once applied to the skin. It is this continuous stretch, which is said to increase skin cutaneous mechanoreceptor activity, which subsequently provides

greater levels of afferent feedback to the central nervous system (CNS) (Murray et al., 2000), which controls movement in part via improving joint position sense (JPS) (Grigg, 1994).

Ankle injuries have been demonstrated to be a perennial problem within soccer (Aoki et al., 2012; Ekstrand et al., 2011), therefore mechanisms which claim to improve muscle and joint function such as KT, need to be investigated to determine whether ankle injury incidence can be reduced.

The aim of this study was to determine whether different brands of KT (KT_1 or KT_2) improve measures of ankle joint function associated with injury incidence and risk. It is hypothesised that both brands of KT will help to improve some measures of ankle joint function when compared to NT. A secondary hypothesis states that there will be differences in performance outcome between both KT_1 and KT_2, due to the differences in the properties from which they are designed.

6.2 Methodology

Participants

The participants used during study two were the same as those that completed study one (please see study one for further details).

Experimental Design

The experimental design was also equivalent; participants completed the same battery of functional tests (please see Study 1), with a specific methodological insertion of therapeutic tape. At each testing session KT_1, KT_2 or NT were applied in a counter-balanced order, by the same practitioner, according to KT guidelines (please see Chapter 3).

Experimental Measures

Additional detail in relation to each measure within study 3 is described in Chapter 3.

Data Analysis

Statistical assumptions were verified using the methods described previously in Chapter 5. A 3x1 repeated measure ANOVA was used to investigate the influence of the different taping conditions for each variable. Where appropriate, post hoc analyses with a *Bonferonni* correction factor were applied.   All statistical analysis was completed using PASW Statistics Editor 18.0 for windows (SPSS Inc., Chicago, USA). For all significant interactions, 95% confidence intervals (CI) and reported in conjunction with the traditional statistical approach, Cohen's *d* effect sizes ($< 0.50 =$ small, $0.50 - 0.80 =$ small to moderate, $> 0.8 =$ large) will be calculated to further assess differences in measures.

6.3 Results

Table 6.1 depicts the average mean and standard deviation scores for the main predictors of performance.

Table 6.1: Ankle performance predictor results

PREDICTOR OF PERFORMANCE	KT$_1$ MEAN AND STANDARD DEVIATION	KT$_2$ MEAN AND STANDARD DEVIATION	NT MEAN AND STANDARD DEVIATION
OSI	1.04 ± 0.30	1.16 ± 0.29	1.03 ± 0.32
AP	0.77 ± 0.23	0.79 ± 0.18	0.67 ± 0.17
ML	0.63 ±0.21	0.75 ± 0.28	0.62 ± 0.28
Θ_{15}(AE°)	1.94 ± 0.57*	1.94 ± .70*	2.39 ± 0.57
Θ_M(AE°)	1.74 ± 0.49*	1.57 ± 0.56*	2.80 ± 0.70
IE	1.19 ± 0.12	1.06 ± 0.12	1.08 ± 0.16
T_E(NM)	21.47 ± 5.98	22.07 ± 4.88	22.22 ± 5.56
T_I(NM)	25.60 ± 6.50	24.28 ± 5.83	24.35 ± 4.36
T (S)	1.58 ± 0.16	1.47 ± 0.16*	1.62 ± 0.16
Θ (°)	57.86 ± 13.41	57.94 ± 18.28	52.86 ± 16.3
$\dot{F}_{XY}$B.WS^{-1}	2.35 ± 0.62	2.43 ± 0.69	2.19 ± .66
$SEBT_T$(CM)	242.64 ± 24.18	247.37 ± 20.95	241.45 ± 19.73
BSS TA EMG$_{MEAN}$	57.60 ± 28.06 µV	52.04 ± 22.51 µV	59.05 ± 24.29 µV
BSS PL EMG$_{MEAN}$	85.90 ± 34.10 µV	115.94 ± 59.34 µV	89.80 ± 34.10 µV
BSS LG EMG$_{MEAN}$	39.64 ± 17.22 µV	39.24 ± 14.90 µV	36.53 ± 7.95 µV

***Denotes a significant difference with NT (P < .05)

Type of tape effects for ankle JPS (θ_{15} and θ_M) are reported in Figures 6.1 and 6.2. A 3x1 Anova demonstrated a significant tape effect (P = .01) on θ_{15}, with post hoc test and Bonferonni adjustments illustrating significant main effects for trial, with KT$_2$ (1.94 ± 0.57°; *P* = .02; 95% CI = -1.68 to -0.15; *d* = 1.90) demonstrating less absolute error when compared to NT (2.92 ± 0.70°). Significant results were also

identified in Figure 6.2 (θ_M) ($P < .01$) with less absolute error demonstrated for KT_1 (1.74 ± 0.49°; P = .04; 95% CI = -1.55 to -0.05; d = 1.60) and KT_2 (1.57 ± 0.66°, P < .01; 95% CI = -1.92 to -0.32; d = 1.68) when compared to NT (2.80 ± 0.80°)
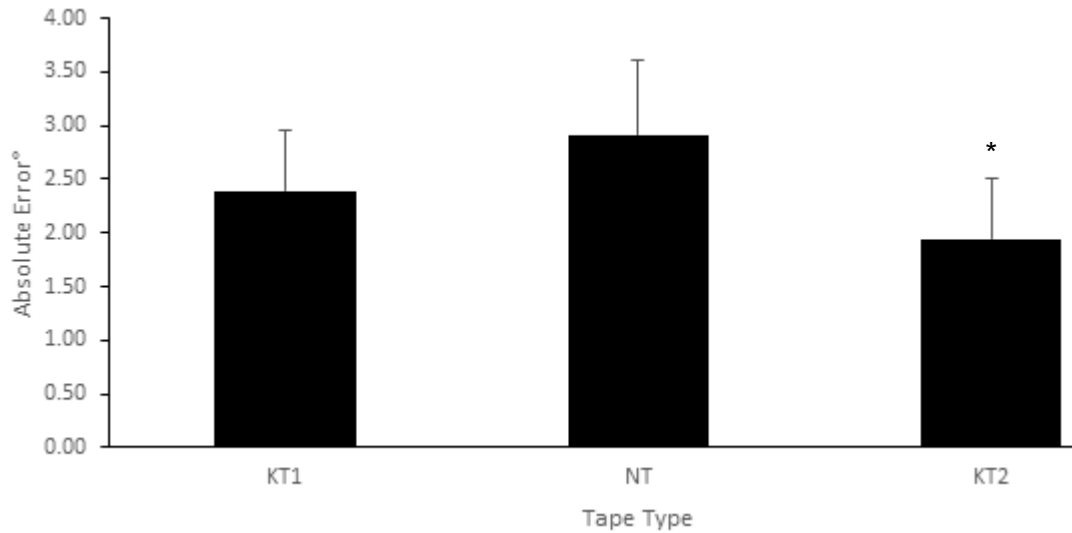
Figure 6.1: Effects of tape type on θ_{15} (* Denotes significant difference, *P* < .05, with NT)
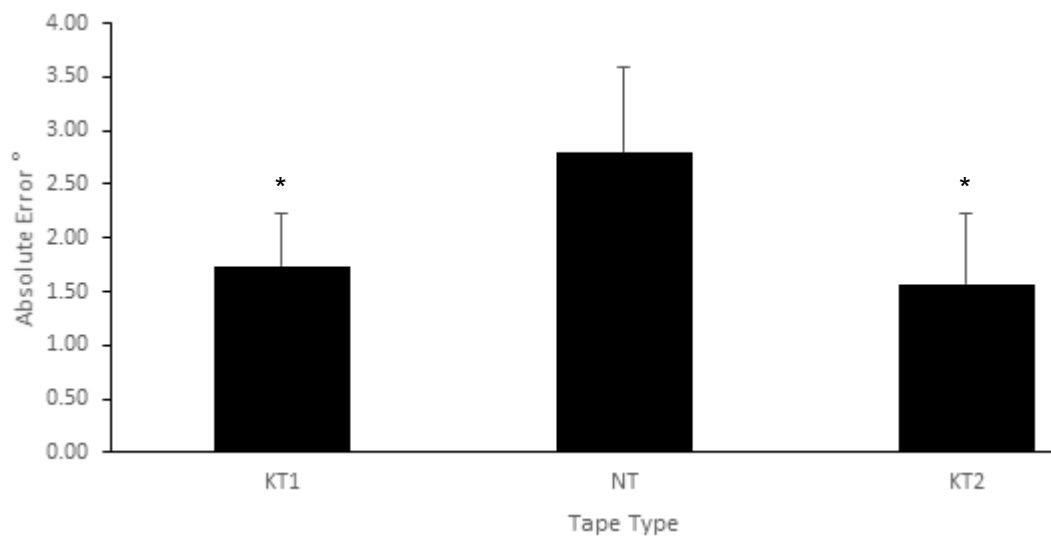
Figure 6.2: Effects of tape type on θ_M (* Denotes significant difference, *P* < .05, with NT)

Figure 6.3 illustrates the effect of different types of tape on T, with significant differences observed (P = .04) with Bonferonni adjustments demonstrating a significant main effect for KT_2 (1.49 ± 0.05 s, P = .02; 95% CI = -0.15 to -0.01; d = 1.80) with the time to complete the task decreasing, when compared to NT (1.58 ± 0.05°). Non-significant force plate results are depicted in Table 6.1.
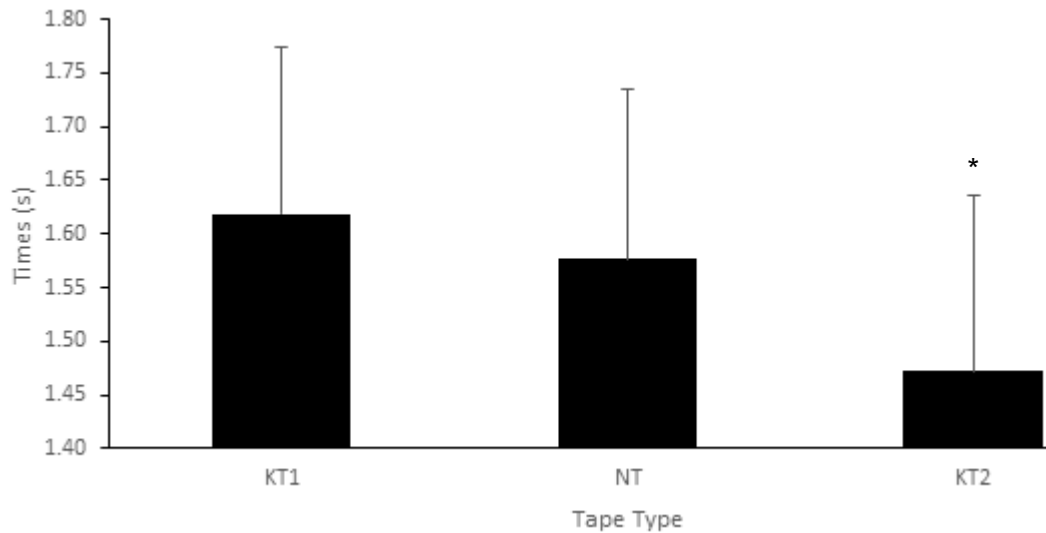
Figure 6.3: Effects of tape type on T (* Denotes significant difference, *P* < .05, with NT)

Figure 6.4 illustrates a significant (P = .05) trial main effect for the A_D of the SEBT, with post hoc Bonferonni adjustments identifying a significantly (P = .02) greater A_D reach distance when KT_2 (73.09 ± 5.96 cm; 95% CI = 0.48 to 4.60, d = 0.44) is applied when compared to NT (70.55 ± 5.39 cm). The GLM failed to identify similar significant findings for either PL_D (85.21 ± 9.87 cm; P = .23) nor PM_D (86.97 ± 9.68 cm; P = .64).
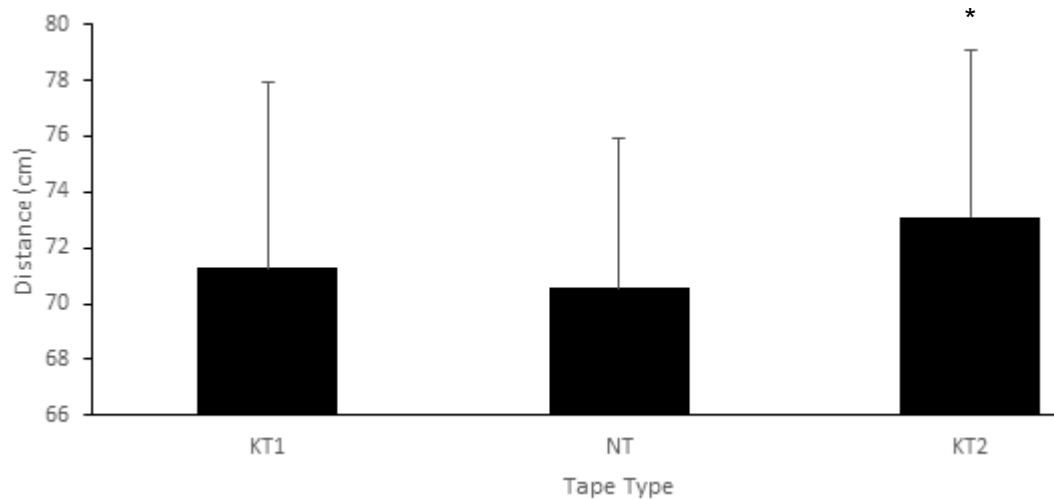
Figure 6.4: Type of tape effect on A_D (* Denotes significant difference, *P* < .05, with NT)

6.4 Discussion

The aim of this study was to determine the effects of different types of tape (KT_1, KT_2 and NT) on a multi-modal battery of tests, which, were designed to examine ankle function and tasks, which are problematic in ankle injury occurrence. The study utilised a multi-modal battery of tests involving intrinsic injury risk factors such as proprioception (Mohammadi et al., 2013; Mohammadi and Roozdar, 2010; Willems et al., 2005), strength asymmetries (Fousekis et al., 2012; Hazdic et al., 2009; Wang et al., 2006), balance and postural stability (McGuine et al., 2000; Semple et al., 2012; Wang et al., 2006) and tests which produced a culmination of the aforementioned variables in the form of a modified drop and drive test (Reiman and Manske, 2009) in order to determine whether a type of tape effect existed in semi-professional soccer players.

Type of tape demonstrated significant results in a small sample of the performance predictors measured within the injury predictive tasks. IKD measures of proprioception, θ_{15} and θ_M, were both shown to be significantly decreased in the form of absolute error, when utilising either KT_2 and KT_1, and KT_2 respectively. KT claims to enhance proprioceptive capabilities via increased stimulation of skin cutaneous mechanoreceptors, thus creating greater levels of afferent feedback to the CNS (Refshague et al., 2009), therefore enabling the body to have a greater sense of

awareness as to where it positioned. A study which investigated the effects of KT on grip strength (Chang et al., 2010) using 21 healthy college students, identified a decrease in force sense error when KT was applied to the forearm extensors, thus indicating an improved proprioceptive effect upon performance. Halseth et al., (2004) questioned these results, measuring JPS for both plantar-flexion and inversion using an equal mix of healthy male and female college students. This study discovered that the application of KT did not appear to reduce absolute error in ankle JPS, hypothesising that this could be due to the fact that they investigated a healthy population; therefore their proprioceptive capabilities are not impaired as is suggested with those who have suffered previous ankle injury (de Noronha et al., 2007). The limited literature surrounding KT and proprioception appears to be divided regarding its effectiveness in improving performance. The results of this study suggest that both KT_1 and KT_2 are able to reduce absolute error, thus enhancing proprioceptive capabilities. All the participants in this study were free of any previous ankle injury and played soccer to a semi-professional standard, thus disagreeing with the results and theories of (Halseth et al., 2004; Miralles et al., 2014). A potential reason for this could be due to the fact that the participants used within this study already possessed enhanced levels of proprioceptive ability due to their level of performance and activity profile. It is therefore hypothesised that KT is able to further improve JPS in trained populations via the stimulation of skin cutaneous mechanoreceptors when the participants are afforded the time to dictate their final position rather than responding to an unpredictable stimuli. This would therefore allow for a heightened level of afferent feedback received regarding the positioning of the ankle joint, leading to less absolute error. It is also worthy of mention, that although insignificant, both KT_1 and KT_2 demonstrated a trend toward significance in improving the time to complete the drop and drive task, potentially due to the mechanisms previously explained regarding proprioception and its ability to improve agility performance, thus reducing the time to complete the task.

Although T did not significantly improve under the influence of tape during the drop and drive task, KT_2 demonstrated a significant improvement T performance (see Figure 6), with a reduction in time to complete the task evident. These results would suggest that KT_2 has an effect in improving speed over a distance of 4m, where the participant has landed from a pre-determined height and responded to an

unpredictable stimulus. Limited studies have been conducted into the effects of KT on more sport functional tests such as speed. However, de Hoyo et al., (2013), investigated the effects of KT on a variety of sport functional tests using elite youth soccer players, which included the 10m sprint test, noting no significant improvement in time when KT_1 was compared to NT. The authors postulated that the negative results observed in their study could be explained by the fact that afferent stimuli generated by KT may not be strong enough to enhance performance of elite healthy soccer players. However, it is believed that the negative results of de Hoyo et al., (2013) and the difference between the significant results achieved for speed in this study may be explained by the difference in tasks and what they required the participants to complete. The drop and drive agility task, requires participant to land from a pre-determined height, absorb forces and respond to a visual stimulus, thus incorporating other risk factors such as balance/postural stability, proprioception, rate of force development, visual alertness and a cutting maneuverer, whereas de Hoyo et al., (2013) required the participants to run as quickly as possible in a straight line for 10m. It is hypothesised that due to KT demonstrating improvements in some studies for aspects such as muscle function (Lins et al., 2009; Vithoulka et al., 2010, proprioception (Chang et al., 2010) and postural stability (Semple et al., 2012) that this is where the improvements in speed could be gained during the current study.

No significant improvement was detected for any postural stability/balance variables measured during the BSS task. This is in disagreement with the study of Semple et al., (2012) who demonstrated an improvement in OSI when KT was applied to semi-professional rugby union players. However, upon further analysis of the results Semple et al., (2012) determined that this significant improvement in performance was only attributable to forwards rather than backline players, who have been proven to be faster and more agile players (Duthie, Pyne and Hooper, 2003). Therefore, it may be assumed that due to the positional demands of backline players, they have developed greater levels of proprioception and postural stability, thus making it more difficult for them to achieve improved levels of OSI when KT was applied compared to forward line players (Semple et al., 2012). This could be potentially due to forward players having less acceleration, deceleration and cutting manoeuvres during training and match play performance. Backline players in rugby union have also

been reported to have body fat levels similar to that of soccer players (Toriola, Salokun and Mathur, 1985) and a similar functional skill set such as agility, speed and balance (Gabbet et al., 2006). Therefore it can be assumed that semi-professional soccer players may also find it difficult to achieve improved performances in functional skills such as balance and postural stability through the medium of KT, due to superior levels already possessed when compared to the general population.

Another method utilised to assess postural stability and balance is the SEBT, where a significant improvement in performance was detected for the A_D when KT_2 was applied. KT_2 provides an increase in the amount of stretch compared to that of 140% achieved by KT_1. Therefore, this increase in stretch could potentially produce an increase in A_D reach distance as the tape was applied along the direction of the muscle fibres, thus facilitating an increase in the strength of the underlying musculature (Vithoulka et al., 2010). Nakajima et al., (2013) investigated the effects of KT on the SEBT using healthy volunteers, observing an increase in the PM_D. Potential reasons for this increase in performance were that the increase in tension provided by the tape could produce greater levels of neural feedback thus facilitating increased balance and postural stability. The difference in improvement in reach distance between this study and Nakajima et al., (2013) could potentially be attributed to the type of participants used, semi-professional soccer players and healthy participants respectively. Soccer players have been shown to have inferior balance levels when compared to dancers and gymnasts (Davlin, 2004; Matsuda et al., 2008), but superior balance compared to basketball players, swimmers and the general population. Therefore, it could be feasible to assume that soccer players, balance and postural stability ability may only improve the reach distance in the A_D of the SEBT as this has been shown to be the most difficult direction to achieve distance (Fullam et al., 2014). This is compared to that of healthy volunteers (Nakajima et al., 2013), who demonstrated increased reach distances in the PM_D, which has been shown to be the easiest direction to achieve greater reach distances, therefore participants would be able to see greater gains in this direction compared to that of semi-professional soccer players.

6.5 Conclusion

The present study demonstrates that therapeutic tape in the form of KT_1 and KT_2 in a trained population can help to produce significant performance enhancements in tasks which involve proprioception, speed, agility and balance/postural stability, all of which are pertinent to soccer performance. It should also be noted that KT had no significant detrimental effects on ankle function and performance. Therefore, whilst also recommending KT as a performance enhancing mechanism, practitioners could advise the use of KT as an injury prevention tool due to the fact that it has been shown to improve athletic performance in tasks, which have been shown by literature to be linked to ankle injury risk. These improvements in ankle function and performance via the use of KT could help reduce the amount of ankle injuries sustained in healthy male soccer players, thus allowing more players to be available for match day selection, reduce injury costs, whilst also limiting the detrimental health issues associated with ankle injuries which have been shown to have a high rate of reoccurrence.

Chapter 7, Study 4: Influence of Therapeutic Tape on Measures of Ankle Function and Performance during Soccer-Specific Fatigue

7.1 Introduction

In the previous study, both KT_1 and KT_2 demonstrated particular positive benefits associated with measures of ankle function, whilst also indicating a lack of commonality between performances on different tasks. Although these were interesting findings, limitations to the study existed as it was performed with the participants in a rested and controlled state, thus lacking ecological validity to soccer match play and injury incidence. Furthermore, study one indicated that it is not sufficient to measure injuries using a univariate approach, suggesting various measures must be investigated to provide a greater understanding as to how injury incidence occurs. Subsequently, it is necessary to investigate how fatigue affects a variety of ankle aetiological risk factors, whilst also determining the influence of KT as a mediator of fatigue.

Concern has been expressed by The Union of European Football Associations (UEFA), regarding the injury risks associated with the physical and mental load experienced by professional soccer players (Ekstrand et al., 2011). The most recent UEFA injury audit (Ekstrand et al., 2011), discovered that both training and match injury incidence remained consistent over a seven year investigation (2001 – 2008), involving 23 of the highest 50 ranked professional members belonging to UEFA. Furthermore, Ekstrand et al., (2011) highlighted an increase in injury incidence with match duration in each half for the three most common categories of injury: strains, sprains and contusions. The authors speculated that an accumulation of fatigue could be culpable for these findings, with previous studies demonstrating that an increase in fatigue is evident towards the end of a soccer match due to less high intensity and technical performances actioned by its participants (Bangsbo, Iaia and Krustrup, 2007; Mohr et al., 2003; Rampinini et al., 2009).

The findings of Ekstrand et al., (2011) are in alignment with those presented ten years previously (Hawkins et al., 2001) in the Football Association (FA) audit, who also cited fatigue as a potential risk factor for the increase in injury incidence observed in the final 15 minutes of soccer match play in each 45 minute period.

Despite advances in sport and exercise medicine in the decade between these two pieces of research, it is apparent that no injury reduction regarding the three main injury subtypes has been observed. Furthermore, the temporal nature of fatigue and injury incidence has not been successfully alleviated. Additionally, fatigue has been demonstrated to reduce muscle force at the ankle, knee and hip (Gribble and Hertel, 2004), with additional studies indicating that neuromuscular control, proprioception and functional stability are impaired after fatiguing exercise, which could potentially increase the risk of ligamentous and muscular injury, especially during dynamic activity (Greig and McNaughton, 2014; Greig and Walker-Johnson, 2007; Mohammadi and Roozdar, 2010; Ribeiro et al., 2008). Subsequently, this causes a deterioration of the sensory proprioceptive and exteroceptive information, and/or motor output and/or efficiency of the muscular system (Palliard, 2012). Further to this, injuries have been demonstrated to occur in a multi-modal manner (Bahr et al., 2003) with various factors contributing towards an injury occurrence.

The potential benefits of using KT have been well described during the previous study. However, utilising KT whilst under the influence of sport specific fatigue has received little research attention. Research suggests that prophylaxes in the form of Zinc Oxide tape, can help to reduce ankle plantar flexion (PF) and inversion (INV) ROM, thus decreasing the risk of ankle joint injury, however this initial benefit has shown to be negated after 20 minutes of exercise (Forbes et al., 2013; Lohkamp et al., 2009), whereas Ricard et al., (2000) claims that a ROM still existed upon the conclusion of exercise. Further ambiguity exists surrounding prophylaxes and performance enhancement. Lohkamp et al., (2009) claimed an initial enhancement in performance in proprioception, only for this improvement to be again negated after 20 minute of exercise, thus demonstrating problems surrounding the efficacy of tape and its ecological validity during sport performance which produces fatigue.

A plethora of research has been conducted into the effects of prophylaxes before, during and after exercise, however these studies were either not sport specific (Han and Lee, 2014;) or used sport specific treadmill based protocols (Lohkamp et al. 2009), with research suggesting that running on a predictable flat surface such as the a treadmill, requires decreased ankle stabilisation and peroneal activity (Baur et al., 2007), thus not fatiguing this important muscle group adequately. Enhanced levels of

HR, RPE and knee joint mechanics were discovered using the SAFT[90] when compared to a matched running velocity treadmill soccer match simulation, with authors hypothesising this could be potentially as a result of the inclusion of utility movements in the free running protocol (Azidin et al., 2015). Investigations into free running sport specific protocols and their effect upon prophylaxes is limited, however the SAFT[90] allows for these conditions to be sustained, whilst implementing utility movements, acceleration and decelerations, speed, changes in direction, number of changes in direction and distance covered, similar to those observed during professional soccer match play (Small et al., 2009), thus providing greater levels of ecological validity. Forbes et al., (2013) investigated the effects of the SAFT[90]on the use of prophylactic support when measuring ankle joint ROM and JPS, discovering Zinc Oxide tape to enhance performance at rest when compared to a brace and control condition. However, upon conduction of the SAFT[90] tape lost its restrictive benefit after 15 minutes and was no different to the control group in either measure, suggesting the clinical effectiveness of Zinc Oxide tape is limited in soccer-specific conditions (Forbes et al., 2013).

