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Training load monitoring in soccer: The dose-response relationships with fitness, recovery and fatigue

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Abstract

The congested fixture schedules in elite soccer leagues around the world has bought the issue of recovery between games and subsequent performance to the fore in soccer related research. Studies have described the time-course of recovery for numerous biochemical and physiological measures of performance, fatigue and recovery from match-play. However, the research also suggests that there is individual variation in the external load both between players and between matches. The external load measured as distance in match-play has been shown to vary by ~30% between games. However it is the internal training load that will determine the magnitude of the physiological responses on an individual basis. Therefore the major aim of this thesis was to examine the dose-response relationships between measures of training load and the physiological and biochemical responses used as markers of recovery from match-play. The thesis also assessed the relationships between these proposed markers of recovery and soccer specific performance.

In meeting the aims of the thesis a number of preliminary studies were conducted. The study in section 3 assesses the extent of fixture congestion in the English Premier League. The results showed over 30% of games for the most successful teams are played with 3 days recovery time, justifying the need for investigating recovery from soccer match-play. Given the variation in soccer match-play section 4 examines the reliability and validity of the modified BEAST$_{90}$ soccer simulation. A measure of performance with less variance would allow changes in soccer specific performance to be identified with greater certainty in section 7. Section 5 assesses the influence of intermittent exercise on the blood lactate response. Given that the new iTRIMP method of measuring internal training load weights exertion with the blood lactate response it was important to assess the influence exercise mode may have on the calculation of

internal training load. The results showed that at higher intensities intermittent exercise produced significantly higher blood lactate responses. Section 6 assesses the dose-response relationships between training and fitness using numerous measures of internal training load over a 6 week training period. The results showed only the iTRIMP method showed a significant relationship with changes in fitness. Section 7 assesses the dose-response relationships between exertion in soccer match-play and various physiological measures of fatigue and recovery. The relationships between these measures and changes in soccer specific performance were also assessed. Finally the internal and external load were integrated and the relationships of this ratio assessed with measures of fitness and performance. The results showed that changes in any of the physiological and biochemical measures used to assess recovery did not relate to changes in performance with the exception of testosterone which showed significant positive relationships with changes in distance covered from the 1st trial of the modified BEAST protocol to 2nd. Testosterone also was the only measure to show a significant relationship during the recovery period with any measure of training load (sRPE). Finally, the novel findings of this thesis is the relationships between the integrated ratio's of internal and external training load with measures of aerobic fitness is also presented in section 7.

The studies provided in this thesis have made a major contribution in demonstrating how data that is routinely collected at elite levels of soccer can be used more appropriately. It has also shown limitations of some the methods currently employed to measure training load. Furthermore changes in many of the markers used to assess recovery of soccer players do not seem to relate to changes in soccer specific performance. This may point to a change in paradigm which is required in both research and practice.

1 - Introduction

There are 265 million male and female soccer players across the world (FIFA, 2007) making soccer one of the most popular sports in the world. Soccer is now a multi billion pound industry, with The English Premier League (EPL) reported to have turned over 2.5 billion Euros during the 2009-10 season, an increase of 200 million Euros on the previous season and around 800 million Euros more than the nearest competitor the German Bundesliga (Deloitte, 2011). The commercialization of the game may be one of many contributing factors that has led to changes in competition structures, resulting in the top teams playing more matches in a season and sometimes three matches in a seven day period. For example, EPL matches at the weekend are split by a midweek European or a domestic cup competition match (Dupont, Nedelec, McCall, McCormack, Berthoin & Wisloff, 2010; Odetoyinbo, Wooster & Lane, 2007; Reilly & Ekblom, 2005). Strudwick (2007) classed a player capable of playing three matches a week as a 'high performance player' and also pointed out that not all players in the squad were capable of producing this type of physical output. The concept of a 'high performance player' is testament to the changing nature of the modern match. The effect of short recovery periods between matches on potential performance decline and the increasing likelihood of injury, both of which are of major importance to players and coaches has only recently been examined in the literature. There are very few studies examining the effects of a congested playing schedule on player performance and/or fatigue.

Odetoyinbo *et al*. (2007) examined the performance profile of 22 teams who had played three matches in a five day period in the EPL and the English Championship. They compared a range of physiological performance parameters. These included the total distance (TD) covered and distances covered in various categories (walking, jogging, running, high speed running and sprinting), the frequency of actions in these categories, the time spent in each category and the recovery time between high-intensity efforts. They also examined the distance covered at high-intensity (HID), defined as activity above speeds of 19.8 $km \cdot h^{-1}$ (which is the default threshold for high speed running used by the Prozone® motion analysis system) when the players were in possession of the ball, without possession and when the ball was out of play. The results showed a significant decline in high-intensity activity from match one to three with respect to the distance covered in possession of the ball (377 ± 259 m vs 274 ± 211 m; $p < 0.05$) and when the ball was out of play (82 ± 41 m vs 53 ± 38 m; $p < 0.05$). Total distance covered did not change between the three matches whereas mean recovery time between high-intensity bouts did change (52.1 ± 13.6 s vs 62.3 ± 22.6 s; $p < 0.05$). The results of that study provide some evidence of performance decline when matches are played with very short recovery periods.

More recently, Dupont *et al.* (2010) compared the physical performance (TD, HID and injury rates) of players involved in either one or two matches a week in a top European team participating in the Champions League across two seasons. This would mean they had three to four days recovery time between matches. The authors reported that physical performance as characterized by the TD covered, high-intensity distance, sprint distance, and the number of sprints, was not significantly affected by the number of matches played per week. However the injury rate was significantly higher with two matches per week versus one match per week (25.6 vs 4.1 injuries per 1000 hours of exposure). The results of Dupont *et al.* (2010) reflect those of Odetoyinbo *et al.* (2007), where there is no decrement in the above stated performance measures after two matches with relatively short recovery time. However the six fold increase in injury rate for those who did play two matches in a week shows that such loads on players may not be manageable and therefore detrimental to the long-term performance of the team. The results of those two studies suggest that on occasions the playing loads imposed on elite professional soccer players are potentially detrimental to performance and health. The playing demands placed on elite soccer players means that achieving a suitable balance between training, competition and recovery is important for maximizing the performance of players. Both training and competition contribute to the ‘load’ imposed on players.

Therefore information on the level of recovery or the ability of a player to perform is a valuable asset for coaches. The dose-response nature of training and recovery has been well documented in exercise prescription guidelines (Beachle & Earle, 2008; Thompson, 2010) and research examining the modeling of endurance performance. (Banister, 1991; Busso, 2003; Morton, 1990; Banister, Carter & Zarkadas, 1999). Banister (1991) proposed that performance at any given time is dependent on both the fitness level and the accrued fatigue or the level of recovery of the athlete from the previous exercise bout. An athlete with high fitness but also high levels of fatigue would provide a poor performance. Likewise an athlete with low fatigue but also low levels of fitness would perform poorly too. Conversely, high levels of fitness combined with low levels of fatigue would provide an optimum performance. Such modeling theories can be more easily tested with endurance athletes as ‘performance’ is more narrowly defined (usually by time), and the factors contributing to that performance are more heavily weighted toward physical attributes such as measures of aerobic fitness. Infrequent competition in endurance events also leads to more opportunities to test athletes in a fully recovered state. In a sport such as soccer where ‘performance’ cannot be as easily defined and competition is frequent, opportunities to test the outcome of training becomes difficult. Therefore, greater understanding of the dose-response relationships for both fitness and fatigue in soccer players could allow predictions of how both components respond to a given exercise dose. However the measurement of the ‘dose’ or ‘load’ that enhances the understanding of the ‘response’ (performance /

fitness / fatigue) has only recently received any attention over the last decade in soccer-related research. In team sports the measurements of exercise ‘dose’ have been either internal through the use of rating of perceived exertion (RPE) (Foster, Florhaug, Franklin, Gottschall, Hrovatin, Parker, Doleshal & Dodge, 2001) and/or heart rate (Impellizzeri, Rampinini & Marcora, 2005), or external through the use of distance measurements (Di Salvo, Baron, Tschan, Montero, Bachl & Pigozzi, 2007; Gregson, Drust, Atkinson & Salvo, 2010) using automated camera systems or more recently global positioning systems (GPS) technology. The validity of these measures of ‘load’ is dependent on their applicability to the dose-response relationships for fitness, fatigue and recovery in soccer.

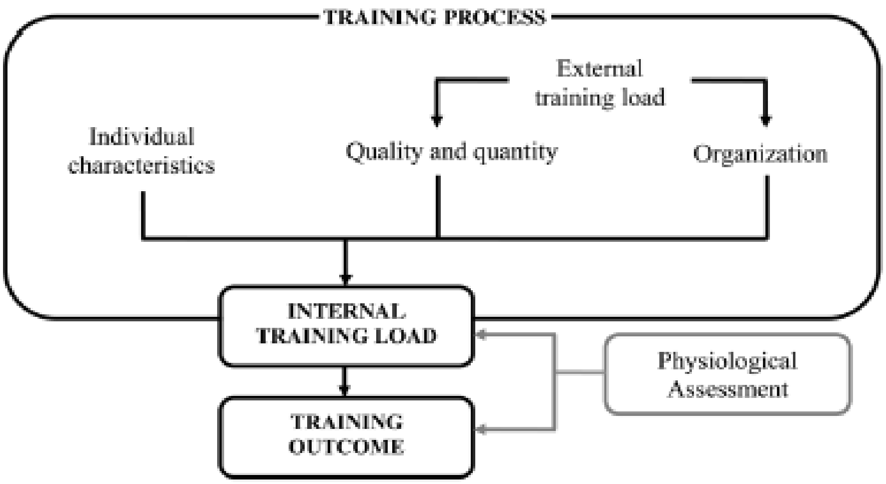

Figure 1.1. Training Process (Impellizerri, *et al.*, 2005)

The model above (Impellizzeri, *et al.*, 2005) shows how it is ultimately the internal training load that affects the training response or outcome and is the stimulus for physiological adaptation. The model also shows how the internal training load is influenced by an individual’s characteristics and how external training load contributes to the internal training load. The measurement of internal training load has to date been largely based on objective heart rate (HR) based methods (Banister, 1991; Edwards, 1993; Lucia, Hoyos, Santalla, Earnest & Chicharro, 2003) or the subjective session-RPE method (Foster, *et al.*, 2001). These methods are reviewed briefly below.

Banister (1991) theorizes that calculation of the exercise dose (the 'load') or 'training impulse' (TRIMP) as he termed it, is defined as;

t x mean ΔHR x y

Where;

t = duration (minutes)

$\Delta \text{HR} = \frac{\text{HRexercise} - \text{HRrest}}{\text{HRmax} - \text{HR Rest}}$ (fractional elevation in HR)

y = weighting factor

The weighting factor used by Banister (1991) was an equation that mirrored the exponential rise in blood lactate concentration during incremental exercise. A generic equation was provided for both males and females for the weighting component (y). Individual characteristics influence the internal training load as shown in the Impellizzeri model. However the use of the same equation for each gender limits the ability of Banister's original TRIMP to reflect the exercise dose for an individual. Furthermore, Banister (1991) advocated the use of mean HR in the calculation of load. This may be suitable for endurance exercise, which is likely to be of longer duration and constant (steady-rate) intensity where HR may not fluctuate to the extent it does during intermittent exercise, however the use of mean HR in intermittent exercise may not be representative of the overall intensity as the HR will fluctuate to a greater extent compared to continuous exercise (Drust, Reilly & Cable, 2000). Use of the mean HR during intermittent exercise could lead to a lowered measure of intensity, as it is thought that the 'stress' imposed on the body rises in an exponential manner with increasing intensity (Norton, Norton & Sadgrove, 2010)

Another popular HR-based ‘TRIMP’ method is that of Edwards (1993). The method of Edwards (1993) is comprised of five arbitrary HR zones that are weighted 1 to 5 from lowest to highest. However, the use of HR zones and the weighting factors applied to each zone are not based on any scientific premise. That is, the utility of HR zones has not been validated in a scientific study demonstrating that training exclusively in a given zone will produce proportionally different physiological adaptations to exclusively training in a different zone. The duration spent in each zone is multiplied by the respective weighting factor and summated to provide a TRIMP score. A similar TRIMP method to that of Edwards (1993) has been reported by Lucia *et al.* (2003). The Lucia *et al.*(2003) method is based on a three-zone model, with the zones weighted 1 to 3. The three zones are anchored around the ventilatory threshold (VT_1) and the respiratory compensation point (VT_2), providing this method with a greater degree of individualization. However the weightings used (1, 2 and 3) are still arbitrary and have not been validated in a manner showing that they produce proportional training adaptation. The method of Banister is the only method that provides weightings based on a physiological rationale (the blood lactate response). However this is still not without its limitations, as described above. Furthermore, applying a weighting factor to each HR based on the blood lactate response from a continuous exercise test may be different to the blood lactate response observed during intermittent exercise, which is the mode of exercise used in soccer. Although there is some evidence to suggest that intermittent exercise produces different lactate responses to continuous exercise (Edwards, Ekelund, Harris, Hesser, Hultman, Melcher & Wigertz, 1973; Essen, Hagenfeldt & Kaijser, 1977)**,** the study of Essen *et al.* (1977) was limited by sample size (n = 3) and both studies were conducted on cyclists. Therefore, the effect of intermittent exercise on the blood lactate response also warrants further investigation as it could affect the blood lactate-heart rate relationship that contributes to the TRIMP calculation. Finally the session-RPE method (Foster, *et al.*, 2001) uses an 11-point intensity scale that corresponds to descriptions of intensity from ‘rest’ to ‘maximal’. The number selected by the athlete is multiplied by the exercise duration to provide a measure of load expressed in arbitrary units. Impellizzeri, Rampinini, Coutts, Sassi & Marcora (Impellizzeri, Rampinini, Coutts, Sassi & Marcora, 2004) compared the session-RPE method to the three HR-based methods described above. The authors correlated the session-RPE from individual training sessions in 19 youth soccer players with Banister’s TRIMP, Edwards HR zones, and Lucia’s TRIMP, reporting that the session-RPE significantly correlated with Edward’s method (r = 0.54 – 0.78), Banister’s method (r = 0.50 – 0.77) and Lucia’s method (r = 0.61 – 0.85). They drew the conclusion that session-RPE was therefore a valid measure of training load. However they failed to critique the existing methods in relation to soccer. The dose-response relationships of the measures of “load” with training were not examined. Session-RPE was simply correlated to the other HR-based measures of “load” that were treated as criterion measures presumably because of the validity of the use of HR as a measure of intensity. However as the brief description of the methods currently employed above suggests, intensity is only one term of three (time, intensity & a weighting factor) in the calculation of load. Hence, assuming the criterion validity of HR-based load measures appears inherently flawed.

Given these limitations the validity of a measure of training load (TL) in intermittent sports needs greater attention. If the dose-response relationship holds true, then there should be a relationship between the training dose and the fitness / performance / fatigue response. The use of session-RPE as a valid tool for the assessment of internal TL cannot be proclaimed until a dose-response relationship has been shown against changes in fitness and/or performance (Manzi, Iellamo, Impellizzeri, D'Ottavio & Castagna, 2009).

Two recent studies have addressed some of the limitations of the HR-based methods described above. Stagno, Thatcher & Van Someren (2007) attempted to individualize Banister's TRIMP, by creating a blood lactate profile for a specific group of hockey players. The data from the players' blood lactate tests were used to generate a team specific weighting factor. Stagno *et al.* (2007) also acknowledged the limitations in using mean HR in team sports, so they created five HR zones anchored around the HR at lactate threshold and the HR at OBLA. Each zone was weighted according to the team blood lactate profile, with the subsequent weighting factors being 1.25, 1.71, 2.54, 3.61 and 5.16. The training load for these eight hockey players was monitored over an eight-week period at the start of the season. The authors reported that the modified TRIMP (expressed as a mean weekly score) shared significant relationships with changes in velocity at 4 $mmol \cdot L^{-1}$ ($r = 0.67$; $p = 0.04$) and VO_{2max} ($r = 0.65$; $p = 0.04$). This study suggests a dose-response relationship, however the usefulness of the modified TRIMP method over the others methods of TL previously examined is difficult to assess and no other methods were used to assess TL in this study.

Banister (1991) originally suggested that the use of mean HR of the whole training session for the calculation of TRIMP as calculating the load for each HR data point recorded would be too problematic. For example, for a HR monitor that samples HR every 5 seconds during a 60-minute training session would produce 720 data points. Calculating the TRIMP for each of these data points and then summating would have posed problems in the 1980's when computing software was not as good or widely available as now. Hence the use of mean HR was popular. Also, given the long duration and constant intensity nature of endurance training, the mean HR would probably be reflective of the intensity of the session. However in intermittent sports this is unlikely to be the case. Therefore the use of HR zones may have been developed as an advancement on the use of mean HR, given its limitations in intermittent exercise as mentioned before. However, the use of zones also creates an issue whereby a player exercising at the lower limit of the zone would accrue the same weighting as if the athlete was exercising at the higher limit of the zone. Moreover, the use of a 'team TRIMP' as developed by Stagno, *et al.*, (2007) still does not account for individual characteristics, although it logically appears to be an advance on the generic TRIMP developed by Banister (1991).

Attempting to overcome many of the limitations in the methods of Banister (1991) and Stagno, *et al*., (2007), Manzi, *et al*.,(2009) recently developed a truly individualized version of the TRIMP. In a training study with recreational runners, a fully individualised TRIMP (iTRIMP) was used, where the weighting component was calculated using each athlete's individual blood lactate – HR profile, with the weighting factor applied to each HR reading recorded (5 s average), and then summated. The recreational runners were monitored over eight weeks with a treadmill test being conducted before and after the training period. The results showed that the mean weekly iTRIMP significantly correlated with changes in velocity at 2 $mmol\cdot L^{-1}$ blood lactate ($r = 0.87$; $p < 0.01$) and 4 $mmol\cdot L^{-1}$ blood lactate ($r = 0.72$; $p = 0.04$). The mean weekly iTRIMP was also significantly correlated with changes in 5000 m ($r = - 0.77$, $p = 0.02$) and 10000 m ($r = -0.82$; $p = 0.01$) running time. In addition to this Manzi, et al., (2009) also reported that Banister's TRIMP was not related to any fitness parameter or performance measure. No study to date has assessed the iTRIMP method in soccer or compared it to other methods of TL to establish the dose-response relationship or assess which method is the most useful.

The studies of Odetoyinbo, *et al.*, (2007) and Dupont, *et al*., (2010) somewhat addressed the performance and injury implications of increased match frequency. Players and coaches have also made reference to what they deem to be increased match frequency and the perceived consequences. As an example, Arsenal FC manager Arsene

Wenger, in response to a poor league performance following a midweek ECL match, was quoted as saying after a weekend EPL match:

> “Maybe we are suffering a little from fatigue and maybe our efforts with nine men in the Champions League have left us tired”
>
> Arsene Wenger (BBC-Sport, 2004a)

Many players in the top teams are also involved with their respective national teams. Thus, a major portion of their recovery and recuperation time after a long season is used to play in international tournaments. This further enhances the load on players. These sentiments were echoed by France international Thierry Henry ahead of the 2004 UEFA European Championships when reflecting on the poor showings of top teams at the 2002 FIFA World Cup:

> “You need to be fresh. At the 2002 World Cup so many great teams went out early. The likes of Italy and Argentina, as well as France, looked like they couldn't play the ball they were all so tired. The team who can win Euro 2004 will be the one with the freshest players. It makes such a difference in this kind of competition."
>
> Thierry Henry (BBC-Sport, 2004b)

In the 1992-1993 season at the conception of the English Premier League, which can be regarded as the start of the globalization of the English match, Manchester United played a total of 50 matches. In the last few seasons they have consistently played more matches. In all competitions in the 2007-2008 season they played 58 matches (16% increase), 66 matches in the 2008-2009 season (32% increase), 56 matches in the 2009-2010 season (12% increase) and 60 matches in the 2010-2011 season (20% increase) respectively (AFS, 2011)**,** excluding matches played in pre season tours.

The anecdotal evidence in the form of the thoughts of players and coaches presented alongside the notable increase in matches for Manchester United in recent seasons would suggest an increase in match frequency. However no study to date has quantified the change in match frequency over time in elite teams and players. Information on the frequency of matches and/or the change in match frequency is important as it represents a major component of the total training and match load for individual players. If match frequency has increased over time then this might suggest that the physiological load imposed on elite players may also have increased. An increase in match frequency has implications for the overall load on players but also their recovery time. However in the absence of a systematic study looking into match frequency and recovery time the evidence remains largely anecdotal and warrants further investigation.

In recent years a number of studies examining the recovery profiles of numerous physiological and biochemical measures after matches have been presented**.** These are described in greater details in Section 2.4**.** The research has described the time course of recovery of acute performance tests (APT), such as jumps, sprints and muscular isokinetic strength measures (Fatouros, Chatzinikolaou, Douroudos, Nikolaidis, Kyparos, Margonis, Michailidis, Vantarakis, Taxildaris, Katrabasas, Mandalidis, Kouretas & Jamurtas, 2010; Ascensao, Rebelo, Oliveira, Marques, Pereira & Magalhaes, 2008; Ispirlidis, Fatouros, Jamurtas, Nikolaidis, Michailidis, Douroudos, Margonis, Chatzinikolaou, Kalistratos, Katrabasas, Alexiou & Taxildaris, 2008; Reilly & Rigby, 2002), biochemical measures such as hormones (testosterone/cortisol), creatine kinase (CK) as an indicator of muscle damage and injury risk and other biochemical measures of exercise stress (Andersson, Raastad, Nilsson, Paulsen, Garthe & Kadi, 2008; Ascensao, *et al.*, 2008; Fatouros, *et al.*, 2010; Ispirlidis, *et al.*, 2008). The changes in all of these measures are detailed later as is the validity of some of the measures used. However these studies remain descriptive and are often conducted on a group level, where the mean changes are often described over time. On the contrary, players are individuals with different capabilities, with different match loads and potentially different recovery requirements. For example, the distance covered (external load) reported in the literature varies from 9 – 14 km per match (Stolen, Chamari, Castagna & Wisloff, 2005) and this has been shown to vary by position (Di Salvo, Baron, Tschan, Montero, Bachl & Pigozzi, 2007) and is also subject to high match-to-match variability especially with high-intensity activity (Gregson, *et al.*, 2010). The model presented earlier in figure 1.1 (Impellizzeri, *et al.*, 2005) shows that the external TL influences the overall internal TL. Given this, it can be assumed that the internal TL from a match will be different for each player. The work of Banister (1991) would suggest that accrued fatigue from an exercise bout is dependent on the exercise dose and will relatively affect recovery time from that exercise dose.

Coaches are ultimately interested in understanding an individual's capability to perform. However the aforementioned recovery studies fail to recognise that not all the players will accrue the same internal load. All of the studies have failed to assess the recovery process in relation to the load. This may partly be due to the earlier discussed issues and limitations with measuring load in soccer. No study to date has examined the measures of fatigue, stress and recovery from soccer match-play in relation to the exercise dose. The establishment of a dose-response relationship could potentially inform future research on the modeling of the recovery and training process from prolonged intermittent exercise. If the level of fitness and fatigue can be obtained from a training session and/or match, then this could lead to the potential prediction of physiological performance capability at a given time similar to work done on endurance athletes (Banister, 1991; Morton, 1990). Therefore the major aim of this thesis is to assess the dose-response relationship in soccer in relation to both fitness and fatigue/recovery. Furthermore this thesis will also assess two additional issues. A systematic analysis of match frequency and recovery time between matches will be conducted as the evidence relating to this is largely anecdotal. Also the physiological responses to intermittent exercise will be examined as these may affect the blood lactate – heart rate relationship which is used in the calculation of iTRIMP (Manzi, *et al.*, 2009).

1.2 Aims

The aims of this thesis are;

- To systematically analyze how match frequency and recovery time between matches has changed over time.
- To compare the physiological responses to continuous and intermittent exercise.
- To assess if an individualised measure of training load relates to changes in fitness in soccer players.
- To assess if an individualised measure of TL relates to measures of recovery/fatigue in soccer players.

2 - Literature Review

The measurement of 'load' is central to the aims of this thesis. Therefore the development of the measurement of load and a more detailed examination of the methods currently used is examined in the first section this literature review (Section 2.1). Thereafter the demands of soccer matches are examined in greater detail (Section 2.2) to gain a better understanding of the load players are exposed to and the factors affecting the load. Fatigue during matches is an aspect that subsequently affects the recovery after the match. Therefore studies examining fatigue during matches and the potential mechanisms by which fatigue occurs are reviewed in Section 2.3. Finally, studies examining the recovery process following soccer matches are reviewed in Section 2.4 to help inform the aims of this thesis.

2.1 Internal Training Load Methods

The dose-response relationship is described as one of the fundamental principles of training by the ACSM (Thompson, 2010). The internal training load (TL) is the component which ultimately influences the training outcome (Impellizzeri, *et al.*, 2005).The methods currently used to monitor internal training loads have been mentioned in the introduction.

The review of literature below will show the calculation of load is the result of three terms; duration, intensity and a weighting factor. Intensity has been measured objectively using HR. New advances in HR telemetry have made monitoring of training using HR relatively easy. Therefore researchers have developed methods using HR to quantify TL. HR has been shown to have a linear relationship with oxygen consumption, which is widely regarded as the gold standard measure of exercise intensity (Thomson, 2010). Consequently, the use of HR as a measure of intensity demonstrates internal validity. However intensity is only one term in the calculation of TL and therefore the validity associated with HR as a measure of intensity cannot be extended to the calculation of TL. The assumption that any method of calculating TL which uses HR is valid due to its validity as a measure of intensity may have been one of the reasons that they have been used as criterion measures to validate methods using HR (Alexiou & Coutts, 2008; Impellizzeri, *et al.*, 2004).

There is evidence to suggest that when duration is controlled and intensity is manipulated the training adaptations are different. Denadai, Ortiz, Greco & de Mello (2006) assessed the effect of two different high-intensity interval training programmes (running velocity at 95% of VO_{2max} vs 100 % of VO_{2max}) on aerobic fitness parameters (VO_{2max}, velocity at VO_{2max}, velocity at OBLA, running economy, 1500 m time trial and a 5000 m time trial) in well trained runners. Despite no change in VO_{2max} in either group after training they reported an increase in velocity at OBLA and 5000 m time trial performance in both groups. However the change in vVO_{2max}, running economy and 1500m time trial performance was significantly greater in the 100%vVO_{2max} group. This would suggest that small manipulations in training intensity have different affects on training adaptations. Therefore the use HR training zones with fixed weightings which encompass a much larger range of the intensity spectrum may not accurately reflect the TL, especially where these weightings are arbitrary.

In controlled studies such as Denadai, *et al.*, (2006) where one of the variables contributing to load can be manipulated the evidence suggests there is construct validity. However most training and competition environments are uncontrolled and the training intensity and duration will be different for different individuals. Therefore the methods used to measure TL previously mentioned aim to unify the contribution of the different variables to produce a universal score. However for any of these methods to be considered the criterion, their validity must be assessed with the dose-response relationship. This section aims to highlight the development of the methods used for measuring TL and highlight their limitations with respect to soccer.

2.1.1 Banisters TRIMP

Banister (1991) developed the ‘training impulse’ (TRIMP) as a method to quantify TL. Banisters TRIMP (bTRIMP) takes into consideration the intensity of exercise as calculated by the HR reserve method and the duration of exercise. The mean HR for the training session is weighted according to the relationship between HR and blood lactate as observed during incremental exercise and then multiplied by the session duration. The HR is weighted in such a manner that it reflects the intensity of effort and prevents disproportionate importance to long durations of low intensity exercise compared with more intense exercise.

Banister (1991) used the TRIMP to model endurance performance by using the TRIMP as a measure of TL from which he modeled the dose-response relationships with fitness and fatigue. Banister (1991) hypothesized that each training bout produced both a fatigue and a fitness impulse. Banister (1991) hypothesized that fatigue decays three times faster than fitness, hence training adaptation and enhanced performance. Performance at any given time is a result of the fitness level less the accrued fatigue. Morton, *et al.,* (1990) examined how predicted performance from such a model fared against measured performance. They used two participants and both visually and statistically examined the goodness of fit between the predicted performance and measured performance at given times during a 28 day training period. The r^2 values for the two participants were 0.71 and 0.96 respectively. These results gave Banisters TRIMP some credence but the difference in the r^2 values between the two participants shows that there is a large variance. Furthermore some statisticians may argue that the assumption of independence has been violated.

