Monitoring Fatigue Status in Elite Soccer Players

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Abstract

The physical demands of soccer players competing in the English Premier League have significantly increased in recent years (Barnes et al. 2014; Bush et al. 2015). Elite soccer players are required to compete on a weekly and often bi-weekly basis during a 9-month competitive season. During periods of fixture congestion, players may participate in three matches within a 7-day period. Previous researchers have reported that some components of performance and physiological measures may still be below a pre-match baseline 72 hours following match-play (Mohr et al., 2003; Andersson et al., 2008; Ispirlidis et al., 2008; Fatouros et al., 2010). Nevertheless, data are sparse for the quantification of player fatigue status during competitive periods. Therefore, the primary aim of this thesis is to evaluate potential indicators of fatigue which may be easily measured and utilised in elite soccer.

The aim of the first study (Chapter 4) was to quantify the test-retest reliability of a range of potential fatigue variables in elite soccer players. During the pre-season period, resting perceived ratings of wellness (fatigue, muscle soreness, sleep quality and stress), counter-movement jump height (CMJ), sub-maximal heart rate (HRex), post-exercise heart rate recovery (HRRbpm and HRR%), heart rate variability (rMSSD and LnrMSSD) and salivary immunoglobulin-A (S-IgA) were measured during the morning on two consecutive non-training days in thirty-five English Premiership players. Mean values of perceived ratings of wellness (7-13 %CV), CMJ (4 %CV) HRex (3 %CV) and HRR% (10 %CV) were not substantially or statistically significantly different between days. HRV measures' rMSSD (28 %CV) and Ln rMSSD (10 %CV), perceived ratings of sleep (CV 13%CV) and S-IgA (63 %CV) were statistically significantly different between days. All morning-measured

fatigue variables with the exception of S-IgA were reliable enough to allow feasible sample sizes in future pre/post studies. These data indicate that the use of perceived ratings of wellness, CMJ, HRR%, and, to a certain extent, HRV (Ln rMSSD) are reliable enough to monitor the fatigue status of a sample of elite soccer players.

The aim of the second study (Chapter 5) was to quantify the relationship between daily training load and a range of potential measures of fatigue in elite soccer players during an in-season competitive phase (17-days). Total high-intensity running (THIR) distance, perceived ratings of wellness (fatigue, muscle soreness, sleep quality), CMJ, HRex, HRR% and heart rate variability (Ln rMSSD) were analysed during an in-season competitive period (17 days). Within-subject fluctuations in fatigue ($r=-0.51$; large; $P<0.001$), Ln rMSSD ($r=-0.24$; small; $P=0.04$), and CMJ ($r=0.23$; small; $P=0.04$) were significantly correlated with fluctuations in THIR distance over the study period. Correlations between variability in perceived muscle soreness and sleep quality and HRR% and THIR distance were negligible and not statistically significant. Perceived ratings of fatigue and heart rate variability were sensitive to daily fluctuations in THIR distance in a sample of elite soccer players. Therefore, these specific markers show particular promise as simple, non-invasive assessments of fatigue status in elite soccer players during a short in-season competitive phase.

The aim of the third study (Chapter 6) was to determine whether the sensitivity of a range of potential fatigue measures studied in Chapter 5 would be improved compared with the training load accumulated over the previous two, three or four days during a short in-season competitive period (17-days). Fluctuations in fatigue ($r=-0.28$-0.51; “small” to “large”; $p<0.05$) were correlated with fluctuations in THIR distance accumulation (1-4-day). Changes in HRex ($r=0.28$; small; $p= 0.02$) was correlated with changes in 4-day THIR distance accumulation. Fluctuations in Ln rMSSD ($r=-0.24$; small; $P=0.04$), and CMJ ($r=0.23$; small; $P=0.04$) were only sensitive to changes in THIR distance for the previous day (Chapter 5). Correlations between variability in muscle soreness, sleep quality and HRR% and THIR distance were negligible and not statistically significant for all accumulation training loads. Perceived ratings of fatigue were sensitive to daily fluctuations in acute THIR distance accumulation although sensitivity attenuated over time. Therefore, the present findings indicate that the sensitivity of morning-measured fatigue measures to changes in training load is not improved when compared with training loads beyond the previous days training.

The fourth and final aim of the thesis was to quantify the mean daily changes in training load and parallel changes in measures of fatigue across typical in-season training weeks in elite soccer players. The training load of 29 elite soccer players was measured using the ratings of perceived exertion approach. Perceived ratings of wellness (fatigue, sleep quality and muscle soreness), sub-maximal heart rate (HRex), post-exercise heart rate recovery (HRR) and variability (HRV) were also recorded across training weeks in the in-season competitive period. Morning-measured perceived ratings of fatigue, sleep quality and muscle soreness tracked the changes in RPE-TL, being 35-40% worse on post-match day vs pre-match day ($P<0.001$). Perceived fatigue, sleep quality and muscle soreness improved by 17-26% from post-match day to three days post-match with further smaller (7-14%) improvements occurring between four days post-match and pre-match day ($P<0.01$). There were no substantial or statistically significant changes in HRex, HRR% and HRV over the weekly cycle ($P>0.05$). Morning-measured perceived ratings of fatigue, sleep quality and muscle soreness are clearly more sensitive than HR-derived indices to the daily fluctuations in session load experienced by elite soccer players within a standard in-season week.

The results of this thesis have shown that simple, ratings of perceived wellness are reliable and sensitive to short training and competition phases and thus may be a suitable strategy for practitioners to use in the attempt to establish fatigue status in elite soccer players. In particular, this thesis has demonstrated that the greatest sensitivity was observed on a daily basis and during typical training weeks and not during short term load accumulation. . Future work is required to quantify whether perceived ratings of wellness and vagal-related heart rate responses are sensitive to changes in training and match load across an entire competitive season in elite soccer players.

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List of Abbreviations

HR	Heart Rate (beats per min)
HRV	Heart Rate Variability
HRR	Heart Rate Recovery
HRRbpm	Heart Rate Recovery (beats per min)
HRR%	Heart Rate Recovery (Percentage)
HRex	Sub-maximal Heart Rate (beats per min)
rMSSD	square root of the mean of the sum of squares of differences between adjacent normal R-R intervals
Ln rMSSD	Log Transformation of the square root of the mean of the sum of squares of differences between adjacent normal R-R intervals
LOA	Limit of Agreement
SEM	Standard error of measurement
GLM	General linear model
s	Seconds
min	Minutes
cm	Centimetres
m	Metres
kg	kilograms

CV	Coefficent of variation
CMJ	Countermovement jump
SD	Standard deviation
GPS	Global positioning system
RPE	Rating of perceived exertion
RPE-TL	Rating of perceived exertion training load
$\dot{V}O_{2max}$	Maximal oxygen uptake ($L.min^{-1}$)
AU	Arbitrary units

CHAPTER 1: INTRODUCTION

1 Introduction

The physical performance of elite soccer players competing in the English Premier League has significantly increased over recent years (Bush et al. 2015; Barnes et al. 2014). Elite soccer players are required to compete in a high number of competitive matches including domestic, European and internationals over the course of a 9-month season. Players will normally play weekly and often bi-weekly although, during periods of fixture congestion, players may play up to 3 matches in a 7-day period (Carling et al., 2015). Competitive matches are intermittent in nature involving high-intensity actions including: sprinting; accelerations and decelerations; jumping and tackling and covering a total distance of around 9-14km (Bradley et al., 2009). This type of activity pattern leads to a high level of anaerobic and aerobic energy turnover during the course of a soccer match (Bangsbo, 1994). The subsequent stress associated with these demands often temporarily impairs a players' performance (Andersson et al., 2008; Ispirlidis et al., 2008; Fatouros et al., 2010; Mohr et al., 2015). This impairment may be acute, lasting minutes or hours and stems from metabolic disturbances associated with high intensity exercise (Bangsbo, 1994). Alternatively, exercise-induced muscle damage and delayed onset muscle soreness, that often follows match-play, with a high eccentric component may also contribute to impairment lasting up to 72-hours (Andersson et al., 2008; Ispirlidis et al., 2008; Fatouros et al., 2010; Magalhães et al., 2010).

Although data exists on the time-course of various invasive physiological and exhaustive performance measures post-match (Andersson et al., 2008; Ispirlidis et al., 2008; Fatouros et al., 2010; Magalhães et al., 2010), little is known of the physiological status and recovery rate of players throughout a training week. During periods of fixture congestion, time between matches may not be long enough to restore physiological and psychological homeostasis. Moreover, during these restricted time periods between matches technical training administered by coaches may further hinder the recovery process of elite soccer players. Given the importance of recovery within the training process, increasing attention in the literature has centred upon developing non-invasive monitoring tools that serve as valid and reliable indicators of the physiological fatigue status in athletes (Meeusen et al., 2013; Halson, 2014). Indeed, potential fatigue measures should be sensitive to acute and chronic fluctuations in training and match load. Perceived ratings of wellness scales have been used in both endurance and team sports in the attempt to understand fatigue and wellness status (Coutts et al., 2007; Gastin et al., 2013; Buchheit, 2014). Consequently, the quick, inexpensive and simple nature of wellness scales makes them an attractive tool in team sports. Neuromuscular performance via the use of jump protocols including countermovement jumps (CMJ) provide a reliable means in which to assess the stretch-shortening cycle in team sport players (Cormack, Newton, McGuigan and Doyle, 2008). Indeed, due to the intermittent high intensity nature of elite soccer the use of countermovement jumps may provide useful information regarding the neuromuscular fatigue status of players. Previous work in endurance sports such as cycling has shown that the use of heart rate (HR) indices (Sub-maximal heart rate, heart rate recovery and heart rate variability) can track aerobic adaptation, performance and fatigue over extended training periods (Manzi et al., 2009; Daniel J. Plews, Laursen, Stanley, et al., 2013a). However, the use of HR indices to track training status or fatigue has yet to be investigated in elite soccer players. The increasing physical demands of elite soccer (Bush et al. 2015; Barnes et al. 2014), combined with the high frequency of matches, indicates the paramount importance of player physiological evaluation throughout competitive periods. The monitoring of physiological fatigue status, therefore, may provide invaluable information to coaches and practitioners regarding training prescription, recovery requirements and well-being of players.

1.1 Background to Research Studies

When selecting any performance or physiological measure, assessment validity or the degree to which a test relates to performance must be an essential consideration (Svensson and Drust, 2005). Another important factor in measure selection, which may be considered, primary importance, is the test reliability (Hopkins, 2000). In the initial investigation, the reliability of potential fatigue measures will be assessed. These protocols will be used subsequently to determine the sensitivity of these measures to training load in elite soccer players.

Recent findings indicate that perceived ratings of wellness (Buchheit et al., 2013; Gastin et al., 2013), submaximal heart rate (Buchheit et al., 2013) and a vagal-related heart rate variability index (Buchheit et al., 2013) are sensitive to subtle changes in daily pre-season training load in elite Australian Rules Football players. However, no research to date has evaluated the sensitivity of different monitoring tools to daily fluctuations in training load in elite soccer players. Since differences exist in the physiological demands between team sports, it is important to determine which potential fatigue variables are most sensitive to changes in load associated with specific sports. Furthermore, no attempt has been made to examine such relationships during an in-season competition phase where the overall loading patterns vary markedly compared to the high volume pre-season training periods. (Jeong et al., 2011; Malone et al., 2014a) Therefore, the second aim of this thesis is to quantify the relationships between daily training load and a range of potential measures of fatigue during an in-season competitive phase.

Further evaluation of the validity of potential fatigue measures can be undertaken by examining their sensitivity to varying degrees of training load accumulation over consecutive days. No research to date has evaluated the sensitivity of a range of potential fatigue measures to fluctuations in daily training load accumulation in elite soccer players. Therefore, the third aim is to establish the relationships between training load accumulated over the previous two, three or four days and a range of morning-measured potential fatigue variables during a short in-season competitive phase in a sample of elite soccer players.

The final aim of this thesis is to evaluate the sensitivity of potential morning-measured fatigue variables to prescribed changes in training load over more extended periods of time. Whilst these relationships have been examined in individual endurance based sports (Manzi et al., 2009; Plews et al., 2012), limited attention has been focused on elite team sport athletes who are required to compete weekly and often bi-weekly across the competition period (Gastin et al., 2013). Gastin et al. (2013) recently reported that subjective ratings of physical and psychological wellness were sensitive to within-week training manipulations [i.e.

improved steadily throughout the week to a game day low (positive wellness)] in elite Australian Rules players. No study has examined the sensitivity of simple, non-invasive potential measures of fatigue across in-season training weeks in elite soccer players. Therefore, the final aim was to quantify the changes in potential fatigue measures alongside training load changes across in-season training weeks in elite soccer players.

1.2 Aims and Objectives

Aims

To investigate the reliability, variability and sensitivity of a range potential morning-measured fatigue variables to changes in training load in elite soccer players

Objectives

1. To determine the reliability of a range of potential morning-measured fatigue variables in elite soccer players.

2. To determine the sensitivity of a range of morning-measured potential fatigue variables during an in-season competitive phase.

3. To determine whether the sensitivity of potential fatigue measures improves when training load is accumulated over a number of days during a competitive period.

4. To determine the sensitivity of morning-measured fatigue variables across in-season training weeks in elite soccer players.

CHAPTER 2: REVIEW OF LITERATURE

2 Review of Literature

The aim of this review of literature is to provide the reader with information regarding the monitoring of fatigue status in elite soccer players. The initial section of the review looks at the physical and physiological demands of soccer followed by an examination of the mechanisms which underpin fatigue. Subsequent sections review the time-course of recovery of elite soccer players in response to the stresses of match-play and training, as well as potential monitoring tools used to monitor the fatigue status of elite soccer players.

2.1 Introduction

In recent years, the physical demands of elite soccer players competing in the English Premier League have significantly increased with high-intensity running and sprint distances increasing by up to 35% between 2006 and 2013 (Barnes et al. 2014). Elite soccer players are required to compete over the course of a 9-month season comprising a high number of matches often only separated by 3-4 days. This longitudinal pattern of competition indicates the paramount importance of recovery in the training process. Various aspects of player physical performance can be impaired for up to 72-hours following competition (Andersson et al., 2008; Ispirlidis et al., 2008; Fatouros et al., 2010; Mohr et al., 2015). However, little is known as to how physical or fatigue status fluctuates throughout a training week between matches. During periods of fixture congestion, time between matches may not be long enough to restore physiological and psychological homeostasis. Moreover, during these restricted time periods between matches, technical training administered by coaches may further hinder the recovery of elite soccer players. Monitoring tools are required to establish changes in physical or fatigue status following both matches and supplementary training load. Evaluation of player fatigue status throughout the competitive and training period can provide beneficial information to coaches and practitioners regarding training prescription and recovery requirements in the lead up to competition.

2.2 Physiological Demands of Soccer

2.2.1 Match activity Profile

The analysis of activity profiling in elite soccer has evolved and been extensive since the initial studies (Reilly and Thomas, 1979; Bangsbo, 1994). Initial methods of soccer match activity profiling consisted of hand annotation and time-motion analysis systems, which were highly laborious compared to the more contemporary semi-automatic camera and global positioning systems (GPS) used today. Contemporary technologies such as semi-automatic and global positioning systems have introduced a more sophisticated measurement method of evaluating complex movements such as jumping, accelerations and decelerations.

The match activity profile of elite soccer is intermittent, involving periods of low intensity running interspersed with high intensity bouts over the course of a 90-min match (Rampinini et al., 2008). Players cover a total distance of between 9-14km distance during match-play comprising approximately 10% high-intensity running with the remaining distance covered via walking and low-intensity running (Bradley et al., 2009; Di Salvo et al., 2009). The physical demand of English Premier League players has evolved over recent years. Recently, Barnes and colleagues (2014) have shown significant increases in high-intensity running (~30%) and sprinting (~35%), whilst total distance remained relatively unchanged (~2%) between 2006 and 2013 (Barnes et al. 2014). Furthermore, maximum speeds of top level soccer players have been seen to peak up to 32 km/h (Mohr et al., 2005), although so far no evidence exists regarding whether peak speed has evolved in a similar fashion. The demands of various playing positions have been seen to differ greatly in elite players (Reilly and Thomas, 1979; Bangsbo, 1994). It is clear that central and wide midfielders cover the greatest total distance while full backs and wide midfielders cover the most high-intensity running (Bradley et al., 2009). Central defenders and strikers consistently show the lowest physical output during matches (Bradley et al., 2009). Bush and colleagues (2015) showed that positional physical performance in the English Premier League has evolved over recent years (Bush et al., 2015). In this study, all positions (central defenders, wide defenders, central midfielders, wide midfielders and attackers) showed large increases in high intensity running (ES: 0.9-1.3), while wide defenders (full backs) displayed the largest increase in high intensity (~36%) and sprint distance (36-63%) from 2006 to 2013. Physical performance also differs between varying standards and leagues (Bradley et al., 2015). Di Salvo et al. (2013) found that Championship players performed more high-speed running and sprinting than players in the Premier League (Di Salvo et al., 2009). The variability in high intensity running and sprinting has been seen to change up to 30% in English Premier League players (Gregson et al., 2010). A study comparing physical performance of players in the top three leagues of English football observed that players in the second and third divisions performed more high-speed running than those in the Premier League (803, 881 and 681 m, respectively), similar results were also found for sprinting (308, 360 and 248 m, respectively) (Bradley et al., 2013).

Observations of how physical performance changes throughout a match have been carried out in the attempt to examine whether player fatigue exists. Many studies have found reductions in physical performance towards the end of a soccer match (Reilly and Thomas, 1979; Mohr et al., 2003, 2004; Krustrup et al., 2006; Russell et al., 2014), and in particular the last 15-min (Mohr et al., 2003; Russell et al., 2014). Moreover, in top-class soccer players, during the 5-min period following the most intense period of the match, high-intensity running declined to below match average values (Mohr et al., 2003). In another study, sprint performance decreased after intense soccer match-play but this reduction was not observed during the half-time break where physical performance appeared to have recovered (Krustrup et al., 2006). Furthermore, accelerations/decelerations were ~10% lower during extra-time compared to the initial 15-mins of a match in elite soccer players (Russell et al., 2015). The inherent variability in match physical output means that it is difficult to attribute the reduction in physical performance solely to player fatigue. Other contributing influences may be related to a number and/or combination of factors including conditioning status, technical qualities, playing position, tactical, style of play, ball possession and quality of opposition (Gregson et al., 2010). Although, tactical (Carling and Dupont, 2011) and pacing strategies (Bradley et al., 2009) exist and have significant effects on performance. Reductions in physical performance measures post-match (Andersson et al., 2008; Ispirlidis et al., 2008; Fatouros et al., 2010) indicates that fatigue appears to have a negative influence on physical performance at the elite level. The exact mechanism of this reduced physical output in elite soccer will be discussed later in the text.

2.2.2 Aerobic energy production

Individual internal load, as categorised by heart rate (HR) may reach 85% and 98% of its average and maximum respectively, and can remain elevated (>65% HRmax) throughout a soccer match (Bangsbo, 1994; Krustrup et al., 2006). In order to estimate aerobic energy expenditure, oxygen uptake derived from HR is likely to be around 70% VO_{2max} taking into account potential overestimations due to dehydration, hyperthermia and central stress (Bangsbo, 1994). A linear relationship between core temperature (rectal temperatures up to 39-40°C) and relative work intensity has been seen in soccer players suggesting an internal energy production (Saltin and Hermansen, 1966; Mohr et al., 2004). No data exists regarding the exact oxygen uptake profile of a soccer match due to the difficulty of the measurement assessment, however, portable gas analysers have been used to quantify the oxygen uptake kinetics during various soccer activity patterns (Esposito et al., 2004). In that investigation, amateur soccer players performed moderate to high intensity soccer specific activity patterns. Oxygen uptake ranged from 2.5 to 4.5 L-min, with a corresponding relative aerobic exertion around 70-95% VO2max. The relationship between oxygen uptake and heart rate was similar to treadmill running, suggesting heart-rate quantification during match-play may be used to estimate relative aerobic exertion. It is unclear whether positional differences exist in aerobic capacity among elite soccer players although it may be deemed likely considering the significant differences in physical output between different positions (Bangsbo, 1994; Reilly et al., 2000; Arnason et al., 2004; Bradley et al., 2009). The activity profile of a soccer match means that consideration of the rise in oxygen uptake during short intense periods may be more relevant than average oxygen uptake over the course of the match (Krustrup et al., 2004). Future work is required, in an attempt to evaluate the aerobic profile of top level players across a season and during high intensity periods.

2.2.3 Anaerobic energy production

As many as 250 high-intensity actions are be performed during an elite soccer match (Mohr et al., 2003) indicating high anaerobic turnover. However, only one study has measured muscle lactate directly. In that study muscle lactate rose up to 15 mmol/kg/dw in non-elite soccer players during a friendly match, only ~30% greater than resting baselines values (Krustrup et al., 2006). Due to the severe invasive nature of muscle blood lactate measurement, the assessment of capillary blood lactate has received more attention. Blood lactate concentrations have been seen to reach between 8-12 mmol/L during elite soccer match-play (Bangsbo, 1994) indicating a high rate of muscle lactate production. Furthermore, no correlation was observed between muscle and blood lactate concentrations unlike in previous findings during continuous exercise (Krustrup et al., 2004). The differences observed are most likely due to the different lactate turnover rates of muscle and blood during the different modes of exercise, with the rate of lactate clearance being significantly higher in muscle than in blood. Additionally, lactate in the blood may be more a reflection of anaerobic energy accumulation over a period of time rather than following high intensity actions. Indeed, timing of lactate sampling appears to offer varying results (Bangsbo et al., 2006). Significant differences in lactate values have been seen following both halves and random sampling during friendly matches in college soccer players (Smith, Clarke, Hale 1993). Evidence of high and moderate levels of blood and muscle lactate respectively, further indicates that the rate of glycolysis is high during high-intensity periods during a match (Bangsbo et al., 2006) In particular, creatine phosphate (CP) breakdown rate may be high especially during shorter periods of high-intensity actions or locomotion whilst re-synthesis of CP levels may occur during periods of low-intensity exercise. Bangsbo (1992) observed significant correlations between high-intensity running and subsequent blood lactate indicating the variable nature during match-play (Bangsbo, 1992). Indeed, post-match muscle biopsy analysis has shown CP levels as low as 70% compared to pre-match concentrations (Krustrup et al., 2006), with levels decreasing as low as 30% during elite soccer match-play (Bangsbo, 1994).

2.3 Mechanisms of Fatigue

2.3.1 Metabolic Fatigue

Activity profiles, and in particular high-intensity running have been seen to fall significantly during the final period of a soccer match (Reilly and Thomas, 1979; Mohr et al., 2003, 2004; Krustrup et al., 2006; Russell et al., 2014). The exact underlying mechanism for reduced physical performance towards the final stages of a soccer match remains unclear due to the myriad of technical and tactical influences. Muscle glycogen stores have been seen to be almost fully depleted (<50 mmol/kg/d.w) after a soccer match in both elite players who had normal (~400 mmol/kg/d.w) and reduced (~200 mmol/kg/d.w) pre-match glycogen levels respectively (Saltin, 1973). Another study found less severe reductions in muscle glycogen (150-350 mmol/kg/d.w) post-match although further analysis of over half of the individual type I and II fibres concluded depleted or partially depleted glycogen capacity (Krustrup et al., 2006). This may then mean that physical performance, in particular high-intensity bouts, running and sprinting will be adversely affected, although, the exact causal mechanism between reductions in glycogen and fatigue remains unclear.