The results of study one, suggest that although there are no global links between the main predictors of injury, commonality does exist between the factors, which contribute to their performance. Therefore, it would seem rationale to suggest that further research is needed to investigate the effects of KT on exercises which have been shown to be predictors of ankle injury, as very little information is available as to whether KT is superior to not tape and/or non-elastic tape (Semple et al., 2012). KT must be investigated using a homogenous group under the influence of soccer specific fatigue, whilst also performing or using a multi-modal battery of tests and equipment.

This aim of this study was to investigate the effects of KT and a control group using the SAFT[90] to elicit soccer-specific fatigue. The effects of fatigue were then examined on a variety of ankle injury risk factors at set intervals, to determine the efficacy and ecological validity of KT for soccer injury prevention. It is hypothesised that KT will help to improve ankle joint function through increased support mechanisms, thus providing improved postural stability. A secondary hypothesis

stipulates that KT will maintain its purported beneficiary effects for a longer duration than those observed with traditional white tapes.

7.2 Method

Participants

Twelve male semi-professional soccer players (Age: 24 ± 1.21 yrs.; Height 178.79 ± 5.81cm; Body Mass 78.89 ± 3.76kg) were recruited to participate in this study. Participant eligibility was determined utilising the inclusion and exclusion criteria described in Chapter 3. Preliminary anthropometric and health screening procedures were also completed as described in Chapter 3, with the current study also conforming to all ethical considerations as previously described within the same chapter.

Experimental Design

Subjects first completed a 30-minute familiarisation of the SAFT^{90} and measures of dynamic balance performance to ensure no anomalies in performance. This was followed by a version of the free running Soccer – Specific Aerobic Field Test (SAFT^{90}), described in Chapter 3, in a randomised order under the conditions of NT and KT$_1$. Application of KT$_1$ is described during Chapter 3, with the same method adopted for this current study. During completion of the SAFT^{90} measures of heart rate (HR) and blood lactate (BLa) were taken as markers of physiological fatigue. In addition to this, therapeutic measures of dynamic balance in the form of the BSS and SEBT were analysed as well as biomechanical variables in the form of kinematic joint, force plate (conducted every 15 minutes) and GPS accelerometry analysis (continuously throughout). Experimental measures and controls are described in greater detail in Chapter 3. Prior to the commencement of each trial, participants were required to complete a standardised warm-up (Chapter 3)

Players were tested in both a taped (KT) and no tape (NT) condition, performed in counter-balanced order, with trials were separated by a minimum of 48 hours. All test sessions were conducted at the same time of day to account for diurnal variation in postural stability (Gribble, Tucker and White, 2007), with all testing sessions

completed at the end of the English 2013 – 14 soccer season. Given the findings observed in study 2, the lack of circadian effect on main outcome measures is acknowledged, thus all testing was conducted at the same time of day to account for any variation in physiological response, and in accordance with regular training times of 19:00 hours.

Statistical Analysis

Assumptions of normality have been previously described in chapters 5 and 6. A mixed method two-way (Trial*Time) repeated measures general model (GLM) was utilised to compare the two trials (NT vs. KT) and over time. To compare baseline differences between groups during the completion of the first trial a two-way (Group*Time) was performed. Post-hoc pairwise comparisons with a Bonferonni adjustment factor were applied where necessary. All statistical analysis was conducted using PASW Statistics Editor 22.0 for Windows (SPSS Inc., Chicago, USA), with statistical significance set at $P \leq 0.05$. All data is reported as mean ± SD unless otherwise stated. For all significant interactions, 95% confidence intervals (CI) and reported in conjunction with the traditional statistical approach, Cohen's *d* effect sizes (< 0.50 = small, $0.50 - 0.80$ = small to moderate, > 0.8 = large) will be calculated to further assess differences in measures.

7.2 Results

Physiological Variables

No significant trial differences were observed for heart rate, (NT = 148.01 ± 9.62 b-min^{-1}; KT 146.96 ± 7.47 b-min^{-1}, P = .23), however significantly ($P \leq$ .05) lower values were observed for HR_{00} (56.96 ± 2.42 b-min^{-1}) when compared to all subsequent time points (P = < .001), t_{0-15} (144.29 ± 9.26 b-min^{-1}; P = < .001; 95% CI = -92.96 to -81.71; d = 12.90), t_{15-30} (148.33 ± 11.95 b-min^{-1}; P = < .001; 95% CI = -98.91 to -83.84; d = 10.60), t_{30-45} (148.67 ± 12.16 b-min^{-1}; P = < .001; 95% CI = -99.30 to -84.12; d = 10.46), t_{60-75} (141.79 ± 11.09 b-min^{-1}; P = < .001; 95% CI =-91.74 to -77.93; d = 10.57), t_{75-90} (146.54 ± 12.14 b-min^{-1}; P = < .001; 95% CI = -97.19 to -81.98; d = 10.23) and t_{90-105} (150.13 ± 10.14 b-min^{-1}; P = < .001; 95% CI =-99.51 to -86.82; d = 12.64). Similar observations are noted for t_{45-60}, with

significantly lower values observed for time points $t_{15\text{-}30} - t_{90\text{-}105}$ ($P < .001$). Furthermore, Trial*Time interactions failed to demonstrate any significance ($P = .21$). A similar trend was observed for Blood Lactate (BLa), with no significant trial effects noted (NT = 2.49 ± 0.69 mmol·l^{-1}; KT = 2.52 ± 0.45 mmol·l^{-1}, $P = .73$), whilst a significant effect was observed for time ($P < .001$), with post-hoc pairwise comparisons identifying a significantly lower value at rest (BLa$_{00}$ = 1.03 ± 0.28 mmol·l^{-1}) when compared to (BLa$_{45}$ = 2.68 ± 0.90 mmol·l^{-1}, $P < .001$; 95% CI = -2.32, to 1.09; $d = 2.47$) and (BLa$_{105}$ = 2.98 ± 0.83 mmol·l^{-1}, $P < .001$; 95% CI = -2.71 to -0.88; $d = 3.15$). In addition to this, no significance was observed ($P = .86$) for Trial*Time interactions. Furthermore, Trial*Time interactions failed to demonstrate any significance ($P = .21$).
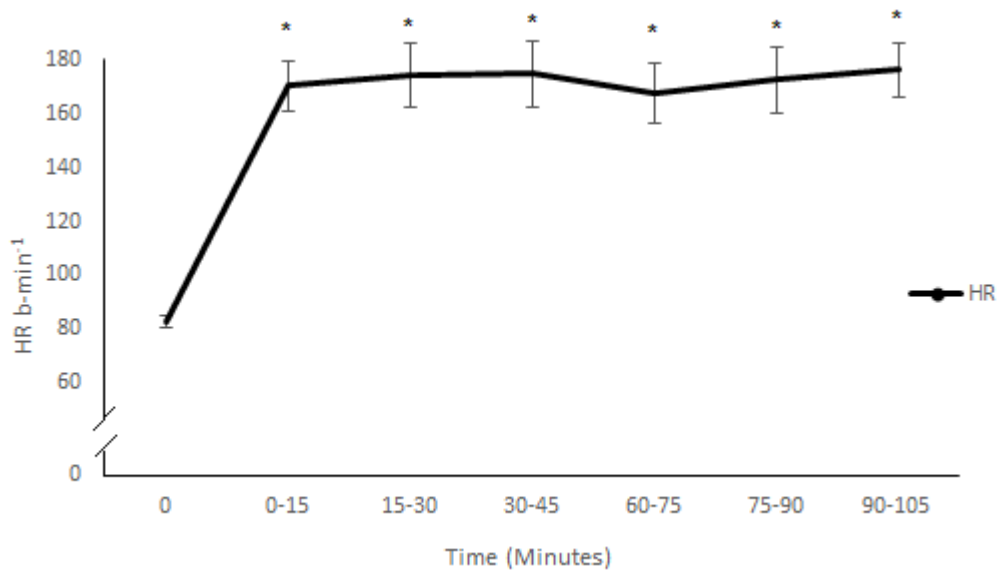
Figure 7.1: HR response across trials and time (* denotes significant difference with t$_{00}$)
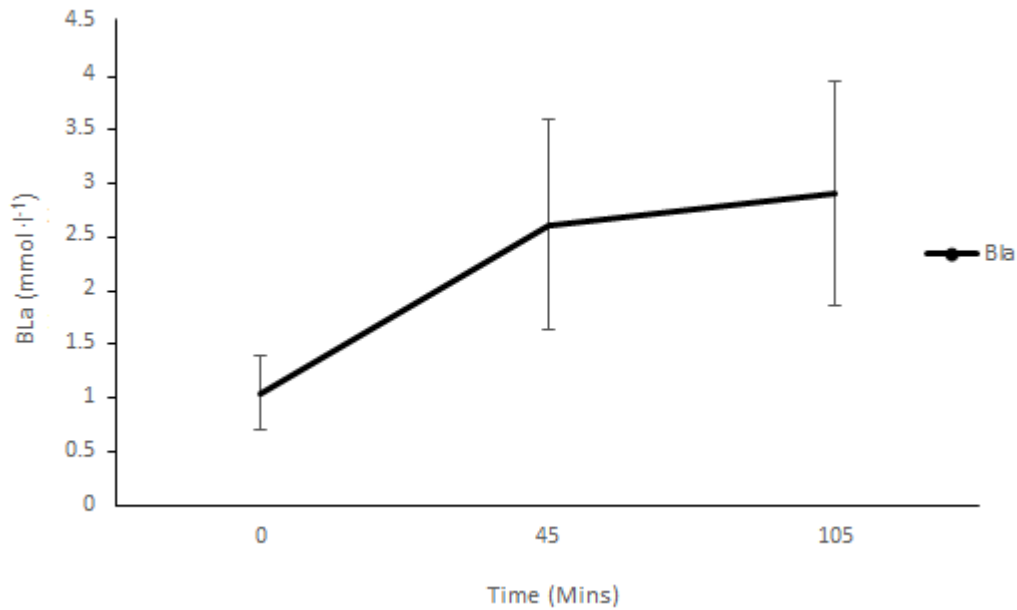
Figure 7.2: BLa response across trials and time (* denotes significant difference with t$_{00}$)

Dynamic Balance Variables

Figure 7.3 identifies a significant main effect for OSI for both trial ($P = .02$) and time ($P < .001$). Post-hoc pairwise comparisons identified significantly increased OSI values (NT = 1.63 ± 0.52, KT = 1.23 ± 0.35 au; $P = .02$; 95% CI = 0.08 to 0.73; $d = 0.90$) in the NT trial, whilst also highlighting a significantly ($P < .001$) lower value at rest (OSI$_{00}$) (1.07 ± 0.70 au), when compared to all subsequent time points OSI$_{15}$ (1.50 ± 0.48; $P = .02$; 95% CI = -0.82 to -0.04; $d = 1.08$), OSI$_{30}$ (1.53 ± 0.41; $P = .01$; 95% CI = -0.80 to -0.13; $d = 1.20$), OSI$_{45}$ (1.59 ± 0.57; $P \leq .01$; 95% CI = -0.88 to -0.15; $d = 1.15$), OSI$_{75}$ (1.41 ± 0.42; 0.42; $P = .02$; 95% CI = -0.62 to -0.04; $d = 1.05$), OSI$_{105}$ (1.57 ± 0.36; $P = \leq .01$; 95% CI = -0.84 to -0.16; $d = 1.53$), excluding the measurement recorded after the half time period of rest (OSI$_{60}$ = 1.41 ± 0.35 au, $P = .25$) and OSI$_{90}$ (1.35 ± 0.37; $P = .20$).

Similar trends were also observed for additional BSS indices AP (NT = 1.28 ± 0.35 au; KT = 0.97 ± 0.14 au, $P = .01$; 95% CI = 0.08 to 0.54; $d = 1.16$), which is further supported by the ML direction (NT = 0.93 ± 0.35 au; KT = 0.69 ± 0.14 au, $P = .04$; 95% CI = 0.01 to 0.48; $d = 0.90$). AP index observes a similar increase in deviation as time progresses ($P = .01$), with a significantly lower value observed for AP$_{00}$ (0.62

± 0.24 au) when compared to AP_{30} (1.15 ± 0.41 au; P = .01; 95% CI = -0.51 to -0.05; d = 1.58), AP_{45} (1.29 ± 0.37 au; P = .01; 95% CI = -0.75 to -0.07; d = 2.14) and AP_{105} (1.30 ± 0.36 au; P = .02; 95% CI = -0.79 to - 0.04; d = 2.22). A significant main effect is noted for ML index and time (P = .01), with post-hoc pairwise comparisons identifying this interaction to occur between ML_{00} (0.62 ± 0.26 au; ML_{75} = 0.82 ± 0.24 au; P = .01; 95% CI = -0.39 to - 0.01; d = 0.80). Both directional indices, AP (P = .55) and ML (P = .82) failed to demonstrate significant Trial*Time interactions.
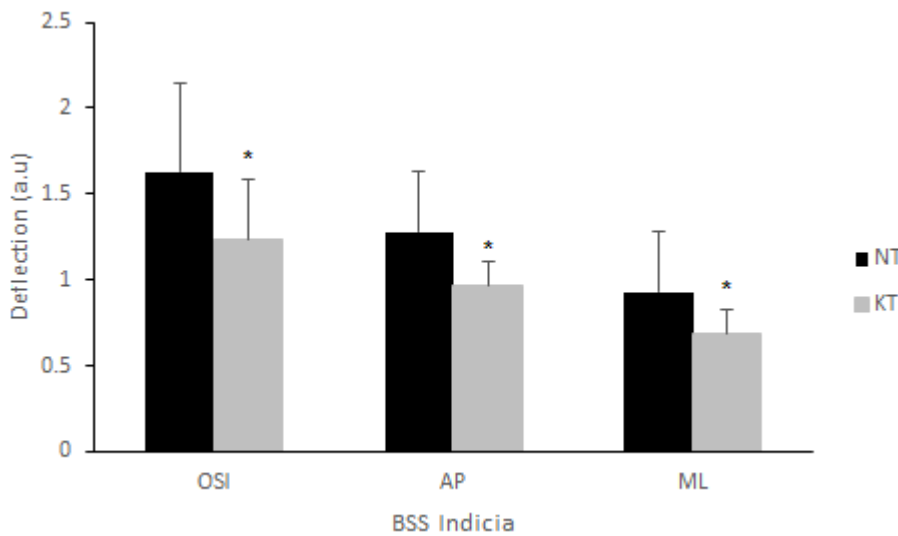
Figure 7.3: BSS indicia deviation across trial (* denontes a significant difference with NT Trial)

Another measure of dynamic balance, the SEBT, failed to display any significant main effects for trial A_D (91.07 ± 7.65cm, P = .21), PL_D (95.91 ± 5.92 cm, P = .35) and PM_D (101.24 ± 6.44cm, P = .75). Both A_D (92.07 ± 7.17cm, P = .01; 95% CI = 0.46 to 6.33; d = .02) and PL_D (98.05 ± 7.25 cm, P = .05; 95% CI = 0.72 to 4.34; d = 0.40) demonstrated significantly higher values at t_{30} when compared to rest $t_{00,}$ (A_D = 88.62 ± 7.96 cm; PL_D = 94.63 ± 6.82 cm). Post-hoc pairwise comparisons identified significant time main effects (P < .01) with lower PM_D values demonstrated at t_{105} (98.14 ± 7.73 cm) when compared to; t_{00} (101.69 ± 7.73 cm; P = .04; 95% CI = 0.08 to 7.02; d = 0.47) t_{15} (102.78 ± 7.69 cm; P = .01; 95% CI = 1.14 to 8.12; d = 0.62), t_{30} (102.08 ± 5.96 cm; P = .01; 95% CI = 0.66 to 7.23; d = 0.59), t_{45} (101.80 ± 5.46 cm; P = .01; 95% CI = 0.99 to 6.32; d = 0.56), t_{75} (102.02 ±

7.61cm; P = < .01; 95% CI = 1.77 to 5.98, d = 0.52), t_{90} (100.65 ± 6.49 cm; P = .04; 95% CI = 0.06 to 4.96; d = 0.36) (Figure 6.4). No significant Trial*Time interactions were observed ($P \geq .20$) for any of the SEBT directional indices.
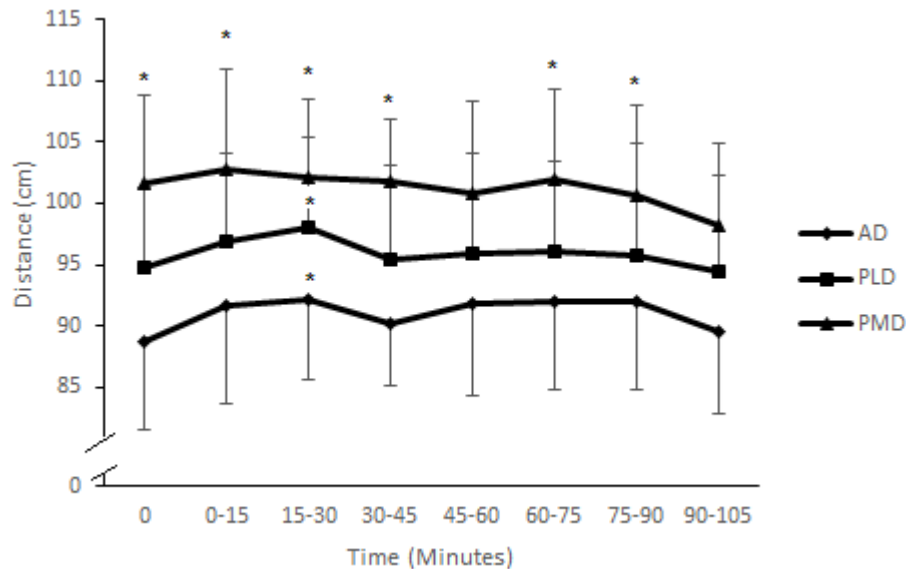
Figure 7.4: SEBT indicia response across time (* denotes significant difference with t_{105})

Kinematic measures of SEBT A_D displayed significant trial interactions for Angle Change (NT = 19.17 ± 0.65°, KT = 11.76 ± 3.29°, $P \leq .001$; 95% CI = 4.55 to 10.27; d = 3.12) as summarised in Figure 7.3. No significant main effects or interactions were displayed for time (P = .60) nor Trial*Time (P = .66). A similar trend was observed for the PL_D direction, with significant trial main effects observed for Angle Change (NT = 13.07 ± 2.94°, KT = 7.54 ± 2.32°, P = .01; 95% CI = 3.19 to 7.89; d = 2.09). Post-hoc pairwise comparisons identified a main effect for time for PL_D Angle Change only (P = .03), with time points PLD_{00} (8.83 ± 3.88°) demonstrating significantly lower values when compared to all second half time points t_{60} (11.16 ± 3.55°, P = .03; 95% CI = -4.36 to -0.30; d = 0.63), t_{75} (10.96 ± 3.27°, P = .03; 95% CI = -3.94 to -0.31; d = 0.59), t_{90} (10.37 ± 4.49°, P = .02; 95% CI = -2.68 to -0.39; d = 0.37) and t_{105} (11.39 ± 5.35°, P = .05; 95% CI = -5.09 to -0.04; d = 0.55). Trial*Time interactions, failed to display significance for all PL_D kinematic variables, ($P \geq .15$). Kinematic measures of PM_D variables demonstrated significant trial main effects for Angle Change (NT = 16.44 ± 4.15°, KT = 13.38 ± 5.22°, P =

.01; 95% CI = 0.85 to 5.26; d = 0.65). No significant Trial*Time interactions were displayed for any PM_D kinematic variables measured ($P \geq .10$).
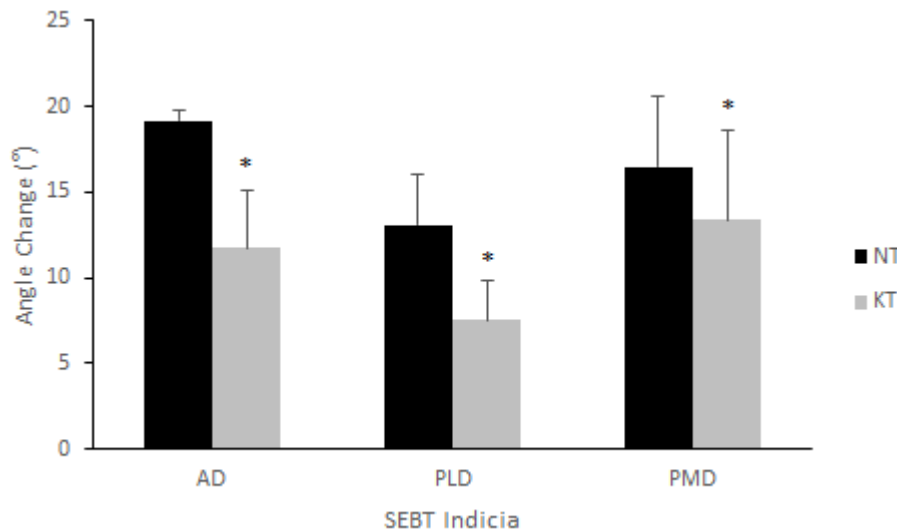
Figure 7.5: SEBT indicia angle change across trials (* denontes a significant difference with NT trial)

Mechanical Variables

Figure 7.6 identifies a significant main effect for trial ($P = .02$) and PL_{AP}, (NT = 53.19 ± 6.31 au, KT = 48.15 ± 6.11 au $P = .03$; 95% CI = 0.48 to 9.60; d = 0.81), PL_{ML} (NT = 45.67 ± 3.94 au, KT = 43.74 ± 3.53 au, $P \leq .01$; 95% CI = 0.86 to 3.00; d = 0.52) and PL_V (NT = 99.90 ± 4.36 au, KT = 97.16 ± 4.64 au, $P = .04$; 95% CI = 0.17 to 5.31; d = 0.61), with KT reducing PL absolute values in all three planes of movement. In addition to this, significantly ($P = .01$) lower PL_{Total} values were observed during the KT condition (NT = 195.07 ± 9.13 au, KT = 188.53 ± 5.64 au; 95% CI = -11.24 to -1.84; d = 0.86) as depicted in Figure 7.7. Absolute values PL_{Total}, $PL_{AP,}$ PL_{ML} and PL_V demonstrated no significant ($P \geq .05$) main effects for time or trial*time interactions.
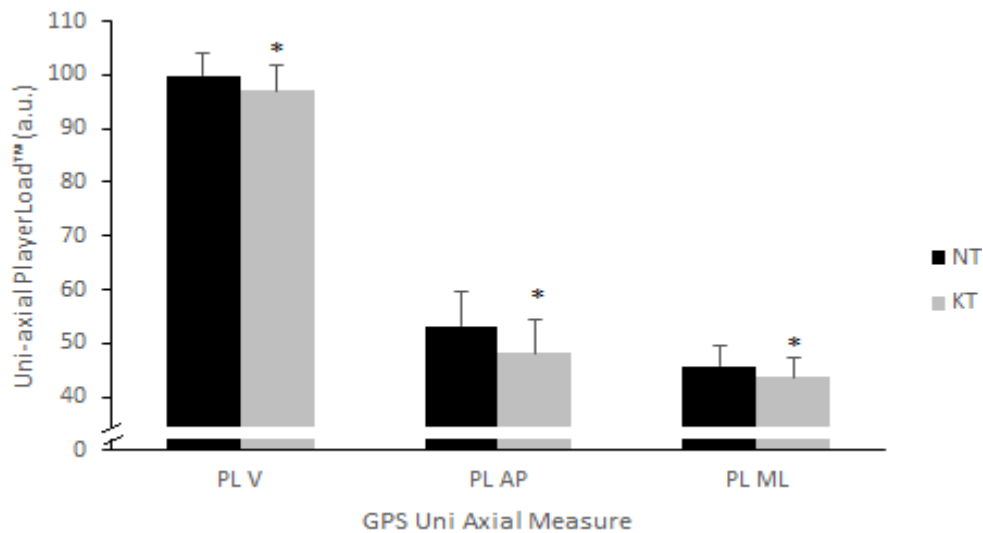
Figure 7.6: PlayerLoad™ uni-axial measures across trials (* denontes a significant difference with NT trial)
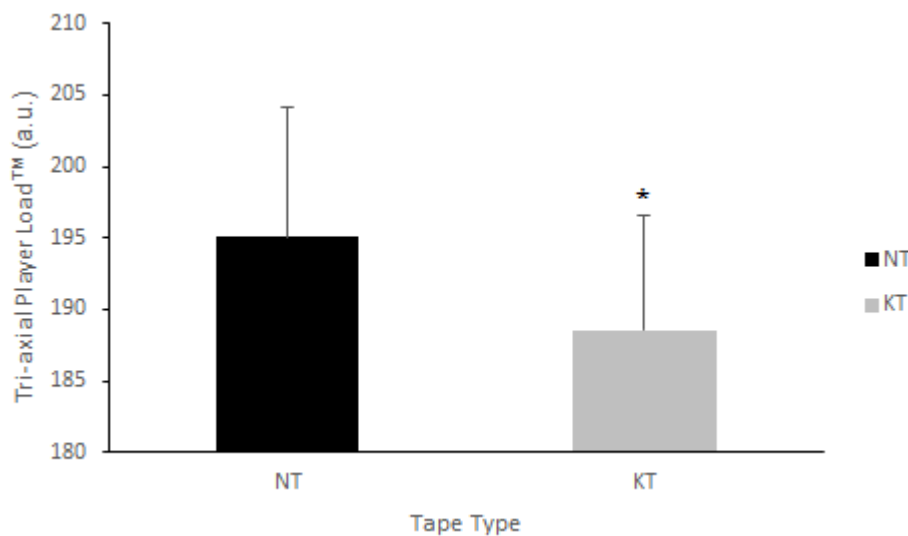
Figure 7.7: Tri-axial PlayerLoad™ measures across trials (* denontes a significant difference)

The GLM failed to identify any significant ($P \geq .05$) trial main effects for all relative contributions, $PL_{AP\%}$, $PL_{ML\%}$ and $PL_{V\%}$ (26.3 ± 2.17 au, 23.19 ± 1.70 au, 50.12 ± 3.82 au). Furthermore, no significant main effects for time ($P \geq .05$) nor trial*time interactions were observed for all relative contributions.