However, the modeling conducted to date has focused on endurance athletes with long training schedules who need to optimize performance for a relatively short competition period from 1 day (e.g. marathon) to a few weeks (e.g. cycling tour). The modeling of performance in endurance sports (Morton, 1990) somewhat validates Banisters TRIMP. However the modeling process has been subject to modifications (Busso, 2003) for improvements in predictions. But these modifications have been made to the terms in the modeling equations associated with the decay of fitness and fatigue rather than the calculation of the initial TL (Busso, 2003). Only one study to date has examined the dose-response relationship between bTRIMP and fitness/performance with a training study. Manzi, *et al.*, (2010) reported non-significant relationships between mean weekly bTRIMP and the change in running velocity at 2 $mmol \cdot L^{-1}$ BLa ($r = 0.61$; $p = 0.11$) or 4 $mmol \cdot L^{-1}$ BLa ($r = 0.59$; $p = 0.12$) for a group of recreational runners after an 8 week training period. There was also non-relationship between mean weekly bTRIMP and 5000 m ($r = -0.41$; $p = 0.31$) or 10000 m ($r = 0.54$; $p = 0.16$) running performance. However, Qualitative interpretations of the correlation coefficients as defined by Hopkins (2002) (0 – 0.09 trivial; 0.1 – 0.29 small; 0.3 – 0.49 moderate; 0.5 – 0.69 large; 0.7 – 0.89 very large; 0.9 – 0.99 nearly perfect; 1 perfect), in relation to correlations would deem these correlations moderate to large.

There are two major limitations in using bTRIMP in intermittent sports such as soccer. Firstly the use of mean HR may not reflect the fluctuations in HR that occur during intermittent exercise. The mean exercise intensity in soccer matches has been widely reported to be around the anaerobic threshold at 85% of HR_{max} (Stolen, *et al.*, 2005) but has also been reported to peak at intensities close to HRmax (Ascensao, *et al.*, 2008). Secondly, the use of generic equations for males and females implies that the gender is the only factor making athletes different and does not necessarily take into consideration individual differences that effect TL that the Impellizzeri, *et al.,* (2005) model implies.

2.1.2 Edwards TRIMP

Edwards (1993) proposed a zone based method for the calculation of TL. The time spent in five pre-defined arbitrary zones is multiplied by arbitrary coefficients to quantify training load. The proposed the zones based on HR_{max} with 10% zone widths and corresponding coefficients can be seen Table 2.1 below.

Heart Rate Zones	**Coefficient**
50-60%	1
60-70%	2
70-80%	3
80-90%	4
90-100%	5

Table 2.1 Edwards (1993) training load zones and coefficients.

This method gained popularity as the default setting on a popular HR telemetry system. However the coefficients are void of physiological underpinning and the zone limits remain predefined and void of any metabolic or physiological performance thresholds. Such zones and weightings would imply the training adaptation in zone 5 is five times greater than in zone one and that the relationship between training intensity and adaptation is linear. However no study to date has suggested this to be case. The study of Denadai, *et al.,* (2006) discussed earlier showed how small changes in intensity resulted in different training adaptations. The weightings used by Edwards (1993) are not validated through a relationship with a known physiological response. Neither has a training study looking at the quantification of the TL from this method been conducted to assess the dose-response relationship. Given the limitations identified it would be difficult to consider such a method as a criterion measure as (Impellizzeri, *et al.*, 2004) did when examining the relationship with session RPE. The strong linear relationship between HR and maximal oxygen uptake in continuous and intermittent exercise (Esposito, Impellizzeri, Margonato, Vanni, Pizzini & Veicsteinas, 2004) shows that HR is a valid measure of 'intensity'. However the validity of TL measurement methods cannot be assumed due to the use of HR as a valid measure of intensity, as intensity is only one factor in determining the overall load.

2.1.3 Lucia's TRIMP

Lucia, *et al.*,(2003) based their measure of TL around the ventilatory thresholds (VT_1; VT_2). The method provides three zones: low intensity ($<VT_1$), moderate intensity (VT_1 - VT_2) and high-intensity ($>VT_2$). Each zone is given a coefficient of 1, 2 and 3, respectively. Time spent in each zone is multiplied by the relevant coefficient and summated to provide a TRIMP score. However, like Edwards (1993), the coefficients appear to be arbitrary. Earlier work by Banister, Calvert, Savage & Bach (1975) with swimmers used the same weighting coefficients (1, 2, and 3) for low, moderate and high-intensity work. This sort of weighting implies that exercise at high-intensity is three times as demanding as exercise at low intensity. Lucia, *et al.*, (2003) used this method to compare the training load distribution in two different cycling tours. Training using this three-zone model in endurance sports has received some attention (Esteve-Lanao, Foster, Seiler & Lucia, 2007; Seiler & Tonnessen, 2009), potentially giving the method inadvertent credence due to the use in elite settings rather than its physiological underpinning. Seiler, *et al.*, (2009) described the polarized training methods popular with endurance athletes where ~80% of their training time is spent in zone 1 ($<VT_1$) and

20% of their time in zone 3 (>VT_2). The metabolic thresholds used to identify the zones have shown to relate well to endurance performance (Amann, Subudhi & Foster, 2006). However the weightings remain arbitrary. This system appears to be best used by monitoring the time in each zone and percentages of training time in each zone. This by no means dictates that a universal score from the associated coefficients is valid. Furthermore the weighting of each zone implies that the training adaptation would be the same regardless of where in the zone an athlete trained. For example if the threshold for VT_2 is identified at 85% of HR_{max} a training session with an intensity of 95% of HR_{max} would be given the same weighting as a training session at 85% of HR_{max}. Here again, the study of Denadai, *et al.*, (2006) discussed earlier raises questions about the application of the same weighting for a zone that encompasses a wide intensity range. To date no training study using this method has been conducted to validate it by showing relationships to either change in fitness, performance or fatigue.

2.1.4 $TRIMP_{mod}$

Stagno, Thatcher, and Van Someren (2007) developed a modified version of Banister's TRIMP ($TRIMP_{mod}$) in an attempt to quantify training load for field hockey. Rather than use a generic equation to reflect a hypothetical blood lactate profile, these authors directly measured the blood lactate profile of the hockey players. The weightings they used therefore reflected the profile of a typical blood lactate response curve to increasing exercise intensity for the specific population, in this case the hockey team. While not truly individualized, their method used the mean blood lactate profile from all of the players to generate the weightings, providing at least some degree of individualization. They then anchored five HR zones around the lactate threshold and OBLA, with the resulting zone weightings being 1.25, 1.71, 2.54, 3.61 and 5.16. The accumulated time in each HR zone was then multiplied by its respective zone weighting to derive an overall $TRIMP_{mod}$. The research by Stagno, *et al.,* (2007) quantified the TL in hockey and established relationships between $TRIMP_{mod}$ and various fitness parameters during the course of a season. They found the mean weekly $TRIMP_{mod}$ shared significant relationships with changes in running velocity at 4 mmol·L^{-1} (r = 0.67; p = 0.04; large) and VO_{2max} (r = 0.65; p = 0.04; large). They also reported significant correlations between time spent in high-intensity activity and the change in VO_{2max} (r = 0.65; p = 0.65; large) and the change in *v*OBLA (r= 0.67; p = 0.65; large). The results of this study suggest that $TRIMP_{mod}$ is a method by which TL could possibly be measured in soccer. The original TRIMP (Banister, 1991) is calculated using the mean HR for a particular exercise session or interval of training. Stagno, *et al.,* (2007) used time accumulated in zones to reflect the different intensities team sport players work at in comparison to the limited range of intensities that endurance athletes may work at, where the use of a mean HR would be more suitable. However Stagno, *et al.,* (2007) failed to compare the two methods. We do not know if there is any significant difference when using the zone method of Stagno, *et al.*, (2007) compared to the mean HR method as used by Banister (1991). The zones used by Stagno, *et al.*, (2007) were based on the HR at lactate threshold (LT), defined as 1.5 mmol·L^{-1} and the onset of blood lactate accumulation (OBLA) defined as 4 mmol·L^{-1}. They used the blood lactate responses at four different speeds from their player sample to create an equation for the weightings or the 'Y' value as defined by Banister. Zones 2 and 4 were created around the mean HR at LT and OBLA. A zone width of 7% fractional elevation was formed at these points. Zones 1, 3 and 5 were then created around zones 2 and 4. The pre requisite for the use of this method was that the HR at LT and OBLA for all players fell within zones. However the use of zones still holds the limitation of giving the same weighting to exercise spanning the whole zone. For example if a zone which was 70-80% of HR_{max} had the same weighting, an athlete training at 71% would get the same weighting as someone training at 79%. It is difficult to ascertain however if this difference would affect physiological adaptation, and there appears to be no study to date that has examined this fundamental training question. The study of Denedai, *et al.*,(2006) mentioned previously would suggest it may. The method of Stagno, *et al.*, (2007) the zones are created around the thresholds, so there may well be a situation where players exercising in the same zone, gaining the same weighting, are working above and below a metabolic threshold. It must be highlighted that although the zones are based on metabolic criteria, they are created with arbitrary values of lactate and are therefore not individualised as are Lucia's. Another consideration overlooked by Stagno, *et al.*, (2007) is the lactate response to intermittent exercise. The oxygen consumption during intermittent and continuous exercise at the same average intensity is similar at low intensities but significantly different at higher intensities (Bangsbo, 1994). Bangsbo (1994) also found higher blood lactate concentrations for intermittent exercise compared to continuous exercise at the same average workloads. The effect of intermittent exercise on any potential TRIMP weighting remains an area to be investigated.

In summary the work of Stagno, *et al.*, (2007) highlighted some of the complexities involved in monitoring TL in team sports. They highlighted the need for specific weightings, although they failed to fully individualize these. Their use of zones was an attempt to move beyond the use of mean HR. However the limitations highlighted exist.

2.1.5 Individualised Training Impulse (iTRIMP)

Most recently Manzi, *et al.*, (2009) introduced the individualized training impulse (iTRIMP). Using this method the TRIMP weighting is based on the individual's own heart rate – blood lactate response to incremental exercise, as measured during a standard lactate threshold test protocol. Furthermore, as a development on previous methods Manzi, *et al.*, (2009) did not use HR zones or mean heart rate. The TRIMP scores were calculated for each HR reading and summated to give an overall TRIMP. Therefore, these authors individualised the weighting to the athlete, which goes beyond the individualization by gender (Banister, 1991) or team (Stagno, *et al.*, 2007). Moreover, the iTRIMP weighting is not arbitrary as in the case of Edwards (1993) and Lucia, *et al.*, (2003). Consequently, the method developed by Manzi, *et al.*, (2009) overcomes many of the limitations of previous methods. The results reported earlier showed that after an 8-week period of training in recreational runners, the mean weekly iTRIMP significantly correlated with changes in velocity at 2 mmol·L^{-1} blood lactate ($r = 0.87$; $p < 0.01$; very large) and 4 mmol·L^{-1} blood lactate ($r = 0.72$; $p = 0.04$; very large). The mean weekly iTRIMP also showed significant correlations with changes in 5000 m ($r = - 0.77$, $p = 0.02$; very large) and 10000 m ($r = -0.82$; $p = 0.01$; very large) running performance. However, Manzi, *et al.*, (2009) reported that Banister's TRIMP showed non-significant relationships with any fitness parameters or performance measures although these were considered moderate to large (Hopkins, 2002). The participants used in their study were recreational runners and therefore the effectiveness of the iTRIMP method needs to be tested in soccer where the activity is highly intermittent. As the HR–oxygen consumption relationship appears to be valid even during intermittent exercise (Esposito, *et al.*, 2004), then the iTRIMP method has potential for use within a soccer environment. In summary, the iTRIMP appears to be the only method that bases weightings on the individual response, which is based on a physiological parameter, a combination which is evidently absent in the methods discussed previously.

2.1.6 Session RPE

Training load (TL) as measured by the session RPE (Foster, *et al.*, 2001) is a subjective method of quantifying the load placed on an athlete. It is calculated by multiplying the session intensity by the duration to provide a measure of load in arbitrary units. The intensity is described as a number (0-10) on the CR-10 Rating of Perceived Exertion (RPE) scale originally proposed by Borg, Hassmen & Lagerstrom (1987). The relationship between RPE and other measures of intensity like HR (r = 0.89) and plasma lactate concentration (r = 0.86) have been demonstrated (Gabbett & Domrow, 2007). Foster, Daines, Hector, Snyder, & Welsh (1996) showed that increasing the TL (measured by Session RPE) tenfold over 12 weeks resulted in a 10% improvement in performance with runners and cyclists. However, the incidence of injuries and illness are also at their highest when TL is highest (Foster, 1998; Gabbett, 2004a). Using session RPE, Gabbett (2004b) managed to reduce the injuries in rugby players by reducing the TL in pre-season. One would presume the reduction in injury rates due to reduction in TL would be at the expense of physical fitness, but maximal aerobic power was also found to be higher in the seasons with reduced training load (Gabbett, 2004b). However, in a separate study Gabbett and Domrow (2007) reported no association between session RPE and changes in skinfold thickness, speed or maximal aerobic power during any of the training phases they monitored. Studies such as these highlight the usefulness of simple methods such as session RPE, but this does not equate to validity. In soccer the usefulness of session RPE emerges from its ease of use compared to the technical nature of using HR monitors and downloading data. Issues include loss of data and player compliance.

The study of Impellizerri, *et al.*, (2004) described in the introduction that compares session RPE to the methods of Banister (1991), Edwards (1993) and Lucia, *et al.*, (2003) implies the validity of session RPE with disregard to the limitations of the methods it is using as criterion measures of TL. A similar study was conducted by Alexiou and Coutts (2008) where session RPE was correlated to training sessions for women soccer players. They found session RPE showed significant relationships with bTRIMP ($r = 0.84$; $p < 0.01$; very large); Edwards TRIMP ($r = 0.83$; $p < 0.01$; very large) and a LT based TRIMP ($r = 0.85$; $p < 0.01$; very large) which was based on the Lucia method but used fixed lactate values to delimit the 3 zones. However the criticisms of the Impellizerri, *et al.*, (2004) study can also be made of this study.

In a novel attempt to assess the 'dose-response' relationship of session RPE with performance and recovery Brink, Nederhof, Visscher, Schmikli & Lemmink (2010) monitored the session RPE, total quality of recovery (TQR) and performance in young elite soccer players over a whole season. Daily logs were kept by players and coaches to report TL after sessions and TQR prior to the next session using a scale developed by Kentta and Hassmen (1998). To assess performance they used the interval shuttle run test (ISRT) on a monthly basis. They applied multi-level modeling techniques to examine if session RPE could predict performance and recovery outcomes. They reported that the number of training days significantly predicted the performance outcome as represented by a decrease in the HR during the ISRT. However the model did not significantly predict performance with session RPE or TQR.

Although the simplicity of session RPE cannot be denied, the usefulness of the information it provides has to be questioned. The study of Brink, *et al.*, (2010) and Gabbett and Domrow (2007) show that session RPE does not fit dose-response models. Furthermore those studies claiming to assess RPE's validity against HR based methods fail to assess the validity of the HR based methods.

2.1.7 Summary

- The review of measurements of internal TL reveals the limitations of many of the methods employed to assess TL.
- The use of session RPE is based on relationships with TL measures which themselves lack validity.
- The fully individualised method of Manzi, *et al.,* (2010) addresses many of the limitations outlined and shows the best relationships with changes in fitness and performance.
- The validity of a fully individualised measure of TL is yet to be assessed in intermittent sports such as soccer.

2.2 Physiology of Soccer

2.2.1 Match Demands

Determining the change in physical match demands over time is a difficult due to the changing nature of the measurement techniques employed in some earlier studies. However, a brief review of notation studies will now be outlined in order to show how the physical performance of players in matches may have changed over time.

An early study by Winterbottom (1952) on professional players in England reported a total distance (TD) covered of 3361 m during the whole match. This value was obtained using a manual tracking method using a scaled plan of a pitch, probably resulting in imprecision. Later Wade (1962) reported the TD covered to range from 1600 m to 5486 m also for professional players in England. However Wade (1962) provided no indication as to methods employed to determine this. Knowles and Brookes (1974) reported the TD the covered to be 4833 m by using another variation of a manual method whereby they noted each distance of five yards (4.6 m) covered for professional players in England. This value is in stark contrast to that of 11.5 km reported by Saltin (1973) for non-elite players in Sweden. Saltin (1973) tracked players for a 3-minute period and extrapolated the results to 90 minutes. Using a similar method but with a 10 minute period Whitehead (1975) reported a mean distance of 11.7 km for professional players in England. Reilly & Thomas (1976) reported the TD covered as 8.7 km for professional players in England but this was based on audio commentaries recorded during the match, again raising the probability of imprecision. A mean value of 11.5 km was reported for Australian national team players by Withers, Roberts, & Davies (1982) when using video recordings of each player during the entire match. Ekblom (1986) reported a mean value of around 10 km by noting the action of a player every second minute for players across divisions in Sweden. By the 1980's the use of video cameras was widespread and Van Gool, Van Gerven & Boutsman (1988) reported values of 10.2 km for Belgian university level players. The increase in distance covered could be a result of the match becoming more demanding but could also be influenced by more valid and accurate methods of notation being developed over time as values of between 10 – 12 km were now being reported.

More recent research matched some of the values estimated in earlier studies. Bangsbo, Norregaard, & Thorso (1991) reported a mean distance covered of 11.4 km in Danish league players, whilst Mohr, Krustrup, & Bangsbo (2003) reported a mean distance of 10.86 ± 0.18 km for top class soccer players from the Italian league playing in the European champions league. Di Salvo, Baron, Tschan, Montero, Bachl & Pigozzi (2007) reported data on 300 top class players playing in La Liga (Spanish 1st Division) and in the UEFA European Champions League. These authors reported the mean distance covered as 11393 ± 1016 m, ranging from 5969 m to 13746 m, highlighting the large variance in these data. A mean distance covered of 10012 ± 1024 m for 55 players in the top division of Brazilian football was also reported (Barros, Misuta, Menezes, Figueroa, Moura, Cunha, Anido & Leite, 2007). Rampinini, Bishop, Marcora, Ferrari Bravo, Sassi, & Impellizzeri (2007a) reported a mean distance of 10864 ± 918 m for 18 top class players. Finally Bradley, Sheldon, Wooster, Olsen, Boanas, & Krustrup (2009), reported that the mean distance covered in 370 English premier league matches was 10714 ± 991 m. Figure 2.1 below shows that over time the distances covered have remained similar with mean values of 10 to 12 km consistently reported.

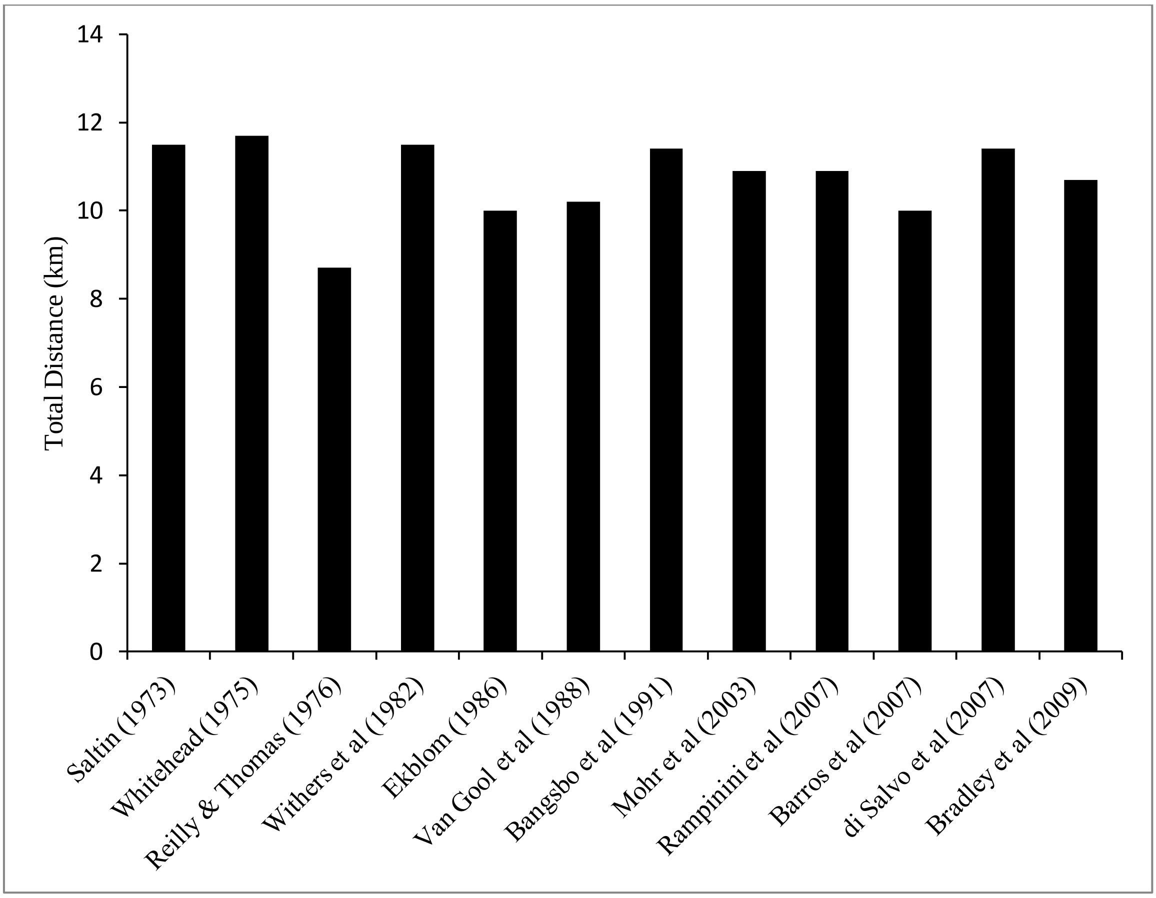

Figure 2.1. The reported TD covered in soccer match over the last 36 years.

The research presented would suggest that TD has not changed in the last 20-30 years. Mohr *et al.,* (2003) also compared their top class players (Italian league) to moderate level players (from Danish league). They reported that top class players performed 28% more running at high-intensity (HID) and 58% more sprinting when compared to moderate level players. This gives HID some construct validity and would suggest the ability to carry out more high-intensity exercise seems to differentiate between levels of play. High-intensity activity in this instance was identified as running at speeds above 15 $km \cdot h^{-1}$ and sprinting at speeds above 30 $km \cdot h^{-1}$. This has led to high-intensity activity in matches being examined as a performance measure. The TD covered appears not to have changed. Table 2.2 below shows how the activity profile has changed in recent years when comparing the same level Danish players in 1991 & 2003. The mean TD was reported to be 10.8 km (Bangsbo, *et al.,* 1991) and 10.3 km

(Mohr, *et al.*, 2003) further corroborating the conclusions that can be made from Figure 2.1. Given that the TD appears similar between the two studies the percentage distance covered in Table 2.2 also shows similarities.

Table 2.2 Comparison of % distances and given intensities reported by Bangsbo, *et al.*, (1991) and Mohr, *et al.*, (2003).

Activity	**Bangsbo, *et al.*, (1991)**	**Mohr, *et al.*, (2003)**
Standing	17.1	18.6
Walking	40.4	43.6
Jogging	16.7	19.1
Low speed	17.1	9.4
Moderate Speed	5.3	3.8
High Speed	2.1	1.9
Sprint	0.7	0.9
Backwards	1.3	2.9

The important factors in this comparison are that the method of data capture was the same (video camera), the research group was the same, and the competition was the same. All of these factors increase the likelihood that changes between 1991 and 2003 are the result of a real increase, decrease or no change, in the physical demands of match play rather than changes in methodology. However no such increases are apparent in high-intensity activities. It must also be noted however that this comparison is on moderate level players. No such data exist to enable a comparison of top class players with regards to HID. Table 2.2 also shows the distribution of activities at different intensities and why the use of mean HR in soccer may not be representative or valid. The high-intensity distance (HID) of soccer players in recent studies is shown in Table 2.3 below.

Table 2.3. Reported values of HID.

Study	High-intensity thresholds (km·h^{-1})	Mean HID (m)	Standard Deviation.
Mohr, *et al.*, (2003)	>15	2430	140
Rampinini, *et al.*, (2007)	>14.4	2530	532
Bradley, *et al.*, (2009)	>14.4	2492	625
Barros, *et al.*, (2007)	>19	1128	-
Di Salvo, *et al.*, (2007)	>19.8	930	161

The similarities in the means between the studies of Mohr, *et al.*, (2003), Rampinini**,** *et al.*, (2007a) and Bradley, *et al.*, (2009) suggest there has been little change over recent time as they delimit HIR at similar speeds. However the SD is more than four times greater in the Bradley, *et al.*, (2009) study suggesting HID has become more variable. This wide variability in high-intensity running is also similar in the Rampinini, *et al.*, (2007) study. The studies of Barros, *et al.*, (2007) and Di Salvo, *et al.*, (2007) also show similar means given similar HID thresholds. Barros, *et al.*, (2007) reports a higher value which may partly be due to a slightly lower HID threshold. The SD for Barros, *et al.*, (2007) could not be reported as the HID has been calculated by summating to sub categories which encompass HID, but were reported separately. The variance in soccer matches has already been highlighted. To counteract this variance a large sample of data is imperative. Mohr, *et al.*, (2003) studied 18 top class players individually in up to seven matches over two seasons. Di Salvo, *et al.*, (2007) studied 300 top class players only once. Bradley, *et al.*, (2009) conducted an extensive study on a sample of 370 English Premier League players. Despite the difference in sample sizes, Rampinini, *et al.*, (2007) and Bradley, *et al.*, (2009) report similar values.

The distance measurements from the studies reported in this section are subject to between-subject variation as some of the standard deviations suggest. However in recent years measures relating to high-intensity activity have been subject to scrutiny.

Gregson, *et al.*, (2010) and Mohr, *et al.*, (2003) reported a high coefficient of variation (CV) with respect to high-intensity activity. Gregson, *et al.*, (2010) reported short-term analysis of CV for between-match variation where players had played a minimum of 4 matches in an 8 week period was 17.7 ± 6.8%. Across three consecutive seasons the CV ranged from 17.06 ± 9.8 to 18.4 ± 4.7%. Mohr, *et al.*, (2003) measured short term CV by using data from players who had played two consecutive matches in a 3 week period and reported a CV of 9.2% for high-intensity activity and 3.1% for TD. Long term CV was measured by calculating the CV from matches more than 4 months apart. Mohr, *et al.*, (2003) found this raised the CV to 24.8% for high-intensity activity and 6.4% for TD. The results highlight that TD is considerably less variable. Also where Gregson, *et al.*, (2010) found little difference between short term and longer term CV, the results of Mohr et al., (2003) suggest that longer term comparisons increase the CV. Due to the high variability in measures of HID any meaningful inferences from changes are difficult to make and must be made with due consideration of the CV.

The reported data also emphasize the highly aerobic nature of soccer. Although it has been suggested anaerobic events cannot be ignored as these often contribute to important events in matches such as goal scoring opportunities (Bangsbo, 1994). It appears that the ability to perform more high-intensity activity also differentiates between playing level (Mohr, *et al.*, 2003). The high variability also raises issues with respect to using high-intensity activity in matches as a performance measure. The varied nature of the demands of the match has implications for the internal training load. This is important as recovery studies that have not considered the TL cannot be sure if the TL has been similar for each player from matches. The possible reasons for this variation are examined later in this section.