As concentrations of glycogen diminish, free fatty acids (FFA) are known to increase during a soccer match with observations of increased values seen at half time and post-match (Krustrup et al., 2006). The frequent rest and low-intensity periods during soccer allow for adequate blood supply to adipose tissue and the release of free fatty acids (FFA). Increased rate of lipolysis is evident with higher levels of FFA at half time and during the second half of matches (Bangsbo, 1994; Krustrup et al., 2006), leading to increases in glycerol. This increase may represent the elevated uptake and oxidation of

FFA to the contracting muscle consequently maintaining blood glucose (Turcotte et al., 1991). Evidence of such metabolism further suggests the reduction in glycogen content of muscle tissue.

In addition to progressive fatigue over the course of a match, time motion analysis has indicated that temporary fatigue may also occur during a soccer match (Mohr et al., 2003) with a reduced ability to undertake high-intensity running and sprinting during the 5-min period following the most intense period (Krustrup et al., 2006). A number of potential mechanisms may explain temporary fatigue seen in elite soccer match-play. Reduced muscle pH via lactate and hydrogen ion coupling has been seen to cause fatigue during intense exercise (Street et al., 2005), however, muscle pH measured during a soccer match was only transiently reduced (<6.8) and no association with performance decrement was observed (Krustrup et al., 2006). In the same study, a small non-significant correlation was found between reduced sprint performance and lactate accumulation, however, the absolute increase in muscle lactate was to moderate values (15.9 to 16.9 mmol/kg/d.w). Muscle lactate and acidosis per se are unlikely sources of fatigue during soccer match-play. As previously mentioned, muscle CP levels may contribute to reductions in physical performance over the course of a soccer match (Bangsbo, 1994; Krustrup et al., 2006). CP may also contribute to temporary fatigue following intense periods of a soccer match with individual fibre levels of CP being almost fully depleted following match-play (Krustrup et al., 2006). However, the quick re-synthesis rate (15-30 sec) of CP in muscle means this is an unlikely cause for temporary fatigue during soccer. Krustrup et al. (2006) also found that muscle inosine monophosphate (IMP) and blood NH_3 levels were significantly higher than before the match, indicating a stimulation of an adenosine monophosphate (AMP) deaminase reaction in the muscle cell. However, IMP levels failed to increase significantly during exhaustive knee extensor exercise in healthy males (Hellsten et al., 1999). Similarly, only moderate reductions in adenosine triphosphate (ATP) concentrations were observed post-match, therefore as a result, energy status of the contracting muscles is an unlikely cause of fatigue after intense periods during a soccer match. Other potential contributors may be potassium accumulation in the muscle interstitium leading to electrical disturbances in the muscle cell (Bangsbo et al., 1996). Blood potassium concentrations after exhaustive exercise have been seen to rise to 11 mmol/l (Mohr et al., 2004; Nielsen et al., 2004). This level of blood potassium may well be high enough to depolarise the muscle membrane potential and reduce force development (Cairns and Dulhunty, 1995). Collectively, these findings suggest that increases in muscle lactate, acidosis and reductions in CP and ATP are questionable causes in their own right of temporary fatigue in soccer, however, a negative collective combination effect may be more likely. The intermittent nature of elite soccer means that a culmination of factors and mechanisms may lead to fatigue in players. Metabolic factors such as reductions in adenosine triphosphate (ATP); creatine phosphate; glycogen (Krustrup et al., 2006) and pH (Brophy et al., 2009) may contribute to the diminishing physical performance. Furthermore, biochemical changes in electrolytes and calcium may also have negative effects alongside hypoxia at the muscle cell level.

2.3.2 Mechanical Muscle Damage

High-intensity actions such as sprinting, high-speed running, acceleration, deceleration, change of direction, ball striking, tackling, jumping and occasional impacts/contacts are repeatedly performed over the course of a soccer match (Reilly and Thomas, 1979; Bangsbo, 1994; Bradley et al., 2009; Di Salvo et al., 2009). Indeed, sprinting; changes in direction; acceleration and deceleration actions involve many eccentric contractions which have previously been associated with the potential to induce muscle damage (Byrne et al., 2004). Muscle damage is characterised by a temporary reduction in muscle function, an increase in intracellular proteins in the blood and an increase in perceptual muscle soreness and evidence of swelling (Howatson and van Someren, 2008). Initially, muscle damage results from the mechanical disruption of the fibre, including membrane damage, myofibrillar disruptions characterised by myofilament disorganisation and loss of Z-disk integrity form (Raastad et al., 2010). Secondary damage is linked to the subsequent inflammatory response and infiltration of neutrophils which further, in isolation compromises the mechanically damaged area (Butterfield et al., 2006).

Elevated levels of potential muscle damage markers have been reported at the end of a soccer match in elite and sub-elite players (Ispirlidis et al., 2008; Fatouros et al., 2010; Thorpe and Sunderland, 2012; Silva et al., 2013). Mechanical muscle damage derived from high-intensity activity involving an eccentric component may, therefore, contribute to a reduction in physical performance seen during a soccer match. The time-course of potential muscle damage markers immediately and in the hours and days following soccer will be discussed later in this review.

2.3.3 Neuromuscular Fatigue

It has been demonstrated that the neuromuscular system is largely taxed via high-intensity running, sprinting, jumping and tackling during elite soccer match-play (Bradley et al., 2009; Di Salvo et al., 2009). Indeed, studies evaluating the neuromuscular system (maximal voluntary contractions, maximal sprint tests and jump performance) have found decrements immediately and up to 48-hours post-match in elite soccer players (Andersson et al., 2008; Ispirlidis et al., 2008; Fatouros et al., 2010; Magalhães et al., 2010; Rampinini et al., 2011). Central and/or peripheral mechanisms may be largely associated with this match-related neuromuscular fatigue found post-match. Increased motor drive leading to increased perception of effort and peripheral muscle contractile alterations have been suggested as potential mechanisms of neuromuscular fatigue (Rampinini et al., 2011). Moreover, biochemical alterations have been suggested to impair spinal and/or supraspinal neural drive (Gandevia, 2001). Peripheral mechanisms linked to fatigue accumulation may alter calcium ion release, and decrease calcium ion binding to troponin (Allen, 2001). Furthermore, the altered muscle potassium and pH levels may stimulate group III and IV muscle afferents, inhibiting motor neurons at the spinal level (Meeusen et al., 2006). Additionally, structural muscle damage may impair excitation contraction coupling increasing neuromuscular fatigue (Jones, 1996). In the only study to examine the central and peripheral mechanisms linked to match-related fatigue in soccer, Rampinini et al. (2011) observed significant moderate-to-large correlations between voluntary activation (central marker) and total distance covered in elite players. No correlations were found between match physical performance characteristics and peripheral markers of fatigue indicating central mechanisms more likely the cause of neuromuscular fatigue during match-play. Although there is a paucity of data examining the relationships between central and peripheral markers of fatigue and physical performance, central fatigue appears to be the main cause for reductions in maximal voluntary strength. Peripheral fatigue may, therefore, be more related to muscle damage and inflammation in elite soccer players (Rampinini et al., 2011), however, further work investigating peripheral and central responses to a soccer match is required.

2.4 Recovery in Soccer

The increase in physical demand (Barnes et al. 2014) and shorter time periods between matches (Carling et al., 2015) indicate the increasing importance of player recovery. It has often been shown that it can take up to 72-hours post-match to return to baseline pre-match physical homeostasis (Andersson et al., 2008; Ispirlidis et al., 2008; Fatouros et al., 2010; Magalhães et al., 2010). The intermittent and multi-energy derived nature of soccer means that perturbations of neuromuscular energy production and the muscle cell itself have shown to be potential causes of fatigue and the decline in physical performance post-match (Andersson et al., 2008; Ispirlidis et al., 2008; Fatouros et al., 2010; Magalhães et al., 2010). The aforementioned specifies the need for greater understanding of the rate of recovery and the variability of fatigue markers during competitive periods.

2.4.1 Physical Performance

2.4.2 Sprinting and Repeat Sprint Ability

Physical performance assessments (Table 2.1-4) have been used extensively to quantify player recovery in the hours and days following soccer matches (Andersson et al., 2008; Ispirlidis et al., 2008; Fatouros et al., 2010; Magalhães et al., 2010). High-intensity bouts and sprinting are fundamental and important aspects to soccer performance (Bradley et al., 2009), therefore, sprint and repeated-sprint tests have become a popular means by which to assess the ability of players to perform high speed locomotion (Table 2-1) (Andersson et al., 2008; Ispirlidis et al., 2008; Fatouros et al., 2010; Magalhães et al., 2010). Studies investigating 20-metre sprint tests in elite and sub-elite players have shown 8% reductions in performance 24-hours post-match with only small improvements 72-hours post-match (5% reduction) (Ispirlidis et al., 2008; Fatouros et al., 2010; Magalhães et al., 2010). Indeed, Malaghaes et al. (2010) observed 9 and 5% increases (performance reduction) in sprint time 24 to 72-hours post-match in trained males respectively. Another study investigating 20-m sprint time observed similar deficits (7 to 5% from 24-72 hours) in trained males (Silva et al., 2013). Only studies involving female soccer players, and following a simulated soccer match protocol, have reported deficits in 20-m sprint post exercise (Andersson et al., 2008; Ingram et al., 2009). Data evaluating repeated sprints following soccer matches is less common due to it's more exhaustive nature compared to single sprint assessments. Repeated-sprints in trained males have shown up to 3% decreases 24-hours post-match (Mohr et al., 2004; Krustrup et al., 2006) and 6% 2-days post match (Mohr et al., 2015). In contrast, non-significant changes were observed in extensive (10 and 11 reps) repeat sprint protocols (20m) in trained males following simulated soccer match-play (Bailey et al., 2007; Ingram et al., 2009). No studies evaluating repeated-sprints exist for scenarios longer than 24-hour post-match. The exhaustive nature of repeated-sprints may explain the paucity of data for soccer players.

Table 2-1: Recovery time-course of sprinting and repeat sprint ability. ***Adapted from Nedelec et al. (2012)***

Study	Subjects	Soccer specific exercise	Performance measure	Time (days post exercise) 0	1-day	2-day	3-day
Sprinting							
Andersson et al.	9 elite F	Soccer match	20m	+3.0	NS	NS	NS
Ascensao et al.	16 trained M	Soccer match	20m	~+7.0	~+6.0	~+5.0	~+5.0
Fatouros et al.		Soccer match	20m		~+8.0	~+5.0	~+3.0
Ispirlidis et al.	14 elite M	Soccer match (68-mins)	20m		+2.0	+2.5	+1.6
Magalhaes et al.	16 trained M	Soccer match	20m	~+9.0	~+7.0	~+6.0	~+5.0
Rampinini et al.	20 elite M	Soccer match	40m	~+3.0	~+1.0	NS	
Ingram et al.	11 trained M	Simulated team sport exercise	20m			+1.7	
Magalhaes et al.	16 trained M	LIST	20m	~+5.0	~+1.0	~+1.0	~+1.0
Repeat sprint ability							
Krustrup et al.	11 trained M	Soccer match	5 x 30m	+2.8			
Krustrup et al.	14 elite F	Soccer match	3 x 30m	~+4			
Mohr et al	16 trained M	Soccer match	3 x 30m	~+2			
Bailey et al.	10 trained M	LIST	11 x 15m			NS	
Ingram et al	11 trained M	Simulated team sport exercise	10 x 20m			NS	
Mohr et al.	40 competitive M	Soccer match	5 x 30m		+~6	+~6	NS

Blank cells indicate no data reported
Data presented are means (%)
LIST Loughborough intermittent shuttle test | **M** Male | **F** Female | **+** Increase | **−** Decrease | **NS** Non-significant

2.4.3 Jumps

The use of various jump protocols has been heavily investigated following a soccer match with a view to quantifying player neuromuscular recovery (Table 2-2) (Andersson et al., 2008; Ispirlidis et al., 2008; Fatouros et al., 2010; Magalhães et al., 2010). Various jump protocols such as squat jump (SJ) and countermovement jump (CMJ) are valid indicators for the stretch-shortening cycle (SSC) and neuromuscular performance, and have displayed very good levels of reliability with co-efficient of variation (CV) values of 2.6-5% in both physically active men and elite team sport athletes (Moir et al., 2004; Cormack, Newton, McGuigan and Doyle, 2008). Investigations in soccer suggest that simple jump tests may serve as valid tools for assessing neuromuscular recovery (Bangsbo, 1994; Andersson et al., 2008; Ispirlidis et al., 2008; Magalhães et al., 2010; Robineau et al., 2012), the majority of the research assessing neuromuscular performance via jump protocols has focused on the time-course change post-match. Immediately following a soccer match, changes in CMJ performance relative to baseline range from 0-12% with full recovery occurring within 48 to 72-hours (Andersson et al., 2008; Ispirlidis et al., 2008; Fatouros et al., 2010; Magalhães et al., 2010; Robineau et al., 2012). Data in trained males (Magalhães et al., 2010) have shown greater disturbances in jump protocols in the days post match compared to elite soccer players (-12 vs -9%) (Ispirlidis et al., 2008). Furthermore, CMJ deficits in trained individuals have been seen to last up to 72-hours post match (Magalhães et al., 2010) whereas neuromuscular performance as derived from CMJ in elite athletes has returned to baseline values 48-hours following competition (Ispirlidis et al., 2008). It appears neuromuscular performance is reduced up to 24-hours post match in elite soccer players and this deficit may last up to 72-hours in non-elite players. However, understanding how neuromuscular status changes in response to training load between competition is important to ensure players are sufficiently prepared for training/competition demands. Only studies in AFL and adolescent soccer players exist on the responses of jump protocols to a phase of training or competition. Variations in force-time parameters were observed over the course of a season in AFL whilst no change in countermovement jump height or correlation to training load was found across a training period in elite adolescent soccer players (Buchheit, Mendez-Villanueva, et al., 2010; Malone et al., 2014b). Further research is required in order to understand whether jump protocols are sensitive to changes in training load in elite soccer players.

Table 2-2: Recovery time-course of jump protocols. Adapted from Nedelec et al. (2012)

Study	Subjects	Soccer specific exercise	Performance measure	Time (days post exercise)			
				0	1-day	2-day	3-day
Andersson et al.	9 elite F	Soccer match	CMJ	− 4.4	~− 2.0	~− 2.0	~− 3.0
Fatouros et al.	20 trained M	Soccer match	CMJ		~− 10.0	NS	NS
Ispirilidis et al.	14 elite M	Soccer match (68-mins)	CMJ		− 9.3	NS	NS
Krustrup et al.	15 elite F	Soccer match	CMJ	NS			
Magalhaes et al.	16 trained M	Soccer match	CMJ	~− 12.0	~− 8.0	~− 8.0	~− 8.0
Thorlund et al.	9 elite M	Soccer match	CMJ	NS			
Bailey et al.	10 trained M	LIST	SJ		~− 2.8	~− 5.6	
Magalhaes et al.	16 trained M	LIST	CMJ	~− 12.0	~− 10.0	~− 9.0	~− 10.0
Oliver et al.	10 trained M	NMT	CMJ	− 10.4			
Robinaeu et al.	8 trained M	Simulated soccer match	CMJ	NS			
Robinaeu et al.	8 trained M	Simulated soccer match	SJ	− 8.0			

Blank cells indicate no data reported

Data presented are means (%)

LIST Loughborough intermittent shuttle test | **NMT** Non-motorised treadmill | **SJ** Squat jump | **M** Male | **F** Female | **+** Increase | **−** Decrease | **NS** Non-significant

2.4.4 Maximal Voluntary Strength

Table 2-3 illustrates recent observations of maximal voluntary strength following soccer match-play. The activity profile of elite soccer, comprising high intensity running, sprinting, accelerations and decelerations involving a large eccentric component, may cause musculature micro-trauma (Ispirlidis et al., 2008). Reduced muscle fibre integrity (peripheral fatigue) and possibly more debilitating this decrease in central drive (central fatigue), may possibly cause a reduction in maximal voluntary strength (Rampinini et al., 2011). Central fatigue appears to be the main cause of reduced maximal voluntary strength, furthermore, the nature of soccer-specific physical activity has seen greater debilitating effects of the knee flexors compared to extensors (Greig, 2008; Delextrat et al., 2010). The change in maximal voluntary strength of the knee flexors and extensors has been widely performed as a marker of fatigue in soccer (Andersson et al., 2008; Delextrat et al., 2010; Magalhães et al., 2010; Robineau et al., 2012). Test-retest reliability of peak concentric forces of knee flexor/extensor have been found to be good-to-excellent (ICC>0.75 and 0.90 respectively) whilst low-velocity indicators have been shown to be the most reliable (Greig, 2008). Knee flexor strength has been seen to range from no decrement to -17% immediately post-match whilst the knee extensors range from no decrement to -25% immediately post match in elite and sub-elite populations respectively (Andersson et al., 2008; Delextrat et al., 2010; Magalhães et al., 2010; Robineau et al., 2012). Indeed, reductions to the degree of 8.7 and 7% in knee flexor and extensors respectively have been seen 3-days following a soccer match in trained males (Magalhães et al., 2010; Silva et al., 2013). In contrast, investigations in elite players have found less debilitating effects. Grieg (2008) observed no changes in flexor or extensor strength following a motorised treadmill test in elite soccer players. However, this exercise protocol may underestimate the true load of a soccer match particularly the eccentric nature of acceleration and decelerations which are limited during a treadmill protocols. In another elite player investigation, knee flexor and extensor strength returned to baseline 2-days post-match in 20 Italian soccer players (Rampinini et al., 2011).

Flexibility assessments have been measured much less than the aforementioned physical performance markers. Although a number of flexibility assessments have good levels of reliability (Sporis et al., 2011) only two studies have monitored range of motion in the hours and days after a soccer match. Ispirlidis et al. (2008) found knee range of motion reduced until 48-hours post-match in elite soccer players. Similarly, Mohr and colleagues (2015) found knee joint range of motion declined 7% at both 24- and 48-hours post-match (Mohr et al., 2015). Structural assessments quantifying hip/groin strength and extensibility have shown good reliability and validity following match-play in youth soccer players (Paul et al., 2014). Future research is required, to understand more regarding the time-course of recovery for flexibility measures post-match.

Table 2-3: Recovery time-course of maximal voluntary strength. Adapted from Nedelec et al. (2012)

Study	Subjects	Soccer specific exercise	Performance measure (°/sec)	Time (days post exercise)			
				0	1-day	2-day	3-day
Andersson et al.	9 elite F	Soccer match	K FL/EX CON (60)		FL~− 6.5 EX~-NS		
Ascensao et al.	16 training M	Soccer match	K FL/EX CON (90)	FL ~− 15 EX ~− 10	FL ~− 14 EX ~− 10	FL ~− 10 EX − 6.6	FL ~− 8 EX ~− 4
Magalhaes et al.	16 trained M	Soccer match	K FL/EX (90)	FL ~− 15 EX − 7.3	FL ~− 15 EX − 7.3	FL ~− 11.5 EX − 6.1	FL − 7 EX − 4.7
Thorlund et al.	9 elite M	Soccer match	K FL/EX (0)	FL − 7 EX − 11			
Bailey et al.	10 trained M	LIST	K FL/EX (0)		FL ~ −21 EX NS	FL ~ −14 EX NS	
Delextret et al.	8 trained M	LIST	K FL/EX CON (60)	FL − 17.7 EX − 16.6			
			K FL/EX CON (120)	FL NS EX − 13.7			
Delextret et al.	14 trained F	LIST	K FL/EX CON (120)	FL NS EX NS			
Grieg	10 elite M	MT	K FL/EX CON (60)	FL NS EX NS			
Ingram et al	11 trained M	Simulated team sport exercise	K FL/EX (0)			FL − 8.4 EX − 5.2	
Magalhaes et al.	16 trained M	Soccer match	K FL/EX CON (90)	FL ~− 17 EX~ − 9.5	FL ~− 16 EX ~− 10.5	FL − 13.7 EX ~− 8.5	FL − 8.7 EX ~− 7

Blank cells indicate no data reported
Data presented are means (%)
ECC Eccentric **|** **CON** Concentric **|** **K** Knee **|** **FL** Flexion **|** **EX** Extension **|** **LIST** Loughborough intermittent shuttle test | **MT** Motorised treadmill | **SAFT90** 90-minute soccer specific aerobic field test | **M** Male | **F** Female | **+** Increase | **−** Decrease | **NS** Non-significant

Table 2-4: Recovery time-course of maximal voluntary strength. Adapted from Nedelec et al. (2012) Continued

Study	Subjects	Soccer specific exercise	Performance measure (°/sec)	Time (days post exercise)			
				0	1-day	2-day	3-day
Rahnama et al	13 trained M	MT	K FL CON (60) (120) (300) K FL ECC (120) K EX CON (60) (120) (300) K EX ECC (120)	FL − 17.3 − 15.2 − 15 −16.8 EX − 15.5 − 8.2 − 8.5 − 6.8			
Robinaeu et al.	8 trained M	Soccer match modelling	K FL CON (0) (60) K EX CON (0) (60) K EX ECC (60)	FL − 8.2 − 12.3 EX − 18.5 − 12.2 − 25.4			
Small et al	16 trained M	SAFT90	K FL/EX CON (120)	FL NS EX NS			
Rampinini et al.	20 elite M	Soccer match	K EX (0)	EX ~− 11	EX ~− 6	EX NS	

Blank cells indicate no data reported
Data presented are means (%)
ECC Eccentric **|** **CON** Concentric **|** **K** Knee **|** **FL** Flexion **|** **EX** Extension **|** **LIST** Loughborough intermittent shuttle test | **MT** Motorised treadmill | **SAFT90** 90-minute soccer specific aerobic field test | **M** Male | **F** Female | **+** Increase | **−** Decrease | **NS** Non-significant

2.4.5 Biochemical

Biochemical markers found in blood plasma and saliva have been used in the attempt to underpin the physiological mechanisms associated with the demands and fatigue of soccer (Bangsbo, 1994; Andersson et al., 2008; Ispirlidis et al., 2008; Mohr et al., 2015). Markers of anaerobic energy production, muscle damage, inflammation, immune status, oxidative stress and hormone activity have mostly been assessed in the hours and days following matches (Bangsbo, 1994; Bangsbo et al., 2006; Ispirlidis et al., 2008; Thorpe and Sunderland, 2012; Morgans et al., 2014a). Creatine kinase (CK) and myoglobin are proteins which have been seen to leak into plasma following the damage of skeletal muscle tissue (Brancaccio et al., 2007). As a result of muscle damage, CK and myoglobin pass from the damaged cells through the muscle membrane into the interstitial fluid before entering the circulation via the lymphatic system. Rises in CK (70-250%) have been seen immediately post-match and have peaked between 24-48-hours and return to baseline values from 48-120-hours (Andersson et al., 2008; Ispirlidis et al., 2008; Fatouros et al., 2010; Magalhães et al., 2010; Thorpe and Sunderland, 2012). Although widely used, questions remain regarding the exact mechanism of CK activity following exercise. Baird and colleagues (2012) suggest energy control processes as well as muscle damage may result in increases in serum CK following exercise. It appears that age, ethnicity and gender can also affect the activity of CK (Baird et al., 2012). Future research is required in order to fully understand the exact reason for increased CK levels following soccer match-play.