Force Plate

No significant ($P \geq .05$) main effects for trial were observed for any of the variables measured. A similar trend was observed for time, with no significant ($P \geq .05$) main effects observed, with the exception of $\dot{F}z_D$, demonstrating significantly ($P < .01$) higher values at $t_{00\text{-}15}$ (5.54 ± 2.25 au) when compared to all subsequent time points, $t_{15\text{-}30}$ (4.13 ± 1.76; $P = .01$; 95% CI = 0.45 to 2.38; $d = 0.70$) $t_{30\text{-}45}$ (4.16 ± 1.98; $P = .05$; 95% CI = 0.01 to 2.78; $d = 0.65$), $t_{60\text{-}75}$ (3.86 ± 1.59; $P = .01$; 95% CI = 0.47 to 2.90; $d = 0.86$), $t_{75\text{-}90}$ (3.76 ± 1.83; $P = .01$; 95% CI = 2.79 to 4.72; $d = 0.87$) and $t_{90\text{-}105}$ (3.93 ± 1.63; $P = .02$; 95% CI = 3.18 to 1.63; $d = 1.20$). Furthermore, the GLM failed to identify any significant ($P \geq .05$) trial*time interactions for all force plate variables.

EMG Variables Sprint Task

The GLM failed to identify main effects for trial and EMG_{Mean}, with TA (75.28 + 30.41μV, $P = .10$) and LG (68.34 + 31.38μV, $P = .49$) failing to display any significance. However, as demonstrated in Figure 6.8, PL EMG_{Mean} demonstrates a significant main effect for trial (NT = 75.73 ± 37.53μV; KT = 133.88 ± 44.15μV, $P < .01$; 95% CI = 29.70 to 86.59; $d = 1.43$), with increased values observed during the KT trial. The GLM identified a significant ($P < .05$) main effect for time and EMG_{Mean} for all muscles. Significantly lower values were observed for TA EMG_{Mean} $t_{30\text{-}45}$ (68.18 ± 21.59 μV, $P = .01$; 95% CI = -41.11 to -5.11; $d = 0.48$), $t_{75\text{-}90}$ (69.50 ± 26.03μ, $P = .05$; 95% CI = -39.10 to -0.09; $d = 0.42$) and $t_{90\text{-}105}$ (56.67 ± 21.16μ, $P = .04$; 95% CI = -42.59 to -0.24; $d = 0.85$) when compared to t_{00} (83.65 + 39.61μV). A similar decrease in performance is observed for the final time point of PL EMG_{Mean} with increased values observed at t_{00} (122.34 ± 51.44μV) when compared to $t_{90\text{-}105}$ (83.89 ± 37.99, $P = .03$; 95% CI = 10.96 to 61.24; $d = 0.85$) The GLM identifies the same fatigue effect for LG EMG_{Mean} as those noted for PL and TA, with significantly increased values observed at t_{00} (83.65 ± 31.64μV), when compared to $t_{75\text{-}90}$ (62.30 ± 25.47μ, $P = .03$; 95% CI = 3.11 to 39.61; $d = 0.74$) and $t_{90\text{-}105}$ (56.67 ± 25.93μV, $P = .01$; 95% CI = 9.25 to 44.72, $d = 0.93$). Trial*Time interactions failed to display significance for PL and LG ($P \geq .10$), whereas significance was indicated for TA ($P = .04$) with post-hoc pairwise comparison identifying this difference to occur at T_{30}

[45] (NT = 42.63 ± 14.58 µV; KT = 87.08 ± 28.61 µ, $P = < .01$; 95% CI = -59.26, -29.64; $d = 1.96$).
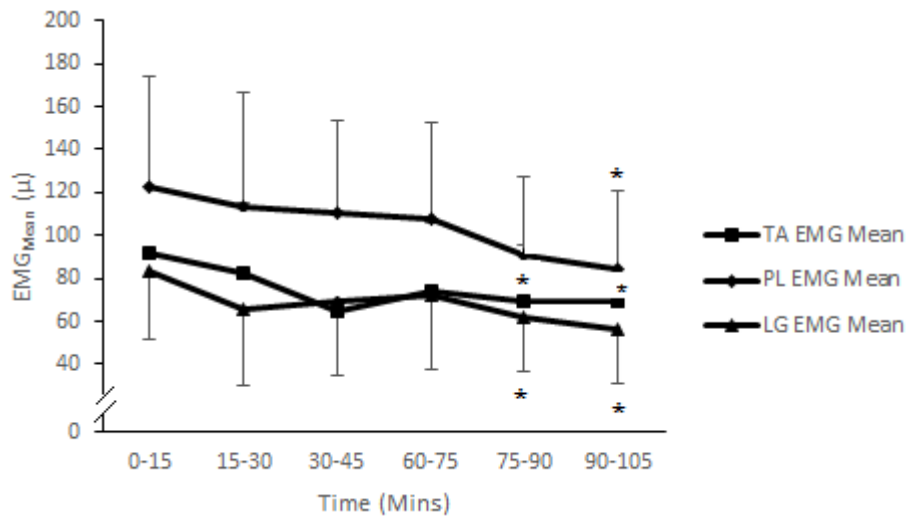
Figure 7.8: Sprint EMG_{Mean} response across time (* denotes significant difference with t_{00})

EMG Variables BSS

EMG_{Mean} failed to identify any significant trial main effects for each of the three muscles ($P \geq .05$), whilst also failing to identify significant Trial*Time interactions ($P \geq .10$). Exercise duration failed to display any significant main effect for LG EMG_{Mean} ($P = .53$), with the converse relationship identified for TA EMG_{Mean} ($P = .02$), with post-hoc pairwise comparisons identifying the significant difference to occur between T_{00} (33.44 ± 10.22µ) and t_{90} (44.19 ± 13.43µ, $P = .03$; 95% CI = -20.25 to -1.25; $d = 0.90$).

EMG Variables SEBT

EMG_{Mean} failed to demonstrate any significant main effects for Trial for each of the muscles analysed ($P \geq .11$), whilst also failing to identify significant main effects for Time ($P \geq .31$) and Trial*Time interaction ($P \geq .25$), for TA, PL and LG whilst also displaying no significant Trial*Time interactions.

7.4 Discussion

The aim of this study was to investigate the effects of KT on aetiological risk factor associated with ankle sprain injury and measures of functional performance, with specific reference to soccer specific fatigue. Deficiencies in postural stability are a commonly cited risk factor for ankle sprain injuries (Hiller et al., 2008; McGuine et al., 2000; Wang et al., 2006). Subsequently, prophylactic support has been a commonly investigated mechanism (Fayson et al., 2013; Halseth et al., 2004; Semple et al., 2012) for the prevention of ankle sprain injuries. Various results of this study support the use of KT as a mechanism for reducing measures associated with aetiological risk factors linked to ankle sprain injury. Quantified improvements of 24.54%, 24.21% and 25.81% were observed for OSI, AP and ML respectively, indicating that postural stability was improved when the players wore KT compared to the control trial, with this improvement seeming to be multi-directional. With regards to a functional perspective, these results appear to be advantageous to sport participants as postural stability has been demonstrated to be a critical component of successful movement (Kwon et al., 2014), which was not impaired using KT. Perhaps more pertinently, improved performance in all indicia on the BSS indicates improved levels of postural stability, which has been demonstrated to reduce ankle injury incidence (Huurnink et al., 2014; Witchalls et al., 2012). It has been proposed, that KT is different to traditional "white" tapes, as it is designed to stretch rather than restrict performance (Semple et al., 2012). The continuous stretch applied to the skin via KT is postulated to stimulate cutaneous mechanoreceptors, which in turn relay a greater level of information to the CNS (Murray and Husk, 2001), which in turn improves the ability of the neuromuscular system to control movement via improved proprioceptive capabilities. However, the results of this current study indicate that KT failed to elicit an improved EMG response during the BSS, SEBT and sprint task of the ankle musculature, TA, LG and PL. These findings further support Briem et al., (2011) who noted no improvement in EMG activity during the SEBT, with Soraino et al., (2014) also indicating no change in triceps surae EMG when KT was applied during movement, which required acceleration, which this current study vindicates further. Reasons for a lack of significant improvement in EMG activity when KT is applied, could potentially be attributed towards a lack of aggressive pull

exerted by the tape to the skin, thus not triggering the desired proprioceptive response (Briem et al., 2011).

One potential mechanism for the improved BSS performance is ankle stiffness (Fayson et al., 2013) through static and dynamic restraints, which have been demonstrated to be associated with ankle sprain risk factors (Hertel, 2002). Static restraint is defined as the mechanical restraint provided by the passive structures of the ankle, such as ligaments, bone and the joint capsule (Stormont, et al., 1985), with this property often being assessed via the amount of anterior displacement or internal rotation permitted. In contrast, dynamic restraint is the ability of the musculotendinous unit to prepare for and react to unexpected loads (Gutierrez et al., 2009) and is often measured using tasks of postural stability. Both the ankle and knee joints have been demonstrated to rely heavily on dynamic restraints of the lower extremity, which increases joint stability and has been suggested to reduce injury incidence (Reimann et al., 2002). External restraints are a popular mechanism of improving dynamic stiffness, with traditional "white" taping been commonly utilised to improve restraint of the ankle joint via providing increased mechanical support (Cordova et al., 2005; Miller et al., 2012; Wikstrom et al., 2006) and subsequent movement reduction. However, KT has also been demonstrated to improve ankle stiffness (Fayson et al., 2013), although it does not have the same restrictive effects when compared to more traditional tapes. Fayson et al., (2013) demonstrated improvements in mechanical stiffness when KT was applied to the ankle joint, subsequently improving measures of postural stability. Proposed mechanisms for this improvement in performance were postulated, with results indicating that KT helped to limit passive ankle anterior stiffness, thus improving postural stability (Fayson et al., 2013). These findings concur with the results of the current study and, therefore, it is postulated that although not a primary aim of KT, as it claims to improve muscle support without restricting muscle function (Kase, 2002), improved static restraint from KT application is enough to improve joint stability.

Kinematic analysis of the BSS task failed to uncover any significant difference with regards to Qualisys change in angle. These findings are in agreement with previous research (Soo-Yong, 2015), which indicated that KT did not alter the movement or

technique of the ankle complex. One potential reason why KT failed to elicit a change in ankle angle is that for this to occur, movements are required at anatomical locations more proximal in the kinetic chain, to which no tape was applied, thus not affecting their structures. Secondly, kinematic analysis during the current study was performed using a 2-D maker system in the sagittal plane only, which may not be sensitive enough to determine kinematic changes during movements such as inversion or eversion due to the positioning of the reflective markers.

Further improvements in performance are elicited by KT when compared to the NT control group, in the form of a reduction in GPS PlayerLoad™. Reductions of 2.74%, 10.80%, 4.20% and 3.35% are observed for measure of tri-axial PlayerLoad™ PL_V, PL_{AP} and PL_{ML} and PL_{Total} respectively. As previously stated, it would seem apparent that KT produces a restrictive, although not inhibitory, effect on ankle joint and musculature performance, therefore not allowing the same degree of movement as observed during the control trial. The LG and soleus are the primary muscles observed during the propulsion phase of the gait cycle (Hamner et al., 2010; Hamner et al., 2013), therefore if KT is applied in a manner which reduces the ROM available at the ankle joint, less translation and acceleration is going to occur in both the PL_V and PL_{AP} planes of motion, subsequently reducing the amount of load experienced in these directions. Furthermore, a reduction in PL_{ML} is observed, reasons for which are hypothesised in the form of KT being applied to the ankle ligament complex, thus potentially placing a restriction on the amount of movement permitted in the form of inversion and eversion, subsequently reducing the amount of PL_{ML} experienced.

The main focus of biomechanical injury prevention mechanisms is to adjust the external and/or internal loads experienced by the body (McIntosh, 2005). In the context of KT as an injury prevention mechanism, the aim is to reduce the loads experienced below the injury threshold or enhance the ability of the body to tolerate greater loads (Nigg, 2009). It is postulated that using KT as an external mechanism will help aid the musculature surrounding the ankle joint to produce quick postural adjustments, whilst also enabling the body to utilise smaller muscles to further increase joint stability. This in turn will help to reduce the loading experienced at the joint and insertions of larger muscles surrounding the ankle joint (Nigg, 2009). It is

postulated that if the amount of load experienced can be reduced in planes of movement which have been linked to ankle injury risk (plantar-flexion and inversion) (Hesari et al., 2009), the probability of an ankle injury occurring will be further minimised. It should be noted that although reductions in PlayerLoad™ occurred, no significant improvements were observed during the cutting maneuverer when participants performed the sprint task. Furthermore, although no significant gains in functional performance were observed, it is worthy of mention that no significant deleterious effects with regards to functional performance were noted.

There were no significant main effects for time observed in any of the tri-axial variables measures. These results suggest that not only has KT altered participant running technique, but it has also managed to maintain this for the duration of the 90 minute soccer-specific protocol. Under the guise of soccer-specific simulations such as the SAFT[90], traditional white tapes have been demonstrated only to affect ROM during the first 15 minutes of exercise, before losing its mechanical effect upon performance (Forbes et al., 2013). With a greater incidence of ankle injuries occurring during the latter third of each half of soccer match play (Woods et al., 2003), it is postulated that KT provides a greater and constant mechanical effect on soccer-specific exercise, thus potentially helping to alleviate mechanisms associated with injury during this stage of the game. This is in contrast to those findings observed with the BSS, with KT failing to offset the deleterious effects of fatigue on postural stability. Potential reasons for this include the disturbances of postural stability related to fatiguing running are inclined to produce adverse effects on motor tasks that require minimal postural stability to be successful (Bermejo et al., 2015). Subsequently, the body will develop compensatory strategies to limit these disturbances (Palliard, 2012), one of which is to change from an ankle to a hip strategy when fatigue disrupts proprioception and/or motor output of the lower limb (Bisson et al., 2009; Palliard, 2012). Furthermore, these continued disturbances in BSS performance could be attributed to PlayerLoad™ being continuously measured throughout the whole 90 minute protocol replicating movements similar to those observed in match play, compared to that of the BSS, which requires participant to complete ten seconds of unipedal stance. It is, therefore postulated that the continuous period of recruitment the muscles undergo during the BSS task will elicit a greater level of fatigue in that period of time, when compared to the gait cycle,

where muscles will alternate between periods of high and low activity dependent upon the phase of the movement. Subsequently, it appears that during a ten second unipedal stance, KT fails to alleviate the effects of fatigue.

Another measure of postural stability, the SEBT failed to demonstrate any significant improvement in reach distance when KT was applied. The results of the current study support the findings of previous research (Bicci et al., Briem et al., 2011; Nakajima et al., 2013; Nunes et al., 2013), which reported no positive performance effects in male subjects. One potential reason for the lack of significant changes in reach distance when KT was applied could be due to the fact that the participants involved in this study were semi-professional soccer players, whose balance levels have been shown to be only second to those of gymnasts and dancers (Golomer et al., 1999; Palliard and Noe, 2006). This suggests that for this population, performance levels for balance and muscle function are already at a near maximum level; subsequently possible gains provided by KT were not significant or detectable using the SEBT. During training and match play, soccer players are constantly faced with situations that stimulate muscles, which are required to maintain balance for optimal performance (Nunes et al., 2013). However, it is possible that KT could have a significant influence on non-athletes who demonstrate weak balance and strength such as those who exhibit symptoms of chronic ankle instability (CAI), or those who do not train on a regular basis (Nunes et al., 2013).

Soccer specific fatigue appears not to have a deleterious effect on SEBT performance, as parameters A_D and PL_D demonstrate improved performance at t_{30} when compared to resting values. It is hypothesised that the soccer specific warm up utilised before the SAFT[90] commenced may not have been sufficient enough to ensure joint lubrication and muscle pliability, both of which have been shown to effect flexibility (Behm et al., 2011). Furthermore in the PL_D, significant kinematics were observed for angle change, with reduced values demonstrated at rest when compared to the subsequent 15 minute period. It is postulated that reduced angle change at the ankle complex from a standing upright position, decreases the amount of CoM translation in the anterior plane, thus not enabling sufficient knee flexion in order to achieve greater reach distances. Similar observations are recorded when analysing angle change in each of the SEBT three directions for both KT and NT.

A_D, PL_D and PM_D are significantly reduced by, 38.63%, 42% and 18.57% respectively when KT is applied, suggesting that elastic tape has an inhibitory effect upon angle change. However, this difference in angle change did not translate into a negative effect upon SEBT performance, with no significant differences detected in reach distance in any of the three directions. With ankle sprains occurring in a rapid fashion (Fong et al., 2009) and KT demonstrating no deleterious effect upon reach distance, it is suggested that KT may help to inhibit rapid angle change at the ankle joint, thus potentially helping to aid the prevention of excessive plantar-flexion and/or inversion occurring too quickly. This inhibition will provide the ankle with fractionally more time to respond to an unexpected perturbation, potentially allowing the appropriate muscles sufficient or a greater amount of time to respond to the event.

7.5 Conclusion

The findings of this current study demonstrates that therapeutic tape in the form of KT in a healthy trained soccer population can help to produce significant performance enhancements in tasks which involve measures of postural stability and general locomotor action. This study helps to progress current literature in the area, as investigations have taken place under the influence of soccer specific fatigue, thus inducing appropriate physiological and mechanical responses for testing to occur. Furthermore, it should be noted that KT had no detrimental effects on functional ankle performance, whilst also providing sustained mechanical load reduction during locomotive activity, suggesting that KT has longer lasting mechanistic benefits when compared to traditional white tapes. With a greater number of ankle injuries sustained in the latter periods of soccer match play, external support, which provides sustained mechanistic benefits, could help to potentially reduce injury incidence in healthy male soccer players. Improvements in performance through the application of KT appear to derive from providing a restrictive effect on joint motion, rather than the proposed increase in cutaneous mechanoreceptor stimulation as proposed by the KT manual (Kase, 2002). Improvements in ankle function and performance through the use of KT, could potentially help to reduce the amount of injuries sustained, subsequently allowing a greater number of players to be available for training and

match day selection, reducing injury costs, whilst more pertinently limiting the detrimental health issues associated with ankle injury occurrence.

Chapter 8, Study 5: The effects of an interchange rule on ankle aetiological risk factors

8.1 Introduction

The previous chapter considered the efficacy of kinesiology tape in mediating the effects of fatigue during soccer match-play, demonstrating improvements in measures of performance when compared to the control trial, however failing to mediate the effects of fatigue in certain measures of postural stability. With no change in the temporal pattern of ankle sprain incidence from Hawkins et al., (2001) to Ekstrand et al., (2011), an effective intervention is required to combat cumulative fatigue. The increased incidence of injury in the final 15mins is indicative of a cumulative fatigue issue, which might be mediated by therapeutic tape. An alternate strategy might be to simply reduce the total volume of work, as study four demonstrated measures of postural stability in the form of the BSS to decline with increased volume of work, a finding.

The influence of cumulative fatigue and the temporal pattern of injuries associated with soccer match play, is similar to that observed in another intermittent team sport, Rugby Union (Fuller et al., 2012). The authors demonstrated a significant increase in the number of injuries observed in each quarter of the game, with a slight reduction observed after a passive half-time recovery period. Although Rugby Union permits seven permanent substitutions compared to soccer's three, both sports may use these player changes in a more tactical rather than fatigue preventative manner (Reilly et al., 2008), thus providing a rationale as to why injury incidence increases with match duration. These results do not align with Rugby League, where a protective fatigue effect is observed (King and Gissane, 2009), demonstrating an increase in injury incidence in the two middle quarters of match play, with Rugby League allowing 12 non-permanent interchanges. This increase enables interchanges to occur more frequently and for players to re-enter the field of play once suitably recovered, thus potentially providing a protective fatigue effect. Another intermittent team sport, Australian Rules Football, introduced four players on the substitute bench with an unlimited amount of interchanges permitted. This new rule change and its effects on hamstring injury incidence was investigated (Orchard et al., 2012) with results

indicating that regular interchanges protect individual players against increased hamstring injury risk, potentially by reducing cumulative fatigue.

Interpretation of the laws of soccer has been influenced by scientific research; since 1998, tackling from behind should be sanctioned by a red card, and more recently, since 2006, contact made to an opposition player's head with the elbow should also result in the same outcome (Fuller et al., 2012), as both of these incidents have the potential to cause severe injury. Recent research (Dvorak et al., 2006; Fuller et al., 2012; Junge and Dvorak, 2014; Tscholl et al., 2007) suggests that since these rule changes have been implemented, a reduction of these type of injuries has been observed, thus suggesting that adapting the rules of soccer can help to potentially reduce injury incidence.

The aim of this study was to assess the impact of an increased utilisation of interchanges on risk factors associated with ankle sprains in soccer players, with participants performing both a 90 minute free running soccer protocol (SAFT^{90}) and an interchange version of the same activity, totalling 60 minutes (SAFT^{60}) in duration. It is hypothesised that the SAFT^{60} intervention will reduce levels of fatigue, subsequently improving physical measures of performance associated with both postural stability and locomotive activities.

8.2 Method

Participants

The participants who completed study four (Chapter 7) are the same as those who completed this current study (5), with the same inclusion criteria observed (please see section 7.2 for details). The experimental design was also equivalent; participants completed the same battery of functional tests, with a specific methodological insertion of increased utilisation of interchanges (see Figure 8.1). Similar measurements were taken during the SAFT^{60} trial, with the exception of GPS and force plate parameters during the rest periods (see Figure 8.1).

SAFT^{90}

0-15	**15-30**	**30-45**	*45-60*	**60-75**	**75-90**	**90 - 105**
Activity	Activity	Activity	*Rest*	Activity	Activity	Activity

[--- 15min ---] [--- 15min ---] [--- 15min ---][   ] [--- 15min ---] [--- 15min ---] [--- 15min ---]

SAFT^{60}

0-15	**30-45**	**60-75**	**90 - 105**

[--- 15min ---][   ][--- 15min ---] [   ] [--- 15min ---][   ][--- 15min ---]

	15-30		*45-60*		*75-90*	
	Rest		*Rest*		*Rest*	
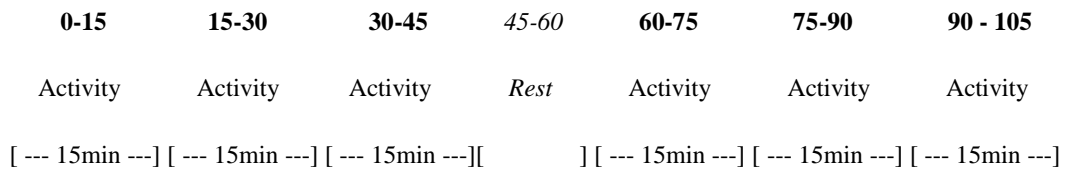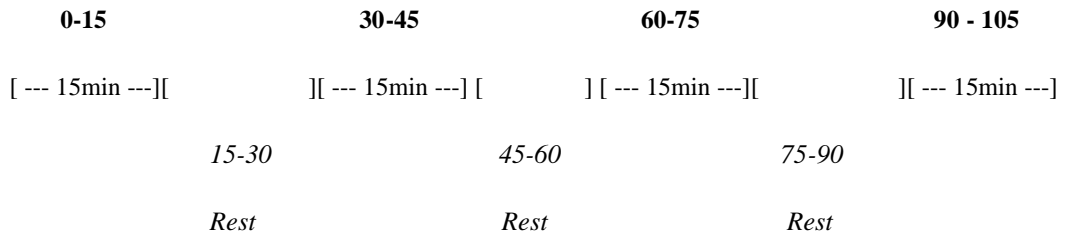
Figure 8.1: Schematic of SAFT^{90} and SAFT^{60} protocols

Statistical Analysis

Assumptions of normality have been previously described in chapters 5 and 6. Subsequently, a mixed method two-way (Trial*Time) repeated measures general model (GLM) was utilised to compare the two trials (SAFT^{90} vs. SAFT^{60}) and over time. To compare baseline differences between groups during the completion of the first trial a two-way (Group*Time) was performed. Post-hoc pairwise comparisons with a Bonferonni adjustment factor were applied where necessary. All statistical analysis was conducted using PASW Statistics Editor 22.0 for Windows (SPSS Inc, Chicago, USA), with statistical significance set a t P ≤ 0.05. All data is reported as mean ± SD unless otherwise stated.