The intensity of exercise during a soccer match is close to the anaerobic threshold or 80-90% of maximal heart rate (HR_{max}). Maximal oxygen uptake varies from 50-75

$mL \cdot kg^{-1} \cdot min^{-1}$ in top level soccer players, with the mean oxygen uptake during match-play reported to be around 75% of VO_{2max} (Stolen, *et al.*, 2005). However averaging intensity over 90 minutes may lead to the loss of some specific information. Mohr, e*t al.*, (2003) found that in top-class players the amount of high-intensity running in the 5 minute period immediately following the most intense 5 minute period of the match was less than the average for the whole match, suggesting temporary fatigue occurs. So players may exercise at a higher intensity but this is then compensated for by a period of lower intensity exercise. the variability in match intensity is demonstrated by mean and peak values of 87.1 and 99.7% HR_{max} respectively, being reported for second division Portuguese players (Ascensao, *et al.*, 2008).

Oxygen consumption (VO_2) remains the criterion measurement of exercise intensity (Thompson, 2010) but measuring this during a match is difficult. An early attempt at measuring oxygen uptake during match-play was made by Ogushi, Ohashi, Nagahama, Isokawa, & Suzuki (1993) who showed that players failed to cover the same distance when wearing the measurement equipment (Douglas bags) as they did without the measurement equipment which led to the oxygen uptake being underestimated. Newer more portable gas analyzers may allow more accurate measurements to be obtained, but restrictions with such equipment will always apply. Therefore the HR-VO_2 relationship has been used in many studies to estimate the oxygen consumption. There are concerns that this method may lead to an overestimation of exercise intensity as factors such as dehydration, hyperthermia and mental stress elevates heart rate without elevation in oxygen consumption (Bangsbo, Mohr & Krustrup, 2006). To that effect sprinting has also been found to increase heart rate but without an elevation in $VO_{2,}$ but sprinting only accounts for about 1% of total match time (Stolen, *et al.*, 2005) and will only lead to a small overestimation. Laboratory studies by Bangsbo (1994) comparing continuous and intermittent exercise showed that the HR-VO_2 relationship is still valid during intermittent exercise. This has since been supported by numerous other studies (Castagna, Abt & D'Ottavio, 2005; Esposito, *et al.*, 2004; Hoff, Wisloff, Engen, Kemi & Helgerud, 2002). The reported results suggest that the nature of soccer is highly aerobic with the intensity fluctuating and also reaching max.

2.2.2 Sources of variation in soccer match load

The variance in the reported workloads and between-mach variation has been discussed in the previous section. There are numerous factors that may contribute to this. The style of play may influence match demands. For example, Barros, Misuta, Menezes, Figueroa, Moura, Cunha, Anido, and Leite (2007) reported the mean distance covered by Brazilian teams to be 10,012 ± 1024 m, somewhat lower than mean values reported for European players (11393 m ± 1016 m) by Di Salvo, *et al.*, (2007). This shows how the difference in tactics/style of play potentially leads to variation in the distance covered. Playing position has also been a source of variation identified by numerous authors (Bangsbo, 1994; Barros, *et al.*, 2007; Di Salvo, *et al.*, 2007). For example, Barros, *et al.*, (2007) showed that external defenders and central and external midfielders covered a significantly greater distance than forwards ($p < 0.05$). Forwards covered a significantly greater distance than central midfielders ($p < 0.05$). Di Salvo, *et al.*, (2007) found that all midfielders covered a greater distance than all defenders and forwards ($p < 0.05$). Central defenders covered significantly less distance than any other position ($p < 0.05$) which is congruent to the findings of Barros, *et al.*, (2007). However external defenders did not differ from forwards. This is an example of how style of play associated with European and South American soccer could again potentially be leading to variation in the distances covered, this time in different positions. However both studies found that there was no significant difference in the amount of high-intensity running between positions, suggesting the capability to produce high-intensity bouts of running is needed to be successful regardless of position. The greater distance covered by midfielders overall has been found to be due to greater distances covered at lower intensities (Di Salvo, *et al.*, 2007).

Rampinini, *et al.*, (2007b), examined the influence of opposition on the distances covered by a reference team in the Italian 1st division (Serie A). Matches from one season were examined using the Prozone® match analysis system. They reported players from the reference team covered a significantly higher TD ($p < 0.05$; 11097 ± 778m vs 10827 ± 770m) & HID ($p < 0.05$; 2770 ± 528m vs 2630 ± 536m) against the best teams (top eight in the national league) than against the worst teams (the rest of the teams in the league). Although the effect size of the difference was reported to be small, it does show that against better teams players would have to exercise harder. Significant correlations were also reported for TD ($r = 0.62$, $p < 0.001$; large) and HID ($r = 0.51$, $p < 0.05$; large) when correlated with the distances covered by the opposition. The analyses demonstrate that the opposition also has an influence on the distances covered in a match and therefore another source of variation for the TL in a match. In another study researchers compared the most successful teams (top 5 in the league) and the least successful teams (bottom 5 in the league) in Serie A (Rampinini, Impellizzeri, Castagna, Coutts & Wisloff, 2007c). Data from players who finished the top 5 and bottom 5 teams in the 2004-2005 Serie A season were collected using the SICS® match analysis system. They found that players from the less successful teams covered a greater TD (+4%), more high-intensity running (+11%) and more very high-intensity running (+9%). In contrast, players in the most successful teams covered a greater TD with the ball (+18%) than players in the less successful teams indicating the technical aspects of soccer contributing to success. This somewhat contradicts earlier research that suggested successful players covered more HID (Mohr, *et al.*, 2003). These studies further highlight the variation in workloads in top-level soccer. The research presented in this section shows the potential variation in the TL for soccer players in matches and the variety of factors that may influence this. The level of exertion will ultimately determine the fatigue accrued and time required for recovery. The studies examining recovery, discussed later in this thesis, fail to examine recovery in relation to the variable TL in matches.

2.2.3 Summary

- The mean TD covered over the course of a match ranges from 9 to 13 km.
- Top class football players are required to exercise at a meanintensity of around 80-90% HR_{max}.
- The ability to perform high-intensity activity differentiates between standards of play.
- Studies from 2003 to 2009 have reported similar levels of HIR however with greater variability in recent studies.
- It is also evident that numerous factors lead to variance in the values of distance reported.
- The style of play, context of the match and position of the player all lead to variation in the distance covered.

2.3 Fatigue

The challenge that appears to face soccer players from the anecdotal evidence previously presented is the high frequency of matches and relatively short recovery time. The role of a coach is to enable their players to perform optimally. Banister's (1991) modeling theory would suggest that low fatigue alongside high fitness levels provides high performance. The prolonged nature of soccer has led some authors to research fatigue during the match. Fatigue is the transient decrease in performance capacity of the muscles, usually seen as a failure to maintain or develop the expected force or power output (Gastin, 2001). Therefore the first evidence of fatigue would be changes in physical performance. There is evidence of such declines in physical performance during the process of a match. Studies have measured a number of what have been considered performance parameters by various researchers, during the recovery period. These are examined in the sections below.

2.3.1 Notational evidence of performance decline

Notational data have provided an insight into performance declines during a match. However the sources of variation that have been previously mentioned must be considered when interpreting the results. Bangsbo, *et al.*, (1991) noted that there was a 5% decline in the distance covered from the 1st to 2nd half. Mohr, *et al.*, (2003) found that there was a difference between top-class and moderate-class players. Top-class players ran more at both low and high-intensity during the first half compared with the second half. The top-class players also sprinted more in the first half than in the second half and performed more bouts of low and high-intensity running in the first half than in the second half, but moderate level players showed no significant difference between the two halves. The amount of high-intensity running independent of standard was significantly lower in the last 15 minutes than in the first 15 minutes. The decline seen in top class players from first to second half may potentially be due to their capability to exert themselves to a greater extent during the first half, hence leading to fatigue in the second half of play (Rampinini, *et al.*, 2007c).

Barros, *et al*., (2007) corroborated the findings of the above study by reporting a 7% decline in the distance covered from the first to second half. However, they found no significant difference in the distance covered at high-intensity (> 19 $km \cdot h^{-1}$). However Rampinini, *et al.,* (2007c) did find a significant 2% decrease from first to second half for the distance covered at high-intensity (> 14.4 $km \cdot h^{-1}$) and a 7% decrease for the total distance covered. The study of Di Salvo, *et al*., (2006) showed no significant change between halves for total distance and high-intensity running. Bradley, *et al*., (2009) reported a significant ($p < 0.01$) decrease in the total distance covered. The contradictory findings in these studies could be explained by the findings of Rampinini, Coutts, Castagna, Sassi & Impellizzeri (2007b), who found that the total distance covered, high-intensity running and very high-intensity running in the second half were influenced by the work output in the 1st half. Those who had covered the greatest distance in the 1st half covered significantly less distance in the second half. Those players who had covered the lowest distance in the first half (determined using the median split technique) did not see their performance decrease. On the contrary, those who had covered less distance in the first half covered a significantly greater distance running at very high-intensity in the second half.

As well as finding that player's performance had declined over the duration of a match, Mohr, *et al*., (2003) also found that players temporarily fatigued. They found that the 5 min period following the 5 min period of highest intensity exercise in a match was significantly different from the mean 5 min value for HID during the match. Bradley, *et al*., (2008) reported similar results. They found that HID in the 5 min period following the peak 5 min period was 6% lower ($p < 0.05$) than the mean 5 min HID value for the entire match.

The distance covered by sprinting in the last 15-minutes of a match was found to be significantly less than in the first four 15-minute periods of a match for top-class players by Mohr, *et al*., (2003). There was no difference with the moderate players studied. Bradley, *et al*., (2009) also reported the distances covered in the last 15 minutes of each half to be significantly ($p < 0.05$) lower than in the 1st 15 min. Krustrup, *et al*., (2006) showed how repeated sprint performance declines significantly during and after a match compared to pre match measures. Although the validity of using such a test (5 x 30m sprints, 25s rest) can be questioned, it shows that sprinting performance is also impaired during a match. However, it could be argued that many of these declines in performance might be cause by tactical changes as a match progresses. In order to factor out match factors such as tactics, some studies have used simulations. For example, Abt, Reaburn, Holmes, & Gear (2003) used a non-motorized treadmill to simulate the activity profile of team sport play over a 90-minute duration. These authors showed that peak sprinting speed decreased by 7.9%, which demonstrates that physical performance declines independently of match tactics. Overall these studies show there is evidence supporting the view that performance declines in numerous ways during a match.

It can be concluded that if the situation of the match (which is influenced by the numerous factors addressed before) determines that players have to work harder in the first half, then they will show signs of decreased performance in the second half. It could also be concluded that those players that do fatigue (top class players) do so because of their ability to cover a greater distance than their lesser counterparts. Overall there is substantial evidence that players suffer from a decline in performance during the process of playing a soccer match. The data above suggest that players fatigue in different ways during the course of a soccer match. There is ‘progressive fatigue’ where the distance covered from first to second half decreases and the amount of high-intensity running is reduced in the final 15 minutes alongside the progressive decline in sprinting performance. There is also the phenomenon of 'temporary fatigue' where players show a below average work rate for the 5 minutes after the highest intensity 5 minute period in a match.

Currently a substantial amount of money is spent by football clubs on notational analysis systems that collect statistics like those expressed above. They use various derivatives of the data collected as measures of physical performance. It is important to note though that these data may not always reflect what players are physically capable of in relation to the TD or HID. As discussed before there are numerous sources of variation that can affect these values so these results must always be analyzed with caution. The advantage of such data is that it is actual match performance data, with the disadvantage being it is hard to tell what is an individual's best performance, as it could be curtailed by numerous factors other than his or her physical capability. This limitation was also highlighted by Bangsbo (1994). Therefore the external performance needs to be analysed in relation to the internal load (Impellizzeri, *et al.*, 2005) for greater insight into the reasons why performance declines. However some authors have looked at more acute performance measures pre, during and post-match. These are discussed below.

2.3.2 Neuromuscular fatigue throughout match-play

Some authors have studied parameters of strength and power and their relative decline from pre-match values. Although some of these parameters may not be valid measures of soccer performance, it gives an insight into neuromuscular fatigue during soccer.

Ascensao, *et al.,* (2008) examined the recovery of lower limb function post match in sixteen Portuguese soccer players . They reported 20 m sprint times significantly increased by ~7% ($p < 0.05$) post-match. Peak quadricep and hamstring torque was reported to be significantly decreased ($p < 0.05$) by 10 % and 15 %, respectively. All of these measures remained significantly different to pre-match values through the course of a 72-hour recovery period through which players were monitored. Anderson, *et al.*, (2008) compared the effect of active and passive recovery interventions on the recovery of 20 m sprint performance, countermovement jumps, knee flexion peak torque and knee extension peak torque in Swedish female players. No significant differences were found between interventions. However 20 m sprint performance was significantly higher post-match (~3 %; $p < 0.05$), countermovement jump height significantly lower (~5%; $p < 0.05$), knee flexion peak torque significantly lower (~9%; $p < 0.05$) and knee extension peak torque also significantly lower (~7%; $p < 0.05$).

The parameters tested can all be considered measurements of power and strength. Fatigue can be seen as a failure to maintain a particular power output or a reduced power output as can be seen in the tests administered in these studies. Small, McNaughton, Greig, and Lovell (2008) reported that a multi-directional soccer specific simulation did not decrease concentric hamstring and quadricep peak torque with semi-professional players. However, they found that eccentric hamstring peak torque decreased significantly by 16.8 % through the match ($p < 0.01$), and was also significantly lower at half time by 5.2 % ($p < 0.01$) compared to pre-match values. Greig (2008) reported similar results with ten professional players using an intermittent treadmill protocol. He measured concentric knee extensor and flexor torque alongside peak concentric and eccentric knee flexor torque every 15 minutes. Concentric knee extensor and flexor peak torque were maintained throughout the duration of the exercise protocol. However, peak eccentric knee flexor torque at the end of the match was significantly lower ($p < 0.01$) at half time (~20%) and full time (~24%) when compared to pre-match values. Eccentric muscle contractions are involved in dissipating energy and decelerating the body (LaStayo, Woolf, Lewek, Snyder-Mackler, Reich & Lindstedt, 2003). Turning and such like movements which are frequent during soccer often use the muscles eccentrically. There is also evidence to suggest that eccentric muscle contractions that players are not accustomed to induces muscle damage (Clarkson & Hubal, 2002) and greater delayed onset of muscle soreness (DOMS) (Jamurtas, Fatouros, Buckenmeyer, Kokkinidis, Taxildaris, Kambas & Kyriazis, 2000). The structural muscle fiber damage caused by eccentric muscle exercise has previously been identified by Friden, Sjostrom, & Ekblom (1983). Therefore muscle damage caused by eccentric muscle contractions may also contribute to performance decline during and after a match. In soccer studies with both females (Andersson, *et al.*, 2008) and males (Ascensao, *et al.*, 2008; Ispirlidis, *et al.*, 2008) have examined muscle damage through the measurement of creatine kinase (CK) alongside measurement of muscular power. Although these studies did not examine the relationship between the two variables post-match, CK levels appear to rise significantly and leg power measured with isokinetic dynamometry is reduced. These studies are discussed in greater detail in section 2.4. The role of muscle damage in recovery is discussed in further detail later in this section.

In summary, the development of neuromuscular fatigue during a soccer match or simulated match activity using a number of performance parameters has been demonstrated. However, some authors (Bangsbo, 1994; Krustrup, *et al.*, 2006; Reilly, 1997) also suggest that performance declines as the energy demands of the exercising muscles cannot be maintained. The contribution of the energy systems to soccer match play is examined below.

2.3.3 Energy contribution to soccer match play

To better understand the development of fatigue the energy contribution to soccer match play must be understood. Reduced performance may occur as a result of insufficient energy being available to the contracting muscle (Krustrup, *et al.*, 2006). The universal energy molecule that allows muscle contraction is Adenosine Tri-Phosphate (ATP). This is produced by either aerobic or anaerobic metabolism via three possible pathways (phosphocreatine hydrolysis; anaerobic glycolysis; aerobic glycolysis). The type of activity determines the extent to which a system is involved in the supply of ATP. Due to the dynamic intermittent nature of soccer this is difficult to determine, as all three pathways are likely to be used in different proportions at different times. The majority of the energy requirements in a football match are aerobic but the most important and demanding activities like sprinting are largely anaerobic. The discussion below will attempt to establish some potential mechanisms as to why players may develop fatigue.

Aerobic energy contribution to match play

As the activity profile data (Bangsbo, *et al.*, 1991; Mohr, *et al.*, 2003) discussed earlier show the majority of the work done in a match is aerobic in nature. The prolonged and high-intensity nature of soccer means that aerobic (oxidative) metabolism makes the most significant contribution to energy provision during a match (Bangsbo, 1994). The aerobic contribution occurs via the process of oxidative phosphorylation. Add to this the need to recover from anaerobic bouts of exercise and the stress placed on the aerobic energy system soon becomes apparent. The extent to which ATP can be generated via this pathway depends on the oxygen supply to the mitochondria.

Maximal intensity sprinting has been shown to produce 3-5 times the peak muscular power output elicited at $VO_{2\ max}$ (Lamb, 1995). Lakomy (2000) reported the mean rate of ATP utilization of 15 mmol ATP·kg $dm^{-1}{\cdot}s^{-1}$ for a 6 s sprint on a cycle ergometer. This is beyond the capabilities of the aerobic system alone. Blomstrand, Ekblom, and Newsholme (1986) reported maximal rates of ATP production by aerobic metabolism of 26 and 29 µmol•g $ww^{-1} \cdot min^{-1}$ for males and females respectively. This amounts to 1.73 and 1.93 mmol ATP·kg $dm^{-1}{\cdot}s^{-1}$, which is well below the mean ATP utilization rate of 15 mmol ATP·kg $dm^{-1}{\cdot}s^{-1}$ reported by Lakomy (2000). Therefore the anaerobic energy pathways are required to meet the ATP demand for this level of work as the aerobic system cannot provide the ATP at a high enough rate. This situation arises repeatedly in soccer match-play. Although the aerobic energy system fails to supply enough energy for arguably the most important aspects of soccer (i.e. high-intensity bursts and sprinting) it plays a role in;

i) Contributing to ATP production during maximal / high-intensity exercise

ii) Synthesis of PCr

iii) Removal of metabolites potentially detrimental to performance

Bogdanis, Nevill, Lakomy, and Boobis (1998) demonstrated the role the aerobic system plays in energy provision during maximal exercise. They reported a 51% drop in the rate of anaerobic ATP utilization during the 2nd 10 s of a 20 s sprint. The mean power output during this period had only decreased by 28%. This was accompanied by an increase in oxygen uptake from 1.30 $\pm$ 0.15 $L{\cdot}min^{-1}$ to 2.40 $\pm$ 0.23 $L{\cdot}min^{-1}$ showing a greater reliance on aerobic metabolism. The aerobic ATP turnover increased from 13 ± 2% in the 1st 10 s to 27 ± 5% in the 2nd 20 s. As well as the aerobic energy system being used to generate ATP for sub-maximal activities, it also provides ATP for the resynthesis of phosphocreatine (PCr) and aids in the removal of lactate (Wilmore, Costill & Kenney, 2008). After its hydrolysis, PCr must be rephosphorylated, which can happen during sub-maximal periods of exercise when the oxygen demands of the body are more adequately being met.

Anaerobic energy production

Blood lactate concentrations in soccer matches have been shown to be between 2-14 $mmol\cdot L^{-1}$ (Krustrup, *et al.*, 2006; Stolen, *et al.*, 2005) which shows a high anaerobic energy turnover in matches. Decreased muscle pH has been linked with decreased contractile function in muscles (Fitts, 1994). Krustrup, *et al.*, (2006) found that muscle pH decreased significantly ($p < 0.05$) after intense periods in both the 1st and 2nd half but had recovered to pre match values post match. Significant correlations were found between performance decrement in a repeated sprint ability (RSA) test (5 x 6 s cycle test) and plasma pH ($r = 0.75$; $p < 0.05$) (Edge, Bishop, Goodman & Dawson, 2005). Production of hydrogen ions results in a decrease in pH, but the pH decrease seems to be dependant on the buffering capabilities of the muscle. Increasing the buffering capacity of the muscle by ingestion of blood buffers also enhanced sprints 3, 4 and 5 along with the total work performed in the RSA test. Further investigations by these researchers found that interval training was more effective than continuous training at increasing buffering capacity despite both programs producing similar improvements in aerobic fitness. The intensity of training and not the total work performed is the stimulus for change. Interval training is now common practice with many professional football clubs (McMillan, Helgerud, Macdonald & Hoff, 2005b). The results from the Krustrup, *et al.*, (2006) study show the likelihood of fatigue post-match being due to muscle acidosis is relatively small, if muscle acidosis contributes to fatigue. However this is a debate beyond the scope of this thesis.

As discussed in the previous section, aerobic metabolism cannot supply ATP at a high enough rate during maximal intensity exercise. Therefore ATP supplied by anaerobic metabolism becomes predominant. Anaerobic ATP production takes place via three routes. First, the muscle has a small store of ATP (~ 25 mmol·kg dm^{-1}) that can be used directly for muscle contraction. However, given the maximal rate of ATP utilization during maximal intensity exercise of around 15 mmol ATP·kg dm^{-1}•s^{-1} reported by Lakomy (2000), this would mean that this store would be exhausted within approximately 2 s of maximal intensity exercise if no other form of rephosphorylation was available. The muscle can also generate ATP through PCr hydrolysis or anaerobic glycolysis (producing pyruvate and lactate). As mentioned before, a 6 s cycle sprint requires a mean ATP utilization rate of around 15 mmol ATP·kg dm^{-1}•s^{-1}. This is similar to the 14.9 mmol ATP·kg dm^{-1}•s^{-1} reported by Gaitanos, Williams, Boobis, & Brooks (1993) for the same test. They also found that glycogen stores depleted by 14%, ATP by 13% and PCr by 57%. Peak power output (1253 ± 335 W) was approximately five times greater than that elicited at VO_{2max} (254 ± 58 W). The mean power output was 870 ± 159 W. Anaerobic glycogen breakdown contributed to 44% of the ATP produced where the rest was produced mainly via the PCr hydrolysis. However, for a 30 s sprint on a non-motorized treadmill the mean ATP utilization averaged 6.13 $\pm$ 1.76 mmol ATP•kg dm^{-1}•s^{-1} (Cheetham, Boobis, Brooks & Williams, 1986). There was a 25% decrease in glycogen concentration, a 64% fall in PCr and a 37% fall in ATP. Muscle glycogen this time contributed to 64% of the ATP produced with the rest predominantly supplied by PCr hydrolysis. Although there is a difference in testing modality, the results above suggest that longer duration maximal efforts result in an inability to maintain ATP production. Hence there is a reduction in power output. The average duration of a soccer sprint is approximately 2-4 seconds (Stolen, *et al.*, 2005). Add to this the high-intensity running and the repeated nature of such activities and the energy from anaerobic sources becomes vital.

Gaitanos, *et al*., (1993) examined the performance, recovery and metabolism in ten 6 s sprints separated by 30 seconds of recovery. The mean power output (MPO) decreased by 12.6% and 26.6% after the 5^{th} and 10^{th} sprints, respectively. After sprint 1 there was a 57% reduction in PCr, 13% reduction in ATP and 14% decrease in muscle glycogen concentration from resting values. Before the last sprint there was a 32% decrease in ATP concentration accompanied by a 30% decrease in glycogen. PCr had fallen to 51% of resting values. After the final sprint PCr fell to 16% and there was a further 6% decrease in glycogen levels (not significant). However ATP concentration showed little change. During the 1^{st} sprint muscle glycogen breakdown contributed to 44% of the ATP produced with the rest predominantly down to PCr hydrolysis. In contrast in the last sprint 80% of the anaerobic ATP was supplied by PCr hydrolysis. The decrements in power output were accompanied by a reduction in the rate of ATP production by anaerobic processes. There was a 10-fold decrease in the rate which glycogen degraded to lactate from the first to the last sprint signifying a reduced rate of glycolysis. The dramatic fall in PCr shows the extent to which it was relied on to generate ATP compared to the insignificant drop in glycogen. The authors also estimated that only approximately 35% of the ATP derived in the last sprint was from anaerobic metabolism. This illustrates the greater role of the aerobic system in generating ATP in repeated bouts of exercise. However, as highlighted before optimal rates of ATP generation from aerobic metabolism are only around ~2 mmol $ATP^{\cdot}kg\ dm^{-1}\cdot s^{-1}$. Therefore the mean power output decreased as the ATP resynthesis rate required to maintain performance could not be matched. The decrease in PCr could potentially inhibit the ATP production from the ATP-PC system. However the evidence above suggests that although PCr concentrations are reduced they are never completely depleted. Despite PCr concentration being only 16% of resting PCr after sprint 10 it must also be considered that prior to sprint 10 PCr had replenished to 51% of resting PCr. Therefore we can assume that PCr would replete to a level where ATP production via PCr hydrolysis is not substantially impaired. Also this study shows muscle glycogen stores only depleted 30% and there is a marked decrease in the contribution to ATP production via anaerobic glycolysis. The reason for this is still cause for much debate amongst researchers and beyond the scope of this thesis. The findings from the aforementioned studies would suggest that in repeated sprint situations there is still aerobic ATP production required. It is clear from these studies that the recovery time, intensity and frequency of such activities affect the athlete's ability to generate enough ATP to reproduce the same performance. Some authors (Bangsbo, 1994; Krustrup, *et al.*, 2006; Reilly, 1997) have suggested that this fatigue this is due to the depletion in energy stores (PCr and glycogen). The evidence relating to this is examined below.

2.3.3.3 PCr and muscle glycogen depletion

The depletion of PCr has been shown to occur during short and maximal exercise of both single and repeated bouts. However, when afforded adequate recovery, PCr will replete. Dawson, Goodman, Lawrence, Preen, Polglaze, Fitzsimons, & Fournier (1997) examined PCr depletion and repletion following single and repeated sprints on a cycle ergometer. They found that following a single 6 s sprint PCr concentration was 55% of the resting value after 10 s of recovery ($p < 0.01$), 69% after 30 s of recovery ($p < 0.01$) and 90% after 3 minutes of recovery (not significant). Therefore the evidence would suggest that 3 minutes between sprints would allow almost complete PCr resynthesis. However, with less than 3 minutes between sprints PCr would not be fully resynthesised and would therefore deplete to even lower levels, thereby taking even longer to return to resting levels. This may be one of the causes of performance decline observed after high-intensity activity but also progressive sprint fatigue if as the match continues inadequate recovery time between sprints and high-intensity efforts gradually lead to lower PCr levels.

Krustrup, Mohr, Amstrup, Rysgaard, Johansen, Steensberg, Pedersen & Bangsbo (2003) showed that after intense periods in soccer reduced sprint performance was correlated with the decline in PCr. However repeated periods of high-intensity running without full replenishment of PCr stores will surely lead to a gradual decrease in PCr stores. However in soccer the average duration of a sprint is 2-4 seconds which takes place every 90 seconds (Stolen, *et al.*, 2005), which represents a different challenge on PCr stores than those faced by the participants of the aforementioned studies. However, decreases in peak speed (Abt, *et al.*, 2003) and sprinting distance have been observed over the duration of a match suggesting that soccer specific activity also leads to PCr depletion.

Krustrup, *et al.*, (2006) found pre-match PCr levels of 88 ± 2 $mmol \cdot kg^{-1}$ d.w. significantly reduced to 79 ± 3 $mmol \cdot kg^{-1}$ d.w post-match. They also assessed PCr levels after intense periods in the 1st half (PCr: 76 ± 2 $mmol \cdot kg^{-1}$ d.w) and 2nd half (PCr: 67 ± 3 $mmol \cdot kg^{-1}$ d.w). The lower level of PCr after the intense period in the second half may be due to a lower absolute concentration prior to the intense period. The results of this study show that PCr concentration falls during intense periods, but can recover to a certain extent. Although by the end of the match there is still a significant decrease in PCr levels. The evidence suggests that there is a decrease in PCr stores following high-intensity exercise and that PCr depletion maybe partly responsible for decreased performance during a match. However PCr can be re-synthesized rapidly as the study of Dawson, *et al.*, (1997) shows. In addition to this, even though Krustrup, *et al.*, (2006) showed a significant decrease in PCr levels during the match, by the end of the match PCr levels were approximately 90% of pre-match levels. From the evidence presented in these studies replenishment of PCr post-match is more likely to take minutes and hours rather than days and can be excluded as a factor that may prove detrimental to soccer performance when there are days between matches.