Muscle damage post-match signals a local inflammatory response which facilitates the repair, regeneration and growth of the muscle cell (Tidball, 2005). The cytokine interleukin-6 (IL-6) is signalled immediately post-match as part of the acute phase response, IL-6 is produced in larger amounts than any other cytokine which has prompted its popularity as a global measure of inflammation. (Tidball, 2005) Studies in both men and women have shown IL-6 to peak immediately following the cessation of soccer and then rapidly return to baseline values after 24-hours (Andersson et al., 2008; Ispirlidis et al., 2008). C-reactive protein (CRP) and uric acid have been found to be more sensitive following soccer match-play which may provide a more consistent and valid representation of inflammation in players (Ispirlidis et al., 2008; Fatouros et al., 2010). Indeed, Fatouros and colleagues (2010) observed increases of up ~50% 48-hours following a match in elite soccer players (Fatouros et al., 2010). Furthermore in a similar study in elite soccer players, uric acid peaked 72-hours following a match (Ispirlidis et al., 2008). Anabolic and catabolic hormones testosterone and cortisol have been collected in soccer players immediately and in the days post-match (Ispirlidis et al., 2008; Moreira et al., 2009; Thorpe and Sunderland, 2012), however, the results have been contradictory. Testosterone has been diminished up to 72-hours post match in young soccer players (Ispirlidis et al., 2008; Silva et al., 2013) whereas a significant 44% increase were seen in semi-professional players immediately post-match (Thorpe and Sunderland, 2012). Levels of cortisol decreased immediately and until 48-hours post-match, however, a study in Brazilian top level players found minimal change in cortisol concentrations post-match (Moreira et al., 2009). In a recent investigation observing the effects of three matches in 1-week on muscle damage and immune markers in elite soccer players, Mohr and colleagues (2015) found creatine kinase, c-reative protein and cortisol peaked ~48 h post-games. Leukocyte count, testosterone, IL-1β and IL6 altered 24 h post game and Plasma TBARS and protein carbonyls rose by ~50 % post-match. Total antioxidant capacity and glutathione peroxidase activity increased 9-56 % for 48 h in response to the matches. Furthermore, reductions in the majority of markers were larger following the second game in the week. A common finding in all studies was that there was a high variation in hormone concentration between players which must be considered when interpreting results.

New technology has made it more accessible and affordable to monitor immune markers found in human saliva. Indeed, during fixture congestion, salivary IgA (s-IgA) concentrations decreased in English Premier League soccer players (Morgans et al., 2014a). Furthermore, a significant reduction was found in S-IgA in the lead up to matches in international players (Morgans et al., 2014b). In these studies S-IgA variation ranged from ~40 - 140 µg mL $^{-1}$ and 256 – 365 µg mL $^{-1}$ respectively (Morgans et al., 2014a; Morgans et al., 2014b). Concurrent measures of s-IgA have been found to have good (9%CV) reliability (Coad et al., 2015), however, test re-test data confirming the reliability on a day-to-day basis in elite soccer players has yet to be defined. It appears that a number of biochemical markers which represents the global status of muscle fatigue must be quantified in order to fully understand the exact physiology. High inter and intra-variability in blood and saliva markers is a common finding in players (Moreira et al., 2009; Thorpe and Sunderland, 2012; Morgans et al., 2014a); this also adds complexity in interpreting results amongst a group of athletes.

It appears biochemical measures may be useful to determine the underlying physiology of fatigue, however considerations must be made regarding the differences between players and the reliability and validity of the assessment method.

2.5 Time Course of Recovery in Soccer: Approaches to Monitoring Fatigue in Soccer Players

In order to optimise training responses and adaptation in athletes, a balance between match/training load and recovery is paramount. Overtraining/reaching and/or fatigue accumulation can be the result of an increased training load whereas detraining may be a result of a reduction in training load (Meeusen et al., 2013). Given the importance of recovery within the training process, increasing attention in the literature has centred upon developing non-invasive monitoring tools that serve as valid and reliable indicators of the fatigue status in athletes.

In order to serve as a valid indicator of fatigue in elite soccer, prospective tools should be simple, quick, inexpensive and easy to administer. Furthermore, potential measures should be sensitive to training load and their response to acute exercise should be distinguishable from chronic changes in adaptation (Meeusen et al., 2013). Furthermore, in team sports such as soccer, any fatigue assessment employed must be quick and easy to administer and non-exhaustive in order to permit frequent application over the long and congested competitive period. In sports such as cycling, competition periods are interspersed with extended training periods where systematic periodisation of the training load occurs in order to ensure the athlete peaks at the desired time point. This inherent competition and training pattern means endurance athletes have greater opportunities for specific fitness and physiological performance assessments often conducted during training sessions (Manzi et al., 2009; Plews et al., 2014). Soccer players compete on a weekly basis during the competitive phase and in some instances on two to three occasions across a seven day period. As a consequence, training periodisation often occurs over a period of less than 7 days in an attempt to ensure the players are in the best physical condition prior to each successive match. Therefore, tools to evaluate fatigue status must be non-exhaustive, time-efficient and be sensitive to daily and within-week changes in load.

2.5.1 Perceived wellness scales

Subjective mood state scores have been used extensively to assess the overall well-being of the athlete during training and competition (Hooper et al., 1995; Coutts et al., 2007; Kellmann, 2010; Saw et al., 2015). A recent review has shown that subjective measures may even report greater sensitivity to acute and chronic training load, fitness and fatigue compared to objective measures (Saw et al., 2015). Many endurance sports and to lesser extent team sports (Hooper et al., 1995; Buchheit et al., 2013; Gastin et al., 2013) have adopted the use of available psychometric tools and checklists such as POMS (Raglin & Morgan 1994; Buchheit 2014), DALDA (Coutts et al., 2007), TQR (Kenttä and Hassmén, 1998) and REST-Q (Coutts and Reaburn, 2008; Kellmann, 2010) in attempt to assess athlete wellbeing. However, these methods have been developed for use over more extended periods (monthly) and therefore can be time consuming and extensive for athletes to complete. Many team sports prefer the use of shorter, quick, custom-designed questionnaires which can be administered on daily basis. Furthermore, the high frequency of competition in team sports and in particular elite soccer indicates the potential usefulness of these scales on a daily basis. Indeed, observations on endurance athletes demonstrate that mood assessments which are quick, inexpensive and easy to administer, and may be sensitive to alteration in performance and biological markers indicative of overtraining (Hooper et al., 1995; Urhausen and Kindermann, 2002; Coutts et al., 2007; Meeusen et al., 2013). Hooper and colleagues (1995) showed that short, simple wellness scales provided valid indications relating to overtraining in elite swimmers (Hooper et al., 1995). Contemporary AFL research has also shown custom psychometric scales to be sensitive to daily, within-weekly and seasonal changes in training load (Buchheit et al., 2013; Gastin et al., 2013). Indeed, daily perceived ratings of wellness (fatigue, sleep quality, stress, mood and muscle soreness) were significantly correlated with daily training load in a pre-season camp in AFL players (Buchheit et al., 2013). Significant reductions in perceived fatigue (3.81 to 2.38) were also seen following intensified training in elite volleyball players (Freitas et al., 2014). Similarly, sensitivity of perceived ratings of wellness was found over longer periods during typical weeks in AFL players across the course of the season (Gastin et al., 2013). In that study significant but weak negative correlations with performance were observed for general muscle (r = 20.105, p= 0.042) and hamstring strain (r = 20.110, p = 0.033) and for the standard deviation of quadriceps strain (r = 20.178, p = 0.001) and hamstring strain (r = 20.121, p = 0.022). Stress levels over the week were also positively correlated with performance (r = 0.216, p = 0.001). A recent study in Rugby League suggested changes in perceived ratings of wellness could provide useful insights into possible illness in players (Thornton et al., 2015). On the other hand, research from highly trained young handball players failed to find sensitivity of monthly psychometric measures (Buchheit 2014).

It seems the use of psychometric questionnaires to evaluate elite athletes' well-being is well established in endurance and some team sports (Hooper et al., 1995; Coutts and Reaburn, 2008; Gastin et al., 2013). Although limited data does exist of the validity and sensitivity of psychometric tools to training load and performance in elite team sport (Rushall and Shewchuk, 1989; Main et al., 2009; Gastin et al., 2013), only data derived from adolescent players (Buchheit, Mendez-Villanueva, et al., 2010) has investigated the use of perceived ratings of wellness in elite soccer. Instead, assessment of perceptual wellness has been used to measure the subjective feelings of fatigue, muscle soreness, sleep quality and stress in soccer players post-match (Ispirlidis et al., 2008;

Fatouros et al., 2010). Muscle soreness in particular has been seen to peak 24-48-hours after soccer (Ispirlidis et al., 2008; Fatouros et al., 2010). Delayed-onset muscle soreness (DOMS), an exercise phenomenon, is likely derived from myofibrilar disruption driving an inflammatory response and hence forming the sensation of pain and sensitivity. Interpretation of perceptual scales can be misleading, thus consideration must be made for player familiarisation and inter-individual variability. Future research is required to understand the global well-being of soccer players such as fatigue, sleep quality, muscle soreness and stress in the days post-competition.

2.5.2 Autonomic Nervous System

Recent attention in the literature has centred upon the use of heart rate (HR) derived indices such as resting heart rate (RHR), exercising heart rate (HRex) (Buchheit 2014), heart rate variability (HRV) (Buchheit 2014; Borresen & Lambert 2007), and heart rate recovery (HRR) (Buchheit 2014; Lamberts et al. 2010) as potential means through which to evaluate the responsiveness of the autonomic nervous system (ANS) to training. The ANS is interlinked with many other physiological systems (Borresen and Lambert, 2007), consequently, its responsiveness may provide useful information regarding global physiological/adaptation/fatigue status during training and competition. Although, HRV indices have been more closely associated with long-term modulation of the ANS in response to aerobic adaptation to training (Buchheit, Al Haddad, et al. 2009; Buchheit 2014). While the collection and analysis of HR was initially only possible through expensive laboratory ECG equipment, recent availability of non-invasive, inexpensive beat-to-beat HR telemetry and more recently smartphone applications (Esco and Flatt, 2014) has advanced global application in athletes (Buchheit 2014). However, due to differing methodologies, contradictory findings have been observed in HR indices and reflection of the ANS in athletes (Plews, Laursen, Stanley, et al. 2013a).

2.5.2.1 Sub-maximal heart rate

Exercising heart rate (HRex) response has previously been used to assess aerobic fitness in athletes (Buchheit 2014). Generally, decreases in HR over time during standardised exercise bouts have been associated with increases in aerobic fitness, although recent investigations in elite team sport and endurance athletes have found varying results (Buchheit et al., 2013; Le Meur et al., 2014). Furthermore, large to very-large correlations have been observed between reductions in HRex and improvements in high intensity performance in both endurance and teams sports (Buchheit et al. 2008; Buchheit, Chivot, et al. 2010; Buchheit et al. 2012; Lamberts et al. 2010; Lamberts et al. 2011). In AFL, Buchheit and colleagues (2013) found large negative associations between daily training load and exercising heart rate although the authors concluded this was more likely the effects of training/environmental induced changes in plasma volume than acute changes in fitness or fatigue. Contrastingly, heart rate during intensified training and during varying intensities showed significant reductions in overreached triathletes. Ye Meur and colleagues suggested a hyper-activation of the parasympathetic nervous system via central, cardiac and/or periphery mechanisms (Le Meur, Hausswirth, et al., 2013; Le Meur, Pichon, et al., 2013). The use of HRex in healthy athletes to predict negative effects in performance or fatigue should be treated with caution and interpreted together with other potential measures of fatigue (Buchheit et al. 2012; Buchheit 2014).

2.5.2.2 Heart rate variability

Vagal related time domain parameters of HRV have recently received greater attention than more traditional spectral analyses due to their superior reliability and assessment capture over short periods of time (Esco and Flatt, 2014). Al Haddad (2011) observed greater reliability of these measures compared to spectral analyses of HRV during various assessment protocols (Al Haddad et al., 2011). Sensitivity to change in training load and performance have been observed both in endurance and team sports (Borresen and Lambert, 2007; Manzi et al., 2009; Buchheit et al., 2013). Generally, HRV is reduced (sympathetic dominance) in parallel with reduced wellness in the immediate days following intense exercise in elite endurance athletes (Stanley et al., 2013), however, in some instances HRV has increased to more parasympathetic dominance following exercise (Buchheit et al., 2013). Data derived from endurance sports has shown fluctuations in HRV related to different phases of the training cycle (Manzi et al. 2009; Plews, Laursen, Stanley, et al. 2013a). Plews and colleagues (2014) suggested parasympathetic activity followed a bell shaped curve, increasing during the initial stages of training (until an overreached state) then falling in the lead up to competition (Plews et al., 2014). In another study in endurance athletes a reduction in HRV (more sympathetic activity) was linked (r=0.73) to overall marathon performance following a 6-month block of training in recreational marathon runners (Manzi et al., 2009). Furthermore, HRV appeared to reciprocate highly with individual monthly training load dose (r=0.9-0.99) over a the course of 6-month period (Manzi et al., 2009). Whilst studies have reported that HRV indices may be sensitive to marked changes in training load (e.g. weekly/monthly) in endurance sports such as cycling (Borresen & Lambert 2007; Lamberts et al. 2010), only one study to date has examined whether such tools may be sensitive to respond to more acute, subtle fluctuations in training load in team sports (Buchheit et al., 2013). In this study a vagal related HRV parameter (SD1) was largely and statistically significantly correlated (r=~0.5) to RPE-TL during a pre-season training camp in AFL players (Buchheit et al., 2013). Interestingly, as daily training load increased, so did parasympathetic activity, contrary to previous reports (Stanley et al., 2013). However, this data was collected during a pre-season training camp in the heat where physiological changes linked to thermoregulation may have had a contrasting effect. The use of HRV appears an attractive option to monitor ANS status due to the non-invasive, simple and inexpensive nature in elite sports. However, future research is needed to understand whether HR indices are a suitable measure for which to evaluate fatigue status in elite soccer players.

2.5.2.3 Heart rate recovery

The ANS regulates both the initial increase in heart rate after the start of exercise and the decrease in heart rate immediately after exercise ceases (Daanen et al., 2012). Post exercise HRR reflects general haemodynamic adjustments in relation to body position, blood pressure regulation and metaboreflex activity, which partly drives sympathetic withdrawal and para-sympathetic reactivation (Buchheit, Al Haddad, et al., 2009). Recent findings in endurance sports have shown that HRR may serve as a sensitive marker of acute training load alteration (Borresen & Lambert 2007; Lamberts et al. 2010), although this association has yet to be seen in team sports (Buchheit et al., 2012). Lamberts and colleagues (2010) observed significant increases in power output during a 40-km time trial in elite cyclists who had seen a recent increase in HRR following a taper period (Lamberts et al. 2010). Data from physically active men and women have shown a delay in HRR following increases in training load (Borresen and Lambert, 2007). More recently, non-functionally overreached elite triathletes showed a faster (8 beats per min) HRR compared to elite triathlete controls following the same training program (Aubry et al., 2015). It appears that HRR is responsive to both acute and chronic changes in training load however, the exact direction of this change and whether HRR can detect fatigue status remains unclear and should be interpreted alongside training status and with caution (Daanen et al., 2012).

2.6 Summary

In summary, this section describes both competition and match-play physiological demands in elite soccer. Furthermore, potential mechanisms of match fatigue and the subsequent time-course of recovery following matches is discussed. The potential means to quantify and evaluate athlete fatigue status in the attempt to quantify athlete physiological status has predominantly been conducted in endurances sports with only limited data derived from team sports akin to soccer. Therefore, initial investigations in the current thesis will quantify reliability estimates for non-invasive, cheap, quick and easily administered potential fatigue measures. Although data exists observing changes in physical performance parameters in the hours and days following match-play, the present thesis will attempt to quantify the sensitivity of potential measures of fatigue in response to daily training load and within typical training weeks during the competitive phase.

CHAPTER 3: GENERAL METHODOLOGY

3 General Methodology

3.1 Participants

All participants were chosen from a full-time professional soccer team (first team) competing in the English Premier League. Only fit, healthy and training players were included in any experimental trials. All participants were familiarised with the experimental procedures one week prior to the completion of the initial experimental trials and all testing was conducted at the same venue within the clubs' training facility and lab. Written informed consent and assent to participate was obtained from all players. The procedures were approved by the Schools Ethics Committee.

3.2 Procedures

Training load

Individual player daily training and match load was monitored throughout all experimental periods. Load (arbitrary units, AU) was estimated for all players by multiplying total training or match session duration (min) with session ratings of perceived exertion (RPE). (Foster et al., 2001) Each player was also monitored during each training session and match using a portable global positioning system (GPS) technology (GPSports SPI Pro X 5 Hz, Canberra, Australia). This type of system has previously been shown to provide valid and reliable estimates of instantaneous velocity during acceleration, deceleration, and constant velocity movements during linear, multidirectional and soccer-specific activities (Coutts and

Duffield, 2010; Varley et al., 2012). All devices were always activated 15-min before the data collection to allow acquisition of satellite signals. (Waldron et al., 2011) The minimum acceptable number of available satellite signals was 8 (range 8-11). (Jennings et al., 2010) Players wore the same GPS device for each session in order to avoid inter-unit error (Jennings et al., 2010). Based on GPS data, locomotive speed above the threshold of 14.8 km/h was classified as total high intensity running (THIR) distance

3.3 Fatigue measures

Ratings of perceived wellness

A psychometric questionnaire was used daily prior to any training or exercise to assess general indicators of player wellness. (Hooper et al., 1995) The questionnaire comprised three questions relating to perceived sleep quality, muscle soreness and fatigue. Each question scored on a seven-point Likert scale [scores of 1-7 with 1 and 7 representing very, very poor (negative state of wellness) and very, very good (positive state of wellness) respectively].

Countermovement jump

Countermovement jump (CMJ) performance was evaluated using a jump mat (Fusion Sport, Queensland, Australia). Participants performed five CMJ efforts in total, two practice and three assessment jumps ensuring the hands were affixed to the hips throughout the jump. Players were instructed to jump as high and explosive as they could with the highest jump was used as the criterion measure of performance.

5’5 cycle sub-maximal assessment

Players completed an indoor submaximal 5-min cycling /5-min recovery test (Keiser, California, USA) as part of the warm up prior to commencing the training session. (Buchheit 2014) All players were tested together, at a fixed exercise intensity of 130 watts (85 rpm). This intensity was selected to minimize anaerobic energy contribution (Buchheit et al., 2008) and to permit a rapid return of heart rate to baseline for short-term heart rate (HR) variability (HRV) measurements. On completion of exercise, the players remained seated in silence and refrained from any drinking or eating for 5-min.

Exercise heart rate (HRex)

Sub-maximal heart rate (HRex) was calculated using the average of the final 30-sec of the cycle test (Buchheit et al., 2010).

Heart rate variability (HRV)

HRV, expressed as the square root of the mean of the sum of squares of differences between adjacent normal R-R intervals (rMSSD) and the natural logarithm of the rMSSD (Ln rMSSD), was calculated as previously described (Buchheit et al., 2008) using Polar software (Polar Precision Performance SW 5.20, Polar Electro, Kemple, Finland).

Heart rate recovery (HRR)

Heart rate recovery (HRR) expressed as the absolute (HRR) and relative (HRR%) change in HR between the final 30-sec (average) of the 5-min cycling test and 60 sec after cessation of exercise were calculated as previously described (Buchheit et al., 2008; Lamberts et al., 2010).

Salivary IgA

Saliva samples were obtained in the morning prior to breakfast and any training or exercise. Participants also refrained from brushing of teeth for two hours prior, and refrained from alcohol consumption for 24 hours prior to saliva collection

All IPRO LFD test kits contained three components, an oral swab collector, a buffer solution, and a lateral flow immunochromatographic (LFI) test strip. All LFI test strips were analysed using the IPRO LFD (IPRO Interactive, Wallingford, UK). The oral swab collectors were made of a synthetic polymer-based material (10 mm × 30 mm) which was attached to a plastic volume adequacy indicator. Participants were instructed to swallow any saliva present within the oral cavity before placing the oral swab on top of the tongue. Saliva was collected, so to specifically collect saliva from the parotid gland whilst the mouth was closed. Participants were instructed to sit quietly during collection and to avoid orofacial movements. After the oral swabs had collected 0.5 mL (indicated by a change in volume indicator colour to blue) saliva samples were removed from the mouth and placed into a buffer solution, which was designed by the manufacturer (IPRO Interactive, Wallingford, UK) for individual analysis. Once the oral swab had been added to the buffer solution, the container was sealed and shaken for two minutes as per the manufacturer's instructions (IPRO Interactive, Wallingford, UK). Two drops of the buffer/saliva mixture were then placed on the sample pad located on the LFI test strip, with the mixture flowing laterally across the conjugated pad and the nitrocellulose membrane. The LFI test strip contained gold labelled anti-salivary-Immunoglobulin A (anti-s-IgA), which captured s-IgA at a 'test line'. The presence of s-IgA in the buffer/saliva mixture was captured by gold labelled anti-s-IgA, resulting in s-IgA/anti-s-IgA complexes. Unbound gold labelled anti-s-IgA was conjugated with a coloured marker, which was subsequently analysed by the IPRO LFD, and appeared as a vertical red line at the 'test line' on the LFI test strip. The total amount of conjugated s-IgA/anti-s-IgA complexes at the 'test line' was inversely proportional to the colour intensity of the line. Upon the appearances of a red 'test line' a five-minute timer was started to allow for s-IgA binding. Once five minutes had elapsed, the LFI test strip was inserted into the IPRO LFD for analysis. The IPRO LFD measured the colour intensity of the 'test line', which was converted into a corresponding [s-IgA] (μg/mL) based on a specifically programmed standard curve, assigned to the LFI test strip.

CHAPTER 4: RELIABILITY OF A RANGE OF POTENTIAL FATIGUE MEASURES IN ELITE SOCCER PLAYERS

This study was presented as an oral communication at the 8^{th} World Congress on Science & Football, Copenhagen, Denmark 2015

4 Reliability of a range of potential fatigue measures in elite soccer players

4.1 Introduction

In elite soccer, the balance between the stress of training and competition and a sufficient amount of recovery is crucial. An imbalance in these components over extended periods of time has been reported to increase the risk of injury (Gabbett et al., 2014). There are also potentially long-term debilitating effects associated with overtraining (Nimmo and Ekblom, 2007). In light of the importance of recovery, increasing attention has, therefore, centred upon developing non-invasive monitoring tools that serve as valid and reliable indicators of the fatigue status of athletes (Meeusen et al., 2013).

Soccer players need to compete routinely on a weekly basis but sometimes 2-3 times per week. Therefore, prospective monitoring tools should be quick and easy to administer by the practitioners and to complete by the players in order to permit their use on a day-to-day basis. Perceived ratings of wellness have been used extensively to assess the overall well-being of the athlete during training and competition (Hooper et al., 1995; Coutts et al., 2007; Kellmann, 2010). There are also a variety of jump protocols designed as indicators of neuromuscular fatigue (Bangsbo, 1994; Andersson et al., 2008; Ispirlidis et al., 2008; Fatouros et al., 2010; Magalhães et al., 2010; Robineau et al., 2012).

In an attempt to evaluate the responsiveness of the athletes' autonomic nervous system (ANS) to training, recent attention has also centred upon the use of a series of heart rate indices including sub-maximal exercise heart rate (HRex) (Lamberts et al. 2010), heart rate variability (HRV) (Borresen and Lambert, 2007) and heart rate recovery (HRR) (Lamberts et al., 2009). Saliva-based markers such as salivary IgA (S-IgA) have also been used in an attempt to examine the athletes' immune status (Walsh et al., 2011).

A valid marker of fatigue should be sensitive to variability in training and match loads (Meeusen et al., 2013). Another important factor when selecting tests is measurement reliability. The reliability of a test refers to an acceptable level of agreement between repeated tests within a practically relevant timeframe (Atkinson and Nevill, 1998). Factors that influence reliability include any systematic or random changes in the mental or physical state of the individual between trials. The protocol and measurement device used to collect the data may also contribute to the variability of the measurements. A test with poor reliability will be unsuitable for tracking changes in the fatigue status of the athlete (Hopkins, 2000).