8.3 Results

Physiological Variables

Significant differences were observed for heart rate, (SAFT^{90} = 147.85 ± 10.07 b.min^{-1}; SAFT^{60} = 138.43 ± 10.51 b.min^{-1}; $P < .001$; 95% CI = 5.56 to 13.28; $d = 0.92$), with significant main effects observed for HR$_{00}$ (56.96 ± 2.31 b.min^{-1}) and all

subsequent time points (HR_{0-15} = 143.29 ± 10.36 b.min^{-1}, $P \leq$ .001; 95% CI = -92.14 to -80.53; d = 11.50), HR_{30-45} (144.67 ± 11.78 b.min^{-1}, $P \leq$ .001; 95% CI = -94.32 to -81.09; d = 10.33) HR_{60-75} (142.92 ± 11.36 b.min^{-1}, $P \leq$ .001; 95% CI = -90.34 to -77.58; d = 10.49) and HR_{90-105} (140.92 ± 10.73 b.min^{-1}, $P \leq$ .001; 95% CI = -92.03 to - 81.47; d = 10.82). Furthermore, Trial*Time interactions demonstrate significance (P = < .01), with post-hoc Bonferonni adjustments identifying lower SAFT^{60} HR values ($P <$ .05) at all-time points
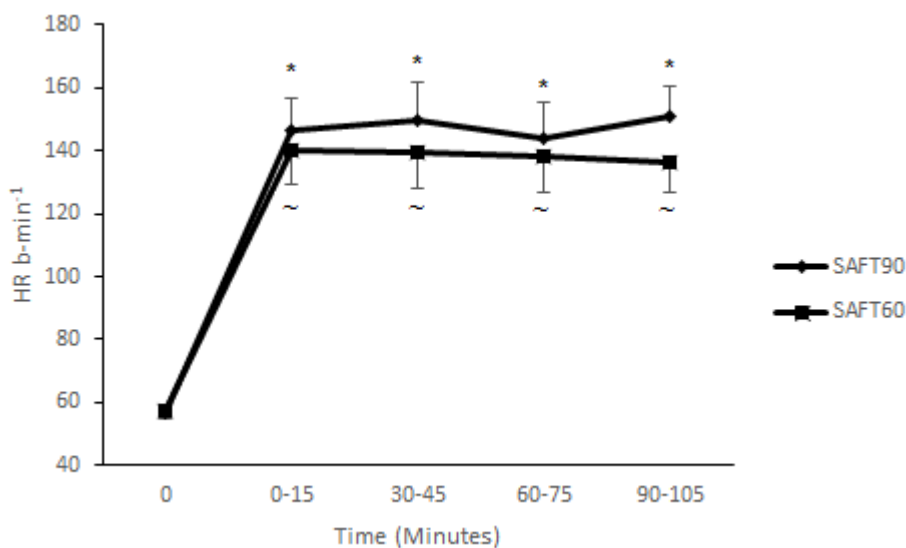
Figure 8.2: HR response across trials and time (* denotes significant difference with t$_{00,}$ ~ denotes significant trial*time interactions)

A similar trend was observed for Blood Lactate (BLa), with significant trial effects noted (SAFT^{90} 2.41 ± 0.55 mmol·l^{-1}; SAFT^{60} 1.64 ± 0.28 mmol·l^{-1}; P = 0.01; 95% CI = 0.10 to 0.84; d = 1.76) whilst a significant effect was observed for time ($P <$.001), post-hoc pairwise comparisons identifying the difference to occur between (BLa_{00} = 1.08 ± 0.21 mmol·l^{-1}; BLa_{45} 2.35 ± 0.45 mmol·l^{-1}; $P <$.001; 95% CI = -1.53 to -0.83; d = 3.62) and (BLa_{00} = 1.08 ± 0.21 mmol·l^{-1}; BLa_{105} 2.31 ± 0.55 mmol·l^{-1}; $P <$.001; 95% CI = -1.72 to - 0.73; d = 2.95) . In addition to this, significant Trial*Time interactions were observed (P = .02), with post-hoc pairwise comparisons identifying the difference to occur at BLa_{105} (SAFT^{90} = 2.88 ± 0.48, SAFT^{60} = 1.73 ± 0.59 mmol·l^{-1}; 95% CI = 0.20 to 2.08; d = 2.14).
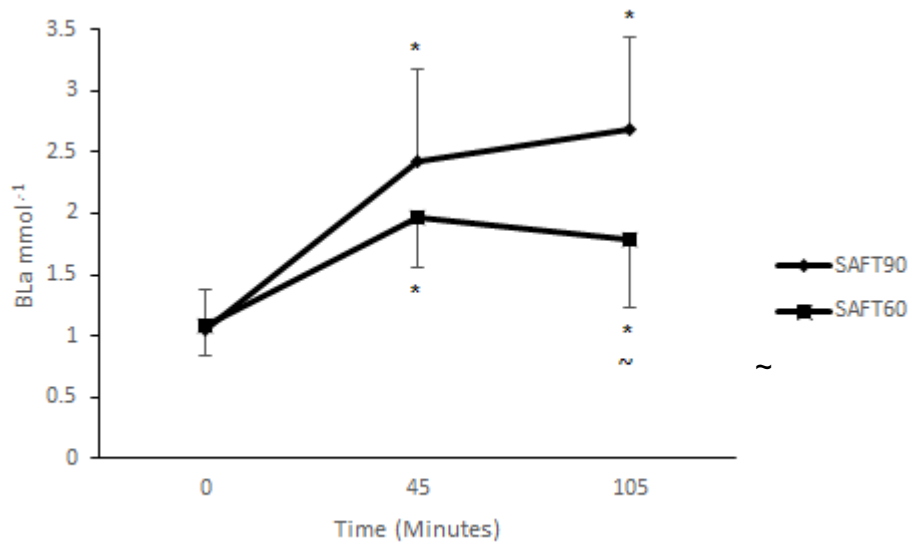
Figure 8.3: BLa response across trials and time (* denotes significant difference with t_{00}, ~ denotes significant trial*time interactions)

Dynamic Balance Variables

Figure 8.4 identifies a significant main effect for trial and OSI (P = .03) Post-hoc pairwise comparisons identified significantly increased OSI values ($SAFT^{90}$ = 1.63 ± 0.52 au, $SAFT^{60}$ = 1.23 ± 0.31 au; P = .03; 95% CI = 0.05 to 0.65; d = 0.93) across trials, whilst also highlighting a significantly (P <.001) lower value at rest (OSI_{00} = 1.30 ± 0.28 au), when compared to OSI_{15} (1.49 ± 0.42 au, P = .04; 95% CI = -0.33 to -0.04; d = 0.53), OSI_{45} (1.44 ± 0.35 au, P = .05; 95% CI = -0.59 to -0.07; d = 0.44) and OSI_{105} (1.58 ± 0.38 au, P = .02; 95% CI = -0.50 to -0.05; d = 0.84), with OSI increasing with duration in both halves. Trial*Time interactions failed to demonstrate any significance for OSI (P = .25).
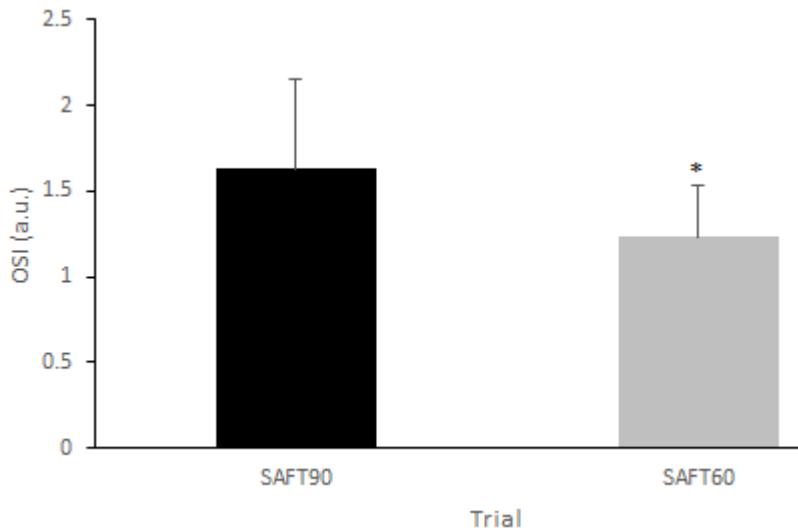
Figure 8.4: Trial differences in OSI (* denotes significant difference between trials)

Similar trends were also observed for additional BSS indices AP ($SAFT^{90} = 1.28 \pm 0.35$ au, $SAFT^{60} = 0.99 \pm 0.32$; $P = .01$; 95% CI = 0.08 to 0.51; $d = 0.86$), which is further supported by a trend towards significance in the ML direction ($SAFT^{90} = 0.93 \pm 0.35$ au, $SAFT^{60} = 0.73 \pm 0.17$ au; $P = .07$). No significant main effects for time are noted for duration for either AP or ML ($P = .11$), with a similar pattern observed for Trial*Time interactions for AP ($P = .23$) and ML ($P = .70$).
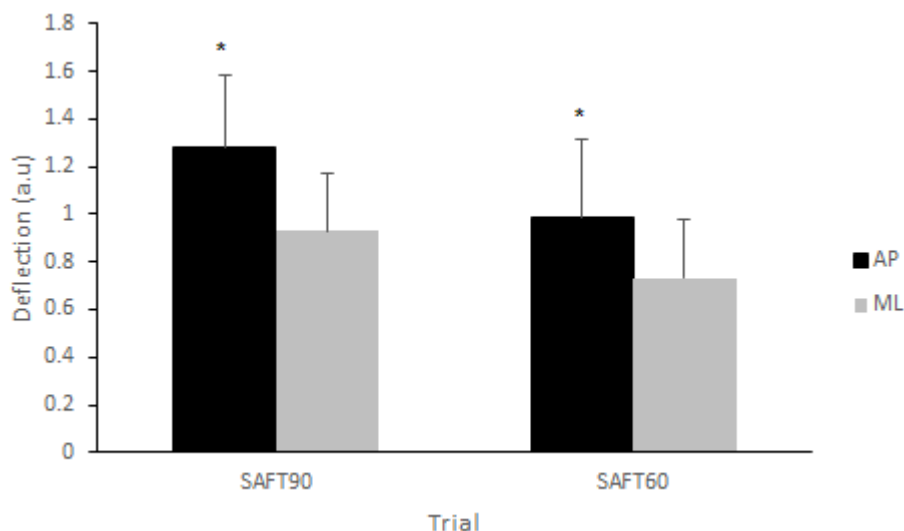
Figure 8.5: Trial changes in AP and ML across trials (* denotes significant difference between trials)

Another measure of dynamic balance, the SEBT, failed to display any significant main effects for trial A_D (90.01 ± 1.69 cm, P = 0.64), PL_D (95.17 ± 1.91 cm, P = 0.62) and PM_D (99.72 ± 5.85 cm, P = 0.18). A significant main effect for exercise duration ($P \leq .01$), is observed for A_{D00} (87.61 ± 5.22 cm) and all subsequent A_D time points, t_{15} (90.09 ± 8.93 cm; $P < .01$; 95% CI = -3.98 to -0.98; d = 0.34), t_{30} (89.87 ± 8.89 cm; $P = .01$; 95% CI = -3.85 to -0.67; d = 0.31), t_{60} (90.14 ± 9.61 cm; $P = <$ .01; 95% CI = -4.07 to - 0.99; d = 0.31), t_{75} (91.20 ± 10.22; $P = .01$; 95% CI = -5.59 to -1.58; d = 0.44) and t_{90} (90.26 ± 10.51; $P = .01$; 95% CI = -4.54 to -0.77; d = - 0.32) with the exception of A_{D45} (88.56 ± 5.92 cm) and A_{D105} (89.12 ± 6.54 cm). Significant main effects for exercise duration and PM_D were also observed ($P = .05$), with baseline value (t_{00} = 98.65 ± 9.71 cm) being significantly less than time points (t_{30} = 101.08 ± 7.86 cm, $P = .01$; 95% CI = -3.97 to -0.90; d = 0.28; t_{60} = 100.80 ± 8.92 cm, $P = .03$; 95% CI = -4.02 to -0.24; d = 0.23; t_{75} = 100.18 ± 7.51 cm, $P = .05$; 95% CI = -3.06 to 0.00; d = 0.18), with further significant differences observed for time points (t_{105} = 97.69 ± 7.47 cm) with measurements $t_{15} - t_{75}$ ($P \leq .05$), indicating a potential fatigue effect in the PM_D direction post t_{75}. However, this trend was not highlighted for PL_D ($P = .14$). No significant Trial*Time interactions were observed ($P \geq .13$) for either the A_D and PM_D directional indices, however a trend towards significance is observed for PL_D ($P = .06$), with SAFT^{90} values decreasing with exercise duration compared to that of SAFT^{60} which maintain PL_D distance values throughout the trial, thus potentially offsetting fatigue.

Exercise type displayed no significant main effects for any of the PL_D kinematic variables measured ($P \geq .10$), with time displaying a similar pattern ($P > .11$), in addition to Trial*Time interactions ($P > .10$). Kinematic measures of PM_D variables demonstrated no significant main effects for either Trial ($P \geq .18$) or Time ($P \geq .10$). No significant Trial*Time interactions were displayed for any PM_D kinematic variables measured ($P \geq .12$).

Mechanical Variables

No significant main effect for both trial ($P = .08$) and PL_{AP} is observed, with post-hoc pairwise comparisons identifying non-significant values for (SAFT^{90} = 99.89 ± 4.19 au, SAFT^{60} = 96.62 ± 5.16 au) whilst also highlighting no significant main effects for time ($P = .18$) and Trial*Time interactions ($P = .11$). $PL_{AP\%}$ failed to

indicate a main effect for trial, (P = .21), or Trial*Time interactions (P = .08), however a main effect for time was noted (P = .01) with post-hoc pairwise comparison identifying the difference to occur (T_{30-45} = 27.06 ± 1.87 au; T_{90-105} = 27.44 ± 1.94 au, P = .01; 95% CI = -0.66 to -0.11; d = 0.20) and (T_{60-75} = 27.15 ± 1.80 au, T_{90-105} = 27.44 ± 1.94 au, P = .01; 95% CI = -0.50 to - 0.08; d =0.15).

No significant main effects for trial are highlighted for PL_{ML} (44.99 ± 14.49, P = .40), with no further significance highlighted for either time (P = .17) nor trial*time interactions (P = .26). Variable $PL_{ML\%}$, failed to demonstrate significance across trials (23.02 ± 1.83 au, P = .71), time (P = .21) and Trial*Time interactions (P = .80).

The GLM failed to identify significant main effects for trial for PL_V ($SAFT^{90}$ = 99.89 ± 4.19 au, $SAFT^{60}$ = 96.62 ± 5.16 au, P = .36) whilst highlighting no significant main effects for time (P = .72) nor Trial*Time interactions (P = .09). Although the latter is not significant, a difference can be observed in the data, with $SAFT^{90}$ PL_V increasing with time, compared to $SAFT^{60}$ which maintains similar values throughout the trial $PL_{v\%}$ failed to indicate a main effect for trial, (P = .21), time (P = .41) and Trial*Time interactions (P = .08), which observed a similar trend to PL_v.

No significant main effects are noted for exercise condition on PL_{Total}, however a trend towards significance is highlighted ($SAFT^{90}$ = 197.81 ± 10.38 au, $SAFT^{60}$ = 194.35 ± 8.82 au; P = .09). Exercise duration failed to demonstrate any main effects for time (P = .41), however a trend towards significance was observed for Trial *Time interactions (P = .09), with $SAFT^{90}$ PL_{Total} values increasing with exercise duration compared to the reduced values of $SAFT^{60}$.

EMG and Force Plate Variables Sprint Task

The GLM failed to identify any significant trial main effects for PL EMG_{Mean} (67.22+ 18.78 μ, P = .21) and LG (77.87 ± 20.93 μ, P = .39). However, as demonstrated in Figure 7.6, TA EMG_{Mean} demonstrates a significant main effect for trial ($SAFT^{90}$ = 62.40 ± 16.12, $SAFT^{60}$ = 91.39 ± 33.43 μ, P = .02; 95% CI = -51.57 to -6.41; d = 1.10), with increased values demonstrated during the $SAFT^{60}$. A

significant main effect was identified for time and EMG_{Mean} for all muscles, TA (P = .02) with post-hoc pairwise comparisons identifying increased values at T_{0-15} (87.05 ± 27.15µ), when compared to T_{30-45} (64.24 ± 19.20 µ, P = .02; 95% CI = 8.49 to 37.12; d = 0.97). The GLM identified significantly (P = .01) lower values for LG EMG_{Mean} at t_{105} (59.09 ± 24.79 µ), when compared to t_{00} (105.71 ± 42.17 µ; P = .01; 95% CI = -79.39 to -13.83; d =0.83), whilst PL EMG_{Mean}, t_{105} (84.30 ± 26.17 µ) demonstrated significantly lower values when compared to all previous time points (t_{15} = 109.47 ± 49.69 µ, P = .03), t_{45} (98.46 ± 34.40 µ, P = .04) and t_{75} (96.05 ± 40.55, P = .04). Trial*Time interactions failed to display significance for PL and LG (P ≥ .05), whereas significance was indicated for TA (P = .02) with post-hoc pairwise comparisons identifying increased values during the $SAFT^{60}$, with these differences occurring at T_{30-45} ($SAFT^{90}$ = 47.63 ± 20.07 µ, $SAFT^{60}$ = 80.86 ± 36.68 µ, P = .03; 95% CI = -61.98 to -4.49; d = 1.12), T_{60-75} ($SAFT^{90}$ = 55.47 ± 22.01µ, $SAFT^{60}$ = 100.29 ± 45.98 µ, P = .03; 95% CI = -80.22 to -9.42; d = 1.24) and T_{90-105} ($SAFT^{90}$ = 59.20 ± 20.48 µ, $SAFT^{60}$ = 97.64 ± 38.65µ, P < .01; 95% CI = -66.55 to -10.34; d = 1.24).
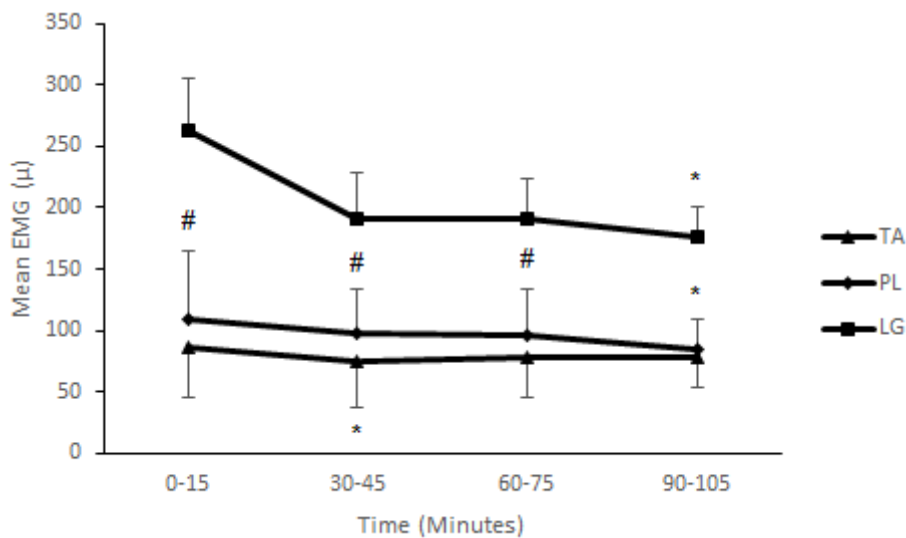
Figure 8.6: Time history changes in TA, PL and LG EMG_{Mean} (* Denotes significant difference with t_{00}, # denotes significant difference with t_{105})

During the performance phase of the cutting movement during the sprint task, no significant main effects for trial were observed for any of the variables during the impact phase, PFz, PFy, PFx, Ḟz, Ḟy, Ḟx (P ≥ .10), or the propulsion phase, ḞzD,

ḞyD, θ, I-D and T ($P \geq .13$), with the exception of ḞyD, which demonstrated significantly ($P = .04$) lower values during the SAFT^{90} (1.50 ± 0.23 bw.s^{-1}) when compared to the SAFT^{60} (2.13 ± 0.27 bw.s^{-1}; 95% CI = -1.23, -0.04; $d = 4.66$). Furthermore, no significant ($P \geq. 08$) main effects for time were observed for any of the variables measured during both the impact and propulsion phase, a theme which is further continued with no significant ($P \geq .10$) time*trial interactions observed.

EMG Variables SEBT

EMG$_{Mean}$ identified significant trial main effects for both TA (SAFT^{90} = 53.11 ± 16.61 μ, SAFT^{60} = 66.57 ± 25.78 μ, $P = .04$; 95% CI = -25.81 to -1.11; $d = 0.62$), and PL (SAFT^{90} = 41.67 ± 16.47 μ, SAFT^{60} = 53.21 ± 13.28μ, $P = .04$; 95% CI = -22.47 to -0.43; $d = 0.77$), whilst failing to identify any significance for LG ($P = .56$).
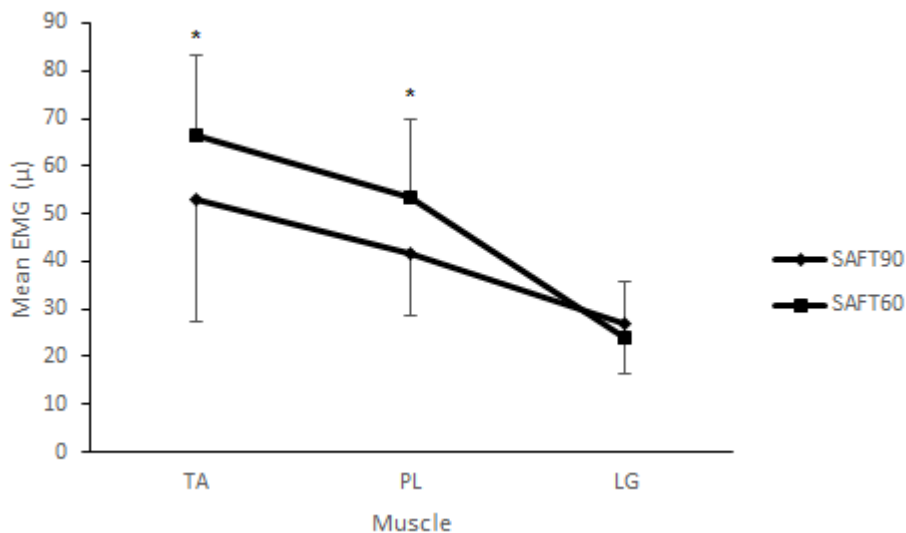
Figure 8.7: EMG$_{Mean}$ response across cutting maneuverer trials

Exercise duration failed to display any significant main effect for LG ($P = .39$), with the converse relationship identified for TA, with increased values observed at T$_{00}$ (430.00 ± 190.51 μ,) when compared to T$_{45}$ (292.56 ± 111.45 μ, $P = .01$; 95% CI = 1.39 to 58.40; $d = 0.88$), and all subsequent second half time points T$_{60-105}$ ($P \leq .03$). PL demonstrated significantly ($P = .04$) decreased values at T$_{105}$ (35.18 ± 15.43 μ; 95% CI = -57.57 to -5.23; $d = 1.33$) when compared to T$_{00}$ (61.56 ± 23.39 μ). Conversely, no significant Trial*Time interactions were noted for any of the three muscles ($P \geq .17$).
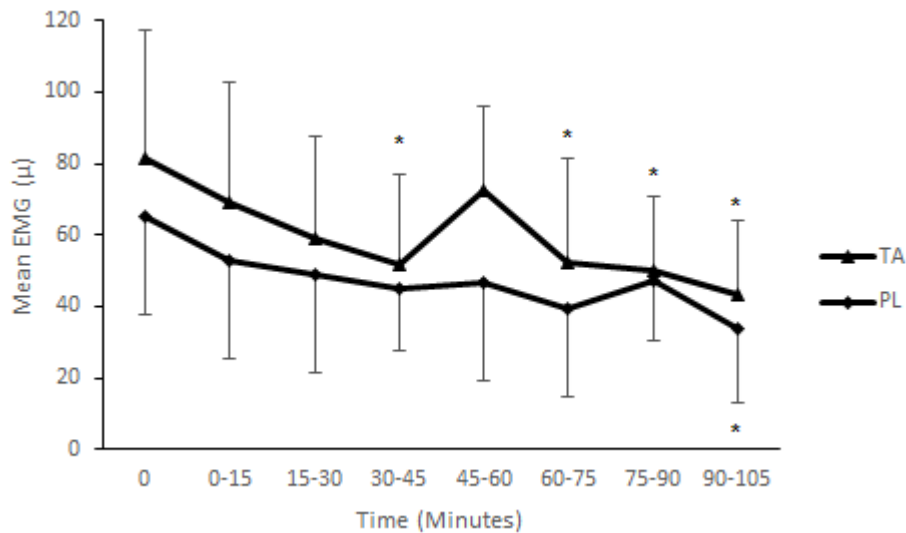
Figure 8.8: Time history changes in TA and PL EMG$_{Mean}$ cutting maneuverer (* Denotes significant difference with t$_{00}$)

EMG Variables BSS

EMG$_{Mean}$ failed to demonstrate any significant main effects for Trial for each of the muscles analysed ($P \geq .25$), whilst also failing to identify significant main effects for Time for LG ($P = .11$). Conversely, a main effect was noted for time and TA EMG$_{Mean}$, with T$_{45}$ (28.73 ± 11.14 μ, $P < .01$; 95% CI = 4.22 to 27.67; $d = 1.04$) and T$_{105}$ (26.12 ± 10.31 μ, $P = .01$; 95% CI = 1.24 to 8.33) all indicating lower values when compared with T$_{00}$ (44.67 ± 18.51 μ, $P = .01$). A similar significant main effect for Time was also noted for PL EMG$_{Mean}$ (T$_{00}$ = 61.56 ± 23.39μ, T$_{75}$ = 35.18 ± 15.43μ, $P = .04$; 95% CI = 0.73 to 52.02; $d = 1.33$), with lower values highlighted with increased match duration. All muscles failed to demonstrate significant Trial*Time ($P \geq .06$) interaction.