Evidence discussed earlier has also shown how muscle glycogen contributes to ATP production during repeated sprint efforts via both aerobic and anaerobic pathways. During a soccer match, the repeated bouts of high-intensity activity and periods of low intensity activity results in glycogen depletion. Therefore as the match progresses the reliance on glycogen increases as both aerobic and anaerobic glycolysis is required to meet energy demands and stores deplete. Numerous researchers have suggested muscle glycogen depletion as one cause of fatigue experienced by players (Krustrup, *et al.*, 2006; Mohr, *et al.*, 2003; Reilly, 1997). An early study by Agvenik (1970) showed that players were almost emptied of muscle glycogen stores after a match. Furthermore, most of the glycogen depletion took place in the 1st half. Decreases in peak speed (Abt, *et al.*, 2003), sprinting distance and high-intensity running (Mohr, *et al.*, 2003) have been reported towards the end of a match.

A recent study by Krustrup, *et al.*, (2006) provides the most detailed analysis of muscle glycogen depletion in footballers to date. With 73 ± 6% of muscle fibers rated as 'full' before a match, they found muscle glycogen concentration was 43 ± 6% lower post match. After the match, a total of 36 ± 6% of individual muscle fibers were almost empty, and another 11 ± 3% were completely empty of glycogen. However there was still glycogen available and no research to date in soccer that has shown a cause and effect relationship between reductions in muscle glycogen levels and fatigue.

Those players following a high carbohydrate diet pre-match and having higher muscle glycogen stores have been shown to perform 33% more high-intensity exercise when compared to those following a low carbohydrate diet (Balsom, Wood, Olsson & Ekblom, 1999). Krustrup, *et al.*, (2006) suggested that fatigue may be due to the total depletion of glycogen in individual muscle fibers rather than depletion overall. Enhanced performance following a high CHO diet may be due to a potential reduction in the number of muscle fibers completely depleted of glycogen.

Increase in plasma Free Fatty Acids (FFA) have also been reported post match (Krustrup, *et al.,* 2006) indicating a reliance on other fuel metabolites as muscle glycogen decreases. Krustrup, *et al.,* (2006) also reported significantly higher levels of FFA after 45 minutes and post match following a low carbohydrate diet compared to a high carbohydrate diet. Another study showed that a high CHO diet improved performance in soccer simulated activity (Nicholas, Green, Hawkins & Williams, 1997). When a high CHO diet was consumed in the 22 hours between the two simulations the high CHO group performed almost 20% more running in the intermittent running test towards the end of the simulation. The combination of reduced performance alongside depleted glycogen stores and carbohydrate supplementation maintaining performance for longer suggests that levels of muscle glycogen may explain some of the performance decrement seen.

The question then arises, are players optimally fuelled? There is no study to date examining the repletion and depletion of glycogen stores of footballers during the competitive season. The nature of competition and training is such that even a small deficit after each competition and training bout could lead to an accumulated decline in glycogen concentration until adequate rest and recovery is afforded. The replenishment of muscle glycogen is a more long-term proposition when compared to that of PCr. The depletion of glycogen during a match has already been reported in detail above. However to date little research has examined the time scale for muscle glycogen repletion in soccer players.

The synthesis of glycogen post exercise is dependent on the availability of exogenous carbohydrate and regulation of systems associated with cellular glucose uptake (Burke & Deakin, 2000). The increased sensitivity of insulin post exercise (Cartee, Young, Sleeper, Zierath, Wallberghenriksson & Holloszy, 1989) and increased activity of the GLUT-4 protein transporter (McCoy, Proietto & Hargreaves, 1996) have been reported to be two such mechanisms. It has also been demonstrated that the degree of glycogen depletion will affect the initial rate of resynthesis. Zachwieja, Costill, Pascoe, Robergs, and Fink (1991) showed that muscle with lower glycogen concentration exhibited a greater initial rate of glycogen resynthesis when compared to muscle with higher glycogen concentration. Burke & Deakin (2000) report that given adequate exogenous carbohydrate, glycogen stores can be replenished within 24 hours. Krustrup, *et al.*, (2006) reported a mean pre match muscle glycogen content of 449 $mmol\cdot kg^{-1}$ d.w. Post match this was reported to decline to a mean of 255 $mmol\cdot kg^{-1}$d.w. a decrease of 194 $mmol\cdot kg^{-1}$ d.w. With a maximal resynthesis rate of 10 $mmol\cdot kg^{-1}\cdot ww\cdot h^{-1}$ (Doyle, Sherman & Strauss, 1993) and given optimal resynthesis conditions, total resynthesis would take approximately 5 hours. However these conditions are unlikely to always exist. Primarily as this maximal reported rate has only been reported for the first 2-4 hours of recovery. A range of mean resynthesis rates for longer periods of recovery (12-24 hours) of 5 to 10 $mmol\cdot kg^{-1}$ wet $wt\cdot h^{-1}$ have been reported (Blom, Hostmark, Vaage, Kardel & Maehlum, 1987; Burke & Deakin, 2000; Ivy, Katz, Cutler, Sherman & Coyle, 1988; Ivy, Lee, Brozinick & Reed, 1988), given adequate CHO is available. Given these resynthesis rates it could take up to 10 hours to replace the muscle glycogen used during a match, assuming a mean decrease of 194 $mmol\cdot kg^{-1}$ d.w reported by Krustrup, *et al.*, (2006).

No study to date has been conducted on monitoring glycogen resynthesis in soccer players following their normal day to day training, competition and nutrition practices. Given the importance of initial muscle glycogen concentrations on performance as highlighted by Nicholas, *et al.*, (1997) a study examining muscle glycogen resynthesis post match is required using either an actual match or soccer specific simulation that allows measurement of performance variables. Therefore the fatigue that occurs in a football match that manifests itself as a performance decline could be due to the availability of ATP and/or metabolites for ATP production via the various pathways. PCr and glycogen stores have been shown to significantly decrease after short and repeated bouts of maximal exercise. They have also shown to be significantly lower at the end of a match but the data suggests there is still substantial availability of glycogen. If muscle glycogen is still present then there may be other factors that contribute to the observed decrease in physical performance towards the end of a match. One possibility is 'central' fatigue.

Central Fatigue

The concept of a 'central governor' has been hypothesized in a series of papers (Noakes, Gibson & Lambert, 2005). Lambert, St Clair Gibson, and Noakes (2005) hypothesize fatigue as;

> "being the result of the complex interaction of multiple peripheral physiological systems and the brain".

They claim that;

> "all changes in peripheral physiological systems such as substrate depletion or metabolite accumulation act as afferent signalers which modulate control processes in the brain in a dynamic, nonlinear and integrative manner"

The depletion of fuel metabolites could contribute to the fatigue suffered during a match as previous authors have suggested. However the mechanism proposed by the central governor theory is quite different. Previous researchers assumed that decreased availability of muscle glycogen towards the end of the match was the cause of fatigue. However the question that remained was how can glycogen depletion cause fatigue when over 50% of muscle glycogen stores post match remained intact. Lambert, *et al.*, (2005) propose that glycogen concentration is one of many peripheral mechanisms that feed forward and back through afferent pathways to prevent absolute fatigue, creating in effect a protective mechanism. The result of this integrative complex response is an oscillatory power output and physiological response (Lambert, *et al.*, 2005) . Therefore the peripheral mechanisms for fatigue that have consumed soccer fatigue related research deserve to be studied in the context of the 'complex' model of fatigue. It would appear protective mechanisms prevent total depletion of energy stores and absolute or catastrophic fatigue. This would explain how fatigue is apparent towards the end of a match despite substantial glycogen stores being present. If greater initial glycogen stores are present it will take longer for those stores to deplete to levels where glycolytic and glycogenolytic rates are potentially reduced (Gaitanos, *et al.*, 1993) and a reduction in performance through the manifestation of fatigue via a central reduction in power output (Lambert, *et al.*, 2005).

2.3.4 Summary

This review of fatigue highlights several issues that may need to be considered when designing experiments and examining the recovery post match.

- The research presented in this study shows that there is clear evidence of performance decline over the course of a soccer match.

- Therefore it can be assumed that players would not be able to perform optimally again until they recover.
- Muscle acidosis is unlikely to cause fatigue post match as the research suggests that lactate values quickly return to pre match values.
- PCr has been shown to resynthesize quickly and is therefore not a concern for post-match recovery strategies.
- Given optimal replenishment conditions muscle glycogen stores can be replenished within 24 hours, therefore any recovery study should make sure sufficient time and food is provided to negate any effect a lack of energy substrates may have on fatigue.
- The fatigue process is probably more complex than just a cause and effect relationship between one parameter and performance.
- In the context of this thesis fatigue should be considered a consequence of exercise for which a management method is required so that coaches have information on the level of fatigue a player has and the effect this will have on his/her ability to perform.
- The mechanisms of fatigue remain debated amongst researchers. However analysis of both the internal and external performance in soccer matches may help assess if the decrement in performance is due to fatigue alone.

2.4 Recovery from soccer match play

In recent years the study of recovery in soccer has received a little more attention as there is the perception that match frequency has increased and recovery time therefore decreased. Recovery from exercise is a complex process requiring replenishment of energy substrates, repair of damaged muscle tissue and initiation of training adaptation (Ivy, 2004). This requires the body to switch from a predominantly catabolic state to an anabolic state. In this section the current literature on recovery from soccer will be reviewed. Issues concerning fuel repletion have already been discussed previously. This section of the review will focus on;

- the recovery of physiological performance parameters post match
- the recovery of biochemical measures post match
- the possible influence of both physiological and biochemical parameters on performance

2.4.1 Recovery from soccer match play – performance measures

Reilly and Rigby (2002) made an attempt to study the effects of active recovery on physical performance measures. Fourteen university level players were divided into two equal groups and were assigned to either an active recovery group or a passive recovery group. Players were tested using a number of performance measures pre-match, post-match, at 24 h and 48 h after the match. The measures consisted of broad jumps, vertical jumps, 30 m sprints and a sprint fatigue test (7 x 30 m sprints with 20 s rest between sprints). After the match, those in the active recovery group underwent 12 minutes of active recovery whereas the passive recovery group rested in the changing rooms. Broad jump and vertical jump performance was significantly lower for both groups after the match with the experimental group showing decreases of 20 cm and 9.5

cm and the control group showing a reduction of 21 cm and 14 cm, respectively. At 24 h the experimental group had improved by 9 cm and 2.5 cm, whereas the control group had deteriorated further by 7 cm and 1 cm, respectively. Significant differences remained between the groups at 48 h. However the experimental group still hadn't returned to pre-match values. A similar pattern immerged in the results for the 30 m sprints where neither group returned to pre-match values by 48 h, but the active recovery group was found to be recovering quicker. In the sprint fatigue test the active recovery group returned to baseline values 48 h after the match, whereas the control group had not.

It is evident from this study that active recovery has beneficial effects in all areas that have been tested. But to what extent can these imply that active recovery or any recovery modality for that matter improves or maintains soccer performance? The study also did not report any measure of physical exertion during the match. The differing extents to which players fatigue due to different fitness levels and their internal TL has therefore not been taken into consideration. This coupled with the performance measures not really being indicative of football performance greatly affects the validity of this study.

Dawson, Gow, Modra, Bishop, and Stewart (2005) examined pool walking, stretching and hot/cold water immersion therapy as recovery modalities in semi-professional Australian rules football players. In a repeated measures design where the players acted as their own control, players underwent one of the four conditions after a match. Flexibility (sit and reach test) and leg power (vertical jump; 6 s cycling sprint) were measured pre-match, 15 h post-match and 48 h post-match. No significant differences existed between the recovery modalities compared to the control group for any of the measures with the exception of vertical jump performance in the pool walking condition at 15 h ($p < 0.01$; Cohen's *d*: 1.02, large effect) and the 6 s sprint peak power in the stretch condition at 15 h ($p < 0.01$; Cohen's *d*: 1.45, large effect). There was also no significant difference between time points for any of the interventions and tests with the exception of peak power (6 s cycling sprint) for the control group which was significantly lower than baseline at 15 h post-match ($p < 0.01$; Cohen's *d*: 1.02, large effect). The results suggest that in some tests passive recovery is detrimental to recovery as they did in the Reilly and Rigby (2002) study. Again, the application of this study to soccer is inhibited as the performance measures used do not truly reflect the physiological profile of soccer, although they may apply to Australian rules football to a greater extent. Moreover, and in line with Reilly and Rigby (2002), the recovery response was measured without measurement of the dose (internal TL) and neither was the dose controlled.

Ascensao, *et al*., (2008) examined the effect of a single competitive soccer match on the recovery profile of a number of physical and biochemical measures. The authors reported that sprint time (20 m) and quadriceps and hamstrings peak torque levels remained significantly decreased throughout the 72 h recovery period after the match. Mean quadriceps peak torque decreased by approximately 10% until 48 h of recovery and remained about 5% lower than pre-match values at 72 h. The match induced an approximate 15% decrease in hamstring peak torque until 24 h. Hamstrings strength remained around 10% lower than pre-match values at 48 and 72 h. The match also increased 20 m running time by approximately 7% at 30 min after the end of the match. Sprint ability remained lower than pre-match values by around 5% until 72h recovery. However, the same criticisms that are leveled at the previous recovery study can be leveled at this study as the recovery measures were not examined in relation to the TL.

Ispirlidis, Fatouros, Jamurtas, Nikolaidis, Michailidis, Douroudos, Margonis, Chatzinikolaou, *et al*., (2008) examined the recovery profile of 14 elite male soccer players for a number of physical performance measures for 7 days post-match. They reported data on vertical jumps (VJ), a one repetition max (1RM) squat and a 20 m sprint as physiological performance measures. They found that VJ was significantly lower 24 h after the match and returned to pre match values after 72 h. Maximal squat strength decreased significantly and reached its lowest point at 48 h post-match before returning to pre-match values 96 h after the match. Finally sprinting performance decreased significantly, reaching its lowest point 48h post match and returned to pre match levels 120 h after the match. Whereas the previously reported studies in this section have assessed performance for up to 72 h, and have found incomplete recovery of physical performance measures, the study of Ispirlidis, *et al.*, (2008) examined the recovery for one week after the match and identifies when each measure returned to pre-match values. This is advancement in comparison to the other recovery studies. However, again, the recovery of the performance measures were not assessed in relation to the TL.

Andersson, *et al*., (2008) attempted to build on the earlier study of Reilly and Rigby (2002) with their study on female soccer players. The research design consisted of two matches being played 72 h apart and testing taking place periodically pre and post both matches. The experimental group in the study were required to undergo two recovery sessions between the matches. The active recovery consisted of a low-intensity training program (sub-maximal cycling at 60% HR_{peak}) and low-intensity resistance training (<50% 1RM) performed at 22 and 46 h after the first match. They measured 20 m sprint times, counter movement jump (CMJ), maximal isokinetic flexion and extensions as well as biochemical parameters in the form of creatine kinase (CK), urea and uric acid concentrations as measures of muscle damage and oxidative stress respectively. There was no significant difference between the two groups in any of the neuromuscular or biochemical parameters tested through the course of the recovery. However the time course for the recovery of the tested components provides a useful insight with 20 m sprints returning to pre-match values 5 hr post match 1. CMJ was lower than baseline measures throughout the 72 h between the matches. Peak torque in knee extension took 21 h to return to baseline and flexion took 51 h. CK returned to baseline values 69 h post-match 1 with urea and uric acid taking 21 h.

Again, the relevance to soccer of the performance measures used in this study can be seriously questioned. High-intensity running was not credited as a performance measure in this study but was collected as a measure of work intensity and found to be similar in both matches. High-intensity running has been found to differentiate between top class and moderate class players. This measure also takes into consideration the aerobic capability of the players as well as sprinting (anaerobic). The study found there to be no difference between the matches in high-intensity running supporting the study of Odetoyinbo, *et al.,* (2007). The mean HR in the second match was significantly higher. This indicates that maintenance of work rate/performance is possible but at a heightened physiological cost. Despite the CMJ remaining lower for the 72 h it seems players were still able to produce a comparable performance. Therefore the validity of using such acute physiological measures as 'performance' measures for a soccer match has to be questioned. Acute measures of explosive activity such as jumps and sprints are also highly dependent on muscle temperature. Krustrup, *et al.,* (2006) showed that the decrease in sprint time after half time related to the decrease in muscle temperature ($r = 0.60$, $p < 0.05$). This has not been assessed in any of the aforementioned studies. Therefore the use of measures that are influenced by a variable that is largely individual and difficult to measure raises issues about the validity of using the results of such studies to inform practice. The high-intensity nature of soccer will no doubt raise muscle temperature. Krustrup, *et al*., (2006) reported a 3.4 degrees rise after a warm up prior to the match was maintained during the 1st half with no significant increase. The half time interval caused the temperature to significantly drop ($p < 0.05$). However at the end of the match there was no significant difference. Therefore a warm up is imperative to increase muscle temperature. However, the scenario where the muscle temperature rise achieved from a warm up is not as great as that achieved by 45 minutes or 90 minutes of football may arise resulting in an attenuation of any potential leg power measurement. As muscle temperature wasn't measured in the recovery studies reported in this section, but plays such a critical role in many of the power based tests used to examine recovery this should also be considered a limitation. This may also be the reason for the varying time courses to recovery reported in the literature. If muscle temperature does rise during the match it may attenuate any decline in performance. Given the limitations of using such acute measures of physical performance to imply fatigue or recovery in soccer, future studies need to examine fatigue with repeated match performance (Andersson, *et al.*, 2008; Odetoyinbo, *et al.*, 2007) using more valid indicators of soccer performance such as TD and HID to imply fatigue or recovery. Given the high CV in distance measurements previously reported in matches (Gregson, *et al.*, 2010) this may come in the form of reliable match simulations.

The sources of variation in a soccer match have already been outlined in section 2.2, which leads to different a TL for each player even in the same match. According to Banister (1991) the fatigue accrued from a given exercise bout is dependent on the initial training impulse. Therefore the level of recovery is dependent on the level of exertion. Hence, the lack of an accurate quantification of the exercise dose makes interpretation of the recovery response difficult. This criticism can be leveled at all the recovery studies reported in this section. Some of the studies discussed above measured a number of variables including a variety of biochemical measures. These biochemical measures are categorized and discussed further below.

2.4.2 Recovery from soccer match play – biochemical measures

A typical soccer match exposes players to eccentric muscle contractions due to decelerations and changes in directions. There is evidence to suggest that eccentric muscle contractions that players are unaccustomed to induces muscle damage (Clarkson & Hubal, 2002) and greater delayed onset of muscle soreness (DOMS) (Jamurtas, *et al.*, 2000). The structural muscle fiber damage caused by eccentric muscle exercise has previously been identified by Friden, *et al.*, (1983) following eccentric cycling exercise. They reported that the muscle damage originated from the myofibrillar Z-band. This damage was reported in every second to every third fiber up to 3 days after exercise and in one tenth of the fibers 6 days following the exercise. Given the performance decline in certain parameters mentioned previously, muscle damage has been examined as a potential cause.

DOMS is a sensation of discomfort within skeletal muscle experienced by athletes. The intensity of discomfort increases over time, peaking between 24 and 72 h post exercise and has been known to manifest itself for up to 7 days (Cheung, Hume & Maxwell, 2003). Along with DOMS many researchers have used creatine kinase (CK) as a measure of muscle damage. Elevated CK levels are usually a result of muscle damage at the level of the sarcolemma and Z disks (Thorsten, Martin & Theo, 2000). CK release and clearance from plasma is dependent on the level of training, type, intensity and duration of exercise (Brancaccio, Maffuli & Limongelli, 2007). The use of both DOMS and plasma CK levels can potentially be used to assess the recovery of a player and their readiness to exercise.

Ascensao, *et al.*, (2008) reported that both CK and DOMS remained elevated throughout a 72 h recovery period with CK peaking at 48 h post match. They also found significant correlations with sprint ability and DOMS ($r = 0.48$; $p < 0.01$) and also CK ($r = 0.55$; $p < 0.01$). These are only moderate correlations for one aspect of soccer performance, though ones that warrants further investigation. Ispirlidis, *et al.*, (2008) found a similar pattern where CK levels peaked at 48 h and remained elevated until returning to pre-match values at 96 h. DOMS peaked immediately after the match and remained elevated until 96 h after the match. Ascensao, *et al.*, (2008) did not find that 72 h was adequate recovery time for these parameters to recover, similar to Ispirlidis, *et al.*, (2008) who found that an extra 24 h (96 h) was adequate. In contrast to these results Andersson, *et al.*, (2008) reported that both CK and DOMS returned to baseline at 69 h post match. Although recovery was quicker, interestingly both markers returned to baseline at the same time point as was the case in the other studies. This may just be a reflection of less muscle damage during the match or maybe even potentially a gender difference (Mougios, 2007).

CK values show great variability among individuals (Brancaccio, *et al.*, 2007). Athletes have higher resting CK when compared with untrained subjects (Koutedakis, Raafat, Sharp, Rosmarin, Beard & Robbins, 1993b). The time course for recovery of CK to resting levels (discussed above) has been reported to be between 48 and 96 h. Due to the typical soccer player schedule of training and competition it is likely that CK levels would remain elevated when compared to the general population. The studies of Ispirlidis, *et al.*, (2008) and Ascensao, *et al.*, (2008) reported CK peaks 48 h post match in the region of 800-1000 $u \cdot L^{-1}$. The numerous factors affecting CK levels and variability related to CK led Mougios (2007) to determine reference intervals for athletes to determine normal values within the athletic population. Mougios (2007) reported non athletes to have lower CK levels than athletes and also females to have lower CK levels than males regardless of activity status. This is somewhat reflected in the study of Andersson, *et al.*, (2008) who reported peak CK levels post match of around 400-500 $u \cdot L^{-1}$ for female players which is approximately half of that reported for males (Ascensao, *et al.*, 2008; Ispirlidis, *et al.*, 2008). Mougios (2007) found an upper reference limit of 1083 u·L^{-1} (CI: 881–1479) for male athletes. Soccer players contributed to 182 of the participants on the study. Lower and upper reference intervals for soccer players were 83 (53–84) u·L^{-1} and 1492 (924–1908), respectively. The large variation in values is still evident. However these samples were collected over a period of 5 years and were not specific to any level of player. Given the time-course of CK recovery previously reported it appears logical that athletes in regular training would have elevated levels compared to the general population. Therefore the reported higher values of CK in athlete's may be a result of inadequate recovery time between exercise bouts.

To date, only Lazarim, Antune-Neto, da Silva, Nunes, Alves, Brenzikofe, and de Macedo (2008) have studied CK levels in elite soccer players with a view to using it as a marker of overload. They hypothesized that plasma CK is a reliable measure of muscular overload. They used CK levels above reference intervals as a sign of overload and adjusted training accordingly during the course of the Brazilian championship. They reported upper reference limits (97.5th percentile) of 1338 u·L^{-1} (CI: 1191—1639). However they used the values relating to the 90th percentile, which were 975 U/L (CI: 810—1090) to assess muscular overload. Six players were found to have exceeded these values during the course of the season. Five of these were told to reduce their activity levels which resulted in decreased levels a week later. However, one player (CK level: 1800 u·L^{-1}) exhibited high levels of CK above the upper reference limit on the eve of a match. He subsequently participated and was injured.

In summary, the variability of CK and intricacies involved in its measurements may pose problems for its use in the monitoring of fatigue, muscle damage and recovery. However the study above also shows its potential advantages. CK levels post match have been reported to remain elevated for 48-96 h. Whereas recovery studies have looked to total recovery of CK levels to baseline as a measure of total recovery, readiness to perform may be signaled by CK levels falling below certain reference levels. A moderate correlation has been found between sprint ability and CK levels (Ascensao, *et al.*, 2008). However, a 20 m sprint performance does not define soccer performance, although this relationship requires further research. Future research into changes in CK levels during competition in relation to performance need to be considered.

Muscle damaging exercise is also thought to be related to markers of oxidative stress. Oxidative stress is caused by the imbalance between enhanced reactive oxygen and nitrogen species (RONS) and the ability of the antioxidant systems to render these inactive (Ascensao, *et al.*, 2008). During exercise the production of RONS is elevated. RONS (also termed free radicals) produced following contractile activity are associated with muscle damage and there is also an argument for it being involved in the delayed onset of muscle soreness (DOMS) (Close, Ashton, McArdle & Maclaren, 2005).

Increased RONS production during exercise is negatively related to cellular homeostasis and may compromise cellular function (Ascensao, *et al.*, 2008) or even promote molecular modification (Cazzola, Russo-Volpe, Cervato & Cestaro, 2003). It has also been reported that strenuous exercise produces a decrease in antioxidant levels (Cazzola, *et al.*, 2003). Stress is suffered whenever a system is overloaded. Therefore individuals unaccustomed to regular exercise will suffer greater oxidative stress. Increased levels of RONS does not necessarily have a negative effect on health or exercise performance. At low levels they are involved in numerous biological functions such as the regulation of vascular tone, substrate metabolism and muscle contractility (Nikolaidis, Jamurtas, Paschalis, Fatouros, Koutedakis & Kouretas, 2008). They may also be involved in the adaptation process (Vollaard, Shearman & Cooper, 2005). Brites, Evelson, Christiansen, Nicol, Basilico, Wikinski, & Llesuy (1999) found that football players suffered oxidative stress but training had improved their antioxidant capacity, findings supported by Cazzola, *et al*., (2003). The studies mentioned above suggest that training and matches expose players to oxidative stress and consequent damage. Therefore it is likely that RONS and free radicals have a role to play both during and in the recovery from training and match play. The oxidative stress markers studied by these researchers are discussed in greater detail below.

To date only Ascensao, *et al*., (2008) and Ispirlidis, *et al.*, (2008) have examined the oxidative stress response in the recovery from a match in relation to other markers of muscle damage, lower limb function and DOMS. Ascensao, *et al*., (2008) found measures of oxidative damage in malondialdehyde (MDA) remained elevated throughout the 72 hour recovery period and sulfhydryl (-SH) only returned to pre match baseline values at 72 h post match. Total antioxidant status (TAS) was significantly higher at 30 minutes post match and uric acid levels remained significantly higher throughout the recovery period. The increased levels of oxidative stress markers in this study is further testament to the substantial physiological stress faced by modern day soccer players despite the increased levels of antioxidants due to their trained status. However, there was no relationship between any measure of oxidative stress, lower limb function measures and DOMS suggesting a very individual response and limited use of these measures in relation to performance. Although, DOMS remained significantly higher than pre match levels until 72 h after the match.

The results of the Ascensao, *et al*., (2008) study contrasts with the Anderson, *et al*., (2008) study on female footballers discussed earlier. Ispirlidis, *et al*., (2008) used UA, protein carbonyls and thiobarbituric acid – reactive substances (TBARS) as measures of oxidative stress. They found UA to significantly increase at 24 h post match and peak at 72 h before returning to pre match values 120 h post match. Protein carbonyls increased significantly post match, peaked at 48 h and remained elevated before returning to pre match levels at 120 h post match. Finally, TBARS showed a significant increase post match and peaked at 24 h before returning to pre match values at 72 h. Uric acid was the common oxidative stress marker examined in each study however, all studies report different results. Andersson, *et al*., (2008) reported UA returned to baseline 21 h into recovery, Ascensao, *et al*., (2008) reported that UA remained elevated at 72 h, and Ispirlidis, *et al*., (2008) reported that UA returned to baseline at 120 h post match. We can conclude that a soccer match results in oxidative stress for the reasons outlined previously. However, the recovery profile of such markers, are dependent on numerous factors that lead to variation, namely the muscle damage accrued. This in turn is dependent on the quantity and type of activity performed during the match which has already been shown to vary in numerous ways**.** Oxidative stress can also be caused by a reduction in anti-oxidant levels. Therefore diet will also play a crucial role in determining the level of oxidative stress.