Despite their widespread use, little attempt has been made to examine the reliability of perceived ratings of wellness (Kallus 1995). Furthermore, many studies to date have frequently involved extensive, time-consuming mood questionnaires, which prohibit their use on a daily basis with large groups of athletes in team sports. Tests of neuromuscular function (e.g. counter-movement jump) demonstrate excellent day-to-day reliability, with reported coefficients of variations (CV) of 1-5% (Cormack, Newton, McGuigan and Doyle, 2008; Slinde et al., 2008; Kenny et al., 2012).

Similarly, CVs as low as 1-4% have been reported for the daily and weekly reliability of sub-maximal exercise heart rate in endurance athletes (Lamberts et al., 2011). Overall estimates of reliability for vagal-related HR-indices are more difficult to ascertain due to the variety of methodologies employed (e.g. rest vs. post exercise and varied intensities of exercise). Daily variation in post exercise HR recovery range from 8-25% (Lamberts et al., 2009; Al Haddad et al., 2011), whilst HR variability indices measured under laboratory (Al Haddad et al., 2011) and field conditions (Buchheit et al., 2008) typical range from 7-17% with improved reliability derived following exercise.

Day-to-day laboratory-based assays for the determination of S-IgA have demonstrated reliability data of ~10 to 68% CV (Porstmann and Kiessig, 1992; Booth et al., 2009; Dwyer et al., 2010). Nevertheless, this method is expensive and time consuming and, therefore, unrealistic for daily use in elite sport. These issues have recently been addressed through the use of commercially available real-time lateral flow devices which demonstrate good within-day reliability (9% CV; Coad et al. 2015). However, no study to date has examined the between-day reliability of these devices which is essential if they are to be used to assess the athletes' immune status over extended time periods.

To date, little information exists regarding the reliability of potential fatigue markers in elite athletes. Field-based, in situ reliability estimates are required in order to quantify meaningful changes in potential fatigue measures in athletes within their normal training environment and across time periods that are typically used to quantify the effects of any intervention (Atkinson and Nevill, 1998). Therefore, the aim of this study was to quantify the reliability of perceived ratings of wellness, neuro-muscular performance heart rate derived indices (HRex, HRV and HRR), and mucosal immunity in elite soccer players. These estimates can then be used to predict sample size requirements in future studies designed to track the fatigue status of elite soccer players and/or to quantify the effects of any intervention.

4.2 Methods

4.3 Participants

Thirty-five (19.1±0.6 years; 184±7cm; 75.4±7.6 kg) full-time professional soccer players competing in the English Premier League were recruited for the study. All players were familiarised with the experimental procedures and the associated risks and gave their written informed consent to participate. The experimental procedures were approved by the School of Sport and Exercise Sciences, Liverpool John Moores University Ethics Committee (Harriss and Atkinson, 2011).

4.4 Experimental Design

All participants were fully familiarised with the assessments in the weeks prior to completion of the main experimental trials. Morning ratings of perceived wellness (n=35), as well as salivary IgA (n=13), countermovement jump performance (n=27), sub-maximal heart rate, post-exercise HRR and HRV (n=17), were measured (in respective order) on two separate occasions 24 hours apart. On the morning of the assessments, subjects arrived at the laboratory having refrained from exercise and in the 24 h prior to exercise. Players were also asked to refrain from caffeine intake at least 12-hours prior to each assessment point. All trials were conducted at the same time of the day in order to avoid the circadian variation in body temperature (Reilly and Brooks, 1986). Subjects were not allowed to consume fluid at any time during the performance trials.

Perceived ratings of wellness

Perceived ratings of wellness were measured as described in Chapter 3 section 3.

Counter-movement jump (CMJ)

Countermovement jump (CMJ) performance was measured as described in Chapter 3 section 3

Submaximal heart rate (HRex), Heart rate recovery (HRR) and Heart rate variability (HRV)

HRex, HRR and HRV were measured as described in Chapter 3 section 3

Salivary IgA (S-IgA)

S-IgA was measured as described in Chapter 3 section 3.

4.5 Statistical Analysis

Altman (1991) advised that approximately 40 participants should be recruited for an agreement-type study like ours in order to ensure appropriate precision of sample agreement statistics (Altman, 1991). Although, our final sample size of 35 participants is smaller than this number, we have reported confidence intervals for the reliability statistics, which are useful for ascertaining if the precision of estimate affects substantially the inferences that are arrived at.

The mean (SD) systematic bias (and associated 95% confidence interval) between test and retest was first quantified using a paired t-test. Random error between repeated tests was quantified with the within-subjects SD (standard error of measurement) and coefficient of variation. Correlations which collapse different components of bias, as well as random error between and within assessors have been criticized in the literature for obfuscating separate sources of variability (Atkinson and Nevill, 1997; Atkinson and Nevill, 1998).

The test-retest coefficient of variation (CV) was then used as an input in statistical power calculations to estimate whether the random measurement error would be small enough to detect a clinically/practically relevant change in measured outcome with a feasible sample size in a future study (Batterham and Atkinson, 2005). In an attempt to derive an indication of the minimum practically important difference (MPID), a realistic approach (Cook et al., 2014) was taken based upon a scoping review of observed changes in the measured outcome that have been reported in the literature on team sports. Studies meeting the following criteria for each potential fatigue variable were considered for calculation of MPID: 1) The study comprised male team sport players competing at elite or sub-elite level 2) The study design investigated measurements at pre and post training effect or competition. Data were extracted in the form of mean and SD, and in some cases data were calculated using raw baseline values with subsequent percentage changes. Both the smallest change and the average of all observed changes in the measured outcome were used for the MPID in the statistical power calculations.

4.6 Results

Table 4-1 shows the perceived ratings of wellness and mean performance of the players during the two trials. Fatigue ($p = 0.73$), Soreness ($p = 0.38$), Stress ($p = 1.00$), CMJ ($p = 0.99$), HRex ($p = 0.4$), HRR ($p = 0.17$) and HRR % ($p = 0.79$) were not significantly different between trials. rMSSD ($p = 0.05$), Ln rMSSD (0.04), sleep quality ($p=0.04$) and S-IgA ($p = 0.019$) were significantly different between trials 1 and 2.

The standard error of measurement (SEM) for each fatigue measure across trials 1 to 2 is shown in Table 4-1. The SEM for perceived ratings of wellness ranged from 0.42 to 0.90. When expressed as a coefficient of variation (CV) (percentage of the mean) values of 7-13 % were observed. The SEM and CV for CMJ was 1.52 cm and 3.8 % respectively. The SEM and CV for HRex was 4 beats/minute and 3 %. In relation to HRR, a SEM and CV of 5 beats/minute and 14.4 % and 5% and 9.5 % was observed for HRR (beats/minute) and HRR % respectively. A SEM of 5.6 ms and 0.298 ms was observed for the HRV indices rMSSD and Ln rMSSD. These equated to a CV of 27.9 % and 10.3 % respectively. The largest CV (63%) was found for S-IgA with a SEM of 63 μg mL $^{-1}$.

Table 4-2 provides sample size estimations for future single-sample test-retest tracking studies based upon the smallest and the average MPID derived from a scoping search of existing data [selected mean change to detect, 80 % power, two-tailed test, measurement error statistic (%CV) derived from Table 4-1].

Table 4-1: Mean + SD potential fatigue measures during trial 1 and 2 and related SEM and %CV (n = 13-35)

	HRex (beats/minute)	rMSSD (ms)	Ln rMSSD (ms)	HRR (beats/minute)	HRR (%)	CMJ (cm)	S-IgA (µg mL – 1)	Fatigue (AU)	Sleep (AU)	Soreness (AU)	Stress (AU)
Trial 1 (SD)	134.2 (10.0)	22.32 (9.52)	3.02 (0.45)	32.75 (10.95)	51.04 (25.15)	40.4 (5.1)	110.5 (63.7)	5.7 (1.3)	4.8 (1.5)	6.1 (1.0)	6.0 (1.1)
Trial 2 (SD)	133.9 (12.5)	17.88 (8.70)*	2.77 (0.51)*	30.44 (8.01)	51.51 (25.09)	40.4 (5.1)	88.5 (50.7)*	5.7 (1.1)	5.2 (1.3)*	6.0 (0.9)	6.0 (1.0)
SEM (95% CI)	4.05 (3.3-5.4)	5.60 (4.5-7.3)	0.298 (0.2-0.4)	4.55 (3.7-6.0)	4.86 (4.0-6.4)	1.52 (1.2-1.9)	62.9 (50.9-82.4)	0.69 (0.6-0.9)	0.90 (0.7-1.2)	0.54 (0.4-0.7)	0.42 (0.3-0.5)
%CV (95% CI)	2.97 (2.4-3.9)	27.86 (22.6-36.5)	10.28 (8.3-13.5)	14.39 (11.7-18.9)	9.48 (7.7-12.4)	3.76 (3.1-4.9)	63.3 (51.3-82.9)	12.11 (9.8-15.9)	12.84 (10.4-16.8)	9.00 (7.3-11.8)	7.10 (5.8-9.3)

significant difference between trial 1 and 2 (p<0.05)

***SD** Standard deviation **SEM** Standard error of measurement **CV** Coefficient of variation **CI** Confidence interval*

Table 4-2: Sample size estimations for future single sample test-retest tracking studies based upon the smallest and the average minimum practically important difference (MPID) derived from existing data (units or %) [selected mean change to detect, 80 % power, two-tailed test measurement error statistic (%CV) derived from Table 4-1]

	HRex (beats/ minute)	rMSSD (ms)	Ln rMSSD (ms)	HRR (beats/ minute)	HRR (%)	CMJ (cm)	S-IgA (% change)	Fatigue (% change)	Sleep (% change)	Soreness (% change)	Stress (% change)
Smallest MPID (units or %)	-1	--	-0.1	-5	--	1.1	30	17	22	3	--
Sample Size	257	--	141	15	--	32	72	11	8	143	--
Average MPID (units or %)	4	--	-0.5	7	--	2.4	43	29	34	21	--
Sample Size	18	--	8	9	--	9	37	6	5	6	--

Reference source used to derive smallest and average MPID as follows: ***Fatigue*** Hooper et al. 1995; Buchheit et al. 2010; 2013; Gastin et al. 2013. ***Sleep quality*** Hooper et al. 1995; Buchheit et al 2013; Gastin et al. 2013. ***Muscle soreness*** Hooper et al. 1995; Buchheit et al. 2010; 2013; Gastin et al. 2013; Thornton et al. 2015. ***CMJ*** Buchheit et al. 2010; Malaghaes et al. 2010; Buchheit et al. 2012; Gibson et al. 2015; Wiewelhove et al. 2015. ***HRex*** Buchheit et al. 2010; 2010; 2012. ***HRR*** Buchheit et al. 2010; 2010; 2012. **Ln rMSSD** Buchheit et al. 2010; 2010; 2012; 2013. ***S-IgA*** Fredericks et al. 2012; Morgans et al. 2014a; 2014b; Owens et al. 2014.

4.7 Discussion

The aim of the present study was to examine the reliability of a range of potential fatigue measures in a cohort of elite soccer players. This would enable future work to be undertaken in order to establish the fatigue status of elite soccer players.

In the present investigation, overall reliability for perceived ratings of wellness were acceptable, with CV ranging from 7% (muscle soreness) to 13% (sleep) These findings suggest that ratings of perceived wellness may be reliable enough to track mean changes in the fatigue status of a feasible sample size (5-6 players based on an average MPID of 21-34 %, Table 4-2) of elite soccer players. To the authors knowledge, this is the first report to examine the reliability of time efficient wellness scales that are frequently used in elite team sports. The present findings confirm previous observations by Kallus (1995) who observed a large significant test re-test correlation (r = 0.79) using a more extensive (76-questions) recovery mood questionnaire with athletes. Systematic bias was currently small in practical terms with only perceived sleep being significantly (p=0.05; CV%13; SEM 0.9; 0.7-1.2 95%CI) different between days (Trial 1; 4.8 Trial 2; 5.2). The precise factor/s mediating these systematic between day differences are difficult to elucidate. However, the quality of sleep can be manipulated by many variables including hygiene and a number of cognitive, physiological and social factors which are difficult to control for within the athletes training regime (Fullagar et al., 2015).

The measurement of jumping performance represents a popular method by which to evaluate neuromuscular performance in the field, however, to date there is a lack of information relating to the reliability of these measures in elite athletes. In the present study, countermovement jump height showed very good day-to-day reliability (SEM 1.52 cm; CV % 3.8). These results are in agreement with observations on Australian Rules Football (AFL) players with day-to-day reliability estimates of 5% observed (Cormack, Newton, McGuigan and Doyle, 2008). Similarly, recent studies have also shown excellent reliability of countermovement jumps using a variety of testing modalities (e.g. contact mats, force platforms and photoelectric technology) in recreational team sport players (Slinde et al., 2008; Glatthorn et al., 2011; Kenny et al., 2012), with the %CV ranging from 1-5%. Collectively, these findings suggest that CMJ height may represent an excellent method for tracking changes in the fatigue status of a feasible sample size (9 players based on an average MPID of 2.4 cm, Table 4-2) of elite soccer players between days along with sufficient precision for the assessment of fatigue status on a given day.

Vagal-related heart rate-indices have become a popular method to indirectly assess the responsiveness of the autonomic nervous system (ANS) (Buchheit 2014). In the present study, sub-maximal heart rate (HRex) demonstrated very good reliability with a SEM and CV of 4 beats/minutes and 3% respectively. These findings are consistent with previous observations in both recreational subjects (SEM 3 beats/minute; Lamberts & Lambert, 2009); and physically active men and women (SEM 5 beats/minute and 1.1-1.4% CV; R P Lamberts et al., 2011) across a range of exercise intensities. In the present study, an SEM and CV of 4.9 % and 9.5% was observed for HRR% with slightly higher values of 5 beats/minute and 14% observed for HRR (beats/minute). These values are slightly higher than the 3% CV (6 ± 2beats/minute) reported for HRR in physically active men and women (Lamberts et al., 2009). However, the present estimates for HRR are similar to those found in young elite soccer players (%CV 13.3) (Buchheit et al. 2010). Previous data following supra-maximal exercise has shown larger CVs for HRR (beats/minute) (25-27%; Al Haddad et al., 2011; Bosquet et al. 2008). An increase in metabolite accumulation slowing HRR likely reflects the effects of the increased anaerobic energy contribution associated with maximal exercise (Bosquet et al. 2008). Overall, the good reliability of HRR% and HRex suggests these indices may represent excellent methods for tracking changes in the fatigue status of a feasible sample size (9 players based on an average MPID of 7 and 4 beats per min respectively, Table 4-2) of elite soccer players between days along with sufficient precision for the assessment of fatigue on a given day.

Alongside HRR, time-domain estimates of HRV (rMSSD and Ln rMSSD) have received increasing attention in recent years due to their improved reliability and accessibility compared to traditional indices derived through spectral analysis (Al Haddad et al., 2011; Esco and Flatt, 2014). Previous attempts to examine the reliability of vagal-related HRV indices have shown similar reliability following exercise compared to rest (Buchheit 2014). However, an advantage of using post-exercise measurements includes the opportunity to undertake additional assessments for HRex and HRR (Al Haddad et al., 2011; Esco and Flatt, 2014). In the present study, Ln rMSSD demonstrated good reliability (SEM 0.298 ms; CV 10.3 %) and was improved compared to rMSSD (SEM 5.6 ms; and CV 27.9%). Furthermore, the present reliability estimates for Ln rMSSD compare favourably with those previously observed following sub-maximal and supra-maximal exercise (Buchheit, Mendez-Villanueva, et al., 2010; Al Haddad et al., 2011). The reasonable day-to-day variation in Ln rMSSD suggests this measure may be suitable for tracking changes in the fatigue status of a feasible sample size (8 players based on an average MPID of -0.5 ms Table 4-2) of elite soccer players between-days along with sufficient precision for the assessment of wellness on a given day

In the present study S-IgA showed the greatest day-to-day variation (63% CV and 63 μg mL^{-1} SEM) with large systematic bias between trials ($p = 0.019$). To the authors knowledge, this data represents the first attempt to evaluate the day-to-day reliability of S-IgA estimates using a real-time lateral flow device. Coad et al. (2015) previously reported good (9% CV) within day reliability using the same method in physically active university men and women. The precise factor/s mediating the poorer between-day reliability in the present study are difficult to elucidate, however, it may simply reflect the inherent normal biological alteration in S-IgA (Coad et al., 2015). Traditional ELISA techniques have been considered the 'Gold Standard' and have shown greater reliability (<10%CV; (Porstmann and Kiessig, 1992) in S-IgA. Given the tightly controlled nature of the current study, the poorer reliability presently observed and unrealistic sample size required (37 players based on an average MPID of 43%, Table 4-2) suggests that real time lateral flow devices are unlikely to be suitable for tracking changes in the fatigue status of elite soccer players between-days or have sufficient precision for the assessment of wellness on a given day

The present results suggest that the use rMSSD and S-IgA are unsuitable to track fatigue status in elite soccer players, alternatively application of CMJ, HRex HRR%, perceived ratings of wellness and to a certain extent HRV (Ln rMSSD) have good between-day reliability within the typical sample sizes observed in elite soccer teams. These measures will be used in future studies to track the fatigue status of elite soccer players.

CHAPTER 5: MONITORING FATIGUE DURING THE IN-SEASON COMPETITIVE PHASE IN ELITE SOCCER PLAYERS

This study was presented as an oral communication at the 18th annual Congress of the European College of Sports Science (ECSS) 2013, Barcelona, Spain 2013 and also published as a full manuscript in the International Journal of Sports Physiology and Performance. (Appendix, Chapter 11)

5 Monitoring fatigue during the in-season competitive phase in elite soccer players

5.1 Introduction

The stress associated with training and competition often temporarily impairs players' physical performance. This impairment may be acute, lasting minutes or hours and may stem from metabolic disturbances and substrate utilisation associated with high-intensity exercise (Bangsbo et al., 2007). Alternatively, exercise-induced muscle injury and delayed onset muscle soreness that often follows training with a high eccentric component may lead to impairment lasting several days (Barnett, 2006). The balance between the stress of training/competition and sufficient recovery is, therefore, of sufficient importance, since an imbalance over extended periods of time may contribute to potentially long-term debilitating effects associated with overtraining (Nimmo and Ekblom, 2007).

Increasing attention in the literature has centred upon evaluating the effectiveness of a range of monitoring tools which may serve as valid indicators of recovery status in athletes including heart rate derived indices (Martin Buchheit, 2014), salivary hormones, neuromuscular indices (Silva et al., 2014) and subjective wellness scales (Gastin et al., 2013). Alongside reliability (Chapter 4) a valid marker of recovery should be sensitive to variability in training and match load (Meeusen et al., 2013), consequently, research to date has evaluated the sensitivity of monitoring tools in response to changes in training load over extended periods of time (e.g. weekly/monthly) in endurance sports such as cycling (Manzi et al., 2009; Plews et al., 2012). In contrast, limited attempt has been made to determine the effectiveness of these tools for monitoring recovery in elite team sport players (Buchheit et al., 2013; Gastin et al., 2013). Team sport athletes compete on a weekly/bi-weekly basis, therefore, decisions on player wellness and fatigue are frequently required over extended periods of time. Under such conditions, monitoring tools that are sensitive to more acute (e.g. daily) fluctuations in load may serve as the most effective monitoring tools.

Recent findings indicate that perceived ratings of wellness (Buchheit et al., 2013; Gastin et al., 2013), submaximal heart rate (Buchheit et al., 2013) and a vagal-related heart rate variability index (Buchheit et al., 2013) are sensitive to subtle changes in daily pre-season training load in elite Australian Rules players. However, to the author's knowledge, no research to date has evaluated the sensitivity of different monitoring tools to daily fluctuations in training load in elite soccer players. Since differences exist in the physiological demands between team sports it is important to determine which fatigue variables are most sensitive to changes in load associated with specific sports. Furthermore, no attempt has been made to examine such relationships during an in-season competition phase where the overall loading patterns vary markedly compared to the high volume pre-season training periods (Malone et al. 2014a; Jeong et al. 2011). Therefore, the aim was to quantify the relationships between daily training load and a range of reliable (Chapter 4) potential measures of fatigue in a sample of elite soccer players during a short in-season competitive phase.

5.2 Methods

5.3 Participants

Data were collected from 10 outfield soccer players (19.1±0.6 years; 184±7cm; 75.4±7.6 kg) competing in the English Premier League over a 17-day period (February) during an in-season competition phase.

5.4 Experimental Design

Players took part in normal team training throughout the 17-day period as prescribed by the coaching staff. This included two competitive reserve team home matches, twelve training sessions and three rest days. All players were fully familiarised with the assessments in the weeks prior to completion of the main experimental trials. On the day of the fatigue assessments, players arrived at the training ground laboratory having refrained from caffeine intake at least 12-hours prior to each assessment point. Fatigue variables were subsequently taken prior to the players commencing normal training. Only perceived ratings of wellness measurements were taken on match and rest days. All assessments were conducted at the same time of the day in order to avoid the circadian variation in body temperature (Reilly and Brooks, 1986). Players were not allowed to consume fluid at any time during the fatigue assessments. The study was approved by Liverpool John Moores University Ethics Committee. All players provided written informed consent. Prior to inclusion into the study, players were examined by the club physician and were deemed to be free from illness and injury.

Individual player daily training and match load was monitored throughout the 17-day assessment period. Each player was also monitored during each training session and match using a portable global positioning system (GPS) technology (GPSports SPI Pro X 5 Hz, Canberra, Australia). This type of system has previously been shown to provide valid and reliable estimates of instantaneous velocity during acceleration, deceleration, and constant velocity movements during linear, multidirectional and soccer-specific activities (Coutts and Duffield, 2010; Varley et al., 2012). All devices were always activated 15-min before the data collection to allow acquisition of satellite signals (Waldron et al., 2011). The minimum acceptable number of available satellite signals was 8 (range 8-11) (Jennings et al., 2010). Players wore the same GPS device for each session in order to avoid inter-unit error (Jennings et al., 2010).

Perceived ratings of wellness

Perceived ratings of wellness were measured as described in Chapter 3 section 3.

Counter-movement jump (CMJ)

Countermovement jump (CMJ) performance was measured as described in Chapter 3 section 3.

Submaximal heart rate (HRex), Heart rate recovery (HRR) and Heart rate variability (HRV)

HRex, HRR and HRV were measured as described in Chapter 3 section 3.

5.5 Statistical Analysis

Data were analysed with general linear models, which allowed for the fact that data were collected within-subjects over time (Bland and Altman, 1986). Recently, step-wise regression approaches have been criticised for reliable variable selection in a model (Flom and Cassell , n.d.; Whittingham et al., 2006). Our added problem was the predicted high multicolinearity between the various independent variables in our study. Therefore, we used a combination of expert knowledge regarding which variables hold superior practical/clinical importance (Flom and Cassell , n.d.) and a multicolinearity correlation coefficient of >0.5 for initial variable selection. Total HIR distance (THIR; >14.4 km/h) was subsequently selected in order to provide an indication of training and match load (independent variable) in the present study. We then quantified the relationships between the various predictors and outcomes using model I (unadjusted model) and model II (fully adjusted model from which partial correlation coefficients and associated 95% confidence intervals for each predictor could be derived). The following criteria were adopted to interpret the magnitude of the correlation (r) between test measures: <0.1 trivial, 0.1 to 0.3 small, 0.3 to 0.5 moderate, 0.5 to 0.7 large, 0.7 to 0.9 very large, and 0.9 to 1.0 almost perfect. (Hopkins, 2000) The level of statistical significance was set at $p<0.05$ for all tests.

5.6 Results

The variability in training load and fatigue variables over the 17 day period is shown in Figure 5-1. There was significant day-to-day variation (coefficient of variation) in

THIR distance (115%; $p<0.001$). The perceived wellness ratings for fatigue, sleep quality and soreness varied from day-to-day by 16%, 18% and 19% respectively ($p<0.05$). HRR (11%), Ln rMSSD (12%) and countermovement jump (4%) varied to a lesser degree ($p<0.05$).