129
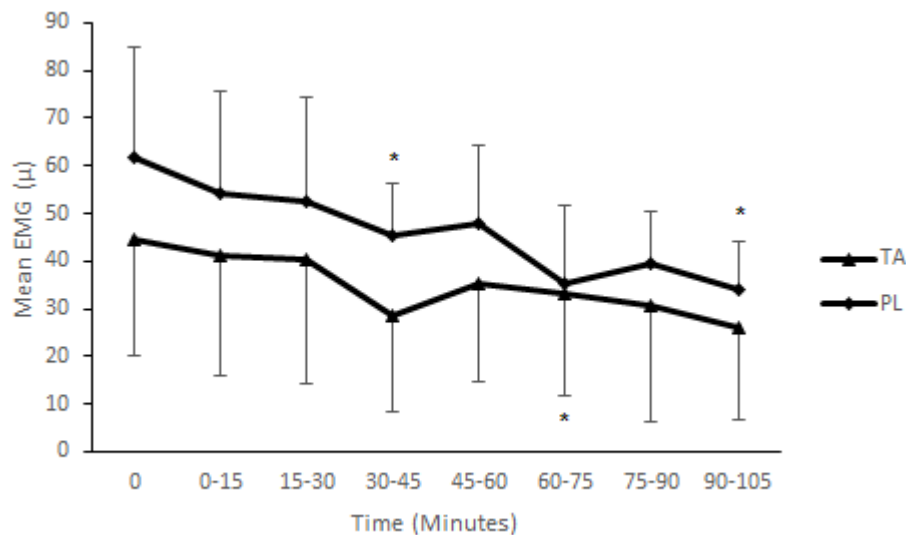
Figure 8.9: Time history changes in TA and PL EMG$_{Mean}$ during BSS (* Denotes significant difference with t_{00})

8.4 Discussion

The aim of this study was to assess the impact of an increased utilisation of interchanges on risk factors associated with ankle sprains in soccer players. Deficiencies in postural stability are a commonly cited risk factor for ankle sprain injuries (McGuine et al., 2001). Subsequently, various studies (Arliani et al., 2013; Brito et al., 2012; Gioftsidou et al., 2009; Greig and McNaughton, 2014; Greig and Walker-Johnson, 2007; Pau et al., 2014) have investigated the effects of soccer specific fatigue on postural stability, however to date, no studies have investigated the effects of increased utilisation of interchanges on this aetiological risk factor.

The findings of the present study demonstrate an improvement in measures of each BSS indicia, OSI, AP and ML during the SAFT^{60} trial when compared to the SAFT^{90}, demonstrating an average improvement of 24.54%, 22.66% and 21.51% respectively. These findings suggest that soccer activity interspersed with period of recovery helps to maintain a greater level of postural stability when persons are placed into an unstable position, which has been linked to ankle injury incidence (Hiemestra, 2001). Improvements in BSS postural stability performance could potentially be attributed to a reduction in muscular exercise performed during the SAFT^{60}, as this has been shown to cause an aggravation of postural stability, as the

130

increase of energy needs enhances liquid movements and respiratory and muscular contractions (Bove et al., 2007). During exercise, increased cardiac and breathing rhythm are observed causing hyperventilation and tachycardia (Bove et al., 2007), accentuating the amplitude of postural deviation. Halson et al., (2014), identified a 6.50% change in HR as a meaningful difference The findings of this current study suggest a 6.37% increase in $HR_{Average}$ during the $SAFT^{90}$ trial, similar to the 6.50% meaningful difference reported (Halson et al., 2014) thus potentially providing a partial explanation as to how increased exercise duration increases postural deviation during the $SAFT^{90}$ trial. Furthermore, when muscular exercise elicits fatigue as observed in both the BSS and SEBT trials, the systems which regulate postural control are affected by its effects on the quality and treatment of sensory information in addition to motor command (Palliard, 2012).

Enhanced levels of displacement place a greater emphasis on the balance and neuromuscular systems, thus creating increased EMG amplitudes during tasks that require movement rather than fixation (Earl et al., 2001). In addition to this, during balance tasks, which are, less demanding and performed upright, the body adopts an ankle strategy, which is sufficient to correct small deviations in CoM position (Karlsson et al., 1997). Conversely, during balance tasks performed on an unstable platform such as the BSS, additional movements proximally in the kinetic chain are required as the amount of force needed to counteract gravity increases, rendering the ankle joint alone insufficient to control and sustain efficient movement (Voight et al., 2000). In addition to this, a change from ankle to hip strategy occurs when fatigue disturbs motor output and/or proprioception of the lower limb (Bisson et al., 2009; Palliard, 2012). Subsequently, this may help to explain why no significant EMG_{Mean} trial effects were observed during the current study, as enhanced levels of EMG activity during the BSS possibly occur in a more proximal direction in musculature around the knee and hip, consequently requiring less muscular input from the ankle joint. The findings of this study might be better interpreted if EMG data was also collected at more proximal locations such as the hip and trunk in order to quantify movement patterns. However, this data was not collected, as it is believed that useful muscle activity data during two difference balance tasks has been generated from this study in an area that is lacking in the literature, which can be subsequently used to better inform knowledge in this area of research. This is similar to the conclusions

drawn from Norris et al., (2011), who focussed solely on EMG data surrounding the hip musculature.

Another measure of postural stability, the SEBT, failed to demonstrate similar improvements in performance; with no significant trial differences observed for reach distance is any of the three directions, A_D, PL_D and PM_D. Movements performed on a more stable surface such as the SEBT are controlled via closed loop feedback mechanisms, as the movements are performed slower and more deliberately, thus activating autonomous rather than conscious postural control responses (Kovaleski et al., 2009). This is in contrast to balance tasks of a more dynamic nature such as the BSS, where additional unexpected perturbations are encountered, requiring participants to utilise a greater array of muscular co-contraction, dynamic stabilisation, proprioception and joint compression in order to maintain balance (Kovaleski et al., 2009), thus potentially explaining why differences are observed between the two protocols. A temporal pattern was observed for both the A_D and PM_D, noting increased reach distances with exercise duration when compared to baseline. At first glance, these results might seem difficult to explain, however the aim of a warm up which contains both an aerobic and dynamic stretching component is to increase body temperature 1-2°C, which has been shown to improve nerve conduction velocity, enzymatic cycling and increased muscle compliance (Young and Behm, 2002; Young, 2007). The short warm-up in comparison to what soccer players generally perform either before training or match play, may not have been sufficient enough to produce these improvements in performance, subsequently producing decreased scores at baseline when compared to subsequent time points within the protocol. A limitation of this current study is observed due to core temperature not being measured. This measurement would have helped to further inform whether the participants had gained a sufficient increase in body temperature to undertake exercise.

Temporary impairments in sensorimotor control have been demonstrated during a fatigued state causing, increased muscle reaction time, decreased muscle activation and altered proprioception and postural control (Sieb et al., 2013). During this current study, measures of EMG_{Mean} failed to demonstrate any trial interactions during the BSS trials, thus potentially questioning whether a reduction in the

exercise duration helps to improve sensorimotor control. However, differences in how the SEBT trials were performed is evident through the increased EMG_{Mean} data observed for both PL and TA during the $SAFT^{60}$, thus potentially indicating that for this type of postural stability task these muscles are more able to actively engage when less exercise is conducted and recovery time permitted. This is a potentially important finding as the ankle musculature plays a vital role in stabilising the ankle joint (Holmes and Delahunt, 2009; Kaminski et al., 2002), with the TA and PL assisting movement in both dorsiflexion and inversion. The SEBT purposefully requires it's participants to move twice into posteriorly directed directions (PL_D and PM_D). These movements require enhanced TA EMG activity as the CoM transfers posteriorly on the foot, requiring the TA to maintain a high level of activity to retain both the knee and leg over the CoP to prevent falling backwards (Earl and Hertel, 2001), which could potentially cause an injury risk and/or render the SEBT trial unsuccessful. The SEBT creates conflict between maximising reach distance and maintaining balance (Gribble et al., 2009). Having to perform the trial under a greater state of fatigue could potentially shift the influence towards a slower and more deliberate movement pattern and reduce muscle activation in order to maintain reach distance in all directions, thus achieving successful performance.

Furthermore, a main effect for time was observed across TA and PL muscles for both the SEBT and BSS task, demonstrating decreased muscle activity with exercise duration, thus suggesting that the $SAFT^{60}$ failed to offset measures of central fatigue. These results are further supported by a 27% reduction in LG EMG_{Mean} activity after the first 15 minutes during the cutting maneuverer, increasing to 33% in the final 15 minute section. Modelling performed by Hamner et al., (2010) demonstrated that the soleus and gastrocnemius musculature provided the greatest contribution towards the propulsion phase with regards to forwards mass acceleration, thus potentially explaining why such a large decrease in LG is observed during this current study.

The results of this study support those observed in male amateur soccer players (Marshall et al., 2014), who noted that a significant reduction in hamstring EMG activity after the first 15 minutes of simulated soccer match play. Evidence highlighted from prolonged locomotor activity indicates that type III/IV groups increase peripheral feedback into the nervous system, thus providing an inhibitory

stimulus which in turn reduces central motor output to the muscles in question during exercise in order to maintain performance and restrict peripheral fatigue (Amman, 2011; Sidhu, Cresswell and Carroll, 2013). Greig et al., (2008) using semi-professional soccer players, reported a similar reduction in muscular performance immediately post half-time, postulating that the 15 minute half-time recovery period had a deleterious effect on mechanical measures. These results indicate that once initial fatigue has been accumulated during the first 15 minutes of soccer match play, within the current regulations and suggested interchange rule in this study, it is not possible to recover EMG activity to baseline values. Early and significant reductions in EMG activity may potentially occur as a protective mechanism, to ensure that activity levels can be maintained for the duration of soccer match play, further supporting the preservation of high intensity running in matches (Smith, Marcora and Coutts, 2015).

However, no significant difference was observed for trial and LG EMG_{Mean}, for both the BSS and SEBT. This could potentially be explained as the LG is a primary plantar-flexor, which allows participants to move into a more anterior based position by moving onto their toes, which is not a permitted foot position during the SEBT, resulting in a null and void trial (Gribble and Robinson, 2007). Furthermore, a plantar-flexed position would not be the preferred balancing strategy during the BSS as the aim of the task is to fixate the foot rather than move into a more open packed position (Arnold and Schmitz, 1998), which engagement of the LG would produce. It is postulated that the insignificant finding for LG $EMG_{Mean,}$ explains why no technical differences were observed through Qualisys measures for the BSS. As the LG is a primary plantar-flexor, changes in start and touchdown angle would only be indicated by moving into a position where the heel is raised from the platform due to increased elevation further distal in the foot. In addition to this, no significant differences were observed for any of the kinematic variables measured during the SEBT trial, suggesting that the technique by which the participants performed the trial remained similar throughout the trial. The kinematic analysis used in this study reported only sagittal-plane movement; however there are multiple combinations of mulitplanar movements that might be occurring during each of the three reach distances that were unable to be quantified in this study. Furthermore, the camera set up may not have been sensitive enough to detect inverted and/or everted positions,

which could also potentially compromise the ankle joint under the influence of fatigue.

If GPS tri-axial loading can be linked with changes in running technique, the results from this study suggest that the participants performed the experimental trials using a similar strategy, as no significant differences were observed for any of the variables measured. These findings correlate with those observed during force plate analysis, with no main effects for time or trial*time interactions observed for any of the variables measured. Furthermore, no main effects for trial were noted with the exception of $\dot{F}yD$, which demonstrated a 42% increase during the SAFT^{60} when compared to the SAFT^{90}. This increase in force production could potentially be explained by an increase in TA EMG$_{Mean}$ observed during the same trial when performing the cutting maneuverer of the sprint performance. TA acts as dorsiflexor of the ankle joint, which along with other groups of muscles such as the quadriceps activates before foot contact with the ground, thus achieving landing with a stiff leg, enabling a greater rate of propulsion in the required directions (Gazendam and Hof, 2007). Furthermore, it appears that the SAFT^{60} trial enables maintenance of the TA EMG$_{Mean}$ signal throughout the trial, compared to a reduction in the same variable throughout the SAFT^{90}. It is suggested that a reduction in exercise duration is able to alleviate fatigue for this muscle group during running activity, thus allowing the participants to complete the required task in a more efficient manner if a reduction in time to complete the task is the overall outcome.

8.5 Conclusion

The findings from this present study indicate that increasing utilisation of interchanges in soccer match play has potential benefits for aetiological risk factors associated with ankle sprain injury. Increasing the number of interchanges, reduced physiological variables associated with fatigue such as HR and BLa, whilst also producing an improved level of postural stability during the BSS trials, indicating that performing less exercise helps to maintain/improve balance during unipedal stance on an unstable platform. Conversely, a lack of significant improvements were noted with regards to sensorimotor improvements in the form of EMG, with a similar trend also observed with regards to technique analysis in the form of Qualisys, GPS and force plate measures, potentially suggesting that improvements in

performance occur as a result of physiological rather than mechanical measures. Limitations of the research have been discussed in greater detail during the discussion, however it is hypothesised that analysing musculature more proximal in the kinetic chain and completing frontal and transverse kinematics may potentially elude to a greater degree of mechanical change associated with increased use of interchange. Due to the nature by which ankle sprain injuries most commonly occur, future research needs to be conducted regarding potential mechanisms to improve mechanical measures of performance associated with this type of injury.

Chapter 9, Study 6: Warm Up or Cool Down? The Effect of Timing of an Ankle Injury Prevention Programme in Elite Male Soccer Players

9.1 Introduction

Chapter nine comprises the final study (6) within this thesis. The previous two chapters within the thesis, investigated the effects of both kinesiology tape and an enforced rule change in the form of increasing the number of interchanges permitted in an attempt to mediate fatigue, which could potentially help to reduce injury incidence. Although both studies had their merits via improving measures of performance associated with ankle sprain aetiological risk factors, both studies failed to mediate all detrimental effects of fatigue. Furthermore, without the expertise of medical staff or qualified personnel to apply the KT, in addition to the potential difficulties in enforcing rules changes, it is necessary to investigate alternative and more traditional interventions, such as multi-modal injury prevention programmes which have been demonstrated to match the requirements of the multivariate nature of injury incidence (Ekstrand and Gilquist, 1983; Hubscher et al., 2010). The first experimental study of the thesis highlighted the need for a multi-modal battery of aetiological tests, whilst the fourth and fifth studies demonstrated the potential deleterious effects of fatigue, whilst also highlighting some potential worth in both interventions. Subsequently the studies to date, have been able to better inform the design and implementation of an injury prevention programme, which is further discussed in this chapter.

Further detailed epidemiological analysis has been conducted regarding the time pattern of ankle injury incidence during soccer match-play. A greater number of ankle injuries have been demonstrated to occur towards the end of each half (Ekstrand et al., 2011). Increased injury incidence during this period has been linked to changes in lower limb neuromuscular control and joint dynamic stability as a result of fatigue (Hiemstra et al., 2001), with (McGuine et al., 2000; Trojian and McKeag, 2006) demonstrating a link between poor levels of postural stability and increased ankle injury incidence. Gribble and Hertel (2004) demonstrated muscle force reduction of the ankle, knee and hip as a result of fatigue. Furthermore (Greig and Walker-Johnson, 2007; Ribeiro et al., 2008), indicated neuromuscular control, proprioception and functional stability are impaired after fatiguing exercise, which

could potentially comprise ligamentous structures during dynamic movements, thus enhancing injury risk. In specific relation to balance performance and soccer players under the influence of soccer specific fatigue (Brito et al., 2012; Greig and Walker-Johnson, 2007; Greig and McNaughton, 2014; Pau et al., 2014), have all demonstrated reductions in postural stability, thus potentially indicating why injury incidence increases with match duration (Brito et al., 2012).

Various systematic reviews have investigated the effectiveness of exercise programme for the prevention of ankle injuries (Hubscher, 2008; Laersen et al., 2014), comprising of proprioceptive, strength, plyometrics and sport specific exercises or a combination of several aforementioned components, which is often referred to as neuromuscular training (Zech et al., 2009). Research has demonstrated that performing both strength (Myer et al., 2006) and proprioceptive (Winter et al., 2015) exercises improves ankle joint performance. Plyometric training is utilised for lower extremity muscle control and stability (Myer et al., 2006), placing greater emphasis on the stretch-recoil principle, whilst also affecting JPS (Myer et al., 2006), balance (Myer et al., 2006) and co-ordination (Chimera et al., 2004) throughout functional movement.

Subsequently, this method of training has elicited positive changes in the neural and musculoskeletal systems, muscle function and athletic performance of healthy individuals. Furthermore, short-term plyometric sessions have been shown to change various elastic components of the muscle-tendon complex of plantar-flexors in athletes (Markovic and Mikulic, 2010), via improving the lower-extremity strength, power and stretch-shortening cycle. This further helps to improve lower extremity reaction time, allowing surrounding musculature to respond quicker to unexpected perturbations which could potentially cause ankle injury (Markovic and Mikulic, 2010).

Current soccer training practice often dictates that injury prevention training is performed at the start of the training session whilst the players are in a non-fatigued state, with the rationale being that players can conduct the exercises with better form, allowing the musculature to provide appropriate responses to maintaining, balance and postural control. However, the law of specificity states that the specific nature of a training load produces its own specific response and adaptations (Small et al.,

2009), therefore it would seem logical to suggest that if the majority of injuries occur in a fatigued state (Kofotolis et al., 2007; Woods et al., 2003), injury prevention programmes should also occur in a similar condition in order to provide the required gains in performance. Research conducted surrounding soccer player hamstring musculature and training in a fatigued sate, demonstrated a significant reduction of the negative influence of fatigue on eccentric hamstring strength after an eight-week injury prevention programme (Small et al., 2009). Participants who performed the hamstring exercises post-training in a fatigued state demonstrated greater maintenance of eccentric hamstring strength when compared to the pre-training non-fatigued group, thus preserving a more balanced Hamstring: Quadriceps (HQ) under soccer-specific fatigue (Small et al., 2009).

The aim of this study was to design a multi-modal ankle injury prevention programme, comparing the effects of performing the exercises during either a warm-up or cool-down of soccer training session on ankle injury risk factors during simulated soccer match play. It is hypothesized that the training intervention improves physical measures of performance irrespective of group, whilst a secondary hypothesis stipulates that an improvement in physical performance measures will occur dependent upon group, whilst highlighting differences in response to fatigue.

9.2 Method

Participants

Eighteen male, first team professional soccer players from the fifth tier of the English Football League system (23.50 ± 2.47 years, height 179.49 ± 3.88 cm, weight 72.78 ± 5.97 kg) participated in the investigation. Each player conducted a minimum of four soccer specific training sessions and two matches per week. Inclusion criteria required participants to play in an outfield position, have no injury history in the lower limb for the previous six months and no neurologic or balance disorder or chronic ankle instability as determined by the Cumberland Ankle Instability Tool. In addition to this, subjects needed to complete $\geq 75\%$ of all intervention sessions. Subsequently, this reduced the amount of subjects able to complete the study to 14, due to injuries sustained within the intervention period,

with a further two players also removed from the study due to permanent transfers to other soccer clubs, leaving 12 subjects to meet all of the inclusion criteria. Ethical approval for the study was granted in accordance with the Departmental and University ethical procedures, with participants providing informed consent prior to data collection.

Experimental Design

Participants

A between-subjects matched-pairs design was selected to determine the effects of training state on physical performance measures associated with soccer match play. Participants were matched based upon: age, playing position, height, mass and their physical response to a 30 minute familiarisation trial of the soccer protocol. Thereafter, one participant from each pair was randomly assigned to either the warm up (WU) (N = 6) (23.17 ± 2.14 years, height 178.78 ± 3.15cm, body mass 72.15 ± 5.93kg or cool down (CD) group (N = 6) (23.83 ± 2.93 years, height 180.20 ± 3.69cm, body mass 73.41 ± 6.51kg).

Participants were required to attend the laboratory on three occasions, firstly to complete a 30-minute familiarisation trial of the SAFT[90], plus all postural stability tasks, followed by two experimental trials prior to and upon completion of a six-week period. Experimental trials consisted of participants completing the SAFT[90] (please see Chapter 3) protocol, divided into two 45-minute periods interspersed with a 15-minute half-time passive rest period.

Experimental Measures

Measurements of dynamic balance in the form of the SEBT and BSS, force plate analysis and HR (please see Chapter 3) were taken prior to exercise (t_0) at half time (t_{45}) and immediately post exercise (t_{105}). The physiological dependent variables were chosen to represent measurements regularly associated within an applied setting (Halson et al., 2014), whilst measures of postural stability have been associated with soccer performance and injury risk (Hiller et al., 2008; McGuine et al., 2000; Semple et al., 2012; Wang et al., 2006). In addition to these

measurements, the use of GPS based tri-axial accelerometry also offers a novel method of assessing the mechanical demand and loads associated with soccer (Page et al., 2015). Experimental controls are described in greater detail in Chapter 3. Baseline and post-intervention testing being conducted during the first two months of the 2014/15 English competitive soccer season.

Intervention

Upon completion of baseline testing, subjects were randomly allocated into either a Warm-up (WU; n = 6) or Cool-down (CD; n = 6). Each group consisted an equal amount of defenders, midfield and attacking players. Each group conducted an ankle injury prevention programme three times a week over the six-week intervention period, with the groups performing the exercises either before (WU) or upon the completion of each training session (CD), placing them in either a state of rest (WU) or an exercised state (CD) respectively. The injury intervention programme involved increasing the load, sets and repetitions gradually over the first three weeks (see Table 9.1), whilst maintaining the training load over the subsequent three week period

Table 9.1: Exercise programme used to prevent injury in male soccer players

Exercise	Repetitions
1. Single leg reach Level 1: Standing on dominant leg, hands on hips and looking straight ahead, using contralateral leg reach behind you towards coloured cones at an angle of 45°. Your partner will note the colour you achieve. Repeat action for 30 seconds before swapping legs. Level 2: As per level 1, with addition of partner throwing the ball to you from 2m, catch the ball and begin to place down on the floor whilst reaching out with the contralateral leg simultaneously. Level 3: As per levels 1 and 2, with the addition of standing on an inflated stability disc. **2. Partner Tap** Level 1: Face your partner at a distance of 1m using your dominant leg for single leg balance. Take it in turns to attempt to "tap" your partner off balance. Swap legs after 30 seconds.	30 seconds per leg

30 seconds per leg

Level 2: Stand on dominant leg, with knee flexed at 90°, whilst partner manoeuvres around you tapping you with a football in an attempt to put you off balance. Swap legs after 30 seconds.

Level 3: As per level 1 with the addition of a stability disc.

3. Z Hop Drill

Level 1: Starting in the top left hand corner of the 4 cone drill, each cone placed 2m apart, hop using the dominant leg only to the end of the drill, making a Z shape. Slowly walk back to the beginning of the grid and repeat using the opposite leg.

1 minute in total

Level 2: As per Level 1 with emphasis placed on hopping for height and absorbing impact forces in a stable manner.

Level 3: As per Level 2, with the addition of circling round the first and last cone, repeating the

movement back to the start point on the same leg, then repeating the set on the opposite leg.

4. Hop and Feed

Level 1: Starting at the first cone (Placed 1m apart) hop in the spaces between the cones, before responding quickly to where your partner throws the ball (Partner will shout left or right when the participant is hopping through the last cone). You will then control the ball and feedback to the partner, before returning to the start position to perform the task again on the opposite leg.

1 minute in total

Level 2: As per level 1, however the participant will hop through the cones quickly for height. The partner instead of calling left or right will call the colour of the cone, which the participant will respond to by travelling in that direction.

Level 3: As per level 2, however the participant will diagonally hop through the course on the same foot, again hopping for height and speed.

5. W Drill

Level 1: Starting in the top left hand corner of the W, the participant will stand on the dominant foot, reaching forward as far as possible with the contralateral limb, touching the floor with the distal portion of the foot. The participant will then proceed to jog backwards diagonally to the next cone before performing a Posterior Lateral movement with the same limb and the same goal. Upon completing this movement the participant then jogs forward to the next cone and reaches in an anterior direction, before jogging backwards diagonally and performing Posterior Medial movement with the same limb. The final movement in the sequence is to then jog forward and complete the final anterior movement. The participant will then repeat the process going in the reverse direction, this time standing on the non-dominant foot.

1 minute in total

Level 2: Same as level 1, however the participant is asked to sprint between cones with the partner following and throwing a football for the participant to catch and return, whilst performing the reach movement.

During the six-week injury intervention programme, compliance rate of the prescribed protocol were logged by the sole practitioner on a specialised form, in addition to both training and match exposure. To be considered for final inclusion of the study, players had to perform ≥ 75% of all training sessions were the injury prevention programme was conducted. Upon completion of the six-week period, all participants who met the inclusion criteria were re-tested using identical methods previously employed during the baseline testing.

Statistical Analysis

Assumptions of normality have been previously described during Chapters 5 and 6. A mixed method three-way (Group*Trial*Time) repeated measures general model (GLM) was utilised to compare the two groups (WU vs. CD), the two trials, and over time. To compare baseline differences between groups during the completion of the first trial a two-way (Group*Time) was performed. Post-hoc pairwise comparisons with a Bonferonni adjustment factor were applied where necessary. All statistical analysis was conducted using PASW Statistics Editor 22.0 for Windows (SPSS Inc, Chicago, USA), with statistical significance set at $P \leq .05$. All data is reported as mean ± SD unless otherwise stated. For all significant interactions, 95% confidence intervals (CI) are reported in conjunction with the traditional statistical approach, Cohen's *d* effect sizes (< 0.50 = small, $0.50 - 0.80$ = small to moderate, > 0.8 = large) will be calculated to further assess differences in measures.