In summary, a soccer match results in oxidative stress. The time course for recovery of oxidative markers varies considerably between markers and studies as the results of UA demonstrate. One of the potential reasons for this could be the variability in the amount and type of exercise between players. Therefore to make accurate judgments about the response, the dose (volume and intensity of exercise) must be accurately quantified. Although the mean match intensity was reported in these studies, a does-response relationship must be established and this is only useful if the measured variables show relationships with changes in performance. Further to those studies examining the oxidative response to exercise, no study has reported relationships between any of the oxidative stress markers and soccer related performance measures. Future studies examining the oxidative stress response should examine the relationships with specific and valid measures of soccer performance.

After exercise and during recovery the body's objective is to shift from a mainly catabolic state to an anabolic state. Some authors have used hormonal responses to study this and this is reviewed below.

Salivary cortisol can increase significantly post-match compared to pre-match baseline levels (Haneishi, Fry, Moored, Schilling, Li & Fry, 2007). Cortisol regulates blood glucose homeostasis by stimulating amino acid release from muscle, by stimulating hepatic gluconeogenesis from amino acids and by helping mobilize free fatty acids from adipose tissues (Brooks, Fahey, White & Baldwin, 1999). Post match cortisol levels have found to be 250% higher than pre match levels in female players (Haneishi, *et al.*, 2007). A significant increase in post match levels was also reported by Ispirlidis, *et al.*, (2008) for elite male soccer players but 24 h is adequate for elevated levels to return to baseline. Elevated cortisol levels signify the catabolic status of the body. This may result in decreased physical performance due to reduced protein synthesis, contractile proteins, neurotransmitters and muscular force which eventually manifests itself as strength reductions (Florini, 1987). Cortisol is also an immunodepressant. This subjects athletes to a period of reduced immune function after strenuous exercise. Changes in hormonal status can be useful for quantifying the effect of exercise on the body by tracking the time taken for biochemical markers to return to homeostasis. Gleeson, Blannin and Walsh (1997) found that competitive matches reduced the functional capabilities of leucocytes. Reductions in natural killer cells and a weakening in the response to pathogens have also been noted (Reilly & Ekblom, 2005). However, other researchers have argued that the immune response to exercise, cortisol and testosterone (also thought to be an immunodepresant) is much more complex (Mackinnon, Ho, Blake, Michon, Chandraker, Sayegh & Wetzler, 1999). Malm, Ekblom and Ekblom (2004) found cortisol appeared to suppress some lymphocyte populations whilst enhancing some neutrophil populations. Increased cortisol levels were negatively correlated to the decrease in one natural killer cell population and positively correlated to the increase in the neutrophil:lymphocyte ratio.

Cortisol can also be used effectively in conjunction with testosterone (T:C ratio) as an indicator of the anabolic-catabolic balance in the body. Heightened cortisol levels post exercise reduces the T:C representing a period where there is a reduction in anabolic processes required for adaptation and recovery. Malm, *et al*., (2004) found T:C to be reduced following two consecutive matches but the ratio returned to pre match values 6 h after the 2^{nd} match. T:C may have a role in investigating the effect evening matches may have on the recovery of players. Sleeping time represents the period when the hormonal profile is most anabolic (Kern, Perras, Wodick, Fehm & Born, 1995). It has also been shown that elevation of cortisol levels in the evening has a more profound detrimental effect on glucose regulation than in the morning (Plat & Balasse, 1999). Therefore players playing in evening matches rather than afternoon matches maybe disadvantaged in their recovery as cortisol levels remain elevated to a greater extent during their sleep, compromising the most anabolic period of their recovery. This also has a role to play when players are flying considerable distances to and from matches and are deprived of sleep, or sleeping patterns are disturbed.

In summary, the T:C ratio is a useful measure of the status of the body during recovery. However, the T:C seems to return to baseline within a few hours after a match. Performance measures previously discussed have remained impaired for much longer. To date no studies examining the performance relationship with the T:C ratio in soccer have been conducted, possibly because there is unlikely to be any when comparing the time scales of recovery of performance parameters and T:C.

2.4.3 Summary

- As recovery time decreases between matches information on the level of recovery is a valuable asset for coaches as this may determine their performance in a match.
- The studies reporting the recovery of acute performance measures and biochemical measures post match have been largely descriptive at the group level without due consideration to the individual.
- All of the studies have failed to assess recovery in relation to the exercise dose.
- Establishment of a dose – response relationship may allow future prediction of the time course of recovery.
- Acute performance measures are not representative of overall soccer performance.
- CK shows some moderate relationships with sprint performance and DOMS.
- The relationships between measures of oxidative stress and performance seem to absent from the literature.
- Future studies should examine the recovery process in relation to the TL.
- Future studies should also examine the relationship between biochemical measures and soccer related performance.

3- Analysis of Recovery Times in the English Premier League

3.1 Introduction

The apparent increase in workload for soccer players has been discussed (Section 2.2). This could be a result of the match becoming more intense, an improvement in fitness and training regimes over the years, or an increase in match frequency. In recent times numerous managers and players have made reference to a congested fixture lists (section 1.1) and evidence exists of matches being played within 48 hours of each other. This occurrence is particularly common in England, where the authorities have yet to introduce a winter break and traditional holidays (Christmas and Easter) usually play host to matches on given days. In response to this fixture congestion coaches have in some instances resorted to player rotation making use of their squads.

However, no study to date has examined the frequency of matches and the recovery period between them. Furthermore no study has examined the changes (if any) in match frequency over a number of seasons to help answer questions relating to the increase in demands on players over time. It can also be argued that teams are victims of their own success. If you progress to win knock-out cup competitions you inevitably play more matches. Some of this may be counteracted by rotating players. Given the growing research focusing on soccer recovery strategies and the time course of recovery of different markers (Section 2.4) the frequency of matches being played in a short period of time requires attention. Therefore a descriptive analysis of the current demands is required to assess to what extent research in the area of recovery from soccer match-play is warranted.

Hence this study had four aims;

1) Calculate the current match frequency for EPL teams.
2) Establish if this has changed over a number of seasons.
3) Establish if the match frequency is different for successful teams compared to less successful teams.
4) Establish if squad rotation is being used to address any potential fixture congestion.

3.2 Methods

Three seasons from the English Premier League (EPL) were chosen for analysis as these represented the 1st season of the EPL, the most recently completed season of the EPL and a season in-between which represented the year when Manchester United were successful in three competitions, as this would give an indication of match frequency when teams are successful. These were the 1992/93 season (S1) when the EPL started along with the 1998/99 (S2) and 2007/08 (S3) seasons respectively. In each of these seasons the fixture lists from the Association of Football Statisticians (AFS, 2011) website were used to gather information of all the matches played in all competitions (EPL, FA Cup, League Cup, European Cups) for the top 4 and bottom 4 sides in the EPL. Where information on kick off times was missing the EPL official website (www.thepremierleague.com), the Times newspaper and the Independent newspaper archives were used.

In total 1014 matches were indexed in a database in SPSS (SPSS Inc, Version 16 for Windows). Team recovery time (RT) was computed for all matches in relation to the previous match and calculated as the difference in kick off times in hours. Functional squad size (FSS) was characterized as the number of players who made at least one appearance in the given season.

The data were not normally distributed therefore a descriptive analysis was conducted using medians, modes, ranges, frequency distributions and relative changes.

3.3 Results

3.3.1 Recovery Time

Median RT across seasons for all teams showed little variation (100-101 hours), however when this was divided into the top and bottom it showed considerable changes over time and an increasing disparity (Table 3.1).

Table 3.1 Descriptive statistics of recovery time (hours)

	Median		Mode		Range (min)		Range (Max)	
Season	**Top 4**	**Bottom 4**	**Top 4**	**Bottom 4**	**Top 4**	**Bottom 4**	**Top 4**	**Bottom 4**
S1	100	100	67	168	48	48	311	361
S2	100	164	67	168	51	48	311	311
S3	91	168	76	168	52	67	244	357

The median RT for the bottom 4 increased by 64% from S1-S2 by increasing from a 100 hours to 164 hours. This further increased by 4 hours in S3. Comparatively the only reduction in the top 4 was from S2-S3 where median RT reduced by 9 hours. However this does leave an 84% disparity between the top 4 and bottom 4 in S3, showing that current demands are much higher for successful teams than for less successful teams. This disparity can also been seen in the mode and the higher and lower limits of the range. The most frequent recovery period is 76 hours for the top 4 compared to 168 hours for the bottom 4 which equates to a difference of 92 hours or almost 4 days. The minimum amount of time between matches is also much lower for the top 4 (52 hours) compared to the bottom 4 (67 hours). The longest time between matches is also much lower for the top 4 (244 hours) compared to the bottom 4 (357 hours). This points towards a trend indicating a greater load on more successful teams.

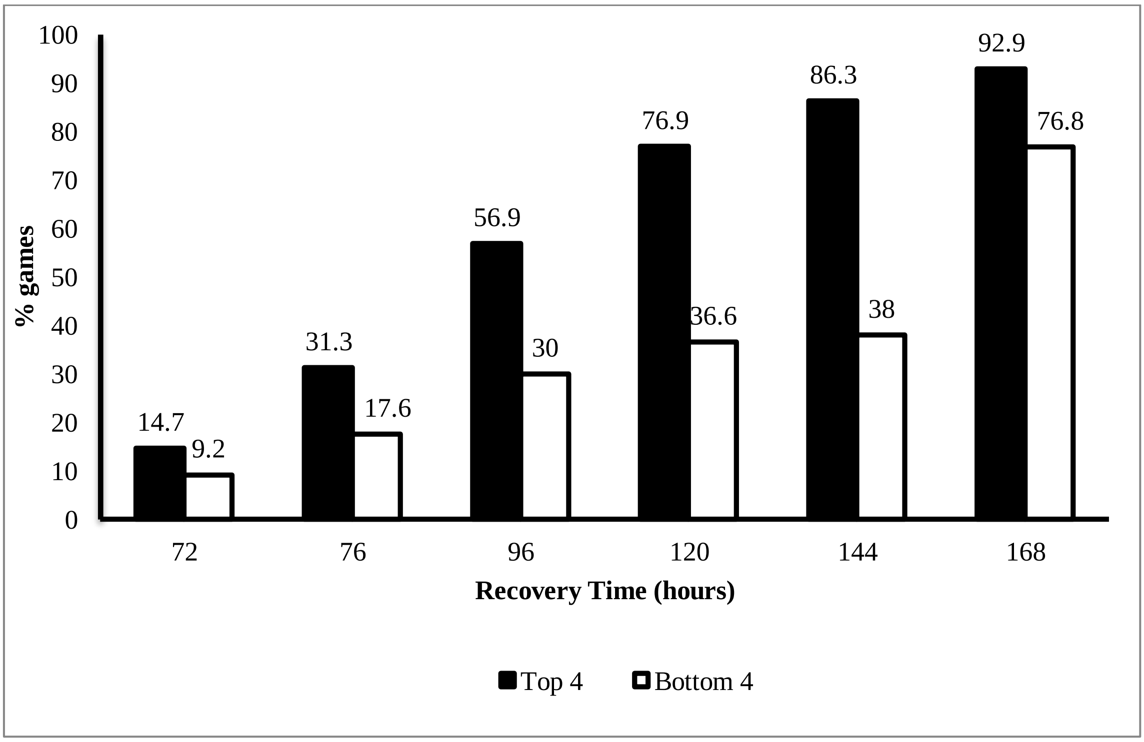

Figure 3.1 Cumulative recovery times for top and bottom 4 during S3.

Figure 3.1 above shows the cumulative recovery times with almost a third of matches being played with <76 hours recovery in top 4 teams. At the other end ~23% of matches are played with > 168 hours RT for bottom 4 sides compared to only ~7% for top 4 sides. This reinforces the earlier judgment that top 4 teams have a greater workload.

However the trend over time is less clear. The median from S1 to S3 has only decreased 9% for the top 4 compared to an increase of 68% for the bottom 4. Therefore the disparity between the top 4 and bottom 4 may not be because of an increasing demand on the top 4 but maybe a decreasing demand on the bottom 4. Although the max range would suggest there is a considerable decrease (~2 days) in the maximum time between matches. Further analysis of the percentage of matches played with < 76 hours RT revealed very little difference across seasons (Figure 3.2). Figure 3.3 shows that the percentage of matches played with >168 hours RT increased by over 10% for the bottom 4 teams whereas this decreased by over 4% for the top 4 teams. This points to any change in demands over time being caused by the decrease in the number of matches with over one week of recovery as compared to an increase in matches with ~3 days recovery.

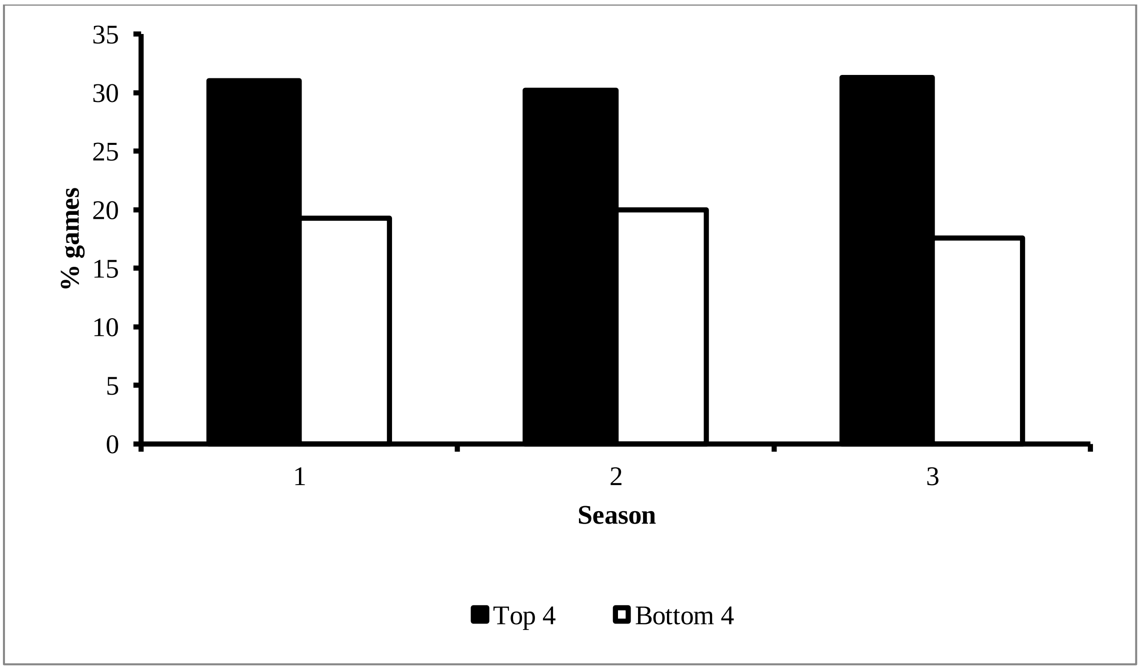

Figure 3.2 Percentage of matches played with <76 hours recovery across seasons

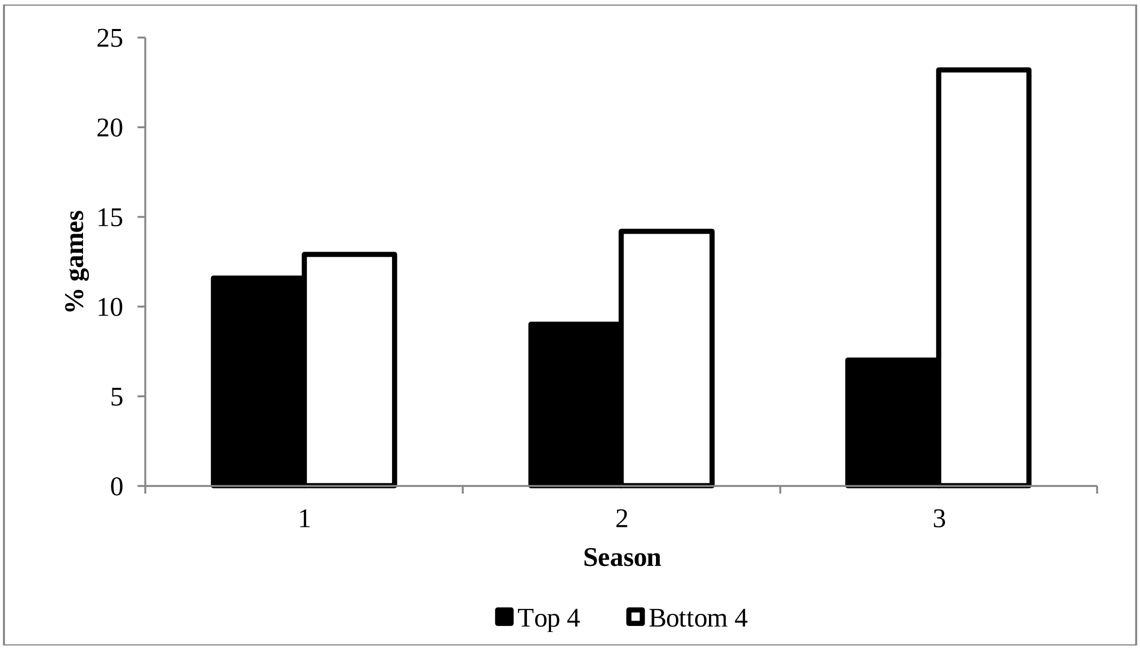

Figure 3.3 Percentage of matches played with >168 hours recovery across seasons.

3.3.2 Functional Squad Size

Table 3.2 below shows the changes in squad sizes for the top 4 and bottom 4 across the seasons. This shows that the number of players used increased each season. There is also an increasing disparity across the seasons with the bottom 4 teams increasingly using more players.

Table 3.2 Mean number of FSS

Season	Top 4	Bottom 4
S1	25	24
S2	27	31
S3	28	34

3.4 Discussion

This is the first study to examine the recovery time between matches comparing successful and unsuccessful teams across multiple seasons. The results showed that the demands of the top 4 and bottom 4 teams differed. The median RT was 84% higher in the bottom 4 teams than in the top 4 teams. The difference in the percentage of matches played with <76 hours recovery was ~15% higher in the top 4, who played 31% of matches within this recovery period. In addition to this, the minimum recovery time in S1 was 48 hours, which increased to 52 and 67 hours for the top and bottom 4 respectively by S3, justifying studies examining recovery over such a short period.

The change in demands over time can be partly contributed to the reduction in matches played with more than one week recovery as shown in Figures 3.2 and 3.3. The disparity in current demands between the top 4 and bottom 4 appear to be more a consequence of a more relaxed fixture schedule for the bottom 4 than in previous seasons. It is easy to see from Table 2.1 that for the bottom 4 the schedule has become less demanding. The increase in demands for the top 4 are slightly harder to see but a combination of a reduction in the max RT (Table 3.1) and percentage of matches with >168hours RT (Figure 3.3) helps show this trend and explain the lower median RT.

A potential explanation for these changes for the bottom 4 teams could be the financial rewards of staying in the EPL or subsequent financial ruin from relegation, leading teams to field weaker players in cup competitions and subsequently being knocked out thereby reducing their match frequency. There have also been several structural changes in the administration of the competitions with the league cup ties now being played over one leg instead of two and also the reduction in the number of EPL teams to 20 from the original 24. For the top 4 teams the demands of European cup competitions would have an influence but these have been somewhat suppressed by the changes made in competition structure that were introduced primarily to help the most successful teams. To this effect the results of this study show that structural changes have been partially successful.

The FSS seems considerably higher in the bottom 4 teams than the top 4 teams. The FSS increased in both groups across seasons. The differences in FSS between the top 4 and bottom 4 could be explained by a number of factors. The top 4 teams could possibly be less willing to change a successful team and would want their better players playing as often as possible keeping changes to a minimum. However, given that the demands are higher for top teams it is somewhat surprising to see that the number of players used are higher in the bottom four teams. This could be explained by a number of factors including change of managers at clubs that are not doing so well and the subsequent change in playing personnel that may bring. Teams that are relegated early may also use this as an opportunity to provide younger players with some experience. Also as the EPL has progressed and the increased revenue that has been bought into clubs may allow them to keep larger squads.

The current demands identified of successful teams with around a third of matches being played with 3 days of recovery time or less demonstrates that studies assessing the recovery profile from soccer matches are justified given that the studies reviewed in section 2.4 suggest that there is evidence of incomplete recovery within this timescale. Therefore studies examining the dose-response relationship between soccer match-play and recovery (Section 7) are also justified so that informed judgments on a player's level of recovery and capability to perform can be made.

3.5 Conclusions

- The most successful teams have a higher match frequency than those that are less successful.
- The top 4 teams play ~31% of matches with < 76 hours of recovery, therefore studies examining recovery over such periods of time are justified.
- The current median RT for top 4 and bottom 4 teams are 91 and 168 hours, respectively.
- This disparity is largely due to the increasing time between matches in the bottom 4 teams.
- The percentage of matches played with < 67 hours RT has not changed much for all teams over the seasons.
- The percentage of matches played with >168 hours RT over S3 increased for the bottom 4 but decreased for the top 4.
- The FSS is higher in the bottom 4 teams than in the top 4 teams.

4. Reliability & Validity of the modified Beast$_{90}$ soccer simulation

4.1 Introduction

Banister (1991) conceptualized that the training impulse has both a fitness and fatigue component**.** The dose-response relationship of iTRIMP with fitness appears to be the most valid TL measure through the research presented by Manzi, *et al.,* (2009). However the one of the problems identified in this thesis was the short recovery time between matches and the absence of valid objective measures of a players' ability to perform, assessment of their recovery status and fatigue without invasive, exhaustive or time consuming tests or procedures. Hence using the information we can collect from training and match play to make informed decisions on a players' ability to physiologically perform would be of great advantage to players and coaches alike. In addition to this establishment of a dose-response relationship for exercise and recovery/fatigue would also allow modeling of the recovery process.

Previous studies examining recovery in soccer have examined a plethora of biochemical responses and acute performance tests (Andersson, *et al.*, 2008; Ascensao, *et al.*, 2008; Cazzola, *et al.*, 2003; Haneishi, *et al.*, 2007; Ispirlidis, *et al.*, 2008; Lazarim, *et al.*, 2008; Malm, *et al.*, 2004; Reilly & Rigby, 2002), as discussed in section 2.4. The applicability of acute physiological tests to overall football performance has to be questioned. One of the ways to assess the actual physiological performance is through the measurement of the distance covered and distance covered at high-intensity in actual matches. However, the high variability of these measurements during match-play have previously been shown (Gregson, *et al.,* 2010), resulting in the use of such data being problematic. Therefore the use of a simulation which allows the distance to vary to reflect the physical capabilities of the players, yet has good reliability, is required. Treadmill based simulations (Abt, *et al.*, 2003; Drust, *et al.*, 2000; Thatcher & Batterham, 2004) are often criticized for their lack of external validity due to the lack of changes in directions. Whereas the popular LIST simulation (Nicholas, Nuttall & Williams, 2000) has also been criticized for part B of the simulation, which is a 20-min run to exhaustion. A recent study also showed that the physiological and biochemical responses from the LIST are significantly different to that in a real match (Magalhaes, Rebelo, Oliveira, Silva, Marques & Ascensao, 2010). Williams, Abt & Kiliding (2010) produced the BEAST$_{90}$ (B$_{90}$) as a soccer specific simulation which was self-paced but offers instructions for the different intensities. Figure 4.1 below shows the circuit and the breakdown of each activity.

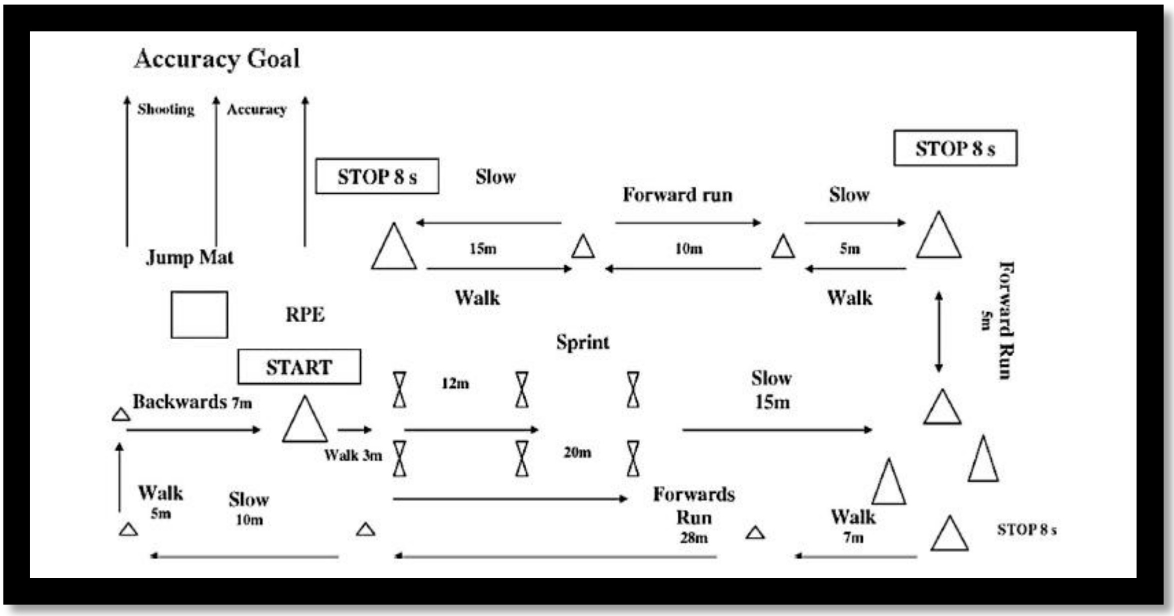

Figure 4.1 Diagram of BEAST$_{90}$ simulation

The advantage of the B$_{90}$ is that it is a self-paced simulation. Although the categories are outlined it allows players to express their fitness or fatigue through the distance they are able to cover and the extent to which they can maintain the pace they start with. Williams, *et al.*, (2010) also incorporated jumps and a soccer specific shooting test. The performance measures from the B_{90} included circuit time, distance covered, sprint times (12 m and 20 m), vertical jumps and shooting accuracy. The authors reported mean distances covered during the 90 minutes of 8097 ± 458 m and mean %peak HR of 85 ± 5%. The typical error of measurement (TEM) was reported for the variables measured. Although this wasn't conducted for the distances covered it was done for the mean circuit time with the TEM reported as 2.6% (95% CI: 1.9-4.1). The TEM for 12 m (2.4% ; 95% CI: 1.70-3.97) and 20 m (1.9%; 95% CI : 1.39 – 2.02) sprints, respectively, were low and showed high levels of reliability. The vertical jump test also showed good reliability with a TEM of 5.3% (95% CI: 3.78-8.59). However the soccer specific shooting test in the B_{90} showed poor reliability with a TEM of 19.6% (95% CI: 13.83-33.35). Interestingly the TEM for HR was very low (2.1%; 95% CI: 1.43-3.84).

Therefore it would appear the two main measures of interest in this study, namely the distance covered (mean circuit time) and intensity (HR), appear to show good reliability with such a simulation. The distance covered reported by the authors appears to be amongst the lower end of reported values in the literature. However, the authors explain that the participants were amateur players with an estimated VO_{2max} of <50 $mL \cdot kg \cdot min^{-1}$ and comparisons to motion analysis data from professional players may be unfair. The reported intensity of 85±5% HR_{peak} is within the range previously reported (Stolen, *et al.*, 2005).

The B_{90} appears to have both external and internal validity. It is self-paced and variable in its distance but yet reliable. The distance covered in the B_{90} has shown strong relationships with estimated VO_{2peak} ($r = 0.75$; $p < 0.01$) and distance covered in the YYIRT ($r = 0.76$; $p < 0.01$). It also allows measurements of jumps, sprint times and shooting accuracy, although the TEM of the latter appears to be high (~20%) and has variable sprint distances (12 & 20 m). However, the circuit does take a large area and if all of these measures were to be used only one person could run at a time. The large area of the circuit meant for the purposes of the study outlined in section 7, the circuit would have to be performed outdoors. Also there is a great deal of manpower required to run such a simulation. Therefore the purposes of this study (Figure 4.2) the B_{90} was modified ($B_{90}M$).