Partial correlations, least squares regression slope (B) and significance for the relationship between THIR distance and fatigue variables are shown in Table 5-1. Variability in fatigue ($r=-0.51$; large; $p<0.001$), Ln rMSSD ($r=-0.24$; small; $p=0.04$) and CMJ (0.23; small; $p=0.04$) were correlated to variability in THIR distance covered on the previous days. Correlations between variability in sleep quality, muscle soreness and HRR (%) and THIR distance were trivial to small and not statistically significant (Table 5-1).

Table 5-1: Partial correlations (95% CI), least squares regression slope (B) and significance for the relationship between training load (total high-intensity running distance) and fatigue variables

Variable	Correlation Coefficient (95% CI)	Magnitude	B	P-value
Fatigue (AU)	-0.51 (-0.62 to -0.39)	Large	-400.168	p<0.001
Sleep quality (AU)	-0.04 (-0.19 to 0.11)	Trivial	-26.174	p= 0.71
Muscle Soreness (AU)	-0.10 (-0.25 to 0.05)	Trivial/Small	-46.353	p=0.37
CMJ (cm)	0.23 (0.04 to 0.41)	Small	65.905	p=0.04
Ln rMSSD (ms)	-0.24 (-0.42 to -0.05)	Small	-295.131	p=0.04
HRR (%)	0.13 (-0.07 to 0.32)	Trivial/Small	7.844	p=0.26

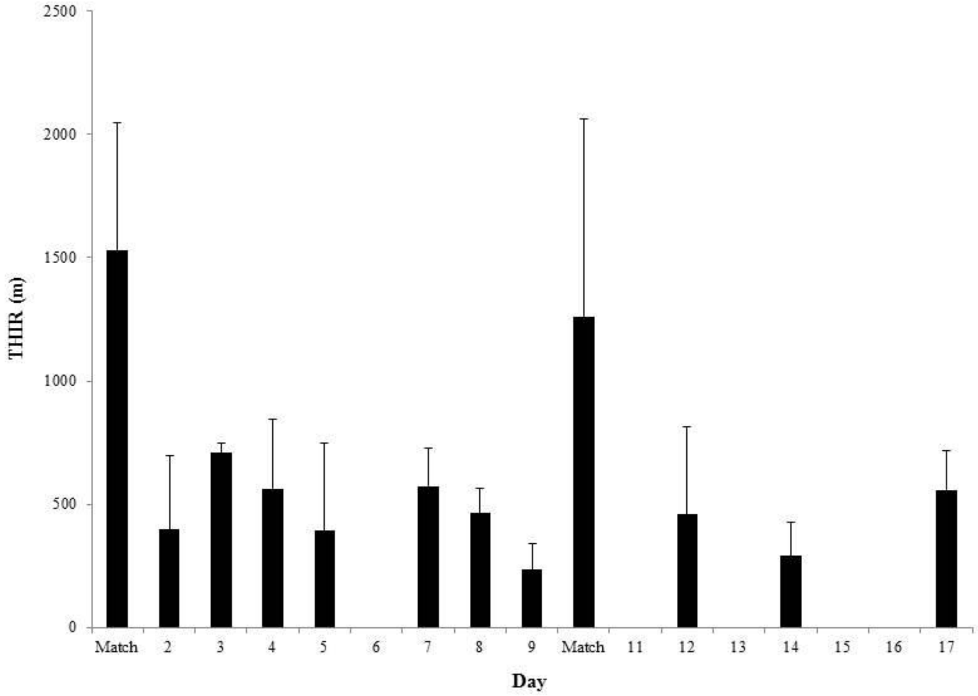

Figure 5-1: Mean (SD) total high-intensity (THIR) distance (m), during the 17-day period

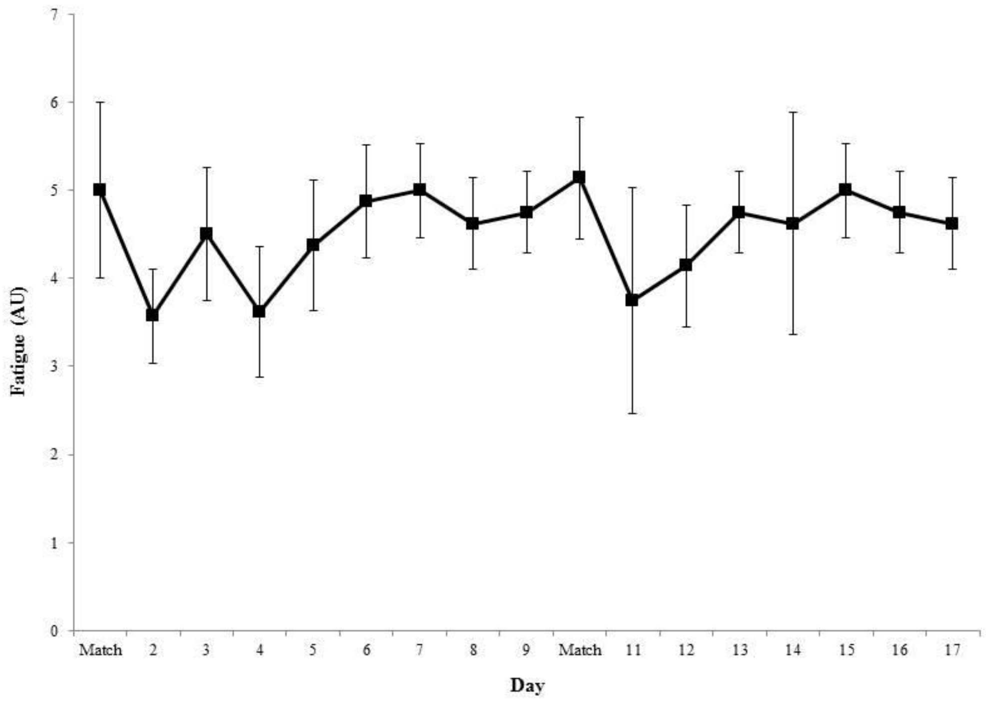

Figure 5-2: Mean (SD) perceived ratings of fatigue (AU) during the 17-day period

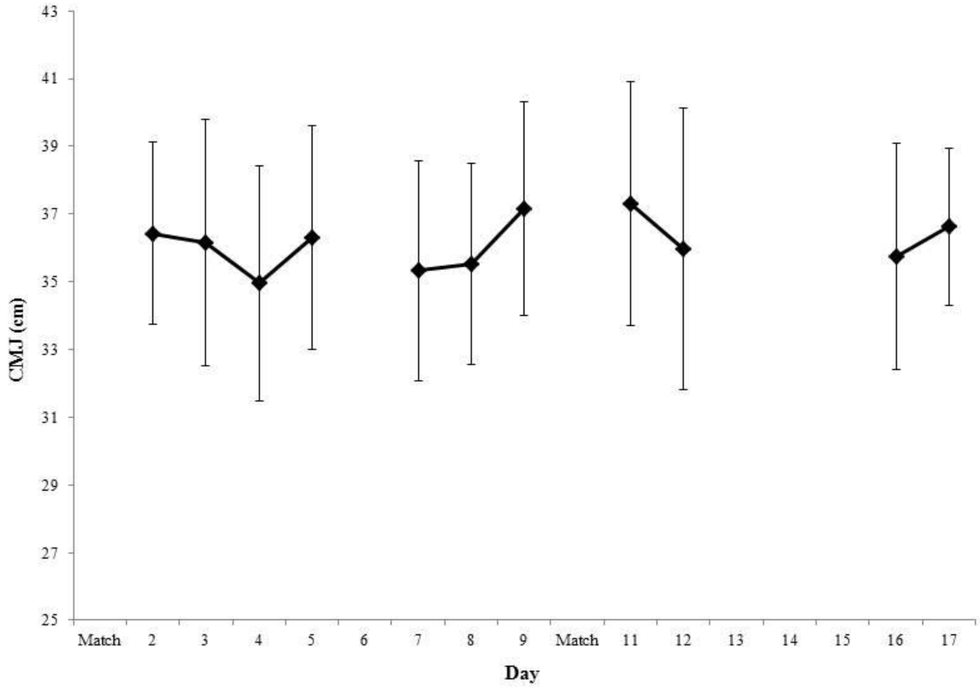

Figure 5-3 Mean (SD) countermovement jump (cm) during the 17-day period

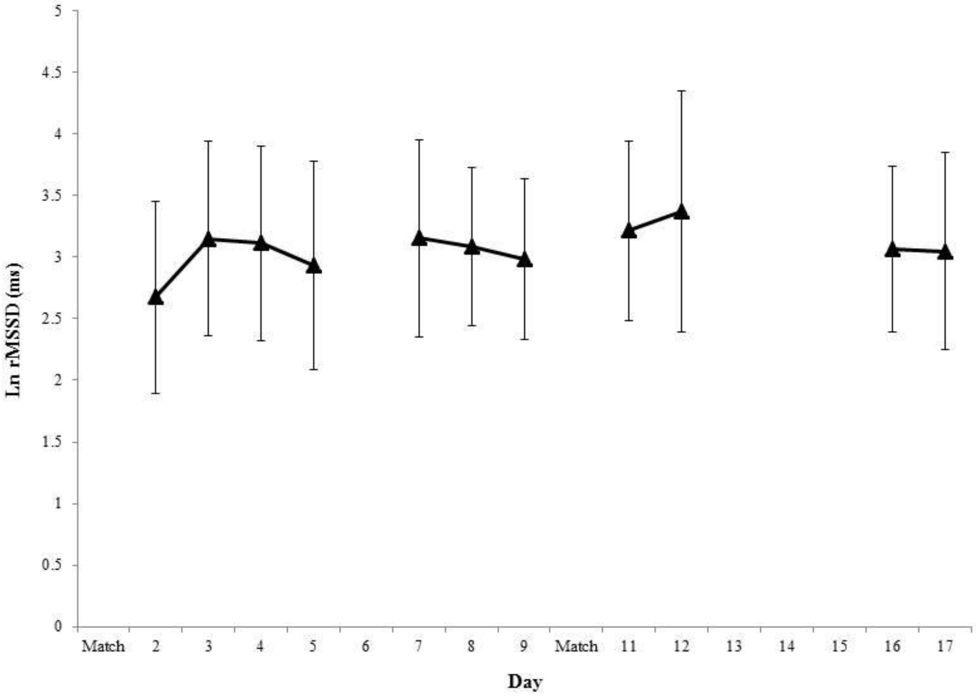

Figure 5-4: Mean (SD) Ln rMSSD (ms) during the 17-day period

5.7 Discussion

The aim of the current study was to quantify how sensitive a range of fatigue measures are to changes in daily training load in a sample of elite soccer players. During a short in-season competitive period, the strongest multivariate-adjusted correlations with daily fluctuations in training load were found to be perceived ratings of wellness compared with the other markers of fatigue measured.

In elite soccer, players are frequently required to compete on a weekly and often bi-weekly basis, therefore the balance between training stimulus/adaptation and recovery is an important consideration for coaches and sport scientists. (Nédélec et al., 2012) Over the course of the 17-day period, training was prescribed by the coaches and followed a typical periodized cycle leading up to matches. (Brink et al., 2014) This was characterised by recovery days following the match, moderate to high loads after 3 to 4 days then moderate to light sessions leading into the forthcoming match. The THIR distance varied by 115% ($p<0.001$), ranging from 1528 m to 235 m during match-play and recovery/low load days respectively.

While the assessment of training load is a popular practice in team sports there is also a requirement to assess the physiological response in attempt to evaluate athlete adaptation, recovery/readiness and fatigue status. (Meeusen et al., 2013) The recording of perceived ratings of wellness is a relatively efficient and practical approach to quantify the fatigue/adaptive responses to team sports such as training in AFL. (Hooper et al., 1995; Gastin et al., 2013) In the present study, a moderate-to-strong correlation was observed between the players perceived rating of fatigue and day-to-day variation in THIR distance ($r=-0.51$; $p<0.001$). The slope of the regression model indicated that every ~400m increase in THIR distance led to a one unit decrease in fatigue (Table 5-1). Nevertheless, whether self-reported fatigue can be used as a valid means to track the fatigue response to training and match load in individual players is not entirely clear at present. We note that the variance in training load explained by all the statistically significant predictors was approximately 37%. The relatively small sample size in the present study would also render prediction intervals for individual players relatively wide. Nevertheless, the present study has helped to identify the variables that are at least correlated to within-player fluctuations in training load in elite soccer players during a typical in-season training period, which is a novel finding.

Daily perceived ratings of sleep quality (r=0.2), fatigue (r=0.2) and muscle soreness (r=0.3) have been found to be statistically significantly correlated with daily training load (training session time x RPE) during the pre-season training period in elite AFL players. (Buchheit et al., 2013) In contrast, the relationship between daily training load and perceived ratings of sleep quality and muscle soreness were trivial and non-significant in the present study. This may partly reflect the fact that previous observations in AFL players (Buchheit et al., 2013) were made during the pre-season period where the high volume and intensity of training may lead to greater disturbances in perceived ratings of sleep and soreness. In soccer, the high frequency of competition during the in-season phase ensures training is more focused around recovery and maintaining physical fitness which may lead to lesser changes in perceived ratings of sleep and soreness across a typical training week.

In recent years heart rate (HR) indices (HRV and HRR) have been used as a popular method to measure variations in the autonomic nervous system (ANS) in an attempt to understand athlete adaptation/fatigue status. (Buchheit 2014) The use of vagal related time domain indices such as Ln rMSSD have been found to have greater reliability and are ideal for assessments over short periods when compared to spectral indices of HRV. (Al Haddad et al., 2011) In the present study a small significant correlation (r=-0.2; p=0.04) was found between the daily fluctuations in Ln rMSSD and THIR. The slope of the regression model indicated that every ~300m increase in THIR distance led to a decrease of one unit in HRV (Table 5-4) i.e. more sympathetic dominance the greater the training load. (Plews et al., 2012; Buchheit et al., 2013) However, a non-significant correlation was observed between HRR and daily fluctuations in THIR. Buchheit et al, (2013) found similar yet stronger correlations (r=0.40) with a comparable vagal related parameter HRV (Ln SD1) during a pre-season camp in AFL players. Previous work in elite gymnastics, rugby and rowing have also found correlations with various measures of HRV and daily/total training load using session ratings of perceived exertion. (Smith et al., 2011; Edmonds et al., 2013; Sartor et al., 2013) Although limited HRV data exists in team sports, the use of vagal related HR indices with endurance athletes is more extensive. (Buchheit 2014; Lamberts et al. 2009; Plews, Laursen, Stanley, et al. 2013a) Indeed, based on data derived from endurance sports it is suggested that the use of one single data point could be misleading for practitioners due to the high day-to-day variation in these indices. (Plews, Laursen, Stanley, et al. 2013a) When data were averaged over a week or using a 7-day rolling average significant large correlations were found with 10-km running performance compared to a single assessment point where negligible relationships were seen. (Plews, Laursen, Stanley, et al. 2013a) As a consequence, if HR derived assessments of fatigue/adaptation are to be effective in team sports a higher volume of assessments may be required. However, undertaking such measures may prove difficult with the large volume of athletes engaged in team sports. (Buchheit 2014)

It is well established that the assessment of neuromuscular function via the use of jump protocols is impaired up to 72-hours post-match, (Silva et al., 2014) indicating a negative effect on neuromuscular performance. (Cormack, Newton and McGuigan, 2008) Interestingly a small positive correlation was currently observed (r=0.23) between countermovement jump (CMJ) performance and THIR, suggesting improved performance with increased THIR distance. This could reflect a priming/post-activation potentiation effect of the THIR distance on the neuromuscular system (Barnes et al. 2014). A small non-significant correlation was previously observed between THIR and CMJ performance over the course of a weeks training in elite adolescent soccer players. (Malone et al. 2014b). The THIR distance reported (36-106 m) was much lower than in the present study (235-1528 m) and may not have been enough to stimulate positive or negative effects on the neuromuscular system. However, irrespective of the underlying mechanisms, these findings collectively indicate that daily monitoring of CMJ provides limited insight into recovery fatigue status of soccer players. Furthermore, elite players are often reluctant to perform maximal and explosive assessments in the days following high training or match loads which may limit its application as a monitoring tool in elite soccer.

Total HIR distance was employed in the present study as an index of training and match load due to its frequent inclusion in attempts to quantify the load incurred by elite players during training and match-play. (Malone et al. 2014a) However, THIR distance will underestimate the true load incurred by the athlete since it does not account for the stress associated with the frequent accelerations and decelerations which occur during soccer. (Gaudino et al., 2013) It should be noted, however, that initial analysis in the present study highlighted a large correlation (r=0.57) between THIR distance and session ratings of perceived exertion (sRPE) which has previously been used as a global indicator of internal load in soccer players. (Impellizzeri et al., 2004) A limitation of the present study relates to the use of an absolute (>14.4.km/h) rather than individual thresholds to determine the high-intensity running speed. (Abt and Lovell, 2009) However, the performance metrics (e.g. maximal speed, maximal aerobic speed and ventilatory thresholds) needed to generate individual speed thresholds were not available in the current sample of elite players.

Future research is needed to understand more long-term fluctuations in fatigue variables in relation to individual load thresholds in elite soccer players. Perceived ratings of wellness show particular promise as a simple, non-invasive assessment of fatigue status in elite soccer players during an in-season competitive phase compared to the other markers of fatigue measured.

CHAPTER 6: DOES TRAINING LOAD ACCUMULATION EFFECT DAY-T0-DAY SENSITIVITY OF MORNING-MEASURED FATIGUE VARIABLES IN ELITE SOCCER PLAYERS

This study is to be presented as an oral communication and winner of Young Investigator Award at the 2nd Aspire Sport Science Conference, Doha, Qatar 2016

6 Does training load accumulation effect day-to-day sensitivity of morning-measured fatigue variables in elite soccer players

6.1 Introduction

The physical demands of elite soccer have progressively increased over recent years (Barnes et al., 2014; Bradley et al., 2015). In addition to this, top level teams are required to compete in a high number of matches over the course of season (Carling et al., 2015), therefore emphasis on recovery is paramount in order to avoid the debilitating effects associated with overtraining and injury risk (Nimmo and Ekblom, 2007). As a consequence, increasing attention in the literature has focused upon evaluating the effectiveness of a range of monitoring tools which may serve as valid indicators of fatigue status of athletes (Meeusen et al., 2013).

A valid marker of fatigue should be sensitive to variability in training and match load. (Meeusen et al., 2013), consequently recent research to date has examined the sensitivity of potential measures of fatigue to daily fluctuations in training load in Australian Rules Football (AFL) (Buchheit et al., 2013; Gastin et al., 2013) In AFL players, perceived ratings of wellness (Buchheit et al., 2013; Gastin et al., 2013), sub-maximal heart rate (Buchheit et al., 2013) and an index (LnMSSD) of vagal-related HRV (Buchheit et al., 2013) were shown to be sensitive to the fluctuations in daily training load during the pre-season training period. Similarly, in Chapter 5, both rating of perceived fatigue and Ln rMSSD were most sensitive to the daily fluctuations training load experienced by elite soccer players during the in-season competition period. Collectively, these findings demonstrate that these measures show particular promise as acute, simple, non-invasive assessments for tracking the fatigue status of elite team sport athletes.

Physiological adaptation to training represents the culmination of repeated daily applications of training load (Pyne et al., 2009). As a consequence, the level of fatigue experienced by an athlete at any one point in time is unlikely to purely reflect the load incurred from the previous day's activity (Chapter 5), but rather the load accumulated from a number of training days. Indeed high-intensity exercise and eccentric type activity has frequently been shown to lead to increases in muscle soreness that may be present for up to 72-hours following the exercise stress (Ispirlidis et al., 2008; Fatouros et al., 2010). In line with such observations, Buchheit (2014) recently suggested that HRV indices, used as an indicator of the athletes training status, may be more sensitive to changes in training loads when averaged across 7-days compared to a single daily measurement (Buchheit 2014). Similarly, reductions and increases in HRR have been seen in response to weekly increases in training load and performance in physically active subjects elite cyclists respectively (Borresen & Lambert 2007; Lamberts et al. 2010).

In Chapter 5, small significant correlations were found between daily training load and morning-measured Ln rMSSD with trivial, non-significant correlations observed between daily training load and ratings of sleep quality and muscle soreness. It is possible therefore, that the relationship between such markers of fatigue and training load may vary as a function of the number of accumulated training days. Therefore, our aim was to determine whether the sensitivity of a range of potential fatigue measures observed in Chapter 5 would be improved when compared to the training load accumulated over the previous two, three or four days during a short in-season competitive phase.

6.2 Methods

6.3 Participants

Data derived from Chapter 5 was subsequently used for the purpose of this Chapter. Please see Chapter 5 section 3.

6.4 Experimental Design

Data derived from Chapter 5 was subsequently used for the purpose of this Chapter. Please see Chapter 5 section 4

The relationship between morning-measured fatigue and accumulated training load over the previous 2, 3 or 4-days was undertaken by calculating the THIR (>14.4 km/h) distance completed across each respective time period. The rolling mean 2, 3 and 4-day THIR distances were then related to the subsequent day's morning-measured fatigue variables. The results from Chapter 5 were used to represent the relationship between morning-measured fatigue and the previous days training load.

Perceived ratings of wellness

Perceived ratings of wellness were measured as described in Chapter 3 section 3.

Counter-movement jump (CMJ)

Countermovement jump (CMJ) performance was measured as described in Chapter 3 section 3.

Submaximal heart rate (HRex), Heart rate recovery (HRR) and Heart rate variability (HRV)

HRex, HRR and HRV were measured as described in Chapter 3 section 3.

6.5 Statistical Analysis

Data were analysed with general linear models, which allowed for the fact that data were collected within-subjects over time. (Bland and Altman, 1986). Total HIR distance was selected in order to provide an indication of training and match load (independent variable) in the present study. We then quantified the relationships between the various predictors and outcomes using model I (unadjusted model) and model II (fully adjusted model from which partial correlation coefficients and associated 95% confidence intervals for each predictor could be derived). The following criteria were adopted to interpret the magnitude of the correlation (r) between test measures: <0.1 trivial, 0.1 to 0.3 small, 0.3 to 0.5 moderate, 0.5 to 0.7 large, 0.7 to 0.9 very large, and 0.9 to 1.0 almost perfect. (Hopkins, 2000) The level of statistical significance was set at $p<0.05$ for all tests.

6.6 Results

Partial correlations, least squares regression slope (B) and significance for the relationship between THIR distance (over 1-4 days) and morning-measured fatigue variables are shown in Table 6-1 – 6-7. Variability in ratings of perceived fatigue were correlated to variability in THIR distance covered on the previous 1, 2, 3 and 4 days ($p<0.05$; Table 6-1) with a large ($r= -0.51$) correlation observed between perceived fatigue and the previous days THIR and small correlations observed between 2 ($r = -0.31$) and 4 ($r = -0.28$) day cumulative THIR. Correlations between variability in perceived sleep quality and muscle soreness and THIR distance across all days were trivial to small and not statistically significant (Table 6-2 and 6-3).

Table 6-1: Partial correlations (95% CI), least squares regression slope (B) and significance for the relationship between morning-measured perceived fatigue and total training load (total high-intensity running distance) over the previous 1, 2, 3 and 4-days.