9.3 **Results**

The GLM identified no significant (P ≥ .05) Group*Time interactions for any of the physical measurements recorded. During the 6 −week ankle injury intervention programmes, the WU and CD groups had compliance rates of 90.4% and 88.6% respectively, with no significant differences observed in the compliance rates between total amounts of soccer training and match play between groups.

Physiological Measurements

The GLM identified significant (*P* <.001) main effects for time for HR, with post-hoc Bonferonni adjustments identifying significantly increased values at t_{45} (138.50

± 8.81b.min^{-1}; 95% CI =75.28 to 91.89; d = 11.98) and t$_{105}$ (138.83 ± 7.35 b.min^{-1}; 95% CI = 77.30 to 90.54; d = 13.69) when compared to t$_{00}$ (52.51 ± 5.05 b.min^{-1}). No significant main effects for trial were associated for HR (P = .10) (140.27 ± 8.08; 138.64 ± 5.60 b.min^{-1}). In direction relation to the fatigue response associated with the two groups (WU vs. CD), the GLM identified no significant Group*Trial*Time (P = .25) nor Group*Time (P = .86) interactions.

A temporal fatigue response (P <.001) was evident for RPE, with post-hoc pairwise comparisons identifying significant main effects for (t$_{00}$ = 6.00 ± 0.00 au; t$_{45}$ = 12.55 ± 0.52 au; P ≤ .001; 95% CI = -6.93 to -6.15), (t$_{00}$ = 6.00 ± 0.00 au; t$_{105}$ = 13.88 ± 0.73 au; P ≤ .001; 95% CI = -8.45 to -7.30) and (t$_{45}$ = 12.55 ± 0.52; t$_{105}$ = 13.88 ± 0.73 au; P ≤ .001; 95% CI = -1.91 to - 0.76; d = 2.10). When comparing the influence of training groups (Wu vs. CD), the GLM identified no significant trial (P = .99), Trial*Group (P = .24) or Trial*Time*Group (P = .41) interactions for RPE.

Performance Variables

As illustrated by figure 9.1, the GLM identified a significant (P =.01) main effect for trial for OSI (Pre = 1.48 ± 0.31 au; Post = 1.08 ± 0.29 au; 95% CI = 1.46 to 6.50; d = 1.33), ML (Pre = 1.38 ± 0.31 au; Post = 0.92 ± 0.16 au; P = .01; 95% CI = 0.07 to 0.41; d = 1.86) and AP (Pre = 1.03 ± 0.14 au; Post = 0.75 ± 0.16 au; P ≤ .01; 95% CI = 0.09 to 0.46; d = 7.00) indices, with each variable demonstrating improved performance post intervention. The GLM failed to identify any further significant main effects for time (P ≥ 0.28), Trial*Group (P ≥ 0.11), Time*Group (P ≥ 0.11) or Trial*Time*Group (P = 0.12)
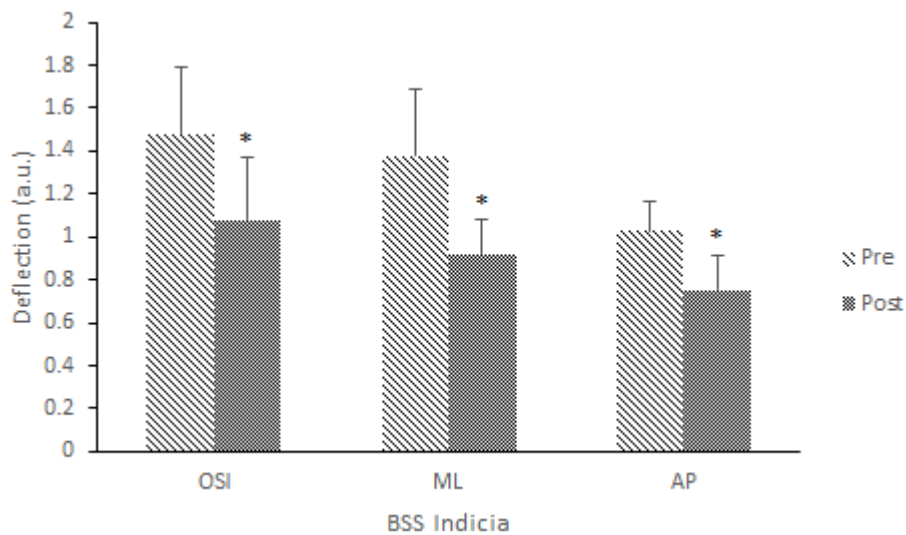
Figure 9.1: Trial changes of BSS indicia (* denotes significant difference between trials)

Performance of the SEBT, identified significant main effects for trial for variables A_D (Pre = 98.08 ± 7.30 cm; Post = 102.92 ± 8.34 cm; P = .02; 95% CI = -8.91 to -8.56; d = 0.62), PL_D (Pre = 106.07 ± 7.42 cm; Post = 113.89 ± 4.95 cm; P ≤ .001; 95% CI = -12.01 to -3.64; d = 1.24), PM_D (Pre = 108.65 ± 6.56 cm; Post = 118.57 ± 5.77 cm; P ≤ .001; 95% CI = -13.70 to -6.13; d = 1.61) and $SEBT_T$ (Pre = 312.80 ± 16.82 cm; Post = 337.24 ± 15.28 cm; P ≤ .001; d = 1.52). In comparing the fatigue response elicited by the two groups, the GLM failed to identify any significant main effects for Time (P ≥ .29), or interactions for Group*Trial*Time (P ≥ .21), Trial*Time (P ≥ .10) and Time*Group (P ≥ .26).
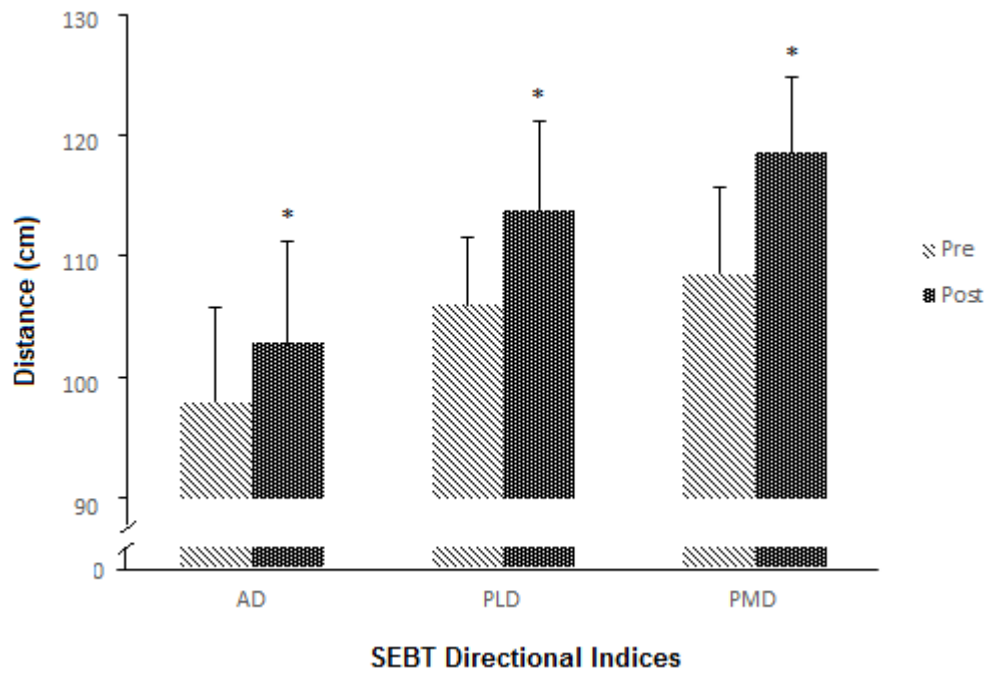
Figure 9.2: Trial changes of SEBT indices (* denotes significant difference between trials)

Mechanical Variables

Tri-axial PlayerLoad™ tended to remain stable throughout each half, thus failing to demonstrate a main effect for time ($P = .73$). The GLM identified a significant main effect for trial and PL_{Total} (Pre = 187.07 ± 20.43 au; Post = 181.44 ± 19.74 au; $P = .02$; 95% CI = 1.16 to 10.09; $d = 0.28$), with lower values highlighted post intervention. In contrast to this, no significant Time*Trial interactions were observed ($P = .15$). In comparing the fatigue response elicited by the two groups, the GLM identified no significant Trial*Time*Group ($P = 0.13$), Group*Time ($P = .33$), nor Group*Trial ($P = .70$) for PL_{Total}.
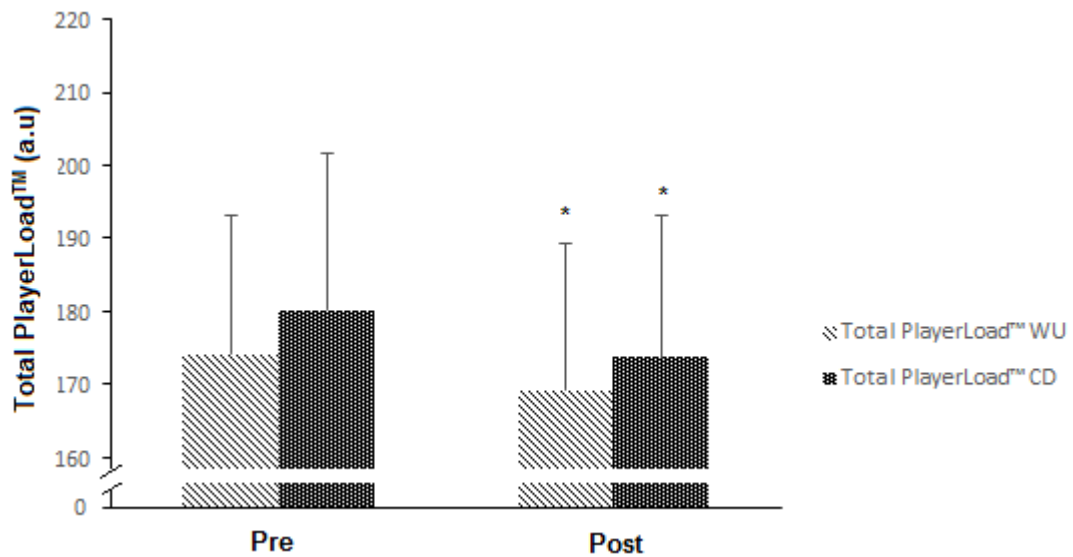
Figure 9.3: Trial changes of PL$_{Total}$ pre and post intervention (* denotes significant difference between trials)

A similar response is highlighted to that observed for PL$_{Total}$, indicating no temporal fatigue effect in each of the uni-axial PlayerLoad™, PL$_{AP}$ and PL$_V$ ($P \geq .55$) values. The GLM identified a main effect for PL$_{ML\ and}$ trial (Pre = 41.81 ± 4.77 au; Post = 38.11 ± 4.82 au; $P = .05$; 95% CI = 1.34 to 2.18; $d = 0.77$), highlighting lower values post intervention. In contrast, this trend was not observed for both PL$_{AP}$ and PL$_V$ ($P \geq .20$), furthermore, no Trial*Time interactions ($P = .13$) were associated with any uni-axial PlayerLoad™. In relation to the uni-axial PlayerLoad™ response associated with the two groups, no significant interactions were noted for Trial*Time*Group ($P \geq .15$), Group*Time ($P \geq .53$) nor Group*Trial ($P \geq .35$).
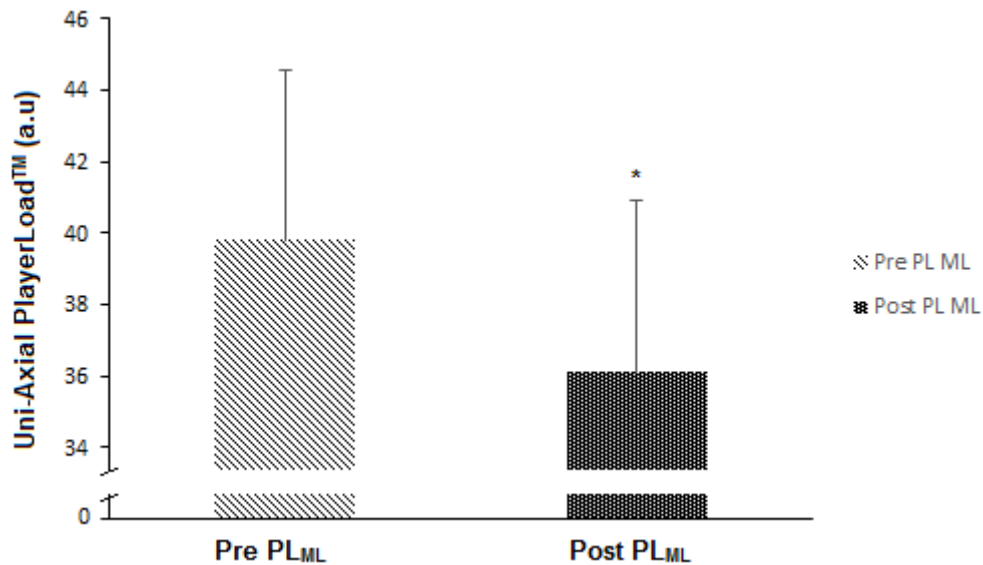
Figure 9.4: Trial changes of PL$_{ML}$ pre and post intervention (* denotes significant difference between trials)

The relative contributions of each uni-axial PlayerLoad™ (PL$_{v\%}$, PL$_{AP\%}$ and PL$_{ML\%}$) highlighted a similar response, with no main effects for time noted ($P \geq .40$). The GLM identified a significant main effect for Trial and PL$_{V\%}$ (Pre = 49.64 ± 2.87 au; Post = 50.86 ± 2.88 au; P = .02; 95% CI = -2.19 to -0.25; d = 0.42), indicating greater values post compared to pre intervention. However, these differences were not observed for either of the remaining uni-axial PlayerLoad™ contributions ($P \geq$ .02). In addition to this, Trial*Time ($P \geq .13$) also failed to demonstrate any significant interactions. In relation to the fatigue response associated with the two groups, the GLM identified no significant Group*Trial*Time ($P \geq .13$), Group*Time ($P \geq .13$) nor Group*Trial ($P \geq .13$) interactions for PL$_{v\%}$, PL$_{AP\%}$ and PL$_{ML\%}$.

The GLM identified a significant (P = .03) main effect for time for variable PFx, with post-hoc Bonferonni adjustment identifying significantly lower values at rest (t$_{00}$ = 0.91 ± 0.29; t$_{45}$ = 1.05 ± 0.29; 95% CI = -0.26, - 0.02; d = 0.48) with simulated match duration. Furthermore, a similar relationship was observed, with time demonstrating a main effect for Ḟx, with significantly higher values demonstrated with increased match duration (t$_{00}$ = 18.17 ± 5.81; t$_{45}$ = 22.66 ± 8.09; P = .03; 95% CI = 0.32 to 8.67; d = 0.63) and (t$_{00}$ = 18.17 ± 5.81; t$_{105}$ = 21.27 ± 8.33; 95% CI = 0.82 to 5.38; d = 0.43). No further main effects for time were noted for any impact

variables (PFz, PFy, Fz and Fy) (P ≥ .10). The GLM highlighted no significant main effect for trial, for all impact variables measured ($P \geq .13$), whilst also identifying no Trial*Time ($P \geq .05$) interactions. In direct relation to the fatigue response associated with the WU and CD groups, the GLM identified no significant interactions for Group*Trial*Time ($P \geq .14$), whilst also identifying no Group*Time ($P \geq .13$), nor Group*Trial ($P \geq .10$) interactions.

During the performance phase of the cutting movement, significant main effects for time ($P \leq .01$) were observed for $\dot{F}yD$ ($t_{00} = 1.04 \pm 0.51$; $t_{45} = 1.65 \pm 0.61$; $P = .02$; 95% CI = -1.13 to -0.84; $d = 1.08$) and ($t_{00} = 1.04 \pm 0.51$; $t_{105} = 1.86 \pm 0.81$; $P = \leq .01$; 95% CI = -1.29 to -0.35; $d = -1.21$), demonstrating improved performance with increased match duration. A similar effect was observed for variable t ($P \leq .01$) with a main effect for time demonstrated ($t_{00} = 0.39 \pm 0.05$ s; $t_{45} = 0.36 \pm 0.06$ s; $P = .02$; 95% CI = 0.00 to 0.05; $d = 0.54$), ($t_{00} = 0.39 \pm 0.05$ s; $t_{45} = 0.36 \pm 0.06$ s; $P = .02$; 95% CI = 0.05 to 0.06; $d = 0.58$), indicating a significantly improved performance with increased match duration. The same trend is observed for I-D ($P = .02$), with post-hoc pairwise comparisons identifying a significant main effect for time ($t_{00} = 0.24 \pm 0.02$ s; $t_{45} = 0.20 \pm 0.02$ s; $P = .03$; 95% CI = 0.04 to 0.07; $d = 2.00$), ($t_{00} = 0.24 \pm 0.02$ s; $t_{105} = 0.20 \pm 0.01$s; $P = .03$; 95% CI = 0.01 to 0.07; $d = 2.52$), indicating a reduction in time to complete this component of the task in association with increased match duration. No further main effects for time were noted for any of the remaining performance variables ($\dot{F}zD$, $\dot{F}xD$ and θ, $P \geq .10$).

The GLM identified significant main effects for Trial for variables θ ($P \leq .001$), with post-hoc Bonferonni adjustments identifying an increase in θ post intervention (Pre = 77.97 ± 4.31°; Post = 82.33 ± 4.61°). A similar observation was identified for I-D and T ($P \leq .001$), with both variables highlighting a significant reduction in time taken to complete the task (Pre = 0.25 ± 0.05s; Post = 0.18 ± 0.04; 95% CI = 0.05 to 0.10; $d = 1.55$), (Pre = 0.40 ± 0.06 s; Post = 0.35 ± 0.05 s; 95% CI = 0.27 to 0.74; $d = 0.91$) respectively. No further significant main effects for Trial were noted for the remaining performance variables ($P \geq .34$). No Group*Time interactions were observed by the GLM ($P \geq 0.10$)

Significant interactions were observed for Time*Trial for variables $\dot{F}xD$ ($P = 0.03$), with post-hoc pairwise comparisons identifying a significant main effect ($P = .05$) at t_{45} (Pre = 2.03 ± 0.85 bw.s^{-1}; Post 1.32 ± 0.50 bw.s^{-1}), highlighting a reduction in the rate at which force is absorbed. For the remaining force plate variables, no further Time*Trial or Group*Trial*Time variables were noted ($P \geq .05$).

9.4 Discussion

The aim of this study was to design a new multi-modal injury prevention programme and examine its effect upon ankle injury risk factors. The injury prevention programme was also investigated to determine if performing the exercises either before (non-fatigued, WU) or after (fatigued, CD) tri-weekly field-based training sessions influenced performance measures associated with ankle injury risk.

Deficiencies in postural stability are a commonly cited risk factor for ankle sprain injuries (Hiller et al., 2008; McGuine et al., 2000; Semple et al., 2012; Wang et al., 2006). Subsequently, injury prevention programmes have included a variety of exercises and training methods, ranging from balance (Eisen et al., 2010; Leavey et al., 2010) to plyometrics (Myer et al., 2006) for the prevention of ankle sprain injuries. Furthermore, these varieties of exercises have been shown not only to reduce ankle injury incidence (Malliou et al., 2004) but also to improve performance parameters associated with soccer match play (Eisen et al., 2010; Leavey et al., 2010). The findings of this present study, support previous research demonstrating improvements in postural stability using a multi-modal battery of exercises (Fitzgerald et al., 2010; Filipa et al., 2010). Post-trial improvements in performance were highlighted for the BSS, with indices OSI, AP and ML, demonstrating an average reduction of 20.22%, 21.03% and 18.71%, respectively, which is in comparison with the values observed by other researchers investigating the effects of neuromuscular programmes (Malliou et al., 2004; Paterno et al., 2004). These results are mirrored by another measure of postural stability in the form of the SEBT, with improvements in performance noted for A_D (5.16%), PL_D (7.74%), PM_D (9.47%) and $SEBT_T$ (7.93%). Similar improvements of post intervention measures of SEBT have been observed in previous research (Fitzgerald et al., 2010; Filipa et al., 2010), who observed improvements in performance of postural stability when a multi-modal

153

battery of exercises were performed during the warm-up of soccer training sessions. Improvements in SEBT performance are potentially due to an increase in neuromuscular control and dynamic balance (Thorpe and Ebersole, 2008). Training programs, which incorporate balance training through either unstable surfaces, disturbance of equilibrium or via reduction of somatosensory input, promote neuromuscular mechanisms, which are responsible for the co-contraction of the agonist and antagonist muscles, which enhance joint stability (Eisen et al., 2010). Through reducing the onset time of these muscles and increasing the sensitivity of feedback pathways, increased joint stiffness is produced, resulting in less joint displacement, subsequently reducing the amount of strain on joint structures (Hrysomallis, 2007). Furthermore, improvements in postural stability are observed due to a greater ability to control the centre of mass (CoM) (Zazulak et al., 2007). Greater amounts of biomechanical deviations occur in the lower extremity when the CoM moves away from the base of support, subsequently causing increased injury risk (Zazulak et al., 2007). Through performing NM intervention programmes, there is an increased ability to control movements, thus decreasing excessive forces placed of the lower extremity (Zazulak et al., 2007).

Plyometric exercises incorporated into neuromuscular training programs produce increases in gluteus medius strength, whose primary role is to provide hip stabilisation during postural stability tasks (Leavey et al., 2010). In addition to this, plyometric training has also been shown to improve lower extremity muscle control and stability, whilst also enhancing JPS, balance (Myer et al., 2006) and co-ordination (Chimera et al., 2004), throughout functional movement. This provides participants with a more stable surface to perform the required tasks, subsequently improving their performance scores in the SEBT and BSS. Furthermore, short-term plyometric sessions have been shown to change various elastic components of the muscle-tendon complex of plantar-flexors in athletes (Markovic and Mikulic, 2010). Via improving the lower-extremity strength, power and stretch-shortening cycle, further helping to improve lower extremity reaction time, allowing surrounding musculature to respond quicker to unexpected perturbations, which could potentially cause ankle injury. What is more, additional losses of balance are implemented into the plyometric component of the programme due to the dynamic nature of the

154

exercises performed, as the participants are placed into positions of single leg balance, thus disturbing equilibrium. This then requires the participants to improve somatosensory systems and pathways. This coupled with aforementioned improvements in CoM deviation, joint stiffness and muscular control, help to explain the improvements in postural stability observed during this study. Tasks such as the SEBT have been demonstrated to be reliant on neuromuscular characteristics such as lower extremity co-ordination, balance, flexibility and strength (Thorpe and Ebersole, 2008).

Postural stability improvements in performance could also be potentially explained via a reduction in the loading forces experienced during simulated soccer match play. A significant reduction in whole body PL_{ML} and PL_{Total}, was observed post intervention, suggesting improved movement economy potentially as a result of the neuromuscular training programme. The reduction in PL_{ML} further indicates that an improvement in performance (T) is observed during the utility movements of the SAFT[90] rather than its linear components. This is further supported through a significant reduction in force plate variables I-D, whilst also observing a more acute θ. Agility has been demonstrated to be a key determinant of elite soccer performance (Reilly et al., 2000), which is shown to be influenced by the ability to co-ordinate lower-limb muscles whilst also regulating foot-ground interactions to stabilise an unstable interface when performing a cutting maneuverer (Lyle et al., 2015). Through reducing the amortization period (I-D) and producing a more acute angle of cut (θ), movement efficiency is improved during the utility phase of the protocol. This in turn could potentially lead to a slight reduction in the overall effort and PL_{Total}, during the remaining linear movements of the protocol due to its standardised nature. These observations and movement patterns would be repeated throughout the SAFT[90], subsequently reducing PL_{Total} and PL_{ML}. It should be further acknowledged, that no main effect for time was noted for PL_{Total} and PL_{ML}, suggesting that these benefits are seen throughout the simulated soccer match play, thus potentially offsetting neuromuscular fatigue impairment. In addition to the potential performance benefits, it is suggested that an improved I-D reduces the amount of time the participant is positioned in a plantar-flexed and inverted position, which has been associated with the greatest risk of lateral ankle sprain occurrence (Halasi et al.,

155

2005). Through strengthening the large and small musculature surrounding and crossing the ankle joint, it is assumed that a change in force distribution will be observed, due to an increase in use of the smaller muscles (Baltich et al., 2014). This change in muscle pattern would be associated with a reduction of joint and insertion forces, therefore benefitting functional performance and injury prevention mechanisms.

A final potential reason or the improved performance measures observed by both groups post multi-modal intervention could be due the high compliance rate observed within the study (Janssen et al., 2015). Participants were only included in the study if they had a compliance rate of $\geq$ 75%, with only a small handful of participants from the original cohort falling below this value. Janssen et al., (2015) performed an ordinal regression with backward selection methods to obtain a descriptive statistical model linking participant's person-related potential predictor variables with monthly compliance measurements for different types of interventions. Janssen et al., (2015) concluded that athletes who participate in sports, which are considered high risk for sustaining ankle sprains, such as soccer, are substantially more likely to comply with intervention programmes, due to acknowledgment of the high injury incidence within their sport.