The B_{90} was modified in an attempt to make it easier to conduct given that for the study design outlined in section 7 we would have numerous people running at the same time. The number of stops was reduced from four to two but the time increased from 8 s to 15 s for each stop. This meant two fewer assistants were required per circuit. The distances were also changed in an attempt to make the simulation less intense. This was a result of some our own pilot testing on some of our group of participants which suggested that the current circuit set up would be too demanding. The alternating sprint distance from 12 to 20 m were replaced by a single distance of 12 m thereby making each lap of the simulation identical and reducing confusion for participants and research assistants. The modified version of the Beast90 ($B_{90}M$) is shown in Figure 4.2 below. Due to the changes proposed to the B_{90} the reliability and validity also needs reassessment.

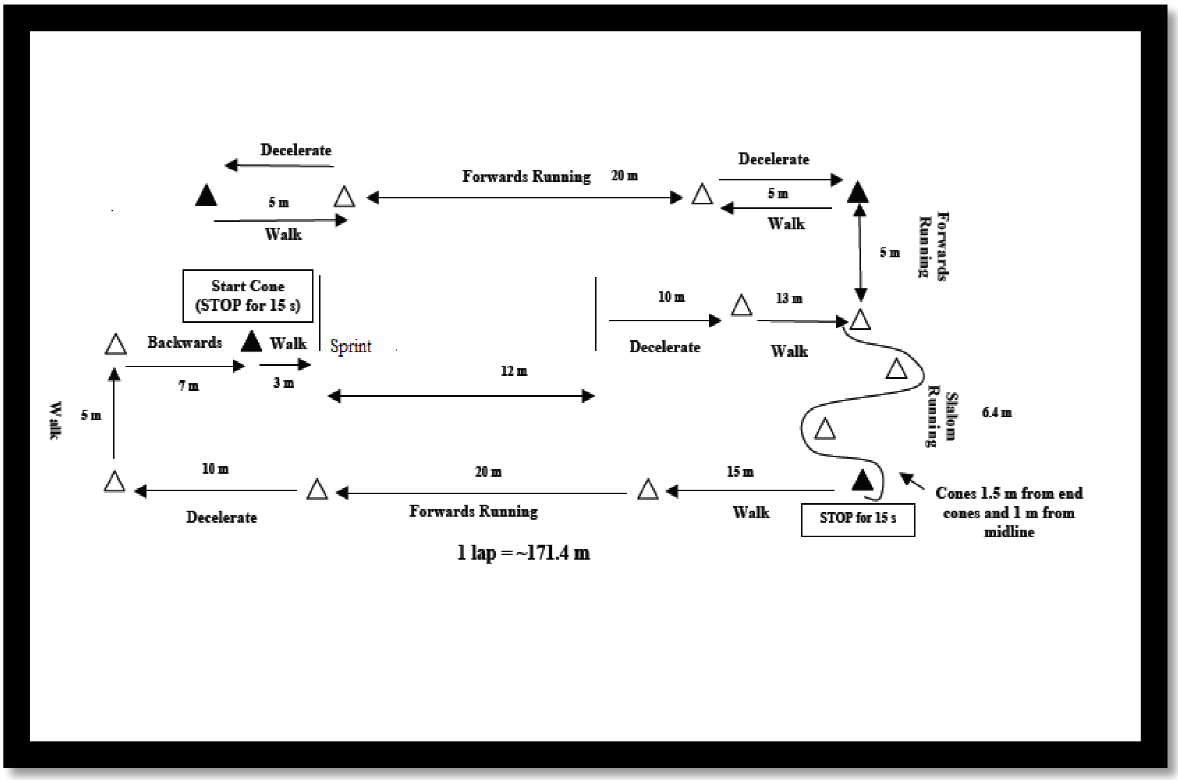

Figure 4.2 Beast$_{90}$ modified

Finally despite the B$_{90}$M being a simulation that requires participants to perform to their maximal ability, to ascertain whether this is actually the case is difficult as motivation may also play a role. If motivation is a factor and participants decide to exert themselves to a lesser degree this will be reflected in a lower iTRIMP and hence keep the ratio constant, not signifying fatigue. Therefore we propose the use of a ratio of internal and external load. These will be determined as iTRIMP:TD and iTRIMP:HID, essentially the distance covered per unit of internal load. The relationships between these ratio's and measures of fitness and changes in performance will be assessed to examine the applicability of such a ratio to predict fitness.

The aims of this section of the study was to check that the measurements of interest in this study (distance covered and intensity) are valid and reliable.

4.2 Methods

Reliability. Six male team sports players were asked to run the $B_{90}M$ on two occasions seven days apart. On each occasion they ran at the same time of the day. They were asked to avoid any strenuous exercise for 48 hours prior to the test. As muscle biopsies were not available to quantify muscle glycogen concentrations, players kept a food diary for the 48 hours prior to the 1st trial and asked to replicate this before their 2nd trial. This at least minimized any effect of changes in muscle glycogen concentration between the two trials. Players attended a familiarisation session prior to their 1st trial where they ran 30 minutes of the $B_{90}M$ to accustom themselves with the circuit.

The distance covered during the full $B_{90}M$ was analysed manually by counting the number of laps and noting where each player stopped on the simulation at half time and full time. This was also further verified with video evidence. HR data were collected using recordable HR monitors (Polar Team System, Polar Electro, OY, Finland). The trials were conducted on a third generation synthetic grass surface and players were required to wear football boots for both trials. Outdoor conditions were similar on both days (Cloud Cover: Overcast; Temperature: 17.4/18.1°C; Barometric Pressure: 1012/1020 mmHG; Relative Humidity: 46/53%). The coefficient of variation (CV), intra-class correlation (ICC) and technical error (TE) for total distance and HR were calculated.

Validity. The validity of the $B_{90}M$ was assessed using data from the reliability trials as described above and trial 1 of the study outlined later in section 7. Briefly, after five days of rest 10 players performed the $B_{90}M$. This time, with the availability of GPS technology, the distance covered was measured using a 5Hz GPS system (Minimax, Catapult Innovations, Australia) and HR was also recorded (Polar Team System, Polar Electro, OY, Finland). The participants had previously been familiarised with the $B_{90}M$.

The total distance (TD) covered and high-intensity distance (HID), which was categorized as speeds above 15km·h^{-1} was measured. The subjects had performed a modified lactate threshold test (see section 7), and therefore, we were able to calculate the intensity of the $B_{90}M$ with respect to their actual HR_{max} values.

4.3 Results

Table 4.1. Total distance covered in reliability study

Participant	Distance Covered (m)						
	$B_{90}M_1$			$B_{90}M_2$			Mean Change
	1stHalf	2ndHalf	Total	1stHalf	2ndHalf	Total	
1	5040	4963	10003	5200	4717	9917	-86
2	4970	5035	10005	5040	5142	10182	177
3	5207	5288	10495	5484	5115	10599	104
4	5298	4970	10268	5400	5135	10535	267
5	4970	4799	9769	5371	5028	10399	630
6	5016	5120	10136	5207	5135	10342	206
Mean	5084	5029	10113	5284	5045	10329	216
SD	137	165	250	163	166	250	236

Table 4.1 above shows the total distance covered in each half. These values correspond with the range of distances previously reported in section 2. The CV, ICC and TE for total distance was calculated as 1.7% (95% CI: 1.1-4.2), r = 0.68 (95% CI: 0.02-0.93) and 167m (112-349), respectively. A paired t-test revealed no significant difference between the trials for TD ($p = 0.08$), although this difference was close to significance.

Table 4.2. Mean heart rates for the $B_{90}M$ in reliability study

Participant	Heart Rate (bpm)		
	$B_{90}M_1$	$B_{90}M_2$	Change
1	176	174	-2
2	168	165	-3
3	164	158	-6
4	171	166	-5
5	167	160	-7
6	155	160	5
Mean	166	165	-1
SD	8	5	-3

Table 4.2 above shows the mean HR in each $B_{90}M$. The CV for mean HR was calculated as 1.9% (95% CI: 2.0-8.2). A paired t-test revealed no significant difference between the trials for HR ($p = 0.15$).

The validity of the of $B_{90}M$ can be assessed using the TD scores reported in the reliability trials (Table 4.2) which shows TD covered is in the range of 9769 – 10599 m. In the study conducted in section 7 the use of GPS technology was available and allows much more detailed analysis of the $B_{90}M$. Trial 1 from the study conducted in section 7 was also used to assess the validity of the $B_{90}M$. Table 4.3 below shows the descriptive data of distance and intensity measurements.

Table 4.3. Physiological responses and performance of $B_{90}M$

Measure	Mean	SD	Range
Total Distance	10810	664	10055-12332
High-intensity Distance	3336	717	2568-4799
Heart Rate (bpm)	176	9	161-189
Heart Rate (%max)	87	4	78-92

4.4 Discussion

The results of this study suggest that the $B_{90}M$ maintains its validity and reliability for distance covered and intensity despite the changes made to the original proposed by Williams, *et al.*, (2010) and these reflect the range of values previously reported from actual match-play (section 2.2). Through the manual determination of the distance covered for the assessment of reliability in this study, the calculation for the reliability of the HID was not possible. The HID appears to be contributing ~30% of the total distance covered. Mohr, *et al.*,(2003) who also used 15 $km.h^{-1}$ as the threshold determining HID reported top class players covered 2.43 ± 0.14 km and moderate players 1.90 ± 0.12 km at high-intensity, which represents approximately 22% of the total distance. Compared to these values it would appear that there is a greater proportion of high-intensity running involved during the $B_{90}M$ (30 v 22%), which represents and 8% difference. However actual match play data does not always represent the maximum potential of player's capability to physiologically perform. Therefore the $B_{90}M$ could potentially be used to judge a players maximal potential to cover distance at high-intensity in an ecologically valid manner.

The distances for each speed category remain unchanged between trials, therefore any substantial variability in HID between trials would manifest itself as a change in the total distance, assuming that lower intensity activities like jogging and walking remained reasonably constant.

Although the instructions at each point of the circuit are clear, should fatigue occur there would be a reduction in speed especially at higher intensities. Therefore concluding that a certain distance was covered sprinting or running at high-intensity just because those instructions were given as Williams, *et al.*, (2010) have done may not be accurate.

In conclusion, the TD covered during $B_{90}M$ is similar previously is soccer match-play (section 2.2). The $B_{90}M$ appears to enable players to cover a greater distance at high-intensity than data previously presented from actual match-play. However the intensity appears to remain in ranges previously reviewed (Stolen, *et al.*, 2005). The assessment of validity of the $B_{90}M$ could be improved by assessing the same participants in actual match-play and comparing the performance variables to that of the $B_{90}M$. However as mentioned before actual match-play performance is highly variable and may not be representative of players' physiological capabilities. Therefore the $B_{90}M$ can be considered to be a valid soccer simulation when compared to previously reported distances and intensity. The $B_{90}M$ also show good reliability with a CV of just 1.7% for TD, which means meaningful inferences can be more easily made with respect to soccer specific performance in the form of distance covered.

5 - Intermittent exercise alters the heart rate-blood lactate relationship used for calculating the training impulse in team sport players.

5.1 Introduction

As discussed in section 2.1 the TRIMP uses the exponential relationship between fractional elevation in heart rate (ΔHR) and blood lactate concentration (BLa), as observed during incremental exercise, to 'weight' exercise at a particular intensity. This method provides a higher weighting for higher intensity sessions. The TRIMP was originally used with endurance athletes such as swimmers, where the heart rate during a training session or competition is normally well within the aerobic range (Banister, *et al.*, 1975). However, with the use of TRIMP recently being extended for use on team sport players (Alexiou & Coutts, 2008; Impellizzeri, *et al.*, 2004; Stagno, *et al.*, 2007) the aerobic range is regularly breached. The high-intensity intermittent nature of matches such as soccer might alter the ΔHR-BLa relationship. The mean intensity in a soccer match has been reported to be around 87% of maximal heart rate (HR_{max}), but the intermittent nature of the sport means the heart rate can also rise to its maximum (Ascensao, *et al.*, 2008). Helgerud, Engen, Wisloff, & Hoff (2001) reported youth players spend about 15-20% of match time at intensities > 90% HR_{max}. Consequently, using mean heart rate for calculating the TRIMP in soccer and other team sports may lead to a loss of specific information and therefore not be reflective of the overall intensity or variation in the intensity of a match or training session. Stagno, *et al.*, (2007) modified the TRIMP for team sport, however the equation used to weight the time in each zone was derived from a continuous incremental test where the sports are largely intermittent. There is evidence to suggest the blood lactate response to intermittent exercise is different when compared to continuous exercise, particularly at higher intensities (Bangsbo, 1994; Edwards, *et al.*, 1973). While these studies shed light on the differences between intermittent and continuous exercise, the results are limited by exercise mode (cycling) and low sample sizes (Edwards, *et al.*, 1973) and lack of control over distance covered in each condition (Bangsbo, 1994). Furthermore although this thesis found a significant relationship between iTRIMP and vLT (r = 0.67) in soccer players, this relationship was weaker than that found by Manzi, *et al*., (2010) with vLT (r = 0.87) and vOBLA (r = 0.74) in runners. Whilst the measurement of the blood lactate response during continuous incremental tests for the determination of training adaptations or monitoring of training loads for intermittent team sports is advocated (Impellizzeri, *et al.*, 2004; McMillan, *et al.*, 2005b; Stagno, *et al.*, 2007) no study has examined the potential effect of intermittent exercise on the BLa response and subsequent calculation of weightings for the determination of the TRIMP. The weaker relationships found with soccer players maybe due to an underestimation of the TL at higher intensities due to potentially higher lactate values.

The aim of the present study was therefore to investigate the effect of intermittent exercise on the ΔHR-BLa relationship and its influence on the weightings used to generate the iTRIMP.

5.2 Methods

Twelve university level male team sport players (age: 19.4 ± 0.5 years; height: 1.75 ± 0.06 m; body mass 67.4 ± 11.6 kg; VO_{2max}: 55 ± 12 $mL \cdot kg^{-1} \cdot min^{-1}$; vVO_{2max} 16.0 ± 1.1 $km \cdot h^{-1}$) volunteered for the study. They all competed regularly in their chosen team sport. Written informed consent was obtained prior to their participation. The study was approved by the Departmental Ethics Committee and conformed to the Declaration of Helsinki.

The resting heart rate (HR_{rest}) of all participants was measured using a HR monitor (Polar FS1, Polar Electro, OY, Finland) sampling at 5s intervals. Participants lay supine in a quiet room for 10 minutes and the lowest 5s heart rate was recorded as the HR_{rest}. HR_{max}, Maximal oxygen uptake (VO_{2max}) and the velocity at VO_{2max} (vVO_{2max}) were measured during an incremental protocol on a motorized treadmill (Woodway PPS 55sport, Woodway, Germany). Treadmill gradient was set at 1% for the entire test to reflect the energetic cost of outdoor running (Jones & Doust, 1996). Oxygen consumption (VO_2) and heart rate were collected throughout the test using a breath-by-breath system (Quark B, Cosmed Srl, Rome, Italy) which was calibrated before and after each test according to the manufacturer's instructions. Cryospec calibration gases of 16.0% O_2, 4.5% CO_2, and N_2 balance were used (Cryoservice Ltd, Worcester, UK). Participants performed a warm up by cycling (Monark 842E, Monark Exercise AB, Varberg, Sweden) at 75 W for 5 min. The treadmill protocol for the measurement of HR_{max}, VO_{2max} and vVO_{2max} started at 8 $km \cdot h^{-1}$ and increased by 1 $km \cdot h^{-1}$ per min until volitional exhaustion. VO_{2max} was recorded as the highest mean VO_2 obtained for any 1 min period during the test (Lucia, Hoyos, Perez, Santalla, Earnest & Chicharro, 2004). At least two of the following criteria were also required for the attainment of VO_{2max}: a plateau in VO_2 (defined as a change of less than 0.2 $L \cdot min^{-1}$) despite increasing treadmill speed, respiratory exchange ratio >1.15, or the attainment of age predicted maximum heart rate (Lucia, *et al.*, 2004). The lowest treadmill speed required to elicit VO_{2max} was considered to be the vVO_{2max} (Billat, Blondel & Berthoin, 1999). Each participant undertook a continuous trial (CT) and an intermittent trial (IT) in a randomised order separated by a minimum of 48 hours. During each trial VO_2 and heart rate were collected using a breath-by-breath system (Quark B90M2, Cosmed Srl, Rome, Italy), which was calibrated prior to and after each trial following the same procedures as for the vVO_{2max} test. The CT consisted of running on a motorized treadmill (Woodway PPS 55sport, Woodway, Germany) at speeds corresponding to 25%, 50%, 75% and 100% of vVO_{2max}. Participants ran at each speed for 4 minutes with a 1 minute rest between each stage, during which a fingertip blood sample was taken and subsequently analysed for blood lactate concentration (YSI 2300, YSI Inc, Yellow Spring, OH). The IT also consisted of running on a motorized treadmill for 4 min periods at 25%, 50%, 75% and 100% of vVO_{2max}. However in the IT, participants ran intermittently at each intensity by alternating their speed between a higher and lower speed for 15 s each, so that the mean of those two speeds was the same as that used in the CT. For example, a participant with a vVO_{2max} of 16 $km \cdot h^{-1}$, running at 25% vVO_{2max} would be stationary for 15 s at 0 $km \cdot h^{-1}$ and then run for 15 s at 8 $km \cdot h^{-1}$; at 50% vVO_{2max} they would run for 15 s at 4 $km \cdot h^{-1}$ and then run for 15 s at 12 $km \cdot h^{-1}$; at 75% vVO_{2max} they would run for 15 s at 8 $km \cdot h^{-1}$ and then run for 15 s at 16 $km \cdot h^{-1}$; at 100% vVO_{2max} they would run for 15 s at 12 $km \cdot h^{-1}$ and then run for 15 s at 20 $km \cdot h^{-1}$, thereby matching the same average speeds as used in the CT. The distance covered for each pair of trials was matched so that the difference was as small as possible (25% vVO_{2max}: CT 264 ± 19 m, IT 266 ± 19 m, difference = 0.6%; 50% vVO_{2max}: CT 527 ± 37 m, IT 529 ± 39 m, difference = 0.5%; 75% vVO_{2max}: CT 790 ± 56 m, IT 784 ± 54 m, difference = 0.8%; 100% vVO_{2max}: CT 1053 ± 72 m, IT 1036 ± 70 m, difference = 1.6%). Treadmill gradient during CT and IT was set at 1%. The heart rate data from the CT and IT were expressed as ΔHR ($HR_{exercise}$ - HR_{rest}/HR_{max} - HR_{rest}) while the oxygen uptake data were expressed in $mL \cdot kg^{-1} \cdot min^{-1}$. The mean ΔHR and VO_2 during the last minute of each stage were used for subsequent analysis.

The individualised TRIMP (Manzi, *et al.*, 2009) was used to determine weightings based on a players own ΔHR-BLa data. Each player's ΔHR-BLa relationship was plotted using SPSS Version 16 (SPSS Inc., Chicago, U.S.A.) and an individual exponential curve generated. From this individualised exponential curve, a TRIMP weighting could then be determined from any ΔHR. To demonstrate the effect of intermittent exercise on the TRIMP weightings we chose four arbitrary ΔHRs (0.7, 0.8, 0.9 and 1.0), which cover the range of ΔHRs that would be observed in both training and match play.

Data are expressed as means ± SD. Prior to parametric analysis the assumptions of normality were verified by using the Shapiro-Wilk test. A two-way repeated measures analysis of variance (ANOVA) with Sidak pairwise comparisons was used to identify significant differences within and between conditions. All statistical analyses were conducted using SPSS version 16. Statistical significance was set at $p \leq 0.05$. When significant interactions were found the mean difference and 95% confidence interval for the mean difference are reported. Cohen effect sizes and their qualitative interpretation as defined by Hopkins (2010) (0 – 0.19 trivial; 0.2 – 0.59 small; 0.6 – 1.19 moderate; 1.2 – 1.99 large; ≥ 2.0 very large) are also reported for significant interactions.

5.3 Results

There was an interaction of intensity and trial where BLa in the IT was significantly higher than CT at 75% vVO_{2max} (mean difference = 1.1 $mmol \cdot L^{-1}$; $p = 0.023$; CI: 0.2 to 2.0 $mmol \cdot L^{-1}$; ES = 1.4; large effect) and 100% of vVO_{2max} (mean difference = 1.6 $mmol \cdot L^{-1}$; $p = 0.012$; CI: 0.4 to 2.8 $mmol \cdot L^{-1}$; ES = 0.8; moderate effect) (Table 5.1).

There was an interaction of intensity and trial where the VO_2 in the IT was significantly higher than CT at 25% vVO_{2max} (mean difference = 6 $mL \cdot kg^{-1} \cdot min^{-1}$; $p < 0.001$; CI: 4 to 8 $mL \cdot kg^{-1} \cdot min^{-1}$; ES = 2.2; very large effect) (Table 5.1).

There was an interaction of intensity and trial where the ΔHRs in the IT were significantly higher than CT at 25% vVO_{2max} (mean difference = 0.14; $p < 0.001$; CI: 0.10 to 0.18; ES = 2.0; very large effect), 75% vVO_{2max} (mean difference = 0.03; $p = 0.03$; CI: 0.003 to 0.05; ES = 0.5; small effect) and 100% of vVO_{2max} (mean difference = 0.02; $p = 0.018$; CI: 0.005 to 0.04; ES = 0.57; small effect) (Table 5.1).

Table 5.1. Mean ± S.D. BLa, VO_2 and ΔHR for both trials at each intensity.

	Bla (mmol.L^{-1})		**VO^{2} (mL.kg^{-1}·min^{-1})**		**ΔHR**	
% vVO2max	**CT**	**IT**	**CT**	**IT**	**CT**	**IT**
25	1.5±0.5^{b}	1.6±0.3^{b}	13±3^{b}	20±2^{ba}	0.21±0.08^{b}	0.35±0.08^{ba}
50	2.4±0.4^{b}	2.2±0.7^{b}	31±3^{b}	31±3^{b}	0.55±0.09^{b}	0.55±0.08^{b}
75	4.5±0.8^{b}	5.6±1.7^{ba}	44±3^{b}	47±4^{b}	0.79±0.06^{b}	0.82±0.05^{ba}
100	10.8±2.1^{b}	12.4±2.9^{ba}	54±5^{b}	55±5^{b}	0.95±0.04^{b}	0.97±0.03^{ba}

^{a}Significantly different to CT ^{b}Significantly different to all other intensities

There was an interaction of intensity and trial where the TRIMP weightings in the IT were significantly higher than CT at 0.9 ΔHR (mean difference = 1.03; $p = 0.018$; CI: 0.22 to 1.85; ES = 1.4; large effect) and 1.0 ΔHR (mean difference = 2.15; $p = 0.005$; CI: 0.80 to 3.5; ES = 1.8; large effect) (Table 5.2).

Table 5.2. iTRIMP weightings (Mean±SD) for CT & IT

	TRIMP Weightings		
ΔHR	**CT**	**IT**	**Effect Size**
0.7	4.26 ± 0.55	4.19 ± 0.85	0.1
0.8	5.46 ± 0.55	5.81 ± 1.17	0.6
0.9	7.04 ± 0.72	8.07 ± 1.73*	1.4
1	9.20 ± 1.22	11.25 ± 2.65*	1.8

**significantly different to CT*

5.4 Discussion

The major finding of the present study is that the ΔHR-BLa relationship is altered by intermittent exercise. This alteration results in large changes to the TRIMP weightings at high-intensities (0.9 ΔHR and 1.0 ΔHR) compared to TRIMP weightings generated from a continuous exercise test and could therefore result in substantial underestimation of the TRIMP in team sport players.

Previous research (Bangsbo, 1994; Edwards, 1993; Edwards, *et al.*, 1973) has highlighted the higher BLa concentrations during intermittent exercise when compared to continuous exercise at the same mean power or speed. In the present study the moderate to large increases in BLa concentration in the IT at 75% vVO_{2max} and 100% of vVO_{2max} compared to the CT supports these previous findings. It is not surprising that higher BLa concentrations are observed with intermittent exercise when the more intense periods are above the lactate threshold (Billat, Slawinski, Bocquet, Demarle, Lafitte, Chassaing & Koralsztein, 2000) as it could be the case in IT at 75% vVO_{2max} and 100% vVO_{2max}. The higher BLa observed during IT in the present study has resulted in a change in the relationship between ΔHR and BLa, thereby altering the exponential curve and its equation. The change in the IT exponential curve resulted in large changes in the TRIMP weightings generated from that curve at the higher intensities (0.9 and 1.0 ΔHR). Measurement of the TRIMP as defined by Stagno, et al., (2008) is dependent on the ΔHR-BLa relationship. However, their method uses a continuous incremental protocol whereas the training and match play requirements for team sport players are very much intermittent. As can be seen in Table 4.2, the differences in the TRIMP weightings at the high end of the intensity continuum where training has been suggested to be most important (Helgerud, *et al.*, 2001) are substantially different between those generated from CT compared to those generated from IT.

It should be noted that the ΔHRs that we have found to be substantially altered by intermittent exercise (0.9 and 1.0) are very high intensities and that the time spent at these intensities during training and playing is relatively small (~ 15-20%) compared to that spent at lower intensities (Helgerud, *et al.*, 2001). However, given that the weightings generated by any of the TRIMP methods increase in an exponential manner, any time spent at these very high intensities will disproportionately increase the total TRIMP.

Although intermittent exercise caused a substantial increase in the TRIMP weightings at high exercise intensities, it appears that most of this increase can be explained by the moderate to large increases in BLa observed at those intensities, rather than changes in ΔHR. This is because the changes in ΔHR at 75% vVO_{2max} and 100% vVO_{2max} were small. Additionally, the VO_2 at 75% vVO_{2max} and 100% vVO_{2max} were not significantly different between CT and IT. The similarity in VO_2 between CT and IT largely supports previous research by Drust, *et al.*, (2000) who reported no significant difference in VO_2 between continuous and intermittent protocols matched for mean speed over a 46 min period. The use of BLa to provide a 'weighting' to the intensity of exercise suggests that it is reflective of the overall physiological 'stress' imposed on the athlete at a given exercise intensity.

5.5 Conclusion

- Intermittent exercise significantly and substantially alters the ΔHR-BLa relationship and subsequent calculation of TRIMP weightings when based on an individualised ΔHR-BLa relationship.

- This alteration could result in substantial underestimation of the TRIMP in team sport players. Our findings have implications for the use of the ΔHR-BLa relationship derived from a continuous exercise protocol for the calculation of heart rate based TRIMP in team sport players.
- It must however be noted that the intermittency of the protocol used in this study is probably not specific to soccer and the results of this study aims to address a methodological issue that could potentially affect TRIMP calculations.

6 - Comparison of training load measurement methods in soccer

6.1 Introduction

In section 2.1 the various methods of monitoring TL were discussed and weaknesses in their validation and application identified. The monitoring of training and match load is important for the periodization of training and assessment of the physical 'dose' during training and match play. Previous studies in soccer have shown how the prescribed external training load can influence the physiological response (Hill-Haas, Rowsell, Dawson & Coutts, 2009; Rampinini, *et al.*, 2007b). However very little attention has been given to the role of the internal training and match loads on changes in fitness, especially in soccer. Two studies have examined the relationships between a number of methods for measuring the internal load in soccer players. Impellizzeri, *et al.*, (2004) and Alexiou and Coutts (2008) both used HR based methods as 'criterion' measures of load to validate the use of session-RPE (Foster, *et al.*, 2001). The implications of these studies and their methodological flaws have been previously discussed (Section 2.1).

There are also potential limitations to the 'criterion' measures of training and match load used in these papers. Edward's TRIMP (Edwards, 1993) is based on arbitrary zones with arbitrary weightings, which does not reflect the individualised response to exercise (Abt & Lovell, 2009). Although the zones used in the Lucia's TRIMP were individualised and based on physiological thresholds, the weightings provided are arbitrary and a relationship between this method and changes in fitness or performance have not been shown. A more appropriate method would be to assign weightings in accordance with an individual's own physiological response to exercise. Although endurance performance has been successfully modeled using Banister's TRIMP (Busso, 2003; Morton, 1990), this method is generic for each gender and the use of mean heart rate is not likely to reflect the intermittent nature of soccer training or match play. In an attempt to alleviate some of these issues Stagno, *et al.,* (2007) introduced a modified 'team' TRIMP for hockey where five zones were created around LT and OBLA, and each zone weighted according to the regression equation of the curve. Although an individual's own data contributes to the generation of the 'team' regression equation, the resultant weightings for each of the five zones are the same for each player. There is also a potential underestimation of the weightings at higher intensities using a "team approach"**.** Pilot data from a squad of professional soccer players in Figure 6.1 below shows the regression curve is well below some of the data points from individual players.