	Correlation Coefficient (95% CI)	Magnitude	B	P-value
1-day	-0.51 (-0.62 to -0.39)	Large	400.168	p<0.001
2-day	-0.31 (-0.51 to -0.78)	Small	149.167	p=0.01
3-day	-0.42 (-0.61 to -0.18)	Moderate	166.509	p<0.001
4-day	-0.28 (-0.52 to -0.01)	Small	108.53	p=0.03

Table 6-2: Partial correlations (95% CI), least squares regression slope (B) and significance for the relationship between morning-measured perceived sleep quality and total training load (total high-intensity running distance) over the previous 1, 2, 3 and 4-days

	Correlation Coefficient (95% CI)	Magnitude	B	P-value
1-day	-0.04 (-0.19 to 0.11)	Trivial	-26.174	p=0.71
2-day	-0.03 (-0.27 to 0.21)	Trivial	-10.633	p=0.83
3-day	-0.1 (-0.35 to 0.16)	Trivial	-9.869	p=0.81
4-day	0.04 (-0.27 to 0.28)	Trivial	15.774	p=0.75

Table 6-3: Partial correlations (95% CI), least squares regression slope (B) and significance for the relationship between morning-measured perceived muscle soreness and total training load (total high-intensity running distance) over the previous 1, 2, 3 and 4-days

	Correlation Coefficient (95% CI)	Magnitude	B	P-value
1-day	-0.10 (-0.69 to 0.57)	Trivial	-46.353	p=0.37
2-day	-0.19 (-0.41 to 0.05)	Trivial/Small	-58.443	p=0.12
3-day	-0.16 (-0.40 to 0.10)	Trivial	-36.258	p=0.23
4-day	-0.13 (-0.4 to 0.15)	Trivial	-28.05	p=0.37

Variability in CMJ was significantly correlated to variability in THIR distance covered on the previous day (r=0.23; small; p=0.04). Correlations between variability in CMJ and THIR distance across the remaining days were trivial to small and not statistically significant (Table 6-4).

Table 6-4: Partial correlations (95% CI), least squares regression slope (B) and significance for the relationship between morning-measured countermovement jump (CMJ) performance and total training load (total high-intensity running distance) over the previous 1, 2, 3 and 4 days

	Correlation Coefficient (95% CI)	Magnitude	B	P-value
1-day	0.23 (0.04 to 0.41)	Small	65.905	p=0.04
2-day	0.13 (-0.11 to 0.36)	Trivial	24.944	p= 0.29
3-day	0.21 (-0.05 to 0.42)	Small	31.478	p=0.11
4-day	0.23 (-0.05 to 0.48)	Small	34.02	p=0.10

Correlations between variability in HRex and THIR across all days were trivial to small and only statistically significant with 4-day cumulative THIR (r=0.28; p=0.02; Table 6-5).

Table 6-5: Partial correlations (95% CI), least squares regression slope (B) and significance for the relationship between morning-measured sub-maximal heart rate (HRex) and total training load (total high-intensity running distance) over the previous 1, 2, 3 and 4 days

	Correlation Coefficient (95% CI)	Magnitude	B	P-value
1-day	0.20 (-0.01 to 0.39)	Small/Trivial	9.736	p=0.05
2-day	0.18 (-0.06 to 0.40)	Trivial	5.17	p=0.10
3-day	0.21 (-0.05 to 0.44)	Small	4.863	p=0.07
4-day	0.28 (0.05 to 0.52)	Small	5.948	p=0.02

Correlations between variability in Ln rMSSD and THIR distance across all days were trivial to small and was only statistically significant with the previous days THIR (r=-0.24; p=0.04; Table 6-6).

Table 6-6: Partial correlations (95% CI), least squares regression slope (B) and significance for the relationship between morning-measured Ln rMSSD (HRV) and total training load (total high-intensity running distance) over the previous 1, 2, 3 and 4-days.

	Correlation Coefficient (95% CI)	Magnitude	B	P-value
1-day	-0.24 (-0.42 to -0.05)	Small	-295.131	p=0.04
2-day	<-0.01 (-0.25 to 0.29)	Trivial	-1.31	p= 0.99
3-day	<0.01 (-0.27 to 0.25)	Trivial	9.426	p=0.91
4-day	-0.15 (-0.41 to 0.13)	Trivial	-95.337	p=0.279

Correlations between variability in HRR (%) and THIR distance for all days were trivial to small and not statistically significant (Table 6-7).

Table 6-7: Partial correlations (95% CI), least squares regression slope (B) and significance for the relationship between morning-measured heart rate recovery (HRR%) and total training load (total high-intensity running distance) over the previous 1, 2, 3 and 4-days

	Correlation Coefficient (95% CI)	Magnitude	B	P-value
1-day	0.13 (-0.07 to 0.32)	Trivial	7.844	p=0.26
2-day	<0.1 (-0.14 to 0.33)	Trivial	0.178	p=0.97
3-day	<0.1 (-0.16 to 0.35)	Trivial	1.138	p=0.76
4-day	-0.03 (-0.23 to 0.32)	Trivial	-1.584	p=0.68

6.7 Discussion

The aim of the current study was to determine whether the sensitivity of a range of morning-measured fatigue variables to changes in training load was influenced by the number of previous days over which the training load was accumulated in elite soccer players. The present findings indicate that the sensitivity of morning-measured fatigue measures to changes in training load is not improved when compared with training loads beyond the previous days training.

The use of simple perceived ratings of wellness is an efficient and practical approach to quantify the fatigue responses to team sports such as elite soccer and AFL. (Hooper et al., 1995; Gastin et al., 2013) In Chapter 5, a moderate-to-strong significant correlation was observed between the players perceived rating of fatigue and daily variation in THIR distance (r=-0.51; p<0.001). Furthermore, the slope of the regression model indicated that every ~400m increase in THIR distance led to a one unit decrease (For example a player may change from very poor level of fatigue to very, very poor level of fatigue following ~400m THIR) in fatigue (Table 6-1) with 37 % of the variance in training load explained by all the statistically significant predictors. In contrast, the current findings demonstrate that the sensitivity of morning-measured perceived fatigue to changes in training load is reduced from significantly large to significantly small when compared with the training load beyond the previous days training (r=-0.51 to -0.28). Indeed the variance in training load explained by all the statistically significant predictors decreased to 15% when training load was accumulated over a number (2-4) of days. This apparent importance of the previous days training load on morning-measured fatigue may to some extent be explained by the nature of training cycles undertaken by elite soccer players. During the in-season competition period, players rotate around weekly cycles comprising one to two matches (very high load) interspersed with training sessions (moderate to high load) and recovery sessions (Malone et al. 2014a). This cycle of daily loading peaks and-troughs within a short time frame may therefore only lead to acute changes in fatigue status that are largely representative of the previous days training. The influence of accumulated training load on morning measured perceived fatigue may be more relevant to endurance based sports where load is distributed and sustained over extended training blocks.

Small significant correlations have been reported between daily perceived ratings of sleep quality (r=0.2), fatigue (r=0.2) and muscle soreness (r=0.3) and the previous days training load during pre-season training in elite AFL players. (Buchheit et al., 2013) In contrast, the relationship between daily training load and perceived ratings of sleep quality and muscle soreness were trivial and non-significant in the previous Chapter 5. Furthermore, in the current study, we demonstrate that the magnitude of these relationships are not influenced by the number of days over which training load was accumulated. Muscle soreness has been found to be significantly elevated between 24 and 72-hours following a soccer match (Ispirlidis et al., 2008; Fatouros et al., 2010; Magalhães et al., 2010). Moreover, sleep quality has been seen to decrease around periods of competition (Lastella et al. 2015) As such, it is surprising that trivial relationships were observed between these subjective wellness measures and short-term THIR accumulation. In the present study, only two match days were included in the sample of 17-days, consequently the limited match exposure and training intensity may not have been sufficient to influence muscle soreness and sleep quality. Indeed the average daily training load in the current study (RPE-TL 361) is considerably lower than that reported during an AFL pre-season training camp (RPE-TL 746) where daily readings of muscle soreness and sleep quality were associated with changes in load (Buchheit et al., 2013). Future work involving a greater frequency of matches is therefore warranted in order to fully examine the influence of changes in loading on morning measured perceived ratings of muscle soreness and sleep.

In Chapter 5 a small, positive daily correlation was observed (r=0.23) between CMJ height and THIR suggesting improved performance with increased THIR distance., It has been reported that the assessment of neuromuscular function via the use of jump protocols may be impaired up to 72-hours post-match (Cormack, Newton and McGuigan, 2008; Silva et al., 2014). However, in the present study, a non-significant trivial to-small relationship was found between changes in CMJ height and THIR accumulation over 2-4-days. Collectively, the findings from Chapter 5 and the current study demonstrate that CMJ height is generally insensitive to acute changes in workload in elite soccer players. CMJ height alone may be too crude of a measure in order to detect changes in training load, however, alternative CMJ derived neuromuscular parameters may hold sensitivity to alterations in load. Indeed, neuromuscular parameters (eccentric, concentric, and total duration, time to peak force/power, flight time:contraction time ratio) derived from CMJ have been found suitable for detection of neuromuscular fatigue (Gathercole et al. 2015). Reductions in 18 different neuromuscular variables were found following a high-intensity fatiguing protocol in college-level team sport athletes (Gathercole et al. 2015). Furthermore, reductions in the flight time contraction time ratio have been found across a season in AFL players indicating a sensitivity to increases in load over time (Cormack, Newton, McGuigan and Cormie, 2008). Future research is required to investigate whether alternative measures derived from CMJ are sensitive to changes in training load in elite soccer players.

In recent years heart rate (HR) indices (HRV, HRR and HRex) have been used as a popular method to measure variations in the autonomic nervous system (ANS) in an attempt to understand athlete adaptation/fatigue status (Martin Buchheit, 2014). The use of vagal related time domain indices such as Ln rMSSD have been found to have greater reliability and are ideal for assessments over short periods when compared to spectral indices of HRV. (Chapter 4 ;Al Haddad et al. 2011; Esco & Flatt 2014). In the previous study a small significant correlation (r=-0.2; p=0.04) was found between the daily fluctuations in Ln rMSSD and THIR. The slope of the regression model indicated that every ~300m increase in THIR distance led to a decrease of one unit in HRV (Table 6-6) i.e. more sympathetic dominance the greater the training load. (Plews et al., 2012; Buchheit et al., 2013). In the current study, non-significant, trivial correlations were observed between fluctuations in 2, 3 and 4-day THIR and changes in morning-measured HRV, implying no additional effect on HRV beyond the previous days of training load. The limited relationships may reflect the low loads incurred by players observed in the current study (Chapter 5). Buchheit et al, (2013) found significant daily correlations (r=0.40) with a comparable vagal related parameter HRV (Ln SD1) during a pre-season camp in AFL players. A possible reason for the small-to-moderate correlation found may be due to the enhanced training load performed by AFL players (Buchheit et al., 2013). Another potential reason for the lack of sensitivity observed for HRV in the present study may be due to the inherent variation of this measure. Indeed, based on data derived from endurance sports it is suggested that the use of one single data point could be misleading for practitioners due to the high day-to-day variation in these indices (Plews, Laursen, Stanley, et al. 2013a). When data were averaged over a week or using a 7-day rolling averages, sensitivity to training load and performance has been improved compared to a single assessment point. A similar observation in young Handball players has also been reported when single monthly assessments were found to have less than 20% sensitivity to training status (Buchheit 2014). Future work is required to observe whether more frequent measures of HRV improve sensitivity to training load. Furthermore, future research is needed to establish how HRV responds to more extended and sustained periods of training and match load in elite soccer players.

In the present study, small significant increases in sub-maximal heart rate (HRex) were associated with increases in both the previous days THIR and 4-day total THIR. Contrastingly, Buchheit et al. (2013) found a large negative correlation between daily training load and sub-maximal heart rate suggesting a reduction in heart rate following increases in training load. However, this data was collected during a short pre-season AFL training camp in the heat where environmental and/or training induced changes in plasma volume are more likely responsible than alterations stemmed solely from the previous days training load (Buchheit et al., 2013). Reductions in heart rate have also been observed in athletes involved in extremely high training loads (Le Meur et al., 2014). Indeed, sub-maximal heart rate during intensified training intensities showed significant reductions in overreached triathletes. Le Meur and colleagues (2013) suggested the cause of this reduction in heart rate to be a hyper-activation of the parasympathetic nervous system via central, cardiac and/or periphery mechanisms (Le Meur, Hausswirth, et al., 2013; Le Meur, Pichon, et al., 2013). In contrast to Le Meur and colleagues (2013) the results of the current study suggest although speculative, an acute stimulation of the sympathetic nervous system thus increasing HRex following a short continued period of training. Indeed, both in recreational marathon runners and world class rowers, a significant increase in sympathetic dominance following a training block in the lead up to competition has been observed (Iellamo et al., 2004; Manzi et al., 2009).

Sensitivity between HRR% and 2-4 day THIR accumulation was trivial and non-significant in the present study. Data from chapter 5 also failed to find a relationship between daily HRR% and THIR over a 17-day competitive period. In contrast, previous studies have observed responses between both acute and chronic training load and HRR. Borresen and Lambert (2007) found that HRR decreased with an increase in training load and subsequently a tendency for a faster HRR with a decrease in training load. The authors speculate, however, that the reduced HRR with an increase in training load may be explained by the severe increase in training load (TRIMP increased by 55%), potentially inducing overreaching, and hence a parasympathetic predominance as previously discussed (Le Meur et al., 2014). The use of HRex and HRR in healthy athletes to predict changes in performance or fatigue should be treated with caution and interpreted together with other measures of fatigue, such as perceived ratings of wellness (Buchheit et al. 2012; Buchheit 2014). As a consequence, if HR-derived assessments of fatigue/adaptation are to be effective in team sports a higher volume of assessments may be required. However, undertaking such measures may prove difficult with the large volume of athletes engaged in team sports (Buchheit 2014).

Future research is needed to understand more long-term fluctuations in fatigue variables in relation to individual load thresholds in elite soccer players. Perceived ratings of fatigue show particular promise as a simple, non-invasive assessment of fatigue status in elite soccer players in detection of acute multiple-day training load fluctuations for during an in-season competitive phase compared to the other markers of fatigue measured.

CHAPTER 7: MONITORING FATIGUE STATUS ACROSS TYPICAL TRAINING WEEKS IN ELITE SOCCER PLAYERS

This study was presented as an oral communication at the 4th World Conference on Soccer and Science (WCSS), Portland, USA 2014 and has been accepted and in press as a full manuscript in the International Journal of Sports Physiology and Performance. (Appendix, Chapter 11)

7 Monitoring fatigue status across typical training weeks in elite soccer players

7.1 Introduction

It is important to allow sufficient recovery between training sessions and competitions. An imbalance between training/competition load and recovery may, over extended periods of time contribute to potentially long-term debilitating effects associated with overtraining (Nimmo and Ekblom, 2007). Consequently, attention is increasingly being given to the evaluation of monitoring tools which may indicate the general fatigue status of athletes. These indicators include heart rate derived indices, (Buchheit 2014) salivary hormones, neuromuscular indices (Silva et al., 2014) and perceived wellness ratings (Buchheit et al. 2013; Gastin et al. 2013; Chapter 5).

Alongside reliability (Chapter 4) a valid marker of fatigue should be sensitive to variability in training load (Meeusen et al., 2013). Researchers have therefore examined the sensitivity of potential measures of fatigue to daily fluctuations in training load in elite team sport athletes (Buchheit et al. 2013; Gastin et al. 2013; Chapter 5). For example, in both elite Australian Rules Football (Buchheit et al., 2013) and elite soccer (Chapter 5) players, small to large and statistically significant correlations were reported between fluctuations in daily training load and changes in both perceived ratings of wellness and vagal-related heart rate variability indices. These findings suggest that such measures show particular promise as acute, simple, non-invasive assessments of fatigue status in elite team sport athletes.

Further evaluation of the validity of potential fatigue measures can be undertaken by examining their sensitivity to prescribed changes in training load over extended periods of time. Whilst these relationships have been examined in individual endurance based sports (Manzi et al., 2009; Plews et al., 2012), limited attention has been given to elite team sport athletes (Gastin et al., 2013), who are required to compete weekly and often bi-weekly across the competition period. Results derived from Chapter 6 demonstrated that sensitivity was not improved with accumulated training load compared to the subsequent day. A key component of the in-season and within-week training prescription resides around the need to periodise the training load in order to minimise player fatigue ahead of the weekly matches (Malone et al., 2014a). Gastin and colleagues (2013) recently reported that subjective ratings of physical and psychological wellness (fatigue, muscle strain, hamstring strain, quadriceps strain, pain/stiffness, power, sleep quality, stress and wellbeing) were sensitive to within-week training manipulations (i.e. improved steadily throughout the week to a game day low) in elite Australian Football players. However, to the best of our knowledge, no researcher has examined the sensitivity of simple, non-invasive potential measures of fatigue across in-season training weeks in elite soccer players. Since differences exist in the physiological demands between team sports it is important to determine which potential fatigue variables are sensitive to changes in load associated with specific sports. Therefore, our aim was to quantify any changes in perceived ratings of wellness and objective measures of vagal-related heart rate indices that occur across standard in-season training weeks in elite soccer players.

7.2 Methods

7.3 Participants

Twenty-nine soccer players (age 27 ± 5.1 years; height 181 ± 7.1 cm; 78 weight ± 6.1 kg) from the same team competing in the English Premier League participated in this study.

7.4 Experimental Design

Player training load was assessed on six days; on the pre-match day, match-day and one, two, four and five days after the match across standard training weeks (no mid-week match; median of 3 weeks per player; range = 1-13) during the 2012/2013 in-season competitive period (August to May). Players were required to complete a minimum match duration of 60-min in order for their weekly data to be included in the present study. Players did not train and were given a day off three days after a match. Players took part in normal team training throughout the period as prescribed by the coaching staff. Players performed a range of recovery interventions the day following the match including low-intensity cycling, foam rolling and hydrotherapy. All players were fully familiarised with the assessments in the weeks prior to completion of the main experimental trials.

Fatigue measures were assessed on the day prior to the match and one, two and four days following the match. On the day of the fatigue assessments (perceived ratings of wellness, sub-maximal heart rate, heart rate recovery and heart rate variability), players arrived at the training ground laboratory having refrained from caffeine and alcohol intake at least 12-hours prior to each assessment point. Fatigue measures were subsequently taken prior to the players commencing normal training. All trials were conducted at the same time of the day in order to avoid the circadian variation in body temperature (Reilly and Brooks, 1986). Players were not allowed to consume fluid at any time during the fatigue assessments. The study was approved by Liverpool John Moores University Ethics Committee. All players provided written informed consent. Prior to inclusion into the study, players were examined by the club physician and were deemed to be free from illness and injury.

Training Load Assessment Individual player daily training load was monitored throughout the assessment period. Load (RPE-TL, arbitrary units, AU) was estimated for all players by multiplying total training or match session duration (min) with session ratings of perceived exertion (RPE). (Foster et al., 2001) Player RPE was collected within 20-30-min following cessation of the training session/match (Gaudino et al., 2015).

Perceived ratings of wellness

Perceived ratings of wellness were measured as described in Chapter 3 section 3.

3.

Submaximal heart rate (HRex), Heart rate recovery (HRR) and Heart rate variability (HRV)

HRex, HRR and HRV were measured as described in Chapter 3 section 3.

7.5 Statistical Analysis

We assumed that if an indicator of fatigue was not, at the very least, sensitive to differences between the different loads on pre-match day and the post-match day, it cannot be considered useful. Therefore, for the purpose of our sample size estimation, our primary comparison was between the pre-match and post-match days. In a previous study, coefficients of variation of approximately 10% have been reported for the indicators of fatigue we studied. (Chapter 4) Using this information of within-subjects variability, we estimated that a sample size of 29 would allow the detection of a difference in fatigue between pre- and post-match days of approximately 9% (two-tailed paired t-test, 90% statistical power, $p<0.05$).

A within-subjects linear mixed model was used to quantify mean differences between days along with the respective 95% confidence intervals. It is difficult to ascertain the exact relative influence of each study outcome on the actual performance of a soccer team, e.g. the standard effect size of a particular outcome may be high in response to training or an intervention, but the relative influence of this outcome on actual soccer performance may be low, (Atkinson, 2003) Nevertheless, standardised effect sizes, estimated from the ratio of the mean difference to the pooled standard deviation, were also calculated for each study outcome and interpreted in the discussion section. Effect size (ES) values of 0.2, 0.5 and 0.8 were considered to represent small, moderate and large differences, respectively (Cohen, 1992). When the model residuals were skewed or heteroscedastic, data were log-transformed and re-analysed. We adopted the least significant difference approach to multiple comparisons in line with the advice in (Bland and Altman, 1995; Perneger, 1998).

7.6 Results

Training load: The RPE-TL was greatest on match-day **(**≈ 600 AU)**.** The peak-trough difference in RPE-TL was approximately 550 AU (95% CI 546-644 AU) between match-day and the following day ($P<0.001$). The RPE-TL progressively decreased by ≈ 60 AU per day over the 3 days prior to a match ($P<0.05$) (Figure 7-1).

Perceived ratings of wellness: All the wellness outcomes showed a 35-40% worsening on the post-match day vs the pre-match day. The 95%CIs for these changes were 1.2-1.6 AU, 1.0-1.5 AU and 1.1-1.5 AU for perceived fatigue, sleep quality and muscle soreness, respectively ($P<0.001$). Wellness outcomes then improved by 17-26% between post-match day and two days post-match. The 95%CI for these changes were 0.7-1.1 AU, 0.7-1.2 AU and 0.4-0.9 AU for perceived fatigue, sleep quality, and muscle soreness. Wellness ratings then remained relatively stable between the second and fourth day post-match. Further smaller (7-14%) improvements occurred between the fourth day post-match and pre-match day ($P<0.01$). The 95% Cis for these changes were 0.2-0.6 AU, 0.1-0.6 AU and 0.4-0.7 AU for perceived fatigue, sleep quality and muscle soreness (Table 7-1).

Heart rate indices: There were no substantial or statistically significant changes in HRex, HRR% and HRV over all the weekdays ($P>0.05$) (Table 1).

Table 7-1: Perceived ratings of fatigue, sleep quality and muscle soreness (AU) and HRex (bpm), HRR (%) and Ln rMSSD (ms) across in-season training weeks (mean + SD).