The current study identified no Group*Trial*Time, Group*Time, nor Group*Trial interactions for any of the performance measures. This is in contrast to the sparse literature investigating the influence of timing and physical state on injury prevention programmes (Small et al., 2009). Research conducted into the effects of a bi-weekly Nordic Hamstring Exercise (NHE) injury prevention programme on soccer players eccentric hamstring strength, indicated that the timing of exercises during soccer training sessions, affected the temporal pattern of strength gains during simulated soccer performance (SAFT[90]) (Small et al., 2009). Upon completion of the programme, the group performing the NHE during the warm-up significantly improved their resting eccentric hamstring strength, however no significant changes were observed either at half-time or immediately post SAFT[90]. This is contrast to the results observed during the cool-down group, who demonstrated maintained eccentric hamstring strength throughout the protocol, thus indicating a potential

resistance to fatigue (Small et al., 2009). No such temporal patterns were observed during the current study, with both the WU and CD groups failing to demonstrate a temporal pattern of postural stability gains during simulated soccer match play. The reasons for the disparity in the results of the current study in comparison to previous literature surrounding this area could potentially be explained by the movement patterns of the intervention exercise(s) and the physical tests associated with it. Improvements are demonstrated in injury prevention programmes, where measures of performance are directly related to the exercises performed in the intervention, due to similar movement patterns (Fitzgerald et al., 2010). NHE are a unilateral movement exercise, with movement patterns similar to the Isokinetic Dynamometry (IKD) tests used to measure eccentric hamstring strength, subsequently, Small et al., (2009) demonstrated improvements in performance. The exercise intervention used during the current study, utilised a greater variety of functional movement patterns associated with the requirements of soccer match play, all of which were not directly related to the measures of performance, thus potentially explaining why no improvements were observed.

Professional soccer players have been demonstrated to have levels of postural stability which are only surpassed by that of dancers and gymnasts (Palliard and Noe, 2006), with a further difference observed between professional and semi-professional players (Rein et al., 2011). Due to enhanced levels of postural stability, it could be potentially inferred that fatigue may not have the same deleterious effect on performance as observed in populations with less training history, as regular soccer training results in greater levels of lower extremity strength and neuromuscular control across limbs (Thorpe and Ebersole, 2008). This regular level of training in addition to the previously mentioned benefits of the neuromuscular training programme utilised during the current study, could help to explain why the timing of exercises did not significantly affect the temporal pattern of postural gains during simulated soccer performance. If participants already possess exceptional levels of postural stability, whilst also potentially alleviating the amount of fatigue accumulation through reducing the amount of loading experienced, then fatigue may not debilitate the systems which control postural stability to the same extent as seen in muscle groups such as the hamstring.

9.5 Conclusion

The findings from this present study indicate that performing the new ankle injury prevention programme helps to improve performance parameters and mechanisms associated with postural stability and functional movement, whilst also highlighting improvements in movement efficiency. However, the timing of the ankle injury prevention programme had no significant effect on measures of postural stability performance or mechanical responses associated with soccer match play. These findings may have implications for future injury prevention programmes aiming to reduce ankle injury incidence. Furthermore, it is suggested that ankle injury intervention programmes need not adopt a strategy of fatigued training, rather that they may occur at any time point during a soccer training session without having deleterious effects upon performance in healthy soccer players.

Chapter 10: General Discussion

10.1 Introduction

The aim of this chapter is to interpret and integrate the findings contained within the thesis, with the realisation of the aim and objectives also addressed in this section. The general discussion, which follows this section, will attempt to contextualise the practical and methodological implication of the study findings. The limitations of the data and recommendations for future research are also discussed in this section.

10.2 Realisation of aims and objectives

The work conducted in this thesis was designed to produce an ankle injury prevention programme for healthy soccer players, which better considered a wider array of aetiological risk factors, whilst also considering lesser-investigated areas such as circadian rhythms, external support and the effects of soccer specific fatigue. The aims of this thesis were to: 1) Examine the commonality in performance, and mechanistic predictors of performance, across a battery of functional tasks considered to evaluate ankle joint function; 2) Determine the influence of time of day on performance tasks and their parameters associated with ankle aetiological risk factors; 3) Determine the influence of different brands of kinesiology tape (KT) on performance tasks and their parameters associated with ankle aetiological risk factors; 4) Investigate the effects of different brands of KT on aetiological risk factors associated with ankle sprain injury and measures of functional performance, with specific reference to soccer specific fatigue; 5) Assess the impact of an increased utilisation of interchanges on risk factors associated with ankle sprains in soccer players; 6) Compare the effects of performing a newly designed ankle injury prevention programme during either the warm-up or cool-down of soccer training session, with specific reference to aetiological risk factors associated with ankle injury incidence during simulated-soccer match play. These aims have been achieved via the completion of a series of studies reported within the thesis, which were designed in conjunction with the objectives specified in the introduction. Subsequently, the following conclusions can be made:

1) Inter-test correlations were generally weak, with the greatest predictive relationship observed between overall stability index (OSI) and invertor: evertor ratios (r^2 = .37, *P* = .05). Hierarchical ordering of task predictors highlighted numerous common performance indicators, however, vertical force during the drop landing inversion sprint task proved to be the most commonly associated across the multi-modal battery of tests.

2) Significant time of day effects were demonstrated for a small number of performance indicators related to postural stability (AP), speed (t) and electromyographic activity (LG EMG_{Mean}), with 12:00 hours demonstrating to have the greatest deleterious effect on performance within these parameters. No significant time of day effects were noted for any other outcome measures or other performance predictors.

3) Application of KT to the ankle complex demonstrated significant improvement in performance for outcome measures of proprioception; $\theta_{15,}$ with KT_2 demonstrating less absolute error when compared to NT; Both KT_1 and KT_2 demonstrated less absolute error when compared to NT for θ_M; time to complete drop and drive inversion sprint task was significantly decreased when KT_2 only was applied; postural stability significantly increased in SEBT A_D, when KT_2 was applied in comparison to NT. No further significant findings were noted for any other outcome measures or performance predictors

4) Under the influence of soccer specific fatigue, KT_1 application to the ankle complex significantly improved measures of postural stability in the form of OSI, AP and ML, whilst also decreasing the amount of PlayerLoad™ experienced during the locomotion phase of the activity. Improvements in postural stability were not elicited through either a mechanical or increased neuromuscular activity, as both measures of Qualisys and EMG failed to indicate a significant main effect for most parameters Furthermore, KT_1 had no detrimental effects upon performance, with results indicating a mediating effect on various performance parameters throughout the 90 minutes of soccer-specific activity.

5) Increased utilisation of interchanges (SAFT^{60}) significantly decreased physiological variables, HR and BLa when compared to the SAFT^{90}. Further significant trial improvements were also observed during measures of BSS postural stability, when participants performed activity interspersed with recovery periods. However, these recovery periods were not sufficient enough to offset the effects of fatigue. Improvements in postural stability performance were not due to mechanical or neuromuscular changes in technique and/or activity, with no significant main effects noted for either measure. Furthermore, the recovery periods afforded every 15 minutes did not elicit a recovery in EMG parameters.

6) Performance of the multi-modal ankle injury prevention programme promoted significant improvements in performance regardless of group for SEBT and BSS variables, whilst also highlighting similar effects for PL_{ML} and $PL_{Total.}$ Grouping players into either a warm-up (non-fatigued) or cool-down (fatigued) group produced no significant differences in all measures of performance, suggesting that the physiological state in which the player's trained had no improvement nor detrimental effect on locomotor activity, mechanical performance or postural stability.

10.3 General Discussion

The first three studies in this thesis provide new knowledge regarding the relationships between aetiological risk factors associated with ankle sprains, whilst adding further evidence with regards to the effects of circadian rhythms and external support on said risk factors. In an attempt to better understand the aetiological mechanisms associated with ankle sprain injuries, study one investigated the commonality in performance, and mechanistic predictors of performance, across a battery of functional tasks considered to evaluate ankle joint function. Copious amounts of research has been conducted regarding aetiological mechanisms associated with ankle sprain injury (Aoki et al., 2012; Bennyon et al., 2002; McGuine et al., 2001; Murphy et al., 2003; Mohammadi and Roozdar, 2010; Tsiagnos et al., 2007; Woods et al., 2003). However, this has often been conducted using univariate analysis, choosing rather to conduct research using the effects of a

161

singular performance measure, rather than investigating the effects of a multi-modal battery of tests which better replicate the complex interaction of multiple risk factors and events which better depict injury occurrence (Bahr, 2003). Direct comparison with previous studies is limited, with tasks such as these typically considered in relation to the efficacy of an intervention or reducing injury incidence (Dallinga et al., 2012).

Results from study one reflect the multi-modal nature of ankle sprain aetiology, with low magnitudes observed in all intra-test correlation coefficients, indicating that each test utilised within the battery is discrete and that good performance on one test is not indicative of the same outcome in another performance measure. Furthermore, the outcome measures of each task were used to develop a hierarchical ordering of parameters measured in each test, with results indicating that multiple rather than one specific parameter helps to predict performance, thus reflecting the complexity of ankle injury aetiology.

The results of study one therefore suggested that it may not acceptable to only measure individual tasks of performance and aetiological risk factors, rather a multi-modal battery is required to investigate performance. Furthermore, if a participant is identified as having performance deficits in certain screening tasks, the mechanisms, which enhance the task, should be trained for improvement rather than the task itself for optimal (p)rehabilitation. Although the research conducted in study one helped to add greater depth and understanding regarding aetiological mechanisms associated with ankle injury, further questions still existed, which would further help to improve the design of an ankle injury prevention programme. These questions surrounded the time of day which tests were performed, whilst also attempting to determine whether external support could help improve performance during tests associated with ankle injury occurrence.

The aim of study two was to examine the influence of time of day on the same multi-modal battery of tests utilised in study one amongst soccer players. The rationale for performing this study, stemmed from the lack of literature surrounding how the time of day at which tests used to screen soccer players for performance and/or injury risk were performed, could potentially influence the outcome/results. This study has

helped add to the dearth of literature surrounding this area, adding to the investigations conducted into postural stability (Gribble et al., 2007; Kwon et al., 2014), whilst providing new detail surrounding measures of ankle joint strength, proprioception and more functional dynamic tasks such as drop landing. Researching this area in greater detail, could influence a clinician's interpretation of aetiological risk factor tasks associated with the ankle joint, helping them to make a better informed decision regarding an athlete's return or abstinence from play.

The results of this study suggest that although certain task parameters such as BSS AP and I-D during the drop-landing task were shown to be significantly affected by circadian rhythm, the vast majority of the tests performed demonstrated no significant differences when time of day was taken into consideration. These findings are in slight disagreement with those (Gribble et al., 2007; Kwon et al., 2014), who suggested that postural stability performance was influenced by the time of day at which it was performed. The difference in results can possibly be explained by the participants used; the participants in this study were semi-professional soccer players, who have been shown to possess superb levels of postural stability, compared to healthy college students (Gribble et al., 2007) and healthy adults (Kwon et al., 2014). Furthermore, soccer players perform sport specific activity at various times of the day, with kick-off times varying from midday through to late evening, with training occurring either in the early morning or mid-evening. Both (Chtourou et al., 2012; Souissi et al., 2002) discovered that adaptation to strength and resistance training is greater at the times of day at which training is conducted for an extended period, when compared to that of other times of day. Although these findings concern that of strength and resistance training, it would seem reasonable to suggest that the participants involved in this study, who have experience of training and match performance in the evening, plus the afternoon for considerable years, may also have improved their levels of balance and postural stability at the aforementioned times. This could therefore infer, that soccer players who have been demonstrated to have balance levels which, are only inferior to that of dancers and gymnasts (Davlin, 2004; Matsuda, et al., 2008), could potentially improve their balance and postural stability in both the afternoon and evening due to the sheer volume of activity conducted. The findings of this study would seem to suggest that

163

the medical team surrounding athletic performance in soccer, would be able to perform tests which either screen players for injury risk or exercises which prevent or help an athlete return to play, can be performed at various times of the day without affecting the reliability of the results.

The findings of study two helped to further inform, the methodologies of studies four and five, which involved semi-professional soccer players performing a soccer-specific protocol, in an attempt to elicit the fatigue effect experienced during match-play. Due to the lack of insignificant findings observed in study two, with overall test outcomes demonstrating no time of day effect in semi-professional soccer populations, results indicated that testing could be performed at any time point during the day, without having a detrimental effect on participant results. However, with the vast majority of semi-professional soccer matches beginning either at 15:00 or 19:45 h, and training generally occurring between the hours of 19:00 – 21:00 h, it was decided that in conjunction with circadian rhythms and the majority of non-significant findings observed in study two, the soccer-specific protocol would be performed during the evening at 19:00 h.

The primary purpose of study three was to provide further information about the effects of different brands of KT used as external support on the same multi-modal battery of tests utilised in studies one and two. Surprisingly, a paucity of literature exists regarding the efficacy of KT as a mediator of sports specific fatigue, therefore studies 3 and 4 aimed to investigate the efficacy of different brands of KT at both rest and under the influence of soccer specific fatigue.

Proposed mechanisms via which KT_1 and KT_2 purport to enhance performance vary, with one of the most popular reasoning attributed to increased levels of proprioception. KT claims to enhance proprioceptive capabilities via increased stimulation of skin cutaneous mechanoreceptors, thus creating greater levels of afferent feedback to the CNS (Refshague et al., 2009), therefore enabling the body to have a greater sense of awareness as to where it positioned. The results of study three seem to support these findings as improvements in absolute error are observed in both θ_{15} and θ_M, when utilising either KT_1 and KT_2, and KT_2 respectively. Mechanisms as to how this improvement in performance is derived are difficult to

164

postulate, due to one of the limitations of this study being that no EMG data was recorded during the proprioceptive tasks, due to the EMG system failing to report consistent and reliable data in the laboratory where the IKD is positioned. EMG data would have been useful to report, as KT claims to exert a pulling force on the skin (Halseth et al., 2004), thus increasing the level of afferent data, from which a more appropriate and accurate response can be determined, subsequently reducing absolute error. However, when EMG was recorded during measures of postural stability, SEBT and BSS, no significant differences were noted in levels of activity when either brand of KT was applied. This could potentially indicate that the same results would be observed during the JPS tasks.

Further improvements were noted in measures of SEBT A_D and t during the drop and drive sprint inversion task; however these improvements were only apparent when KT_2 was applied. Proposed reasons for this could be attributed to the greater degree of stretch permitted by KT_2, thus potentially providing the participants with a greater range of motion surrounding the ankle joint and enhanced stretch recoil action, producing greater levels of force production, subsequently allowing forces to be absorbed and utilised in the next phase of the movement in a more efficient fashion. One of the key components of soccer activity is agility, requiring participants to perform a change of direction in an efficient and timely manner (Reilly et al., 2001). Change of direction first requires deceleration in which force is absorbed, before utilising some of the energy stored from this action for propulsion in a different direction. This study demonstrates that KT_2 can help to improve this fundamental skill of healthy male semi-professional soccer players, thus suggesting that if participants wore KT_2 during soccer match play, change of direction tasks might be performed to a greater standard, thus potentially enhancing the success of the individual and/or team. Furthermore, a reduction in D I-D was observed when KT_2 was applied, suggesting not only a more efficient economy of movement, but also restricting the amount of time available for the ankle joint to fall into a position of plantar-flexion and inversion, which has been shown to be symptomatic of ankle sprain occurrence (Halasi et al., 2009). A note of caution is warranted at this point, all measures during study three were performed at rest; traditional white tapes have been demonstrated to lose their mechanical effects after 15 minutes of soccer

specific exercise (Forbes et al., 2013), thus indicating that KT needs to be tested under the guise of soccer specific activity to determine whether its effects withstand the physiological and mechanical demands of 90 minutes of simulated soccer-match play.

Studies four and five, used information gleaned from the first three studies to develop a more robust methodological approach to investigating the effects of fatigue mediation in simulated soccer match play. As previously explained, a greater number of ankle injuries have been demonstrated to be sustained in the final 15 minutes of each half of soccer matches (Woods et al., 2003), leading prominent authors (Ekstrand et al., 2011; Hawkins et al., 2001; Woods et al., 2003) to propose fatigue as a potential aetiological risk factor. Study four utilised KT_1 compared to the use of an increased number of interchanges in study five to determine the effects of either external support and/or a rule change on the effectiveness of mediating fatigue when compared to a control trial. Both studies demonstrated significant improvements in measures of postural stability in the form of the BSS, thus potentially reducing the impact this risk factor has on ankle joint performance. Both studies failed to demonstrate changes in technique via Qualisys measures or enhanced levels of EMG activity during the BSS trials, suggesting that the improvement in performance did not derive from these areas. Proposed mechanisms for the improvements in performance are different between studies with increased utilisation of interchanges improving postural stability via significantly decreasing physiological functions such as HR, which in turn reduce the amount of postural stability caused due to decreased fluid distribution and hyperventilation as a result of reduced energy needs (Fox et al., 2008; Palliard, 2012; Yaggie and Armstrong, 2004). With regards to the use of KT_1 to mediate the effects of fatigue, it is suggested greater levels of mechanical restriction are enforced by the tape surrounding the ankle joint, thus limiting the potential of the body to deviate into positions, which may enhance risk of injury. A note of caution is advised at this point as performance of OSI, AP and ML all demonstrated a temporal fatigue effect, with values increasing with match duration regardless of either a KT_1 or a SAFT[60] intervention being utilised. This continued fatigue effect demonstrates that although improved trial differences were observed for both interventions, the effect of fatigue could not

be offset; therefore injuries during the latter stages of match play could still be problematic.

A greater number of improved performance measures were noted with KT_1 application when compared to the $SAFT^{60}$. KT_1 demonstrated significant reduction in GPS measures of PL_{Total} in addition to uni-axial measures of PL_V, PL_{ML} and PL_{AP}. If the main focus of biomechanical injury prevention mechanisms is to adjust the external and/or internal loads experienced by the body (McIntosh, 2005), results of study four would suggest that KT_1 modulates load effectively in healthy male soccer players. Potential mechanisms for this improvement in performance whilst also explaining why no significant reductions were observed for the same parameters during the $SAFT^{60}$, could be attributed to KT_1 acting as an external mechanism helping to increase joint stiffness, subsequently enabling musculature surrounding the ankle joint to produce quick postural adjustments, whilst also allowing the body to utilise smaller muscles to further increase joint stability. This in turn will help to reduce the loading experienced at the joint and insertions of larger muscles surrounding the ankle joint (Nigg, 2009).

The $SAFT^{60}$ aims to mediate fatigue through increased recovery periods, thus allowing parameters to return to a level, which is closer to the individual's baseline values. However, this will not recruit more muscles to become involved in repetitive actions such as locomotion, rather utilise the same muscles, which should be in a state of less fatigue as a result of the increased number of rest periods. It should also be noted, that KT_1 maintained lower levels of load throughout the $SAFT^{90}$ trial, indicating that the tape maintained its mechanical properties throughout the trial, which is vital due to the increased injury rate observed during the latter stages of match play (Woods et al., 2003). Furthermore, this appears to be an improvement on traditional white tapes, which have been often utilised to improve performance parameters, associated with injury (Forbes et al., 2013; Lohkamp et al., 2009), although they have been shown to lose their mechanical affects after a period of 15-20 minutes of exercise. Therefore, if reducing the load experienced by players during match-play is the aim of clinicians, it is advised that KT_1 could be applied.

When comparing the effects of the interventions from study four (KT_1) and study five ($SAFT^{60}$), it would seem apparent that KT_1 appears to have more potential benefits in terms of mediating fatigue and reducing potential injury risk as a result. In addition to this, KT_1 is already worn by professional athletes across many sports, with no rules from governing bodies restricting its use during match-play. Although FIFA have implemented rules such as automatic red cards for player elbow to head contact in an attempt to reduce injury incidence, it is suggested that a more drastic rule such as increased utilisation of interchanges similar to those observed in Rugby League would be more difficult to instigate. It is therefore suggested that both KT_1 and the $SAFT^{60}$ have the potential to improve functional performance under the influence of soccer-specific fatigue, however KT_1 appears to have more potential benefits, whilst also being able to be implemented at the discretion of the clinician and athlete.

The primary aim of study six was to compare the effects of performing a newly designed ankle injury prevention programme during either the warm-up or cool-down of soccer training session, with specific reference to aetiological risk factors associated with ankle injury incidence during simulated-soccer match play. The multi-modal injury prevention programme was designed based on evidence achieved during studies one, three, four and five. Study one's contribution to the programme took place in the form of recommending performance parameters such as Fz, coupled with postural stability and torque indicators. This led to dynamic exercises, which required participants to absorb forces, whilst also placing them into unstable positions being designed. The findings of studies four and five further indicated that although external support and/or rule changes can help improve performance parameters associated with ankle aetiological risk factors, fatigue cannot be mediated for all aetiological risk factors measured. These findings suggest that other mechanisms, which attempt to combat the effects of fatigue, must be investigated due to the increased injury incidence, which is observed during the latter stages of soccer match play. Consequently, considering the law of specificity (Kraemer et al., 2002), a strategy of performing exercises designed to stress the ankle joint in either a fatigued or non-fatigued soccer training state was investigated. The efficacy of the

multi-modal intervention programme was assessed alongside an identical programme performed in a non-fatigued state.

No significant interactions were observed between training groups for any of the performances parameters measured. This is in contrast to the sparse literature conducted in this area (Small et al., 2009), who concluded that the fatigued training state was more effective at maintaining eccentric hamstring strength and preserving the functional eccH:conQ strength ratio throughout simulated soccer match-play. Furthermore, Small et al., (2009), postulated that these improvements could help reduce hamstring strain injury incidence during the latter stages of match play. The reasons for the disparity in the results of the current study in comparison to previous literature surrounding this area could potentially be explained by the movement patterns of the intervention exercise(s) and the physical tests associated with it. Nordic hamstring exercises (NHE) are a unilateral movement exercise, with movement patterns similar to the Isokinetic Dynamometry (IKD) tests used to measure eccentric hamstring strength. The exercise intervention used during the current study, utilised a greater variety of functional movement patterns associated with the requirements of soccer match play, all of which were not directly related to the measures of performance, thus potentially explaining why no differences between groups were observed. The fact that no physiological measurements were recorded during training is a limitation of the study. Subsequently it cannot be determined whether the intensity of the soccer training session was sufficient enough to elicit a fatigue response.

The secondary aim of study six was to determine whether the ankle injury prevention programme helped to improve aetiological risk factors associated with ankle injury incidence in healthy male soccer players. Significant improvements in all measures of BSS and SEBT postural stability, in conjunction with decreased PL_{ML} and PL_{Total} were observed, regardless of group. The improvements in performance for all postural stability measures were similar to those observed in previous literature (Fitzgerald et al., 2010; Filipa et al., 2010; Malliou et al., 2004; Paterno et al., 2004). These gains in performance are postulated to derive from a combination of increased neuromuscular control and dynamic balance (Thorpe and Ebersole, 2008) through

training on unstable surfaces which disturb equilibrium; increased joint stiffness (Hrysomallis et al., 2007) resulting in less joint displacement; and a greater ability to control the centre of mass (Zazulak et al., 2007). Furthermore, postural stability improvements in performance could also be potentially explained via a reduction in the loading forces experienced during simulated soccer match play. A significant reduction in whole body PL_{ML} and PL_{Total}, whilst performing the same workload was observed post when compared to pre intervention, suggesting improved movement economy, potentially as a result of the multi-modal training programme. These results were observed in conjunction with improved movement economy associated with force plate parameters, with variables t, I-D and θ all demonstrating improved performance post intervention. Through strengthening the large and small musculature surrounding and crossing the ankle joint, it is assumed that a change in force distribution will be observed, due to an increase in use of the smaller muscles (Baltich et al., 2014). This change in muscle pattern would be associated with a reduction of joint and insertion forces, therefore benefitting functional performance and injury prevention mechanisms.

The findings from this present study indicate that performing the new ankle injury prevention programme helps to improve performance parameters and mechanisms associated with postural stability and functional movement, whilst also highlighting improvements in movement efficiency. However, the timing of the ankle injury prevention programme had no significant effect on measures of postural stability performance or mechanical responses associated with soccer match-play. These finding may have implications for future injury prevention programmes aiming to reduce ankle injury incidence in healthy male soccer players. Furthermore, it is suggested that ankle injury intervention programmes need not adopt a strategy of fatigued training, rather that they may occur at any time point during a soccer training session without having deleterious effects upon performance.

Due to the nature of the participants used throughout this thesis, the findings of all studies cannot be generalised beyond uninjured, male, semi-professional soccer players. A strict inclusion and exclusion criteria, in addition to a desire for a homogenous population resulted in convenience samples of n = 12 being recruited.

Post-priori power calculations (G-Power 3.1) conducted using key variables such as OSI, AP, ML, $SEBT_{AD,PLD, PMD, TOTAL}$ and all PL variables, indicated sample sizes ranging between 6 and 38 dependent upon the study and variable used. Subsequently, the findings of the sample sizes suggest that some variables and their associated findings are underpowered. It is suggested that underpowered studies are unlikely to yield results with practical translation value, whilst also placing subjects at unnecessary risk and wasting resources (Bacchetti, McCulloch and Segal, 2012). However, the projected total burden placed upon subjects is proportional to the sample size, indicating that the ratio of study value to participant burden can only deteriorate as a sample size increases (Bacchetti, McCulloch and Segal, 2012). Subsequently, an underpowered study can provide enough projected value to justify the number of participants placed at risk (Bacchetti, McCulloch and Segal, 2012).

It is the author's opinion that recruiting additional subjects who did not meet the stringent inclusion/exclusion criteria in terms of level of soccer ability and previous injury history, in order to improve statistical power, would decrease the homogeneity of the group. Subsequently, the implications of the findings of all studies within this thesis would be diminished due to variations within the sample size. It is commonly accepted that with a sufficiently large sample size, a significant difference will often be discovered (Sullivan and Feinn, 2012), indicating it is more difficult to achieve both significance and a large effect size in a smaller population. Within the current thesis, the vast majority of significant findings indicate $P < 0.05$ in combination with a large or greater effect size (d > 0.80), thus indicating substantive (effect size) and statistical significance (*P* value) (Sullivan and Feinn, 2012).