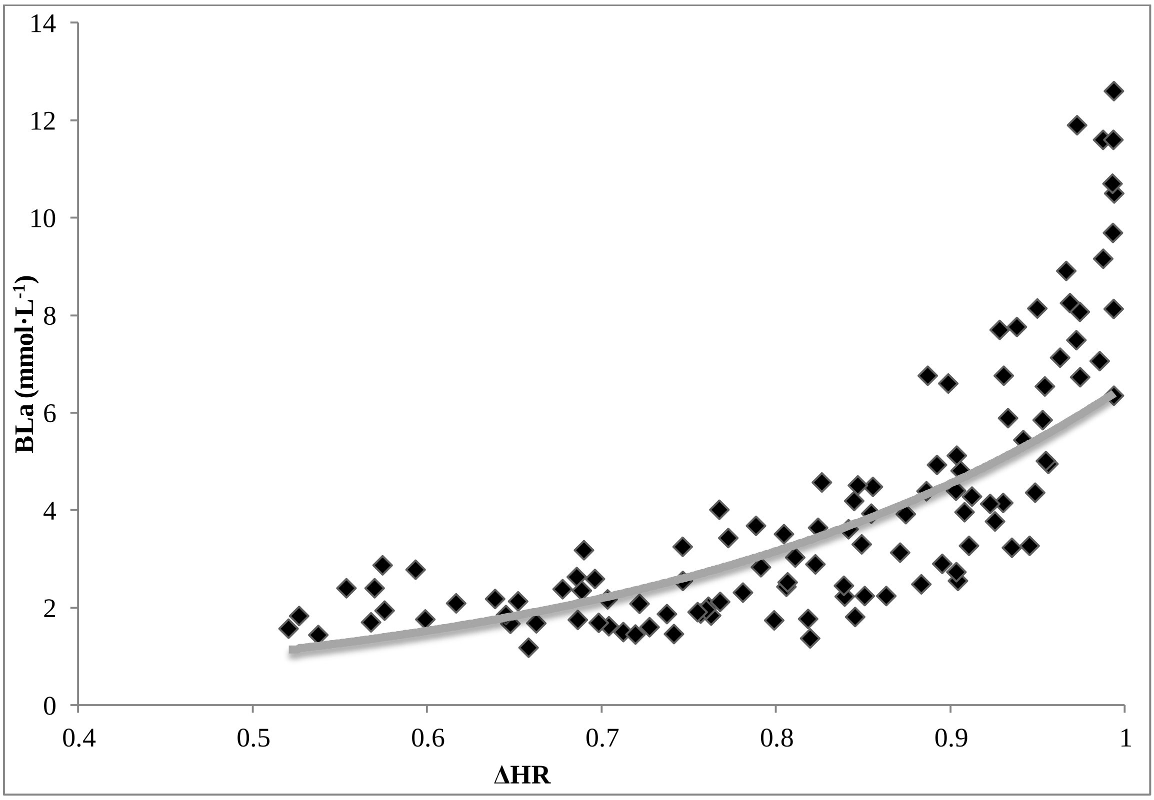

Figure 6.1. BLa-HR data from a squad of professional soccer players

Furthermore the zoning of weightings was developed to counteract the deficiencies from the use of mean heart rate. Banister (1991) stated that the use of mean HR was advocated as summating each data point was too problematic. However the advancement of technology has now alleviated this problem. Therefore for this study the use of a "team formula" was combined with calculating the TRIMP for each HR reading for the calculation of "team TRIMP".

Session-RPE has been popularized due to its efficiency, easy to use nature and relationships with other measures of internal load (Alexiou & Coutts, 2008; Impellizzeri, *et al.*, 2004). However it still requires a subjective judgment by the player. This is difficult enough when exercise is prescribed at a given workload or intensity. This limitation can only be exacerbated with the intermittent nature of soccer. Although the relationship to changes in fitness with an individualised TRIMP has been shown in runners (Manzi, *et al.*, 2009), this relationship has yet to be examined for intermittent exercise such as soccer. Given that heart rate also shows a strong relationship with intermittent exercise (Esposito, et al., 2004) the use of an objective measure of intensity combined with an individualised weighting representative of the players fitness needs to be explored.

In order to address the limitations discussed above the use of an individualised TRIMP (iTRIMP) (Manzi, *et al.*, 2009) in soccer is proposed. Here, each individual's own data is used to calculate the relationship between fractional elevation in heart rate and blood lactate concentration, with each heart rate data point measured during training or match play weighted according to this relationship. Such an approach alleviates the problems encountered with arbitrary zones and weightings (Banister, 1991; Stagno, *et al.*, 2007). Manzi, *et al.*, (2009) have recently shown that in distance runners the iTRIMP method relates better to changes in both aerobic fitness and endurance performance compared to Banister's TRIMP.

Therefore the aim of this study was to compare the relationships between session-RPE, Banister's TRIMP, a modified version of Stagno's Team TRIMP, and iTRIMP, to changes in parameters of aerobic fitness in professional youth soccer players.

6.2 Methods

Nine professional youth soccer players (n = 9; mean age 17 ± 1 years; stature 1.81 ± 0.05 m; body mass 72.9 ± 6.7 kg) agreed to participate in the study**.** The study was approved by the departmental ethics committee and conformed to the Declaration of Helsinki. Informed consent was provided by the players and the club prior to the commencement of the study. All participants played for the same club in the English Football League Youth Alliance, which is the second highest level of competition for youth players in England. On some occasions participants also played in the club's reserve team in midweek. Players trained 4-6 times a week consisting of both technical training and physical conditioning. Training sessions were usually 60 to 120 minutes in duration. Typically the team would play their competitive fixtures on a Saturday and would train twice on Mondays, Tuesdays and Thursdays, which comprised of both technical and physical conditioning sessions such as sprint training, speed endurance training and high-intensity aerobic training. The players had rest days on Sundays and Wednesdays and a light technical session before matches on Fridays. Occasionally players would be called up to represent the reserve team, which resulted in their training being changed with recovery sessions being incorporated into their schedule. Players who didn't play as often as others (substitutes) would typically do individual work to increase their weekly load. Although their training was planned occasional changes were made by the coaches. The TL from training and match play was simply measured and we had no control over their actual training or playing volume. The team played six league matches over the six-week period, although there was a range of four to nine matches per player because of squad rotation and/or players being called up to the reserve team.

Prior to the start of the training period the players performed two laboratory tests. Players avoided any strenuous exercise in the 24 hours prior to these tests. An incremental test on a motorized treadmill (Woodway EL G55, Weil an rhein, Germany) was conducted for determination of maximal heart rate (HR_{max}). The protocol consisted of three minutes at 5 $km \cdot h^{-1}$ and then increased at a rate of 1 $km \cdot h^{-1} \cdot min^{-1}$. Participants were instructed to run until volitional exhaustion. The heart rate was recorded using recordable heart rate monitors (Polar Team System, Polar Electro, OY, Finland). The highest heart rate recorded was taken as HR_{max}. On a separate occasion players completed a modified lactate threshold test on a motorized treadmill (Woodway PPS 55sport, Weil an rhein, Germany) consisting of five stages at 8, 10, 12, 14 and 16 $km \cdot h^{-1}$. Each stage was four minutes in duration with one-minute rest between stages where a fingertip capillary blood sample was taken and immediately analysed for blood lactate concentration (YSI 2300, YSI Inc, Yellow Springs, OH). The dependent variables derived from this test were (1) the velocity at 2 $mmol \cdot L^{-1}$ (vLT), (2) the heart rate at 2 $mmol \cdot L^{-1}$ (LT_{HR}), (3) the velocity at 4 $mmol \cdot L^{-1}$ (vOBLA), and (4) the heart rate at 4 $mmol \cdot L^{-1}$ ($OBLA_{HR}$). These dependent variables were chosen as they are typically used to track changes in aerobic fitness and have previously been used in training load studies (Manzi, *et al.*, 2009; McMillan, Helgerud, Grant, Newell, Wilson, Macdonald & Hoff, 2005a). The high reliability of these dependent variables has previously been reported (Pfitzinger & Freedson, 1998; Weltman, Snead, Stein, Seip, Schurrer, Rutt & Weltman, 1990). The mean heart rate in the last minute of each stage was used for the generation of TRIMP curves. Measurements of resting heart rate were also taken prior to exercise. Players were instructed to lie supine in the morning for 10 minutes. The lowest 5s heart rate average measured was taken as the resting heart rate. At the end of the training period the players again performed the modified lactate threshold test.

Collection of training and match load data started at the beginning of the competitive season in September and continued for six weeks. Players were familiarised with use of the RPE scale and heart rate belts for two weeks prior to the start of the six-week training period during which training and match load data were collected. Heart rate was measured in all training sessions and matches throughout the six-week period. Approximately 30 minutes after each training session or match, players reported their RPE as per the method of Foster, *et al*., (2001). Heart rate data were downloaded using the Polar Precision software (Polar, OY, Finland) and analyzed using a bespoke spreadsheet (Microsoft Excel, Microsoft Inc). Where data were missing due to technical faults, the data from that week was omitted from the analysis. Players were required to have at least five weeks of complete data out of the six week period to be included in the analysis.

Session-RPE was calculated as the RPE multiplied by the duration of the training session or match (Foster, *et al.*, 2001). Banister's TRIMP (Banister, 1991) was calculated as described in formula 1:

(1) Duration (minutes) x ΔHR x $0.64e^{1.92x}$

where ΔHR equals $HR_{exercise} - HR_{rest} / HR_{max} - HR_{rest}$, e equals the base of the Napierian logarithms, x equals ΔHR, and 1.92 is a constant for males. Team TRIMP was modified from the method of Stagno, *et al.*, (2007) by using the exponential formula generated from the pooled data of all players, but without breaking up the subsequent equation into zones. The Team TRIMP equation as used in the present study is described in formula 2.

(2) Duration x ΔHR x $0.2053e^{3.5179x}$

where ΔHR equals $HR_{exercise} - HR_{rest} / HR_{max} - HR_{rest}$, *e* equals the base of the Napierian logarithms, *x* equals ΔHR, and both 0.2053 and 3.5179 are constants for the whole group. The TRIMP for each heart rate measured at 5 s intervals was calculated and then all values summated to provide a TRIMP for the entire session. The same approach was taken for calculating iTRIMP, however each players formula was generated from their own data and hence each had their own equation as per the method of Manzi, *et al*., (2009).

Descriptive results are presented as means ± standard deviations. After verification of underlying assumptions, pre and post vLT, vOBLA, $LT_{HR,}$ and $OBLA_{HR}$ were compared for mean differences using paired t-tests. Statistical significance was set at $p < 0.05$. The mean difference and 95% confidence intervals for the mean difference are also reported. Cohen effect sizes and their qualitative interpretation, as defined by Hopkins (2002) (0 – 0.19 trivial; 0.2 – 0.59 small; 0.6 – 1.19 moderate; 1.2 – 1.99 large; ≥ 2.0 very large) are reported for significant differences. Relationships between the different training load methods and changes in fitness were determined using Pearson's product-moment correlation coefficients. Qualitative interpretations of the correlation coefficients as defined by Hopkins (2002) (0 – 0.09 trivial; 0.1 – 0.29 small; 0.3 – 0.49 moderate; 0.5 – 0.69 large; 0.7 – 0.89 very large; 0.9 – 0.99 nearly perfect; 1 perfect), are provided for all correlations. The Statistical Package for the Social Sciences (SPSS) (Version 16.0 for Windows; SPSS Inc, Chicago, IL) was used for conducting these analyses.

6.3 Results

The mean weekly training and match load (Arbitrary Units) for session-RPE, Banister's TRIMP, Team TRIMP and iTRIMP were 2094 ± 466, 460 ± 98, 1538 ± 359 and 1830 ± 1805, respectively. Table 6.1 shows the weekly TL for each player for each of the methods. There were no significant changes after the six-week period for vLT (mean change: - 0.21 ± 0.98 $km \cdot h^{-1}$; $p = 0.54$; CI: - 0.96 to 0.54), vOBLA (mean change: 0.26 ± 0.53 $km \cdot h^{-1}$; $p = 0.16$; CI: - 0.14 to 0.67), LT_{HR} (mean change: -2 ± 9 $beats \cdot min^{-1}$; $p = 0.51$; CI: - 9 to 5) or $OBLA_{HR}$ (mean change: 0 ± 7 $beats \cdot min^{-1}$; $p = 0.63$; CI: - 6 to 6). Figure 6.2 shows the correlations between mean weekly session-RPE with mean weekly Banister's TRIMP ($r = 0.75$; $p = 0.02$; CI: 0.17 to 0.94; large) and mean weekly Team TRIMP with mean weekly Banister's TRIMP ($r = 0.92$; $p < 0.001$; CI: 0.66 to 0.98; nearly perfect). There were no significant correlations between mean weekly iTRIMP and any of the other training load methods (Table 6.2). Correlations of measures of training and match load against changes in fitness (vLT, vOBLA, LT_{HR}, $OBLA_{HR}$) resulted in only one significant correlation (Table 6.3). The change in vLT was correlated to mean weekly iTRIMP ($r = 0.67$; $p = 0.04$; CI: 0.01 to 0.92; ES = large) (Figure 6.3). However the change in vOBLA showed a moderate correlation with iTRIMP, bTRIMP and sRPE (Table 6.3)

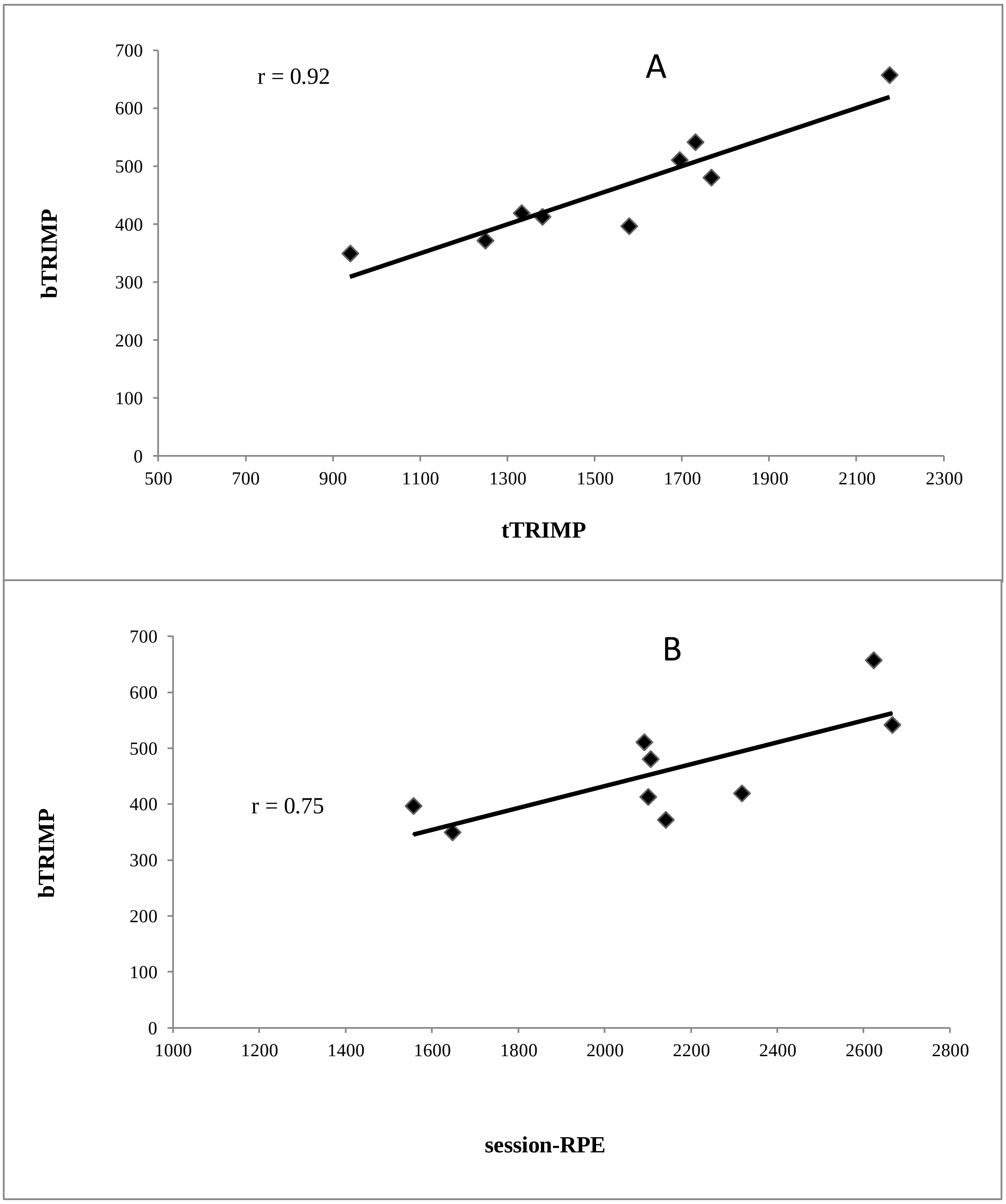

Figure 6.2. Correlations between mean weekly bTRIMP vs tTRIMP (A) and sRPE vs bTRIMP (B) (n=9)

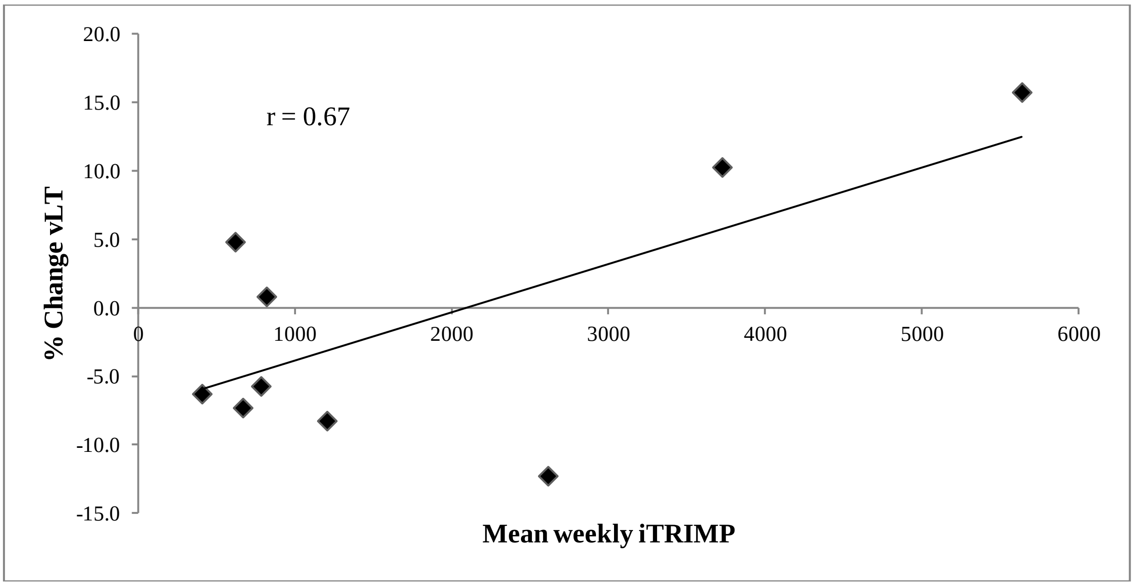

Figure 6.3 Scatter plot showing the significant relationship between vLT and iTRIMP (n=9).

Table 6.1. Mean Weekly TL for all subject for all TL measurement method

Participant	iTRIMP	bTRIMP	tTRIMP	sRPE
1	2614	372	1249	2141
2	818	349	939	1647
3	783	413	1380	2100
4	1204	657	2175	2623
5	667	419	1332	2318
6	5637	511	1694	2091
7	619	480	1767	2106
8	3725	542	1730	2666
9	407	397	1579	1557
Mean	1830	460	1538	2139
SD	1805	98	359	376

-

Table 6.2. Pearson correlation coefficients for mean weekly TL scores.

	iTRIMP	bTRIMP	tTRIMP	sRPE
iTRIMP	-	0.31 (-0.45-0.81) Moderate	0.19 (-0.54 to 0.76) Small	0.32 (-0.58 to 0.73) Moderate
bTRIMP	-	-	0.92** (0.66 to 0.98) Nearly Perfect	0.75* (0.17 to 0.94) Very Large
tTRIMP	-	-	-	0.59 (0.12 to 0.90) Large
sRPE	-	-	-	

*** Significant at P < 0.01. * Significant at P < 0.05.*

Table 6.3. Pearson correlation coefficients for mean weekly TL score relationships with changes in fitness.

	iTRIMP	bTRIMP	tTRIMP	sRPE
%Δ vLT	0.67* Large (0.01 to 0.92)	0.28 Small (-0.47 to 0.80)	0.20 Small (-0.54 to 0.76)	0.13 Small (-0.58 to 0.73)
%Δ vOBLA	0.33 Moderate (-0.43 to 0.82)	0.43 Moderate (-0.33 to 0.85)	0.28 Small (-0.47 to 0.80)	0.40 Moderate (-0.36 to 0.84)
%Δ LT_{HR}	0.17 Small (-0.56 to 0.75)	0.21 Small (-0.33 to 0.85)	0.28 Small (-0.47 to 0.80)	0.20 Small (-0.54 to 0.76)
%Δ $OBLA_{HR}$	-0.25 Small (-0.78 to 0.50)	-0.21 Small (-0.33 to 0.85)	-0.49 Moderate (-0.87 to 0.26)	-0.15 Small (-0.74 to 0.57)

** Significant at P < 0.05*

6.4 Discussion

The novel finding in the present study was the significant correlation between iTRIMP and changes in vLT, which is consistent with the results reported by Manzi, et al., (2009) who examined the same individualised training load method in distance runners. The lactate threshold has previously been found to be a sensitive indicator to changes in fitness in professional soccer players (Edwards, Clark & Macfadyen, 2003). Manzi, et al., (2009) also reported significant relationships between the iTRIMP method and running performance over 5000 m and 10000 m. However ‘performance’ in soccer is not as easily determined, as factors such as skill and decision making also contribute to successful performance. Physical performance in terms of distance covered or distance covered at high-intensity could potentially be used as it has been done previously (Helgerud, *et al.*, 2001). However issues surrounding high match-to-match variability of such measures (Rampinini, *et al.*, 2007b; Gregson, Drust, Atkinson & Salvo, 2010) makes meaningful changes difficult to interpret, and is why we focused on examining the changes in aerobic fitness as opposed to performance.

This is the first study in soccer to relate many of the previous methods of measuring the training and match load to changes in training status and not merely to each other (Alexiou & Coutts, 2008; Impellizzeri, *et al.*, 2004). Results from the present study indicate that mean weekly Banister’s TRIMP correlates with session-RPE and Team TRIMP. However these methods showed moderate relationships at best with changes in aerobics fitness with no significant relationships found, highlighting the limitations of using such analyses as a basis for the validation of a measure of internal training and match load. It has been suggested that only methods that show an association with changes in fitness or performance should be considered as measures of load for that particular group of athletes (Manzi, *et al.*, 2009; Thomas, Nelson & Silverman, 2005). Previous studies have reported a correlation between session-RPE and heart rate based measures, namely Banister's TRIMP (Alexiou & Coutts, 2008; Impellizzeri, *et al.*, 2004). We also found that session-RPE correlated with bTRIMP (r = 0.68), although we correlated the mean weekly training loads and not individual sessions as was done in previous studies. However, given that iTRIMP has been shown to be related to changes in fitness in both runners and now soccer players, the non significant, moderate relationship between session-RPE and iTRIMP in the present study must raise questions about the effectiveness of session-RPE as a method to quantify training load. While previous studies assessing the validity of session-RPE have suggested that RPE correlates well to criterion measures of intensity such as heart rate (Foster, *et al.*, 2001), this does not necessarily mean that this extends to the calculation of 'load' of which intensity is just one term in an equation with two or more. There is also evidence that the correlation between RPE and other measures of intensity such as heart rate may not be as high as previously thought (Chen, Fan & Moe, 2002). It could be that this variability in the relationship between RPE and heart rate partly explains the lack of relationship between session-RPE and iTRIMP.

The results also showed that there was no significant change in aerobic fitness as determined by vLT and vOBLA. The period during which the data was collected for this study can be described as in-season and therefore the present results are similar to those previously described for youth soccer players (Impellizzeri, *et al.*, 2004; McMillan, *et al.*, 2005b). The iTRIMP was not related to any of the other measures of load and showed large variation between players as indicated by the large standard deviation. This might suggest that the iTRIMP is more sensitive to individual differences, that is, how different players respond to the same external load. Although there was a significant relationship between iTRIMP and vLT, there was no such relationship with vOBLA. This is in contrast to the findings of Manzi et al. (2009) who reported a significant correlation of 0.74 between iTRIMP and the percentage speed improvement at OBLA. However, the runners in their study were partially detrained, resulting in quite large increases in both the speed at 2 $mmol{\cdot}L^{-1}$ (mean 21%) and 4 $mmol{\cdot}L^{-1}$ (mean 11%). As previously discussed, the players in our study were at the start of their competition period when large increases in fitness are not typically observed (McMillan, *et al.*, 2005a). However, as discussed earlier and as the model of Impellizerri, *et al.*, (2005) shows, the initial training status of the individual will affect the training outcome. Hence those who are less fit are more likely to see large changes in fitness but also large iTRIMP values as they spend more time at a higher ΔHR for the same external load.

The use of a continuous test to assess changes in an intermittent sport may also lack the required sensitivity to explain such changes. This has been shown with soccer referees where despite no significant improvement in maximal oxygen uptake, Yo-Yo Intermittent Recovery Test performance increased by ~30% over the course of a 12 week training period (Krustrup & Bangsbo, 2001). As such, future studies should aim to include more soccer-specific tests of aerobic fitness and/or physical performance. While there were no changes in mean vLT or vOBLA across the training period, mean changes are not reflective of the individual variation within the group. In the current study we observed individual increases in vLT of ~15% through to decreases of ~12% (figure 6.3). Hence, the presence of a significant relationship between iTRIMP and vLT despite no change in mean vLT demonstrates the sensitivity of such an individualised measure. Although the iTRIMP method has been reported to relate to changes in fitness for both runners (Manzi, *et al.*, 2009) and now soccer players in the present study, closer examination of the correlations show that for similar training loads there are varied changes in fitness and vice versa. The significant correlation between iTRIMP and vLT (r = 0.67) in the current study shows that about 50% of the variation in aerobic training adaptation can be explained by variation in the iTRIMP. This would suggest that other training factors that have an effect on the vLT are not necessarily reflected in the iTRIMP. This is not unexpected, given the intermittent nature of soccer and the mix of aerobic and anaerobic demands during training and match-play. This also highlights the fundamental difference in the physiological demands of endurance and intermittent sports, as Manzi, *et al,*. (2009) reported a significant correlation (r = 0.87) between the percentage change in the speed at 2 $mmol{\cdot}L^{-1}$ and iTRIMP.

The modeling of the individual dose-response relationship in soccer using contemporary approaches that have been used in endurance sports (Busso, 2003; Taha & Thomas, 2003) appears to be a logical step forward with the iTRIMP method. As the quantitative measurement of soccer 'performance' remains a matter of debate amongst researchers, the modeling of performance in soccer still remains a challenge. Furthermore a greater understanding of the dose-response relationship in soccer is required as the response to a training dose is not merely a fitness response but also a fatigue response (Banister, 1991). Although attempts to model endurance performance have been successful using other methods of quantifying load (Busso, 2003; Morton, 1990), the continuous nature of the exercise in those studies may have made the use of such methods appropriate. Given the findings of the present study researchers should consider if these methods are appropriate for intermittent sports. In addition to this if an individuals' training response is dependent on numerous factors (Impellizzeri, *et al.*, 2005; Viru & Viru, 2000) and different to other players, then it is logical to assume that their fitness and fatigue decay constants (Banister, 1991; Busso, 2003) used in the modeling process are also individual and that these will vary not only between players but also over time (Busso, 2003). Therefore future research in soccer should aim to gain a greater understanding and clarity of these issues in order to develop a successful modeling strategy. Therefore studies assessing the dose-response relationship of training with fatigue and recovery need to be done.