	Day			
Fatigue measure	**Post-match day**	**2 days post-match**	**4 days post-match**	**Pre-match day**
Fatigue (AU)	3.4 ± 0.6 †	4.4 ± 0.7 † +	4.5 ± 0.7 † +	5.0 ± 0.6
Sleep quality (AU)	3.9 ± 1.2 †	4.8 ± 0.9 † +	4.7 ± 1.0 †	5.2 ± 0.8
Muscle soreness (AU)	3.6 ± 0.6 †	4.3 ± 0.7 † +	4.4 ± 0.7 † +	5.1 ± 0.8
HRex (bpm)	119 ± 13	117 ± 14	119 ± 15	118 ± 13
HRR (%)	72.1 ± 7.7	71.5 ± 7.5	70.2 ± 7.7	70.9 ± 7.1
Ln rMSSD (ms)	3.31 ± 0.71	3.44 ± 0.69	3.28 ± 0.76	3.33 ± 0.64

† denotes sig. difference vs pre-match day. + denotes sig difference vs post-match day. Scores of 1-7 with 1 and 7 representing very, very poor (negative state of wellness) and very, very good (positive state of wellness respectively)

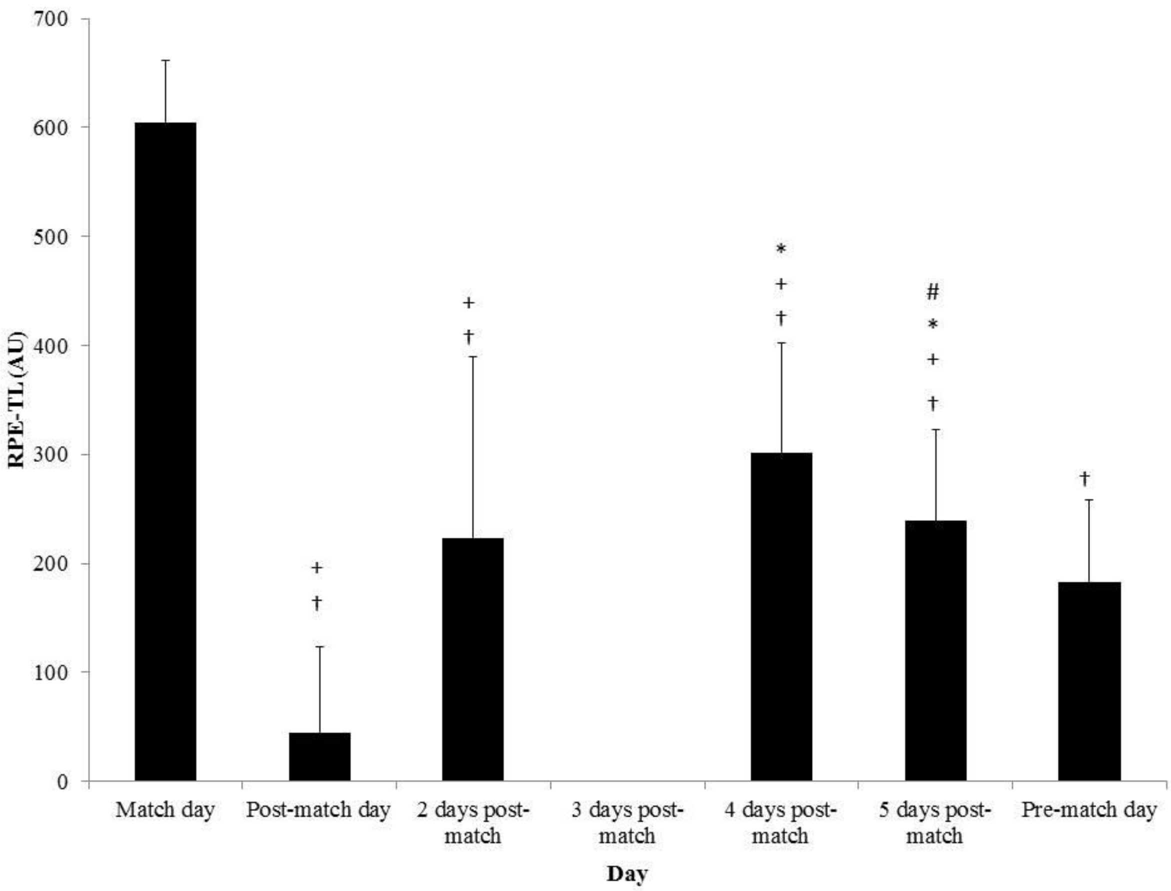

Figure 7-1: Training load (AU) across in-season training weeks (mean + SD)

† denotes sig. difference vs match-day. + denotes sig. difference vs pre-match day. * denotes sig. difference vs two days post-match. # denotes sig. difference vs four days post-match..

7.7 Discussion

The aim of the present study was to quantify the mean daily changes in training load and parallel changes in potential fatigue measures across in-season training weeks in elite soccer players. The main finding was that perceived ratings of wellness but not HR-derived indices are sensitive to the fluctuations in training load experienced by elite soccer players across in-season training weeks which involve only one match per week (no mid-week match).

Elite soccer players are required to compete on a weekly and often bi-weekly (mid-week game) basis with additional training administered in-between matches. Training load prescribed by coaches should therefore serve to ensure that fatigue is reduced on the days when players are engaged in competition. In the present study, only training weeks containing no mid-week game were used in order to examine changes in fatigue across a 'standard' training week. A clear attempt to periodise training load across the week was currently observed with the lowest load prescribed the day following a match with large (ES >1.3) and statistically significant increases in training load prescribed two and four days following the match. During the two subsequent days (fifth day post-match and pre-match day) there was a moderate (ES=0.7) and statistically significant reduction in training load in the lead into the next game (Figure 7-1). So far, little information currently exists with regards to the patterns of training load undertaken by elite soccer players (Jeong et al., 2011; Malone et al., 2014a). Interestingly, the pattern of training load exhibited in the present study differs to that seen in recent observations in Premier League players where only a reduction in daily training load was observed one day prior to a match compared to the other training days (Malone et al., 2014a). However, Malone and colleagues (2014) analysed all training weeks throughout the in-season competition period including those containing a mid-week game. The combination of this and dissimilarities in coaching philosophy and training methodology likely explain the difference in training load periodization to the current study. Further research is warranted to explore the patterns of training load experienced by elite players across different phases of the season.

Perceived ratings of wellness represent an increasingly popular method to assess athlete fatigue. Recent work in both elite soccer (Chapter 5) and Australian Rules Football (Buchheit et al., 2013) players demonstrated that such ratings are sensitive to daily fluctuations in training load. Further information concerning the validity of potential markers of fatigue can be derived by examining their sensitivity to prescribed changes in training load over extended periods of time. Whilst these relationships have been examined in individual endurance based sports (Manzi et al., 2009; Plews et al., 2012) limited attempt to date has been made to determine the sensitivity of tools for monitoring fatigue over extended periods of time in elite team sport players (Gastin et al., 2013). In the current study, the between-day changes in perceived wellness across the weekly training cycle closely reflected the prescribed distribution of training load. Moderate-to-large (ES 0.5-2.4) statistically significant changes (35-40 %) in perceived ratings of fatigue, sleep quality and muscle soreness were observed across the training week with the greatest and least amount of perceived fatigue, sleep quality and muscle soreness reported on the day following and the day prior to a match respectively (Table 1). These observations are consistent with findings in Australian Football where perceived ratings of fatigue, muscle strain, hamstring strain, quadriceps strain, pain/stiffness, power, sleep quality, stress and wellbeing improved by ~30% throughout the week (Gastin et al., 2013). Interestingly, previous work in elite soccer examining the sensitivity of perceived ratings of muscle soreness and sleep quality to acute daily fluctuations in training load failed to observe any association. (Chapter 5) However, any effect of training and match load on muscle soreness and sleep quality, in particular the effects of match-play may materialise over a number of days rather than immediately following the session (Nédélec et al., 2012). Collectively, previous observations examining daily sensitivity in elite soccer (Chapter 5) and Australian Rules players (Buchheit et al., 2013; Gastin et al., 2013) combined with the present findings suggest that attempts to fully examine the sensitivity of potential markers of fatigue to changes in training and match load should be undertaken over both acute (daily) and extended periods of time.

The increased perception of fatigue, poor sleep and muscle soreness currently observed following match play is consistent with changes in biochemical status and reduced physical and neuromuscular performance observed in the hours and days following soccer competition (Andersson et al., 2008; Ispirlidis et al., 2008; Fatouros et al., 2010; Magalhães et al., 2010; Jeong et al., 2011). In contrast to many of the latter assessments, perceived wellness scales represent a valid, time efficient and non-invasive means through which to derive information pertaining to a players fatigue status. Such characteristics are important during the in-season competitive phase, particularly during periods when players are required to compete in two or three matches over a 7-day period where time constraints may restrict the use of more invasive tests, and maximal performance tests may further debilitate the physical status of players and/or increase the risk of injury (Carling et al., 2015). In the present study, perceived ratings of fatigue and muscle soreness remained similar over the second and fourth day post-match despite a rest day three days after a match. This plateau may be due to the magnitude of the training load assigned two days post-match (224 ± 166 AU) which provided sufficient stimulus to blunt a linear improvement in player fatigue/recovery four days post-match and/or the fact that players were relatively well recovered two days post-match (fatigue 4.6 AU; sleep quality 4.8 AU; muscle soreness 4.3 AU). Interestingly, the progressive reduction in training load during the three days leading into a match was accompanied by further moderate-to-large (ES 0.6-0.9) statistical significant improvements in perceived wellness the day prior to a match (fatigue 5.0 AU; sleep quality 5.1 AU; muscle soreness 5.2 AU) which suggests the players were still not fully recovered four days post-match (Table 7-1). The time required to fully recovery following match play has been shown to vary markedly (24-72hr) depending on the nature of the physiological parameter assessed (Nédélec et al., 2012). Furthermore, the rate of recovery is likely to be influenced by a myriad of factors including the inherent variability in match demands (Gregson et al., 2010) and the athletes level of fitness (Johnston et al., 2015). Alongside the changes in perceived ratings of fatigue and muscle soreness, moderate-to-large (ES 0.6-1.4) statistical significant changes in ratings of sleep quality were also observed across the week with the highest and lowest levels of sleep quality observed during the evening of the fifth day post-match and the evening immediately following a match respectively. These changes indicate the severe debilitating effects of the match on perceived ratings of sleep quality. Indeed muscle soreness, inflammation, nervous system activity and central excitation have all been reported as potential mechanisms of poor sleep following competition (Fullagar et al., 2015). Interestingly, data from elite endurance athletes have frequently shown reductions in sleep quantity the night prior to competition (Lastella et al. 2015). Perceived ratings of sleep were not measured the night prior to matches in the present study and therefore a reduction may have occurred. Future work is required in order to further understand the effects of training and match load on perceived and objective measures of sleep quality.

Heart rate (HR) indices (HRex, HRV and HRR) have recently been proposed as a non-invasive method to measure variations in the autonomic nervous system (ANS) in attempt to understand athlete adaptation/fatigue status (Buchheit 2014). The use of vagal-related time domain indices such as Ln rMSSD compared to spectral indices of HRV have been found to have greater reliability and are ideal for assessments undertaken over shorter periods of time (Al Haddad et al., 2011; Esco and Flatt, 2014). Recent work in elite soccer players observed small (r=0.2), significant correlations between daily fluctuations in training load and Ln rMSSD (Chapter 5). Similarly, in Australian Rules Football players undergoing pre-season training, very large (r=0.80) and moderate (r=-0.40) significant correlations were observed between daily training load and sub-maximal heart rate (HRex) and a vagal related index of HRV (LnSD1) (Buchheit et al., 2013). In the present study, HRV (LnrMSSD), HRex and HRR (%) remained unchanged across the training week (Table 7-1) despite the large statistical significant fluctuations in training load (Figure 7-1). This suggests that in contrast to perceived ratings of wellness, such indices lack the sensitivity to provide information concerning changes in the fatigue status of elite soccer players across in-season training weeks. It should be noted that the average daily training load in the current study (RPE-TL 228) is considerably lower than that reported during an AFL pre-season training camp (RPE-TL 746) where daily readings of HRex and HRV were negatively and positively associated with load respectively. It is therefore possible that the magnitude of the fluctuations in daily training load across the training week in the current study were insufficient to elicit changes in HRex and HRV (Buchheit et al., 2013). Alternatively, the shorter seven-day period over which observations were made in the current study may not have been sufficient to detect any physiological change. Indeed data derived from elite triathletes and adolescent Handball players suggests the use of a single data point could be misleading for practitioners due to the high day-to-day variation in these indices (Plews, Laursen, Stanley, et al. 2013a; Buchheit 2014). In elite triathletes when data were averaged over a week or using a 7-day rolling average significant large correlations were found with 10-km running performance compared to a single assessment point where negligible relationships were seen (Plews, Laursen, Stanley, et al. 2013a). Additionally, changes in monthly HRV measurements were not sensitive to changes in performance indices in young Handball players (Buchheit, 2014). Future research is needed to establish whether sensitivity of HR indices are seen over longer training periods in elite soccer players.

Perceived ratings of wellness are clearly more sensitive than HR-derived indices to the within-week fluctuations in training load experienced by elite soccer players during typical in-season training weeks. Therefore perceived ratings of wellness show particular promise as simple, non-invasive assessments of fatigue status in elite soccer players throughout typical in-season weeks in elite soccer players.

CHAPTER 8: SYNTHESIS OF FINDINGS

8 Synthesis of Findings

The aim of this chapter is to interpret and integrate the findings obtained within this thesis. The possible applications and limitations will be discussed. The realisation of the aims of the thesis will be confirmed prior to reviewing the original hypotheses. Within the general discussion and conclusions that follow, the results of the individual studies will be interpreted with respect to the monitoring of fatigue in elite soccer players.

8.1 Realisation of aims

The experimental sections of this thesis have fulfilled all the aims stated in Chapter 1. The reliability of a range of potential morning-measured fatigue variables in elite soccer players was initially determined (Aim 1). This permitted correct experimental procedures (including statistical power calculations) to be formulated for successful completion of future experimental work. Perceived ratings of wellness, CMJ, HRex, HRR, HRR%, Ln rMSSD demonstrated good reliability with the absence of statistical bias. Moreover, sample size estimations derived from MPID indicated that these measures could be applied within feasible squad sizes typically observed in elite soccer, therefore applicable for future experimental work. The sensitivity between morning-measured markers of fatigue and daily changes in training load was then quantified (Aim 2). Perceived ratings of wellness and HRV (Ln rMSSD) were found to be sensitive to daily changes in training load (total high-intensity running distance) in elite soccer players. To determine whether morning-measured markers of fatigue were related to changes in training load over more extended periods was then established. Sensitivity of varying degrees of acute training load accumulation (mean of days 1-4) to fatigue measures was analysed (Aim 3). These findings demonstrated that perceived ratings of wellness, particularly fatigue was significantly sensitive to 1-4 days training load accumulation. The sensitivity of all other morning-measured fatigue markers to changes in training load was not improved when compared with training loads beyond the previous days training, although small changes in HRex over 4-day THIR were observed. Only modest correlations were found between daily HRV (Ln rMSSD) and training load in Chapter 5, therefore it may be that increased sensitivity of HR-indices may only occur over more extended periods of time.

The sensitivity of fatigue measures across competitive in-season weeks was analysed (Aim 4). Perceived ratings of wellness but not HR-indices were found to fluctuate across competitive weeks in parallel with training load.

8.2 General Discussion

The aim of this thesis was to investigate whether a range of potential morning-measured fatigue variables were reliable and sensitive in relation to varying degrees of training load in elite soccer players. Methodological, theoretical and practical implications of the reliability of morning-measured fatigue variables and the sensitivity to acute and chronic training load will be discussed.

Chapter 4 was concerned with evaluating the reliability of a range of potential morning-measured fatigue variables to determine whether such markers could be used in future chapters to quantify the fatigue status of elite soccer players. In Chapter 4, %CV reported for all potential fatigue measures was in line with previous observations found in other team sports and endurance athletes (Al Haddad et al. 2011; Cormack, Newton, McGuigan & Cormie 2008; Lamberts et al. 2010). The high physical demands and frequent competition required in elite soccer mean that assessment of fatigue measures is likely performed on a daily basis. Factors that influence reliability can come from several sources including biological and mechanical variability (Hopkins, 2000), therefore, reliability trials of such measures should be implemented on successive days (Atkinson and Nevill, 1998). Chapter 4 documents the first report to provide sample size estimations for a range of potential fatigue measures. Indeed, based upon the smallest and the average minimum practically important difference (MPID) derived from existing data, all morning-measured fatigue variables with the exception of S-IgA proved feasible in elite soccer. Elite soccer teams typically comprise a squad of around 18-25 players, therefore, any potential physiological or fatigue measure with a required sample size above this would be, therefore, unsuitable for tracking mean changes in soccer players. The quantification of S-IgA via commercially available kits has become a popular method to assess the mucosal immunity in elite soccer players (Morgans et al. 2014a; Morgans et al. 2014b), however, daily assessment via this method may become expensive and time-consuming. Given the very large daily variability (63%CV) for S-IgA and a squad of 37 players required to detect meaningful changes, S-IgA would, therefore, be inappropriate in elite soccer.

Chapter 4 not only highlights the reliability of a range of potential fatigue measures to be used in subsequent chapters but also provides evidence that certain variables may or may not be useful to practitioners evaluating player fatigue status in the field. Perceived ratings of wellness including fatigue, muscle soreness and sleep provided good levels of reliability within a feasible sample size typically seen in elite soccer. This cheap, quick and inexpensive method provides a likely option for practitioners for quantifying potential fatigue status in elite soccer players. However, systematic bias was observed for sleep quality in Chapter 4. This is not surprising since the quality of sleep can be manipulated by many variables including hygiene and a number of cognitive, physiological and social factors which are difficult to control for, within the athletes training regime (Fullagar et al., 2015). Indeed, the importance of sleep quality in athletes has been well established (Mah et al., 2011; Fullagar et al., 2014) and, therefore, these results should be interpreted with care. The monitoring of perceptual ratings of sleep quality should be implemented and remains an important aspect for a fatigue monitoring framework in elite soccer players. Further evaluation regarding the use of perceptual ratings of sleep to monitor fatigue will be discussed later in this section. As a consequence of the findings in Chapter 4, ratings of perceived wellness (fatigue, sleep quality, muscle soreness), CMJ height and HR-indices (HRex, HRR% and Ln rMSSD) were used in subsequent chapters.

Chapter 5 is concerned with quantifying the relationships between a range of potential morning-measured fatigue variables and the subsequent day's training load in elite soccer players. This investigation would provide initial insights regarding the potential validity of such measures to detect changes in fatigue status in response to changes in training load. Large negative daily fluctuations in ratings of perceived fatigue were found to be significantly associated with changes in training load. Small positive and negative fluctuations of CMJ and HRV (Ln rMSSD) respectively were observed in Chapter 5, whilst trivial non-significant associations were found for all other measures. These findings confirm previous reports seen in Australian Rules Football (AFL) (Buchheit et al., 2013), although Buchheit and colleagues (2013) also observed daily sensitivity in ratings of muscle soreness, sleep quality and HRex, contrary to the results in the present study. Unsurprisingly, perceived ratings of fatigue was found to have the greatest sensitivity to training load compared to all potential fatigue measures. This may be due to perceived fatigue reflecting a global indicator of all stressed components following training/match load. Indeed, data derived from this thesis has demonstrated the multifaceted nature (perceptual, physiological, mechanical and neuromuscular) of fatigue in elite soccer. This, therefore, may indicate that perceived ratings of fatigue be utilised as a global representation of player fatigue status. The use of one quick, easy, inexpensive and time-efficient measure to quantify global fatigue status may be more practical when assessing a squad of soccer players on daily basis. On the other hand, the aforementioned multi-faceted nature of fatigue in soccer means this may be too crude an approach. Knowledge pertaining to the various elements of fatigue (perceptual, physiological, mechanical and neuromuscular) require different approaches, therefore, a multi-assessment strategy may be required in order to fully establish which particular systems alone, or in combination, are at risk or atypical on any given day. The small reduction in HRV (Ln rMSSD) (more sympathetic dominance) following increases in total high intensity running distance illustrates the potential application of this HR-derived measure, however, greater sensitivity may be found following a greater number of HRV assessments or following higher training load doses as previously reported in AFL and endurance athletes (Plews et al. 2013; Buchheit et al. 2013; Buchheit 2014). Non-significant small-to-trivial increases in HRex were observed in response to training load in the present study. Buchheit et al (2013) found very large HRex reductions in response to intensified daily training load in AFL players during a short pre-season camp. It is, therefore, possible that the magnitude of fluctuation in daily training load in the current study was insufficient to elicit greater physiological changes in HRex and HRV (Buchheit et al., 2013). Indeed, the average daily training load in the current study (RPE-TL 361) is considerably lower than that reported during an AFL pre-season training camp (RPE-TL 746) where daily readings of muscle soreness and sleep quality were associated with changes in load (Buchheit et al., 2013). Surprisingly, a positive relationship was found between changes in CMJ height and training load, speculatively indicating a possible potentiating effect of training load. Recent investigations investigating the effect of CMJ height performance in team sports have also failed to observe sensitivity to changes in load (Malone et al., 2014b; Gibson et al., 2015). However, data derived from AFL have shown that more sensitive neuromuscular parameters (flight time:contraction time ratio) have changed in response to changes in training load over the course of season (Cormack, Newton, McGuigan and Cormie, 2008). Furthermore, neuromuscular parameters (eccentric, concentric, and total duration, time to peak force/power, flight time:contraction time ratio) derived from CMJ have been found suitable for detection of neuromuscular fatigue. Reductions in 18 different neuromuscular variables were found following a high-intensity fatiguing protocol in college-level team sport athletes (Gathercole et al. 2015). Future work investigating these alternative measures of neuromuscular performance and changes in training load may be required.

Changes in perceived muscle soreness and sleep quality have been previously found to worsen in relation to daily increases in training load (Buchheit et al., 2013). Chapter 5 failed to observe changes in these perceived measures following daily changes in total high intensity running distance (THIR). This may partly reflect the fact that previous observations in AFL players (Buchheit et al., 2013) were made during the pre-season period where the high volume and intensity of training may lead to greater disturbances in perceived ratings of sleep and soreness. Moreover, only two competitive matches were played during the 17-day experimental period in Chapter 5, consequently the limited match exposure and training intensity may not have been sufficient to influence changes in muscle soreness and sleep quality. In soccer, the high frequency of competition during the in-season phase means training is more focused around recovery and maintaining physical fitness which may lead to lesser changes in perceived ratings of sleep and soreness across a typical training week. Moreover, previous reports of sleep quality in elite athletes have found deficits during the night preceding competition (Leeder et al. 2012; Lastella, Gregory et al. 2015). The current study design would therefore not highlight whether sleep was affected around matches in elite players. Another general limitation may be the use of perceptual ratings of sleep quality as opposed to more objective methods. Previous reports in endurance athletes have criticised the method of self-report sleep logs when compared to wrist actigraph devices (Leeder et al., 2012). It is, therefore, possible that the athletes in the current study may have under- or over-estimated sleep quality and hence sensitivity was not observed. Future work may be required to investigate the changes in objective measures of sleep quality and changes in training load in elite soccer players. Chapter 5, although statistical limitations regarding measure variance existed, variables were identified that are sensitive to training load in elite soccer players during a typical in-season training period. Furthermore, due to its frequent use by practitioners, THIR distance was employed in the present study as an index of training and match load in an attempt to quantify the load incurred by elite players during training and match-play (Malone et al., 2014a). However, THIR distance may underestimate the true load incurred by players since it does not account for the stress associated with accelerations and decelerations which frequently occur during soccer. (Gaudino et al., 2013). Although, a sound rationale for the use of THIR distance in Chapter 5 was evident, other measures of training load do exist. Indeed, a recent study has shown total distance to be sensitive as a predictor for injury risk in elite Rugby players (Hulin et al., 2015). Furthermore, the use of intertial analysis via accelerometers has been shown possibly to provide data relating to neuromuscular fatigue (Buchheit et al., 2015). The utilisation of a range of training load variables both relating to internal and external factors may provide greater information regarding sensitivity of fatigue measures. Another viable explanation for the lack of sensitivity in muscle soreness and sleep quality may be that the mechanisms involved manifest themselves over a number of days rather than solely the subsequent day's training load exposure. Therefore, the successive investigation (Chapter 6) would aim to observe daily changes in fatigue measures with changes in acute training load accumulation.

The result of Chapter 5 may imply that it is possible that the relationship between morning-measured variables of fatigue and training load may vary as a function of the number of accumulated training days. Consequently, the aim of Chapter 6 of the thesis was to examine the sensitivity of potential morning-measured fatigue variables to short term (acute) training load accumulation in elite soccer players. Perceived ratings of fatigue were, and remained significantly correlated to the subsequent and

2-, 3- and 4-day THIR distance respectively, providing further support for its use as a global measure of fatigue status. Perceived ratings of muscle soreness, sleep quality and HRR did not correlate to any THIR day while HRV (Ln rMSSD) and CMJ correlated to the previous day's training load only as aforementioned. This data may support the notion that HRV is sensitive to large acute high intensity exposures. This is also supported by previous data showing acute HRV sensitivity to daily training load in AFL players (Buchheit et al., 2013) and also a dose response relationship has been observed in endurance athletes (Kaikkonen et al., 2012) with greater sympathetic activity associated with larger training load bouts. This information can provide valuable insight relating to training load prescription and post-training interventions, in particular methods targeting parasympathetic reactivation such as cold water immersion (Buchheit, Peiffer, et al., 2009; Al Haddad et al., 2010; Douglas et al., 2015). The primary observations arising from this study indicate that increasing the number of training days does not improve the sensitivity of the fatigue measures in elite soccer players. A potential explanation for this may be that the number of accumulating days (1-4) was not sufficient enough to provide a true indication of load accumulation in soccer players. Elite soccer players are required to compete over the course of a 9-11-month season comprising a high frequency of competition. The results of the present investigation may be more associated with acute training load accumulation, and that future investigations should attempt to quantify the effects of training load accumulation over longer periods which may relate more to the chronic demands of elite soccer.