Studies, which are similar in nature (Forbes et al., 2013; Lohkamp et al., 2009; Small et al., 2009) to those conducted within this thesis, conduct their experiments with sample sizes ranging from 8 – 14, providing conclusions specific to the population utilised only. The sample size utilised within the current thesis is greater if not similar to those reported in current and relevant literature, (Forbes et al., 2013; Lohkamp et al., 2009; Small et al., 2009), indicating the difficulty in recruiting a semi-professional soccer specific homogenous sample to conduct time consuming studies

10.4 Recommendations for Future Research

A number of limitations exist within the current thesis. Whilst, study one demonstrated that little commonality exists amongst aetiological risk factors associated with ankle sprains, the sample size was relatively small due to the specific nature of the homogenous group required for investigating ankle joint performance in healthy soccer players. A further limitation of the research is that there were only five tests selected to perform the multi-modal battery of tests. Additional tests could have been selected as these may potentially provide greater levels of commonality amongst the already selected tests.

Additionally, force plate analysis was conducted to determine rates of force development and angle of cut to name but a few measures. What cannot be derived from the method of analysis conducted within this thesis are the loads sustained specifically at the ankle joint, as the ground reaction forces do not reflect the load at one specific anatomical location. Inverse dynamics could have extended the study to quantify segmental force at the ankle joint specifically. Inverse dynamics analysis is a standard method commonly utilised within biomechanical research. The standard inverse dynamics method to calculate joint moments utilises direct measures of external ground reaction force and positional data, whilst segmental acceleration is determined by numerical differentiation of positional data (Bisseling and Hof, 2013). With estimates of mass and inertial properties, joint moments can be calculated. However it is suggested that a strong correlation exists between ground reaction force and ankle inverse dynamic calculations based on small levels of acceleration at the ankle joint when the foot is in contact with the ground, in addition to a relatively low segmental mass of the foot itself. Furthermore, the results are specific to semi-professional soccer players who possess certain levels of fitness and physical attributes, which differ from that of the general population. Subsequently, the results from studies one to three may not be applicable to other athletic and/or general populations.

Studies three and four investigated the effects of KT in a state of rest and under the influence of soccer-specific fatigue respectively. With specific reference to the KT, future studies should consider the use of comparing the effects of KT against traditional white tapes, whilst also considering the use of a sham KT application in an attempt to remove a potential placebo effect, whilst also investigating the guidelines to which KT is applied. This will provide further knowledge with regards to how KT performs against other commonly used methods, whilst also highlighting how other tapes and applications perform under the influence of soccer specific-fatigue.

With specific reference to studies four and five, potential mediators of fatigue were investigated in the form of KT_1 and increased utilisation of interchanges ($SAFT^{60}$). Kinematic analysis of the postural stability tasks proved difficult due to the 2D setup in the sagittal plane only, thus inferring that potential changes in technique and performance may have been missed if they occurred in either the frontal or transverse planes of movement. Furthermore, EMG analysis consisted of muscles surrounding the ankle joint only due to the specific nature of the thesis question, however it is recommended that future research conducted in this area not only includes a greater level of kinematic analysis, but also analyses EMG activity of muscles more proximal in the kinetic chain, which are also commonly used during tasks which require maintenance of balance. This will provide knowledge as to whether a shift in balance strategies exists from proximal to distal or vice versa during soccer-specific performance as a result of fatigue. This information will be further valuable as it will allow clinicians to further understand which muscles need to be trained to a greater extent to counteract the effects of fatigue.

With regards to the GPS and force plate analysis used during studies four and five, reductions in PlayerLoad™ were observed. Future research should conduct a similar methodological approach and course set up, with the force plate positioned where the change of direction cut occurs. Subsequently, with the addition of video analysis, the point of contact where the cut is made onto the force plate can be matched to the same point on the GPS device, to determine whether changes in loading have occurred at the point where the ankle is in its most vulnerable position for injury

occurrence. This recommendation will provide a novel and interesting approach to interpreting and combining data in an attempt to provide a greater understanding as to the mechanisms of ankle injury occurrence.

Study six identified improvements in aetiological risk factors associated with ankle sprain injuries. This study was conducted using one professional soccer team, whilst also suffering from participant dropouts due to unforeseen circumstances such as player transfers and injuries being sustained. Subsequently this reduced the sample size able to complete the intervention. Future research should be conducted utilising the injury intervention programme designed, across a larger number of clubs, thus increasing the sample size and increasing the statistical power of the analysis, thus providing decreased chance of type 2 errors. Furthermore, sports injury prevention programmes often follow the van Mechelen Model (van Mechelen, Hlobil and Kemper, 1992) as described in the general introduction. This thesis has taken into account epidemiology, whilst also adding further detail to the aetiological mechanisms of injury, before finally arriving at producing an injury prevention programme, where acute performance measures were assessed after a 6 week training programme. This therefore satisfies the first three stages of the van Mechelen Model (van Mechelen, Hlobil and Kemper, 1992), whilst also touching upon stage four, evaluation of the programme. However, a limitation of the study would be that no epidemiological data was recorded before or after the programme, thus limiting chronic evaluation with regards to injury incidence. Therefore, future research should investigate implementation of the injury prevention programme over a longer period of time, whilst assessing injury incidence rates during this period. Conducting the suggested study will help to inform whether the implemented injury prevention program helps to reduce injury incidence on a large scale.

Another future direction of research for study six, would be to investigate the effects of the multi-modal injury prevention programme in both youth and female soccer participants. Football is the most popular sport in the world for women and adolescents, (Kunz et al., 2007), thus effectively managing the risks associated with the sport is of particular importance (Fuller et al., 2012). Both sports have demonstrated exceptionally high injury rates (Clausen et al., 2014; Emery et al.,

2015), with recommendations for injury prevention practice in youth sport especially, deriving from studies in adult elite sport populations (Lauersen, 2014; Schiff et al., 2009). Subsequently, there is a need for injury prevention strategies to be investigated in greater details with specific reference to these populations. This is further supported due to the difficulties experienced when attempting to implement injury preventions programmes with elite sports teams (Bahr et al., 2015). The NHE have been demonstrated to reduce hamstring injury incidence in elite and amateur Danish soccer players (Petersen et al., 2011). However, despite this evidence, the UEFA Champions League injury study demonstrates that acute hamstring injury incidence has not decreased over the past decade in elite football (Ekstrand et al., 2013). Bahr et al., (2015), questioned the effect of the NHE programme based on the consistent evidence available documenting a reduction in hamstring injury incidence. The study concluded after conduction of questionnaires with the medical teams of elite clubs, that uptake of the programme was too low to reduce injury incidence. Subsequently, if established researchers in injury prevention are having difficulty in ensuring uptake using an injury prevention programme, which is shown to decrease the most problematic injury within soccer, attention may be better focussed to youth and female soccer where injuries are problematic and uptake and compliance could potentially be greater.

It is acknowledged that a low sample size is a potential limitation of all the studies conducted within the current thesis, subsequently increasing the possibility of type two errors occurring in the statistical analysis. However, considering the thesis as a whole, it is believed that an original contribution to knowledge has been provided. This thesis conducted its investigation into adult male semi/professional soccer players, with ankle injury incidence being reported as problematic, subsequently the findings are applicable to this population only and may not transfer to other athletic, injured or sedentary personnel. Furthermore, the methodological approach utilised during this thesis could be adopted for other common soccer injuries such as hamstring strains and/or anterior cruciate ligament injuries, in an attempt to provide injury prevention programmes which apply a greater consideration to the aetiological mechanisms involved in injury occurrence.

10.5 Conclusions

This thesis has demonstrated that the aetiology, assessment and training of ankle injury and function are multi-modal. The current thesis has established that aetiological risk factors associated with ankle injury incidence have little commonality in performance outcomes. However, some of the performance parameters used to predict tasks are shared across different tests, indicating that a multi-modal rather than univariate approach to screening for injury, returning an athlete to play or conducting prehabilitation exercises is required. The data of this thesis indicates that certain performance parameters are affected by the time of day at which they are performed, however these have been shown to demonstrate no significant effect on overall test outcome measures, suggesting that injury prevention and/or screening tasks can be performed at various time of day without providing unreliable results. This is of key relevance to clinicians as they will be able to conduct tests at various times of the day for male semi/professional soccer players, without the possibility of results being affected by circadian rhythms.

External support in the form of KT, were shown to be effective in certain measures associated with aetiological risk factors at rest, but perhaps more pertinently also under the influence of soccer-specific fatigue, with KT_1 significantly improving measures of postural stability, whilst also reducing the loads experienced during locomotive activity. Furthermore, KT_1 appears to be more effective in improving parameters of performance associated with ankle sprain when compared to an increased utilisation of interchanges in healthy male soccer players. The findings of these studies suggest that although certain measures of performance were improved via the use of either interchanges or KT_1, the effects of fatigue could not be completely mediated for all measures. It is recommended that KT_1 could potentially be used to reduce the risk of ankle injury incidence in healthy semi/professional soccer players, with no detrimental effects on performance observed.

A new multi-modal ankle injury prevention programme involving fatigued training was subsequently developed. Following a 6-week intervention, players displayed no group differences in performance during a soccer-match simulation, however displayed improvement in post measures of postural stability and GPS accelerometry

measures. These findings may have important implications for reducing ankle injury risk during soccer matches, whilst also suggesting that ankle injury intervention programmes for male semi/professional soccer players need not adopt a strategy of fatigued training, rather that they may occur at any time point during a soccer training session without having deleterious effects upon performance in healthy male soccer players.

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211

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Appendices

Appendix 1.0

INFORMED CONSENT FORM AND INFORMATION SHEET

Project title: **The influence of circadian rhythm and therapeutic tapes on global measures of ankle injury risk factors**

- The postgraduate student leading the project is Chris Brogden
- The supervisors of the project are Dr Matt Greig and Dr Kelly Marrin

Thank you for showing an interest in this project. Please read all the information carefully. Think about whether or not you want to take part. I will contact you again to ask you about your decision. If you decide to take part, you will be asked to sign this form. If you decide not to participate, there will be no disadvantage to you

What are the aims of the project?

The main aims of the project are:

1. To investigate whether circadian rhythm has any the effect on a multi modal battery of tests, specific to the ankle complex
2. To determine whether therapeutic tape (RockTape, Kinesio Tape and no tape) influence performance in the multi modal battery of tests
3. To determine whether any relationships occur between ankle injury risk factors

Procedures

If you agree to take part in this study, you will be required to attend Edge Hill University 9 times for testing, which will be completed over a 3 week period. All testing sessions will require the same testing schedule to be completed.

Prior to each testing session, you will be required to complete a health questionnaire and also a screening procedure in which you will have both your heart rate and blood pressure measured. This will help determine whether you are healthy enough to complete the subsequent testing procedures. You will also be required to complete a questionnaire to determine functional ankle instability, whilst also being able to grade the severity of instability.

Each testing session will involve performing the same tests at 3 different times of day, 08:00, 12:00 and 18:00, with day of testing to be interspersed by a minimum of 2 days. Each of the testing sessions will consist of 6 tests, which are as follows;

1. Ankle Joint Position Sense – subject will be asked to replicate a particular degree of ankle inversion using an Isokinetic Dynamometer (IKD)

2. Ankle inversion, eversion, plantar flexion and dorsiflexion strength – Subjects will be required to complete ankle inversion/eversion ratios at a speed of 240°/s

3. Single leg dynamic balance – Subjects will be required to perform a single leg dynamic balance on a unstable platform, whilst trying to maintain their balance within a pre-determined area on a visual screen using a Biodex stabilometer

4. Star Excursion Balance Test – Subjects will be required to stand on a force platform whilst reaching out as far as possible with the dominant foot in anterior, posteromedial and posterolateral directions

5. Drop landing test – Subjects will be required to drop onto the dominant leg from a 35cm height onto a force platform, then responding to a visual stimulus which the subject will respond to

6. Modified hop test – Subjects will be required to perform a single leg hop onto the dominant leg on the force platform, then responding to a visual stimulus which the subject will respond to

7. Each testing session will utilise a different brand of therapeutic tape, RockTape, Kinesio Tape and no tape.

Other participant requirements

- No strenuous exercise must be completed 24hours prior to testing
- No stimulants (caffeine and alcohol) must be consumed during this 24 hour period
- You must be of a semi-professional football standard and free from injury at the time of testing
- You will be required to wear the same clothing and footwear during each of the trials

Risks and discomfort

For a healthy person, the risk involved in completing this study is envisaged to be zero, however you may experience minimal fatigue in the lower limb and in extreme cases minimal loss of balance and some dizziness during testing. All testing will be completed indoors in a temperature controlled laboratory with only you as the participant and the researchers present

Full details of the risk involved in the procedures are detailed in risk assessments; A19 IKD, A19a IKD, A29a treadmill running, C10 Biodex Balance System, Cosmed Gas Analyser A82, Taping and strapping A72, Blood Sampling A6a, Force platform A82, Adapted Treadmill protocol A80 and Appendix A Risk Assessment for Laboratories, which are described in the department health and safety manual (available on request). If you experience any pain or discomfort, please inform the researcher immediately.

Safety

General health and safety procedures will be followed as detailed in the department health and safety manual. Where the test involves strenuous exercise, suitable screening will be carried out involving risk stratification, and resting measurement; for this you will have your heart rate, blood pressure, body fat, weight and height measured to determine resting values and current state of health. A comprehensive pre-exercise questionnaire will be completed, consisting of questions to determine whether there are any factors which may prevent you from participating in the

testing, a copy of the questionnaire is available on request. Appropriately first aid trained personnel will be present at all testing sessions in the event of injury or medical issues.

Benefits

Participants will benefit from taking part in this study as they will experience a wide variety of sports science methods and procedures, whilst also potentially highlighting any predisposing risk to ankle injury which they may have. This study may also help to inform subsequent research and training programmes regarding injury prevention and rehabilitation of the ankle complex

Can I stop taking part?

You can use your right to withdraw from the study at any time, without providing reason and without suffering any disadvantage. You are also within your right to request your data to be withdrawn from the study within 4 weeks of testing completion by contacting the lead researcher.

What information will be collected, and how will it be used?

Quantitative data will be collected from participants in this study, with data being collected in the form of ability to replicate ankle joint position sense, ankle join strength (inversion, eversion, plantar flexion and dorsiflexion), dynamic balance (overall stability index, anterior/posterior index, medial/lateral index) star excursion balance test (postural sway), drop landing and hop test (forces produced). Anthropometrical data regarding height, weight and dominant leg will also be collect. All data will be collected with a view to publish in scientific journals, in which your data will be provided in an anonymous manner

Consent forms will be stored separately from the other data collected and following completion of the informed consent, only the unique ID number which you will be provided with once commencing the study, will be used to identify you as a participant. Although the data will be coded using these ID numbers, the data sets will be stored on a password protected mass storage device or PC

A copy of your results can be provided to you upon request and you will be able to ask any questions surrounding the project at any time by contacting Chris Brogden.

Statement by subject

- I have volunteered to take part in this project
- I am aware that I can stop taking part at any time without being disadvantaged
- I am satisfied that all measures have been taken to secure data securely
- I am aware that the results of this study may be published, however I will remain anonymous
- I am aware of all potential risks and discomfort which may occur via participating in this study
- I agree to inform the researcher immediately if I am in pain, or feel uncomfortable
- I have had the chance to ask any questions which I may have
- I am aware that I will not receive monetary incentives for taking part in this study

I have read this form and understand the requirement of me to participate. I agree to take part in the study titled:

The influence of circadian rhythm on global measures of ankle injury risk factors

Signed (Participant):   **Date:**

Signed (Witness):   **Date:**

INFORMED CONSENT FORM AND INFORMATION SHEET

Project title: The influence of an intermittent free running soccer specific fatigue protocol on global measures of ankle injury risk factors under therapeutic taping conditions and use of increased interchanges.

- The postgraduate student leading the project is Chris Brogden
- The supervisors of the project are Dr Matt Greig and Dr Kelly Marrin

Thank you for showing an interest in this project. Please read all the information carefully. Think about whether or not you want to take part. I will contact you again to ask you about your decision. If you decide to take part, you will be asked to sign this form. If you decide not to participate, there will be no disadvantage to you

What are the aims of the project?

The main aims of the project are:

4. To evaluate therapeutic taping methods as an injury prevention strategy.
5. To quantify the influence of soccer-specific fatigue on injury risk
6. To determine whether any relationships occur between ankle injury risk factors

Procedures

If you agree to take part in this study, you will be required to attend Edge Hill University 4 (one familiarisation) times for testing, which will be completed over a 4 week period. All testing sessions will require the same testing schedule to be completed at the same time of day.

Prior to each testing session, you will be required to complete a health questionnaire and also a screening procedure in which you will have both your heart rate and blood pressure measured. This will help determine whether you are healthy enough to complete the subsequent testing procedures. You will also be required to complete a

questionnaire to determine functional ankle instability, whilst also being able to grade the severity of instability.

You will be required to attend Edge Hill University laboratory 4 times over a period of 4 weeks. Each testing session will involve performing the same 90-minute soccer specific protocol, with days of testing to be interspersed by a minimum of two days. Each testing session will either utilise a different brand of therapeutic tape or no tape, with the final trial involving participants running 15 minutes followed by 15 minutes rest for the 90 minute protocol duration

During each trial measurements of HR, BLa, EMG, Force plate, Qualisys, Biodex stabilometer (level 2, 10 seconds) and Y balance test will be measured every 15 minutes. In addition to this, participants will be required to complete IKD invertor evertor ratios and Joint position sense tasks at 0, 45 and 105 minutes.

Other participant requirements

- No strenuous exercise must be completed 24hours prior to testing
- No stimulants (caffeine and alcohol) must be consumed during this 24 hour period
- You must be of a semi-professional football standard and free from lower limb injury at the time of testing
- You will be required to wear the same clothing and footwear during each of the trials

Risks and discomfort

For a healthy person, the risk involved in completing this study is envisaged to be zero, however you may experience fatigue associated with soccer and in extreme cases minimal loss of balance and some dizziness during testing. All testing will be completed indoors in a temperature controlled laboratory with only you as the participant and the researchers present

Full details of the risk involved in the procedures are detailed in the risk assessment, which are fully described in the department health and safety manual (available on

request). If you experience any pain or discomfort, please inform the researcher immediately.

Safety

General health and safety procedures will be followed as detailed in the department health and safety manual. Where the test involves strenuous exercise, suitable screening will be carried out involving risk stratification, and resting measurement; for this you will have your heart rate, blood pressure, body fat, weight and height measured to determine resting values and current state of health. A comprehensive pre-exercise questionnaire will be completed, consisting of questions to determine whether there are any factors, which may prevent you from participating in the testing; a copy of the questionnaire is available on request. Appropriately first aid-trained personnel will be present at all testing sessions in the event of injury or medical issues.

Benefits

Participants will benefit from taking part in this study, as they will experience a wide variety of sports science methods and procedures, whilst also potentially highlighting any predisposing risk to ankle injury, which they may have. This study may also help to inform subsequent research and training programmes regarding injury prevention and rehabilitation of the ankle complex.

Can I stop taking part?

You can use your right to withdraw from the study at any time, without providing reason and without suffering any disadvantage. You are also within your right to request your data to be withdrawn from the study within 4 weeks of testing completion by contacting the lead researcher.

What information will be collected, and how will it be used?

Quantitative data will be collected from participants in this study, with data being collected in the form of Heart rate, Blood lactate, temperature, EMG analysis and

GPS. Anthropometrical data regarding height, weight and dominant leg will also be collect. All data will be collected with a view to publish in scientific journals, in which your data will be provided in an anonymous manner.

Consent forms will be stored separately from the other data collected and following completion of the informed consent, only the unique ID number, which you will be provided with once commencing the study, will be used to identify you as a participant. Although the data will be coded using these ID numbers, the data sets will be stored on a password protected mass storage device or PC.

A copy of your results can be provided to you upon request and you will be able to ask any questions surrounding the project at any time by contacting Chris Brogden

Statement by subject

- I have volunteered to take part in this project
- I am aware that I can stop taking part at any time without being disadvantaged
- I am satisfied that all measures have been taken to secure data securely
- I am aware that the results of this study may be published, however I will remain anonymous
- I am aware of all potential risks and discomfort which may occur via participating in this study
- I agree to inform the researcher immediately if I am in pain, or feel uncomfortable
- I have had the chance to ask any questions which I may have
- I am aware that I will not receive monetary incentives for taking part in this study

I have read this form and understand the requirement of me to participate. I agree to take part in the study titled:

The influence of a free running soccer specific fatigue protocol on global measures of ankle injury risk factors under therapeutic taping conditions and increased use of interchanges

Signed (Participant):   **Date:**

Signed (Witness):   **Date**

INFORMED CONSENT FORM AND INFORMATION SHEET

Project title: Effect of timing of injury prevention strategies on fatigue as an aetiological factor for ankle joint injury

- The postgraduate student leading the project is Chris Brogden
- The supervisors of the project are Dr Matt Greig and Dr Kelly Marrin

Thank you for showing an interest in this project. Please read all the information carefully. Think about whether or not you want to take part. I will contact you again to ask you about your decision. If you decide to take part, you will be asked to sign this form. If you decide not to participate, there will be no disadvantage to you

What are the aims of the project?

The main aims of the project are:

7. To evaluate the effects of timing of an injury prevention programme on ankle injury risk factors
8. To quantify the influence of soccer-specific fatigue on injury risk
9. To determine whether any relationships occur between ankle injury risk factors

Procedures

If you agree to take part in this study, you will be required to attend your Southport FC training sessions at Edge Hill University as normal, in which you will be separated into either a pre or post training intervention group. Prior to this you will be required to partake in a soccer specific field test which will take place of your normal training session on the 22/07/14. The intervention programme will last 8 weeks and will be conducted at each training session for approximately 10 minutes, consisting of a variety of balance, agility, strength and speed exercises in an attempt to reduce injury occurrence. After the completion of the 8 week intervention

227

programme, the same soccer specific field test will be conducted to determine the effects of the intervention programme on measures of ankle joint function.

Prior to each soccer specific fitness testing session, you will be required to complete a health questionnaire and also a screening procedure in which you will have both your heart rate and blood pressure measured. This will help determine whether you are healthy enough to complete the subsequent testing procedures. You will also be required to complete a questionnaire to determine functional ankle instability, whilst also being able to grade the severity of instability.

You will be required to attend Edge Hill University laboratory 2 times over a period of 8 weeks. Each testing session will involve performing the same free running 90 minute soccer specific protocol (SAFT90).

During each trial measurements of HR (Hear Rate), BLa (Blood Lactate), EMG (Electromyographic activity), Force plate, Qualisys, GPS (Global positioning system Biodex stabilometer (level 2, 10 seconds) and Y balance test will be measured every 15 minutes. In addition to this, participants will be required to complete IKD invertor evertor ratios and Joint position sense tasks at 0, 45 and 105 minutes.

Other participant requirements

- No strenuous exercise must be completed 24hours prior to testing
- No stimulants (caffeine and alcohol) must be consumed during this 24 hour period
- You must be of a semi-professional football standard and free from lower limb injury at the time of testing
- You will be required to wear the same clothing and footwear during each of the trials

Risks and discomfort

For a healthy person, the risk involved in completing this study is envisaged to be zero, however you may experience fatigue associated with soccer and in extreme cases minimal loss of balance and some dizziness during testing. All testing will be

completed indoors in a temperature controlled laboratory with only you as the participant and the researchers present

Full details of the risk involved in the procedures are detailed in the risk assessment which are fully described in the department health and safety manual (available on request). If you experience any pain or discomfort, please inform the researcher immediately.

Safety

General health and safety procedures will be followed as detailed in the department health and safety manual. Where the test involves strenuous exercise, suitable screening will be carried out involving risk stratification, and resting measurement; for this you will have your heart rate, blood pressure, body fat, weight and height measured to determine resting values and current state of health. A comprehensive pre-exercise questionnaire will be completed, consisting of questions to determine whether there are any factors which may prevent you from participating in the testing, a copy of the questionnaire is available on request. Appropriately first aid trained personnel will be present at all testing sessions in the event of injury or medical issues.

Benefits

Participants will benefit from taking part in this study as they will experience a wide variety of sports science methods and procedures, whilst also potentially highlighting any predisposing risk to ankle injury which they may have. This study aims to reduce the amount of injuries which occur to an athlete/team, therefore could possibly increase the amount of player availability to the team.

Can I stop taking part?

You can use your right to withdraw from the study at any time, without providing reason and without suffering any disadvantage. You are also within your right to request your data to be withdrawn from the study within 4 weeks of testing completion by contacting the lead researcher.

What information will be collected, and how will it be used?

Quantitative data will be collected from participants in this study, with data being collected in the form of Heart rate, Blood lactate, temperature, EMG analysis and GPS. Anthropometrical data regarding height, weight and dominant leg will also be collect. All data will be collected with a view to publish in scientific journals, in which your data will be provided in an anonymous manner

Consent forms will be stored separately from the other data collected and following completion of the informed consent, only the unique ID number which you will be provided with once commencing the study, will be used to identify you as a participant. Although the data will be coded using these ID numbers, the data sets will be stored on a password protected mass storage device or PC.

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Statement by subject

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- I am aware that I can stop taking part at any time without being disadvantaged
- I am satisfied that all measures have been taken to secure data securely
- I am aware that the results of this study may be published, however I will remain anonymous
- I am aware of all potential risks and discomfort which may occur via participating in this study
- I agree to inform the researcher immediately if I am in pain, or feel uncomfortable
- I have had the chance to ask any questions which I may have
- I am aware that I will not receive monetary incentives for taking part in this study

I have read this form and understand the requirement of me to participate. I agree to take part in the study titled:

Effect of timing of injury prevention strategies on fatigue as an aetiological factor for ankle joint injury

Signed (Participant):   **Date:**

Signed (Witness):   **Date:**