Interestingly, HRex showed significant small increases following increases in 4-day training load accumulation only. These findings may support the usefulness of HR-indices over more extended periods which have been observed in endurance athletes

(Plews et al. 2013). Further data derived from endurance sports have shown increases in sympathetic activity in relation to increases in training load (Uusitalo et al., 2000; Iellamo et al., 2002). Potential mechanisms proposed include a remodelling of the sinoatrial node, a down-regulation of the sympathetic nervous system, a decrease in norepinephrine and epinephrine excretion and/or a down-regulation of sinus node beta receptors. In AFL, Buchheit et al (2013) found very large negative changes in HRex in response to training load during a pre-season training camp, whilst contrasting data derived from overreached elite endurance athletes showed reductions in sub-maximal heart rate (Le Meur et al., 2014). Although environmental and/or training factors have been proposed for the large reductions in HRex found in AFL players, Le Meur and colleagues suggested a dampening of the autonomic nervous system (ANS) via potential mechanisms noted above, thus increasing parasympathetic activity causing reductions in heart rate. There appears to be differences in the directional change of ANS derived HR-indices following extended periods of training load. This may imply that the exact response of the ANS may involve various stages. Indeed, a recent investigation suggested that four different representations of HRV arrangement may exist over the course of 4-years in Nordic skiers (Schmitt et al., 2015). This data indicates that interpretation should be carefully constructed when evaluating athlete physiological fatigue status using HR-indices. Interpretation based upon HR-indices should, therefore, consider contextual confirming data, such as wellness scales and analyse HR fluctuations from the norm irrespective of directional change. Further work to improve understanding of the relationships between HR-response directional change, fatigue typology and physiological response is required to further enhance athlete/player care.

The absence of sensitivity of perceived sleep quality and muscle soreness to training load accumulation may be explained by the assessment period or relative degree of load previously discussed in Chapter 5. Furthermore, when accruing load over time, the magnitude of physical disturbance will be reduced, thus a reduction of sensitivity in sleep quality and muscle soreness. This was the first report investigating the relationship between potential fatigue measures to short term training load accumulation in elite soccer players, however, it must be noted that the sample size was small and a 17-day period may not be a true indication of an entire season. The results of the Chapter 6 demonstrate the validity and sensitivity of perceived ratings of fatigue to both the subsequent day and acute training load accumulation in elite soccer players. Furthermore, the results of the present study confirm the limited sensitivity of perceived ratings of sleep quality and muscle soreness and HRR to daily changes in subsequent and acute training load accumulation. This, therefore, provides novel information regarding the acute monitoring of fatigue status in elite soccer players.

The final aim of the thesis was to investigate whether changes in training load and morning-measured fatigue variables followed a similar pattern across competitive weeks in elite soccer players. Since players are required to compete weekly and often bi-weekly across the competition period, a key component of the in-season weekly training prescription revolves around the need to periodise the training load in order to minimise player fatigue ahead of the weekly matches. Chapter 7 showed a 35-40% worsening from pre-match day to post-match day in all the wellness outcomes (perceived fatigue, sleep quality and muscle soreness). Also, a 17-26% improvement between post-match day and two days post-match was observed. Similar wellness was then observed during the middle of the week before a small (7-14%) improvement between the fourth day post-match and pre-match day. HR-derived indices (HRV, HRR and HRex) were not sensitive to the within-week fluctuations in training load. These observations are consistent with findings in AFL where perceived ratings of fatigue, muscle strain, hamstring strain, quadriceps strain, pain/stiffness, power, sleep quality, stress and wellbeing improved steadily (30%) throughout the week (Gastin et al., 2013). In the present study, perceived ratings of sleep quality and muscle soreness changed significantly across the week (35-40%) with the highest and lowest levels of sleep quality and muscle soreness observed on the day before and after the match respectively. In previous chapters acute changes in training load failed to alter sleep quality in the sample of soccer players. These changes indicate the severe debilitating effects of the match on perceived ratings of sleep quality and muscle soreness and may explain the lack of sensitivity seen during competitive periods in previous chapters where the limited match exposure and training intensity may not have been sufficient to influence muscle soreness and sleep quality. Practically, this provides evidence indicating the importance of recovery strategies in the hours and days following match-play. Moreover, training load prescription in the days following matches should be periodised with care and avoiding large amounts of high eccentric activities which may further debilitate fatigue status or increase risk of injury. It appears that fatigue measures are mainly more sensitive to the previous day's training/match load rather than load accumulated over a number of days during a short period. This observation shows a similar effect and provides further validation to the results seen in Chapter 5 and 6, where seemingly morning-measured fatigue variables are most sensitive to the previous day's training load.

In the present study, HRex, HRV (Ln rMSSD) and HRR (%) remained unchanged across the training week despite the large, significant fluctuations in daily training load. This suggests that, in contrast to perceived ratings of wellness, such indices lack the sensitivity to provide information concerning changes in the fatigue status of elite soccer players across typical in-season training weeks. One potential reason for the lack of sensitivity in the present study, compared to that of a recent investigation in AFL (Buchheit et al., 2013), may be that the training load was not of sufficient intensity to alter the autonomic nervous system. Secondly, data derived from elite triathletes and adolescent Handball players suggest the use of a single data point could be misleading for practitioners due to the high day-to-day variation in these indices (Plews, Laursen, Stanley, et al. 2013a; Buchheit 2014). In elite triathletes, when data were averaged over a week or using a 7-day rolling average, significant large correlations were found with 10-km running performance compared to a single assessment point where negligible relationships were seen (Plews, Laursen, Stanley, et al. 2013a). Additionally, changes in monthly HRV measurements were not sensitive to changes in performance indices in young Handball players. (Buchheit 2014). Whilst sensitivity was not observed in this study, data from Chapter 5 suggest HRV may be sensitive to changes in daily high intensity load exposures. With this in mind, prospective work should aim to evaluate ANS HR-response following competitive matches in elite soccer players. The present findings suggest that attempts to fully examine the sensitivity of potential markers of fatigue to changes in training and match load should be undertaken over both acute (daily) and extended periods of time. Therefore, it is concluded that the use of perceived wellness measures is a simple, efficient and non-invasive method of assessing player fatigue status during in-season training weeks in elite soccer players.

8.3 Practical Applications

A challenge for all sports science and medical practitioners is to establish daily player physiological/fatigue status prior to the start of a training session. Training preparation, prescription and recovery require, ideally, a multidisciplinary evaluation from a range of stakeholders including the player, technical coaches/management, medical and sports science personnel. The results of this thesis have shown that simple, ratings of perceived wellness are reliable and sensitive to short training and competition phases and thus may be a suitable strategy for practitioners to use in the attempt to establish fatigue status in elite soccer players. There may also be other benefits associated with this approach. These have been identified through the practical application of these approaches during the periods in which the data has been collected for this thesis. Player engagement via this process can be used to further understand player lifestyle habits, behind the particular physiological/fatigue response. For example, the specific location or particular anatomy of muscle soreness reported can be established. Furthermore, repeated reporting's of poor sleep quality and/or perceived fatigue may prompt further medical investigation or player sleep hygiene education. The initial use of perceived ratings of wellness can also create avenues for the further assessment of various physiological systems. For instance, elevated perceived muscle soreness may prompt further investigations into strength and/or range of motion focussed structural assessments. Such approaches may be used in order to explore potential anatomical disruption. . Information from such scales may also lead to further evaluation of the autonomic nervous system via HR-response assessment. For example, during periods of fixture congestion, players may suffer from potential debilitating symptoms associated with overreaching. Further investigation via the use of heart rate indices may provide greater insight to the responsiveness of the autonomic nervous system. This information can then be used to better guide training load/recovery intervention prescription for these individuals. Moreover, data derived from Chapter 5 revealed that HR-indices may be sensitive to large load exposures such as competitive matches. These measures, together with perceived ratings of wellness may be used to quantify and establish individual player recovery rates in the days following competition and whether the athlete is ready for a return to load exposure during the transition between match and return to training. Figure 8-1 depicts this process, and illustrates the transition from a match to return to training/load, whereby, a fatigue monitoring framework including daily perceived ratings of wellness and vagal related heart rate responses may guide prescription of load, recovery, further structural/anatomical assessment or medical intervention.

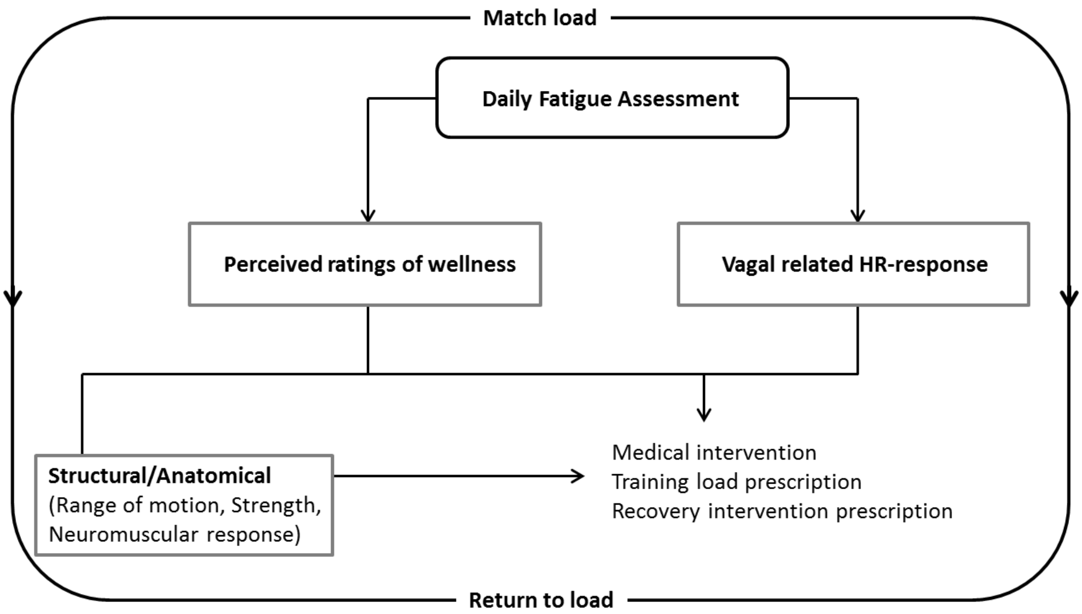

Figure 8-1 Fatigue monitoring framework illustrating process from match to return to load.

In summary, the quantification of player fatigue status may assist multi-departmental processes and guide coaches in their training prescription. The success of such a framework will be heavily influenced by the honesty and compliance of athletes and the buy-in of coaches and management. Therefore, effective feedback and player/coach involvement should be considered in order to establish an effective fatigue monitoring framework. . Future considerations should establish initial relationships between fatigue/physiological responses and performance/injury/illness outcomes in elite soccer players.

8.4 Conclusion

This thesis is the first investigation to examine, evaluate and quantify how potential measures of fatigue fluctuate in response to training and match load in elite soccer players. Chapter 4 documents the first report to evaluate the reliability estimates for potential measures of fatigue in elite soccer players', thereby, morning-measured fatigue variables comprising feasible sample size estimations in elite soccer were established. In light of this novel information, this thesis indicates the importance of quantifying and interpreting such errors when using applied methods to quantify fatigue status in elite soccer players. Chapters 5-7 investigate the daily and within weekly fluctuations in potential fatigue measures in response to changes in training load. The results confirm the findings from other team sports such as AFL, where perceived ratings of wellness, and to a certain extent HR-indices, are sensitive to acute changes in training load and across training weeks (Buchheit et al., 2013; Gastin et al., 2013). However, increasing the number of training days, thus accounting for residual load, does not improve the sensitivity of the fatigue measures. Perceived ratings of fatigue were sensitive to both daily and acute training load accumulation and also across competitive weeks in elite soccer players. However, perceived ratings of sleep quality and muscle soreness only changed across competitive weeks signalling the severe negative effects of competition on sleep quality and muscle soreness in elite soccer players. This may also support the notion that acute training load prescribed in elite soccer is not sufficient enough to alter changes in these measures. This thesis has outlined the initial observations required in order for practitioners to develop a framework/strategy for monitoring fatigue status in elite soccer. The differences observed between environmental infrastructure and coaching cultures in elite soccer indicate that selection, practicality and implementation of all available fatigue measures require important consideration. Practitioners should aim to obtain the greatest amount of data via available fatigue variables whilst limiting player physical and mental exertion. Overall, the application of perceived ratings of wellness may provide the most reliable, feasible and sensitive variable to quantify fatigue status in elite soccer players.

CHAPTER 9: RECOMMENDATIONS FOR FUTURE RESEARCH

9 Recommendations for Future Research

The studies completed within this thesis provided novel detail relating to the quantification of fatigue status in elite soccer players. Furthermore, insights into the determination of potential measures for tracking fatigue status were attained. In achieving this, a number of issues have arisen which have prompted the formulation of recommendations for further research.

Research proposals in response to the findings in Chapter 4

Chapter 4 is the first report of the prospective sample sizes required for monitoring fatigue status in elite soccer. Observations in Chapter 4 outlined that ratings of perceived wellness, CMJ, HRex, HRR% and Ln rMSSD all represent excellent methods for tracking changes in the fatigue status of a feasible sample size often seen in elite soccer. Methods and techniques used in Chapter 4 should, therefore, be used to quantify and establish reliability and sample size estimation for any potential prospective physiological monitoring or assessment tool. Previous data have shown that different aspects of player recovery, such as physical performance, neuromuscular and biochemical measures, are diminished following match-play for varying time periods (Andersson et al., 2008; Ispirlidis et al., 2008; Fatouros et al., 2010). Although the current thesis investigated potential fatigue measures relating to the physiological, autonomic nervous and psycho-physiological systems, a functional mechanical anatomical assessment was not included. Soft tissue muscle injuries are a common issue in elite soccer (Ekstrand et al., 2011), indeed 92%, of all muscle injuries comprised the 4-main lower limb muscle groups: hamstring; adductor; thigh and calf. A recent investigation observed good reliability (~10%) for a novel adductor and hip assessment in youth soccer players (Paul et al., 2014). Further research evaluating the reliability of a range of additional mechanical assessments quantifying hamstring, quadriceps and calf function in elite soccer players would, therefore, provide supplementary insights to the structural status of elite soccer players. Moreover, evaluating these assessments during competitive periods and their relationships to load would further provide insights into the validity and sensitivity in elite soccer.

Countermovement jump height (CMJ) showed very good reliability (4%CV) and, furthermore, feasible for monitoring in elite soccer in the present thesis. On the other hand, sensitivity to daily and acute training load accumulation was limited and, consequently, CMJ was considered unlikely to detect changes in neuromuscular fatigue status in elite soccer players. CMJ performed in the current thesis was measured using a traditional jump mat, however, the utilisation of force platforms has become popular over recent years due to the large quantity of force time parameters available for analysis (Gathercole et al. 2015). CMJ height alone may be too crude a measure in order to detect changes in training load, however, alternative CMJ derived neuromuscular parameters may prove sensitive to alterations in load. Indeed, kinetic and kinematic variables (eccentric, concentric, and total duration, time to peak force/power, flight time:contraction time ratio) derived from CMJ have been found suitable for detection of neuromuscular fatigue (Nibali et al., 2015). Additionally, decreases in 18 different kinetic and kinematic variables were found following a high-intensity fatiguing protocol in college-level team sport athletes (Gathercole et al. 2015). An alternative neuromuscular marker, flight time contraction time ratio, has been found to decrease across a season in AFL players indicating a sensitivity to increases in load over time (Cormack, Newton, McGuigan and Cormie, 2008). Whilst the vast majority of research investigating changes in countermovement jump performance have used traditional bilateral techniques, contempory technology has enabled the calculation of bilateral asymmetry from various jump protocols using a force platform (Gathercole et al. 2015). This method has been shown to be a reliable and valid method of detecting strength asymmetries in athletes (Impellizzeri et al., 2007). However, a potential limitation which must be noted is that the validity of CMJ relies on a maximal effort from participants, therefore, consideration for the utilisation of this method for assessing neuromuscular performance in elite soccer players in the days following match-play and/or large doses of THIR should be considered. Future research is required to investigate whether alternative force time measures of CMJ are sensitive to changes in training load in elite soccer players.

Research proposals in response to the findings in Chapter 5

The data derived from Chapter 5 indicated that daily changes in perceived ratings of fatigue, CMJ and Ln rMSSD were significantly correlated to daily changes in total high intensity running (THIR) distance. THIR distance was chosen as the criterion measure of load because of its frequent use in quantifying training load in elite soccer (Malone et al., 2014a). However, THIR distance will underestimate the true load incurred by the athlete since it does not account for the stress associated with the frequent accelerations and decelerations which occur during soccer (Gaudino et al., 2013). It should be noted, however, that initial analysis in this study highlighted a large correlation (r=0.57) between THIR distance and session ratings of perceived exertion (sRPE) which has previously been used as a global indicator of internal load in soccer players (Impellizzeri et al., 2004). Athlete tracking technology has advanced over recent years with the inclusion of intertial analysis embedded in global positioning system devices. This involves the inclusion of an accelerometer, magnetometer and gyroscope that allows for directional analysis across different anatomical planes. Inclusion of such technology allows the potential for novel metrics of player assessment to be generated, such as the metabolic cost of exercise. Future research should, therefore, investigate the relationships between novel inertial metrics and fatigue measures during competitive periods. Furthermore, the present study relates to the use of an absolute (>14.4.km/h) rather than individual thresholds to determine the high-intensity running speed (Abt and Lovell, 2009). Performance metrics (e.g. maximal speed, maximal aerobic speed and ventilatory thresholds) needed to generate individual speed thresholds were not available in the current sample of elite players. Future work should investigate whether the sensitivity between individual relative rather than absolute training load thresholds and potential measures of fatigue is improved.

Research proposals in response to the findings in Chapter 6

While the current investigation provided significant information regarding the sensitivity of potential fatigue measures to acute training load accumulation, the competitive period of 17-days may not have been long enough to establish relationships. Furthermore, the training load performed by players may not have been of sufficient intensity to render physical disturbance and thus alter changes in morning-measured fatigue variables. Results from the current thesis (Chapter 7) has shown the severe debilitating effects of match-play on sleep quality and muscle soreness, therefore, assessment periods comprising a high frequency of matches and/or training load accumulation over more extended and intensified periods such as pre-season may offer a more significant stimulus to observe sensitivity of load accumulation in elite soccer players.

Research proposals in response to the findings in Chapter 7

The final study in this thesis (Chapter 7) observed changes in perceived ratings of wellness but not HR-derived indices in-line with training and match load across competitive weeks in elite soccer players. Elite soccer players are required to compete over a 9-month season involving periods of severe fixture congestion. During these periods increased attention should focus on recovery between matches and, in turn, a reduction in training load. However, extended periods of increased load may cause more long term debilitating effects (Nimmo and Ekblom, 2007) in players, therefore, to understand how players respond to such periods, future research is required to investigate how wellness ratings, training and match load fluctuate over the course of a season in elite soccer players. HR-indices failed to change in response to training load across competitive weeks in the present study. Previous research in elite endurance athletes has found increased sensitivity to time trial performance when HRV data was averaged over a 7-day period compared to single data points (Plews, Laursen, Kilding, et al. 2013). Moreover, the short seven-day period over which observations were made in the current study may not have been sufficient enough to detect any physiological change in vagal related HR response. Future work is necessary to examine HR indices over the course of longer periods of the season and during periods of exceptionally high training/match loads such as pre-season.

Chapter 7 is the first report to show the fluctuation of perceived ratings of wellness across competitive weeks including following matches in elite soccer players. The time required to fully recovery following match play has been shown to vary markedly (24-72hr) depending on the nature of the physiological parameter assessed (Nédélec et al., 2012). Furthermore, the rate of recovery is likely to be influenced by a myriad of factors including the inherent variability in match demands (Gregson et al., 2010) and the athletes level of fitness (Johnston et al., 2015). Further research is needed in order to fully determine the exact rate of recovery of these measures in the days following matches in elite soccer players.

Ratings of perceived sleep quality were found to change in response to training load across competitive weeks, but not in response to daily or accumulated load (Chapter 5 and 6). Previous research has shown athletes may report poorly perceived sleep quality (Leeder et al., 2012), in fact, more recent work, predominantly in endurance athletes has utilised actigraph technology to objectively measure sleep quality in response to training and competition (Lastella, Gregory D Roach, et al., 2015). To the authors’ knowledge, no data exists evaluating sleep quality using actigraph technology in elite soccer players. Future work is required in order to further understand the effects of training and match load on objective measures of sleep quality in elite soccer.

CHAPTER 10: REFERENCES

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CHAPTER 11: APPENDIX

11 Appendix

MONITORING FATIGUE DURING THE IN-SEASON COMPETITIVE PHASE IN ELITE SOCCER PLAYERS

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MONITORING FATIGUE STATUS ACROSS TYPICAL TRAINING WEEKS IN ELITE SOCCER PLAYERS

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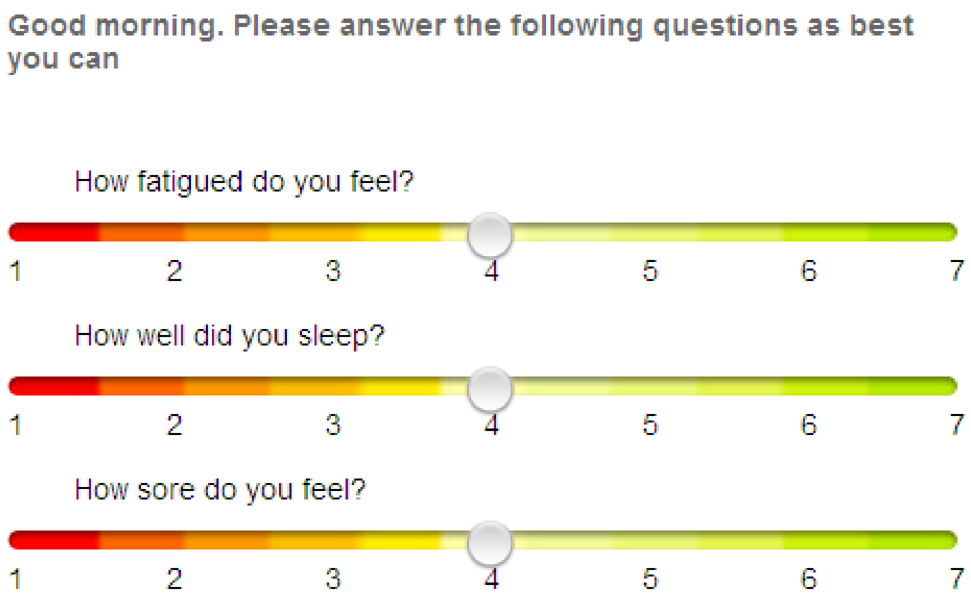
PERCEIVED RATINGS OF WELLNESS SCALES



Each question scored on a seven-point Likert scale [scores of 1-7 with 1 and 7 representing very, very poor (negative state of wellness) and very, very good (positive state of wellness) respectively].