One of the limitations of the present study and others (Manzi, *et al.*, 2009; Stagno, *et al.*, 2007) is the small sample size. Unfortunately in training studies there are a number of factors than can impinge on the sample size including small squad sizes, player compliance and injuries. We have reported the precision of our results with 95% confidence intervals so the results of this study should be interpreted in light of those. While the duration of the study was only six weeks and also in-season, it seems that this period was enough for changes in aerobic fitness to occur. However, the duration of the training period and the time of the season also need to be kept in mind when interpreting the results of the current study.

6.5 Conclusion

- The results of this study suggest that a fully individualised approach to monitoring internal training and match load may be superior to those previously used to understand the dose-response nature of training and competition in soccer.
- The use of mean heart rate does not appear to be useful as shown by the lack of a relationship between Banister's TRIMP and changes in vLT or vOBLA.
- Although a relationship between vLT and iTRIMP was found it is weaker than that found in runners by Manzi, *et al.*, (2009). The use of a continuous test to determine a BLa-HR profile for an intermittent sport may contribute to this through an underestimation of TL as some research has indicated that

the BLa response to intermittent exercise is higher at the same average speeds during continuous exercise (Bangsbo, 1994; Edwards, *et al.*, 1973).

- Although the mode of exercise and testing procedures through which the BLa-HR profile is generated remains beyond the scope of this thesis. In light of some of the evidence presented (Bangsbo, 1994; Edwards, *et al.*, 1973) an investigation into the effects of intermittent exercise on the BLa-HR curve and subsequent weighting may help explain the weaker correlation seen in this study compared to Manzi, *et al.*, (2009).

7 -The relationships between Training Load, Recovery, Fatigue & Performance.

7.1 Introduction

A range of physiological parameters have been measured in studies examining recovery from soccer match play. Previous soccer research has described the time course of recovery of acute performance tests (APT) (Andersson, *et al.*, 2008; Ascensao, *et al.*, 2008; Fatouros, *et al.*, 2010; Reilly & Rigby, 2002), hormones, CK as an indicator of muscle damage and injury risk and other biochemical measures as an indication of exercise stress (Andersson, *et al.*, 2008; Ascensao, *et al.*, 2008; Fatouros, *et al.*, 2010; Ispirlidis, *et al.*, 2008) as discussed in section 2.4. However in an applied setting not all of these are practical and none have shown a relationship with soccer specific performance. The other major limitation of these studies is that they fail to recognise the variation in soccer match-play (section 2.2) and consider the exercise dose from which their respective participants are recovering from. The studies reviewed in section 2.2 demonstrate how factors such and position, the opposition and success of the team all influence the external TL.

The external TL influences the internal TL, which ultimately influences the response from exercise according to the model presented by Impellizzeri, *et al,* (2005) (Figure 1.1). Given that a reliable measure of soccer specific physiological performance has now been identified (B_{90}M) along with a measure of TL which appears to have greater validity than others (iTRIMP), the interaction of the dose-response relationship in soccer in relation to fatigue and recovery can now be more systematically analysed. Furthermore a decline in distance through the match may not necessarily be a result of fatigue and could be a result of the many factors that influence the external load in soccer. This study will examine the novel integration of external and internal TL as an indirect measure of exercise economy and aerobic fitness. The aim of this part of the study was to measure both the external and internal load and examine relationships with aerobic fitness and soccer specific performance. In addition to this, biochemical measures of stress and muscle damage and acute performance measures would also be measured to ascertain any potential relationships between changes in such measures, TL and performance. These relationships would then be assessed to find what information the measurement of load can provide on a players fitness or fatigue to inform future studies on modeling. Current studies on modeling have focused on endurance performance (Busso, 2003; Morton, 1990) using Banister's (1991) TRIMP. Given the previously highlighted limitations of Banister's (1991) method for intermittent sports, modeling of both the fitness and fatigue impulses is dependent on such studies being conducted so that modeling strategies can be implemented in future.

7.2 Methods

Participants

Thirteen competitive amateur team sports players (Age: 20.1 ± 1.1 years; Height: 178 ± 5 cm; Mass: 70.9 ± 7.8 kg; VO_{2max}: 57 ± 7 $mL \cdot kg \cdot min^{-1}$) were recruited for this study. They provided written informed consent after having all procedures explained to them. The study was approved by the departmental ethics committee at the University of Hull. Amateur players were recruited as the extensive and controlled nature of the study made recruiting an adequate sized sample of elite players difficult.

Experimental Procedures

The study was conducted over a two-week period in the English summer time (June). During the 1st week a lactate threshold test was conducted (explained below)

Participants were also familiarised with the testing procedures. Participants were asked to avoid any strenuous exercise during the two-week period. During week 2 (Mon-Fri) they had all their meals standardized to negate any potential effect diet may have on the study. On Monday and Tuesday all participants reported for breakfast, lunch and dinner at 0800, 1200 and 1830h respectively.

Participants completed two $B_{90}M$ simulations ($B_{90}M1$ & $B_{90}M2$) 48 hours apart on the Wednesday and Friday of week 2. On both days the weather can be described as hot and there were clear skies (Temperature: 23/26˙C; Barometric Pressure: 1050/1068 mmHG; Relative Humidity: 43/40%). Samples of venous bloods were taken and acute performance tests (APT) were performed pre $B_{90}M1$ (T1), post $B_{90}M1$ (T2), 22 hours post $B_{90}M$ 1 (T3), pre $B_{90}M2$ (T4) and post $B_{90}M2$ (T5) as outlined in Table 7.1 below. Each participant ran the $B_{90}M$ at the same time on both occasions. Start times were staggered so that the time between each of the tests and the start of $B_{90}M$ remained constant between subjects. The 1st participant started the $B_{90}M$ at 1030h and the last finished by 1415h. This time period was selected to minimize any impact circadian rhythms may have on some performance measures, especially blood measures (Hayes, Bickerstaff & Baker, 2010; Atkinson & Reilly, 1996).

Table 7.1 Summary of schedule during week 2.

Day	Time	Activity / Measurement
Mon	0830	Breakfast
	1200	Lunch
	1830	Dinner
Tues	0830	Breakfast
	1200	Lunch
	1830	Dinner
Weds	0800	Bloods, Urine
	0830	Breakfast
	0930	APT*
	1030	$B_{90}M1$*
	1230	Bloods, APT*
	1830	Dinner
Thurs	0800	Bloods, Urine
	0830	Breakfast
	1030	APT*
	1200	Lunch
	1830	Dinner
Fri	0800	Bloods, Urine
	0830	Breakfast
	0930	APT*
	1030	$B_{90}M2$*
	1230	Bloods, APT*

** denotes activity that was staggered*

On the days where the $B_{90}M$ was conducted participants followed a strict timetable. Participants reported to the laboratory at 0800h. Upon arrival venous blood (10 mL) and urine samples (30 mL) were collected. Urine samples were examined against urine colour charts to monitor hydration (Wakefield, Mentes, Diggelmann & Culp, 2002) due to the unforeseen breakdown of the instrument used to detect urine osmolarity. Wakefield, *et al.*, (2002) have shown significant associations between hydration as measured by a urine colour chart and both urine osmolarity and urine specific gravity. At 0830h breakfast was served, thereafter the first participant proceeded to warm up followed by performance of the APT at 0930h. At 1030h the first participant started the $B_{90}M$. Upon finishing the $B_{90}M$ the participant again performed the APT, provided a venous blood sample and a urine sample. After $B_{90}M1$ and subsequent tests participants were immediately supplied with a banana and isotonic sports drink to start muscle glycogen replenishment and supplied with lunch after they had showered. With all the nutrition taken into account players were provided with a standardized diet containing at least 6 g·kg·bm^{-1} carbohydrate, 1.2 g·kg·bm^{-1} protein and 1.5 g·kg·bm^{-1} fat (Andersson, *et al.*, 2008) providing enough exogenous carbohydrate for complete replenishment of muscle glycogen stores over the 48 h, but also aiming to maintain the rate of replenishment post exercise by taking into consideration timing. The participants all reported for an evening meal at 1830 h. This was repeated on Friday with exception of an evening meal after the study was completed. On the Thursday the participants reported to the laboratory at 0800 h and had venous blood samples and urine samples collected. The blood samples were taken before breakfast to negate any antioxidant effect from the breakfast on blood measures. Thereafter at the same time as they did on Wednesday they performed the APT.

Lactate threshold test (LT)

The LT consisted of six, four minute stages (6, 10, 12, 14 & 16 km·h^{-1}) followed by a ramp to exhaustion, which increased at a rate of 0.2 km·h^{-1} every 12 seconds until the participant could no longer continue. Treadmill gradient was set at 1% for the entire test to reflect the energetic cost of outdoor running (Jones & Doust, 1996). Each stage was separated by one-min rest during which a fingertip capillary blood sample collected in a microvette (Microvette CB300, Sarstedt, Numbrecht, Germany) and immediately analysed for lactate (YSI 2300 Stat, YSI Inc, Yellow Springs. OH) in duplicate with the mean being used as the result. The instrumentation was calibrated before each participant embarked on a test. Maximal oxygen uptake was measured using a breath-by-breath gas analyzer (Cortex Metalyzer 3B, Cortex Biophysic, Leipzig, Germany) that was calibrated before and after each test according to the manufacturers instructions. VO_{2max} was recorded as the highest mean VO_2 obtained for a 1-min period during the test (Lucia, *et al.*, 2004). At least two of the following criteria were also required for the attainment of VO_{2max}: a plateau in VO_2 (defined as a change of less than 0.2 $L \cdot min^{-1}$) despite increasing treadmill speed, respiratory exchange ratio >1.15, or the attainment of age predicted maximum heart rate (Lucia, *et al.*, 2004). HR was recorded using HR belts (Polar Team System, Polar Electro, OY, Finland). Mean HR during the last minute of each stage was used in the calculation of the individualised HR-Bla relationship for the calculation of iTRIMP weightings. The peak HR obtained during the test was considered the participants HR_{max}.

Beast$_{90}$ modified (B$_{90}$M)

Participants were familiarised with the $B_{90}M$ by completing 30 minutes of the test in week 1. The test was conducted on a 3rd generation (3G) astro-turf surface, and arranged with instructions (stop, run, walk etc) placed on cones. Sassi, Stefanescu, Menaspa, Bosio, Riggio & Rampinini (2011) reported no significant difference in the metabolic cost of running on natural grass and artificial turf. A maximum of three participants were on a circuit at any one time. During pilot testing it was determined this was the maximum number that could run on one circuit without player's running together and pacing with each other. The distance covered during the $B_{90}M$ was measured with a 5Hz GPS system (Minimax, Catapult Innovations, Australia) for 10 of the participants as this was the maximum number of GPS units available for use. Where analysis of results does not require data from the GPS unit sample size for these analyses could be increased to include the full 13 participants. All of the participants had their HR recorded during the test using a Polar Team System (Polar Electro, OY, Finland). HR data were downloaded using Polar software (Polar Precision, Polar Electro, OY, Finland) and subsequently analysed using a bespoke spreadsheet (Excel, Microsoft Inc).

Diet

All participants were provided with a standardized diet for the 48 hours before each completion of the $B_{90}M$. This standardized diet provided at least 6 g·kg·bm^{-1} carbohydrate, 1.2 g·kg·bm^{-1} protein and 1.5 g·kg·bm^{-1} fat (Andersson, *et al.*, 2008). The diet consisted of a range of foods including milk, yogurt, fruit, cereal, chicken, rice, bread, pasta, fish and vegetables to ensure an adequate intake of macro and micro-nutrients. During the $B_{90}M$ all players were given 500 mL of water at half time.

Blood Analysis

Venous blood samples were collected from an antecubital vein into a serum separator tube (Vacuette,Greiner BIO-one, UK) and left to coagulate at room temperature for 30 minutes. Serum was pipetted and stored in eppendorf tubes at -80 ^{O}C for later analysis. Serum CK, urea and uric acid were analysed automatically using a Pentra 400 (Horiba ABX, Northampton, United Kingdom). The apparatus was calibrated according to manufacturer's instructions. Reliability results showed a CV of <1% for all 3 reagents through the testing period. Serum Cortisol and Testosterone were analysed automatically (Immulite 1000, Siemens Healthcare Diagnostics Inc, CA, USA). Again the apparatus was calibrated according to manufacturers instructions. The CV ranged from 1.7-2.5% and 1.0–6.6% for a range of different concentrations for testosterone and cortisol, respectively**.**

Acute Performance Tests

Prior to the APT at T1, T3 and T4 participants warmed up on a cycle ergometer (Monark 824E, Monark Exercise AB, Varberg, Sweden) for 10 minutes at 60 W. After the warm up they proceeded with the isokinetic strength tests. Upon completion of these tests participants walked from the laboratory to the outdoor 3G astroturf surface where they performed 3 counter movement jumps (CMJ) on an automated jump mat (Fusion Sport, HaB International Ltd, Warwickshire, UK) and also two 20 m sprints with a 10 m split measured by automated timing gates (Fusion Sport, HaB International Ltd, Warwickshire, UK). The best scores from these were taken as the result. Due to the study design upon completion of the $B_{90}M$ (T2 & T4) participants immediately performed the CMJ and sprint tests and then returned to the laboratory and provided venous blood samples before again performing the isokinetic strength tests. This order was chosen to negate any acute effects muscle damage and stress from maximal voluntary contractions may have on blood measures (Vaczi, Tihanyi, Hortobagyi, Racz, Csende, Costa & Pucsok, 2011).

The isokinetic strength measurement protocol was designed to measure peak torque for concentric and eccentric actions for both the hamstrings (cH & eH) and quadriceps (cQ & eQ). The tests were performed on the dominant kicking leg and subjects were familiarised with procedures in week 1. The tests were performed on an isokinetic dynamometer (Biodex system 3, Biodex medical systems Inc, NY, USA), which was operated by an experienced biomechanist. The actions were performed through a range of 90 degrees (knee flexed at 90 degrees considered 0) at an angular velocity of $120^{\circ}s^{-1}$. This test speed was selected as it has been shown to be acceptable as one of the fastest and safest speeds in which to reliably test eccentric hamstring muscle contractions (Rahnama, Reilly, Lees & Graham-Smith, 2003). Players performed three maximal voluntary contractions. Firstly, cQ and eQ peak torque was tested by asking the players to extend with maximum force. After 3 reps they were allowed 2-mins passive rest thereafter they performed a 2nd set of the same motions. eH and cH peak torque were also measured by asking the players to flex maximally at the knee. Again this consisted of two sets of 3 reps interspersed by 2 minutes of passive recovery. The highest peak torque recorded for each action from all of the reps was recorded as the result on each occasion.

Measurement of external and internal TL

External TL measured as the total distance (TD) covered and high-intensity distance (HID) covered (>15 km·h) were measured using a 5hz GPS system (Minimax, Catapult Innovations, Australia). GPS units were placed in a specifically designed vest worn by the participants as per the manufacturer's specifications. The GPS unit was located on the back of the player, between the scapulae.

The internal training load was calculated using the iTRIMP method described in section 6.2. In brief, the BLa-HR relationship was established using the data from each individuals lactate threshold test. An exponential regression equation was generated from this data for each individual, which was then used to calculate the iTRIMP in a bespoke spreadsheet (Excel, Microsoft Inc) from the HR traces (Polar team system) collected during each run of the $B_{90}M$. In addition to the iTRIMP at T2 & T5, players were asked to rate their exertion on the CR10 RPE scale. This was used to calculate their session RPE by multiplying their rating by the duration of the $B_{90}M$ (Foster, *et al.*, 2001).

Statistical Analyses

Results are presented as means ± SD. Unless otherwise stated, after verification of underlying assumptions a repeated measures ANOVA was performed to ascertain any main effects. Where there was missing data the participant was dropped from the analysis. Where significant main effects were detected, Sidak post-hoc analysis was performed. Where parametric analyses couldn't be conducted results are presented with median values. Pearson's correlation coefficients were also calculated for appropriate relationships. All statistical analyses were conducted using SPSS version 18. Statistical significance was set at $p \leq 0.05$. When significant differences existed the 95% confidence intervals are reported. Cohen effect sizes and their qualitative interpretation as defined by Hopkins (2010) (0 – 0.19 trivial; 0.2 – 0.59 small; 0.6 – 1.19 moderate; 1.2 – 1.99 large; ≥ 2.0 very large) are also reported for significant differences. Qualitative interpretations of the correlation coefficients as defined by Hopkins (2002) (0 – 0.09 trivial; 0.1 – 0.29 small; 0.3 – 0.49 moderate; 0.5 – 0.69 large; 0.7 – 0.89 very large; 0.9 – 0.99 nearly perfect; 1 perfect), are provided for all correlations.

7.3 Results

B_{90}M Performance and Training Load

Paired two tailed t-tests revealed there was no significant difference between B_{90}M1 and B_{90}M2 for TD (p = 0.17; CI: -107 to 519m; ES: 0.47, small). There was however a significant decrease of 467 m (13%) in HID (p = 0.04; CI: 10 to 924 m; ES: 0.64, moderate). Table 7.2 shows the distance data for the ten players who wore GPS units. The table also shows that although the mean distance did not change much although there is considerable variation in the individual changes. Examining the data by half revealed a significant main effect for TD (F = 6.151; p = 0.03). Despite this, Sidak post-hoc analysis revealed no significant differences, although the difference between $B_{90}M2.1$ and $B_{90}M2.2$ showed trends towards significance (mean difference: 358 m; p = 0.054; CI: -6 to 721 m; ES: 1.01, moderate). Similar results were found for HID where there was a significant main effect ($F = 6.151$; $p < 0.001$), however the post hoc analysis did not show a significant difference. On this occasion the difference between $B_{90}M1.1$ and $B_{90}M2.2$ showed trends towards significance (mean difference: 525 m; p = 0.054; CI: -8 to 1061; ES: 1.34, large).

Table 7.2 TD & HID for $B_{90}M1$ & $B_{90}M2$

	Total Distance (m)				**High-intensity Distance (m)**			
Player	**$B_{90}M1$**	**$B_{90}M2$**	**change**	**% change**	**$B_{90}M1$**	**$B_{90}M2$**	**change**	**% change**
1	12332	11384	-948	-8	3206	2332	-874	-27
2	10462	10325	-137	-1	2591	2748	157	6
3	10323	10359	36	0	2578	2393	-185	-7
4	10859	10280	-579	-5	3927	2968	-959	-24
5	11384	11331	-53	-0	4799	4055	-744	-16
6	10383	10986	603	6	3020	3496	476	16
7	10745	10659	-86	-1	2568	2343	-225	-9
8	10055	9777	-278	-3	3886	3849	-37	-1
9	11098	11143	45	0	3430	2870	-560	-16
10	10456	9795	-661	-6	3352	1630	-1722	-51
Mean	10810	10604	-206	-2	3336	2868	-467*	-13
SD	664	592	437	4	718	754	639	14
Effect Size			0.33 (small)				0.64 (moderate)	

**denotes significant difference*

Table 7.3 TD (external load) data split by half

Player	Total Distance (m)			
	B_{90}M1.1	**B_{90}M1.2**	**B_{90}M2.1**	**B_{90}M2.2**
1	6269	6063	5861	5523
2	5212	5250	5256	5069
3	5260	5063	5449	4910
4	5539	5320	5650	4630
5	5797	5587	6062	5269
6	5055	5328	5524	5462
7	5314	5431	5485	5174
8	5221	4834	5011	4766
9	5497	5601	5501	5642
10	5336	5120	5009	4786
Mean	5450	5360	5481	5123
SD	355	341	335	350

Table 7.4 HID (external load) data split by half

Player	High-intensity Distance (m)			
	B_{90}M1.1	**B_{90}M1.2**	**B_{90}M2.1**	**B_{90}M2.2**
1	1884	1322	1291	1041
2	1463	1128	1559	1189
3	1536	1042	1432	961
4	1779	2148	2143	825
5	2384	2415	2309	1746
6	1393	1627	1683	1813
7	1247	1321	1243	1100
8	2141	1745	2067	1782
9	1823	1607	1494	1376
10	2035	1317	1045	585
Mean	**1769**	**1567**	**1627**	**1242**
SD	**360**	**440**	**420**	**427**

Table 7.5 Internal Training Load and Intensity data from $B_{90}M1$ & $B_{90}M2$.

	RPE			iTRIMP			mean HR (%max)		
Player	**$B_{90}M1$**	**$B_{90}M2$**	**Change**	**$B_{90}M1$**	**$B_{90}M2$**	**Change**	**$B_{90}M1$**	**$B_{90}M2$**	**Change**
1	6	7	1	473	276	-197	92	82	-10
2	6	7	1	442	319	-123	90	83	-7
3	6	7	1	837	496	-341	91	85	-6
4	6	7	1	360	351	-9	85	80	-5
5	6	7	1	282	239	-43	87	84	-3
6	5	6	1	344	286	-58	85	81	-4
7	7	7	0	416	380	-36	90	88	-2
8	8	8	0	361	233	-128	84	77	-7
9	5	5	0	281	308	27	79	81	2
10	5	7	2	442	277	-165	86	78	-8
11	5	8	3	459	344	-115	90	82	-8
12	6	5	-1	494	399	-95	93	88	-5
13	5	5	0	198	165	-33	78	76	-2
Mean	6	7	1	415	313	-101	87	82	-5
SD	1	1	1	154	84	96	5	4	3

Verification of underlying assumptions revealed that iTRIMP in $B_{90}M1$ was not normally distributed. Further examination of residuals, using Q-Q plots and box plots revealed this was due to player 3. Removal of player 3 changes the means as shown in the adjusted table below and also allowed parametric analyses to be performed with a normally distributed dataset.

Table 7.6. Internal Training Load and Intensity data from $B_{90}M1$ & $B_{90}M2$ (adjusted for outlier)

	RPE			iTRIMP			mean HR (%max)		
Player	**$B_{90}M1$**	**$B_{90}M2$**	**Change**	**$B_{90}M1$**	**$B_{90}M2$**	**Change**	**$B_{90}M1$**	**$B_{90}M2$**	**Change**
1	6	7	1	473	276	-197	92	82	-10
2	6	7	1	442	319	-123	90	83	-7
4	6	7	1	360	351	-9	85	80	-5
5	6	7	1	282	239	-43	87	84	-3
6	5	6	1	344	286	-58	85	81	-4
7	7	7	0	416	380	-36	90	88	-2
8	8	8	0	361	233	-128	84	77	-7
9	5	5	0	281	308	27	79	81	2
10	5	7	2	442	277	-165	86	78	-8
11	5	8	3	459	344	-115	90	82	-8
12	6	5	-1	494	399	-95	93	88	-5
13	5	5	0	198	165	-33	78	76	-2
Mean	**6**	**7***	**1**	**379**	**298**	**-81***	**87**	**82**	**-5***
SD	**1**	**1**	**1**	**91**	**67**	**67**	**5**	**4**	**3**
Effect Size			**-0.83 (moderate)**			**1.01 (moderate)**			**1.10 (moderate)**

** significantly different to $B_{90}M1$*

Examination of iTRIMP showed that it was significantly lower ($p = 0.001$; CI: -123 to -38; ES: 1.01, moderate) in $B_{90}M2$ compared to $B_{90}M1$ (paired t-test) as was %mean HR ($p < 0.01$; CI: -7.04 to -2.79; ES: 1.10, moderate). RPE on the other hand was found to be significantly higher ($p = 0.03$; CI: 0.07 to 1.42; ES:-0.83, small). However in all of the above data the individual variations can be seen and it is information on the individual the coach is interested in. In addition to this any change in actual performance is still subject to the individual's motivation. There was also no significant relationship between iTRIMP and TD ($r = 0.45$; $p = 0.25$; CI: -0.25 to 0.54; moderate) or HID ($r = -0.48$; $p = 0.20$; CI :-0.85 to 0.20; moderate) although they can both be described as moderate correlations. Analysis of the change in iTRIMP from $B_{90}M1$ to $B_{90}M2$ showed a significant inverse relationship with the iTRIMP in $B_{90}M1$ ($r = -0.68$, $p = 0.01$; CI: 0.12 to 0.89; large), showing that those players who worked hardest in $B_{90}M1$ were the players that didn't or couldn't work as hard in $B_{90}M2$.

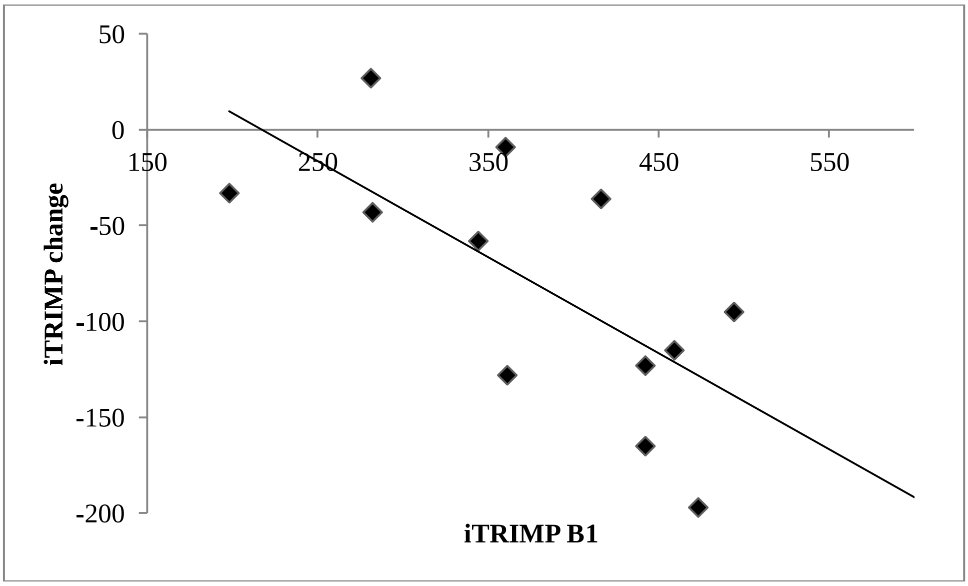

Figure 7.1. Correlation between iTRIMP in $B_{90}M1$ and change in iTRIMP between $B_{90}M1$ & $B_{90}M2$ (n=12)

An integrated measure that combined player's external performance and internal exertion (effectively the distance covered per iTRIMP) was also analysed to assess its viability as a surrogate measures of fitness and fatigue. The ratio's for this integration of data is shown below in table 7.7. These values are for the data collected from $B_{90}M_1$ (as they were in a rested state before this). Correlations between iTRIMP:TD and iTRIMP:HID from $B_{90}M1$ (VO_{2max}, vLT, vOBLA) were produced.

Table 7.7 Values for ratio's and fitness measures

Player	Ratio's		Fitness Measures		
	iTRIMP:TD	**iTRIMP:HID**	**VO_{2max} (ml.kg.min^{-1})**	**vLT**	**vOBLA**
1	26.07	6.78	53.25	8.8	11.4
2	23.67	5.86	53.00	6.3	11.8
3	12.33	3.08	68.50	6.0	9
4	30.16	10.91	61.50	7.9	10.7
5	40.37	17.02	62.50	7.4	13.3
6	24.96	7.26	55.50	5.7	11.8
7	29.76	7.11	53.00	8.0	10.2
8	35.78	13.83	64.00	8.4	11.9
9	25.11	7.76	51.75	6.0	9.6
10	52.81	16.93	60.25	9.1	11.5
Mean	30.10	9.65	58.33	7.36	11.12
SD	10.94	4.81	5.78	1.27	1.26

Table 7.8. Correlation coefficients for ratio values against fitness measures

Ratio	Fitness Measure		
	vLT	**vOBLA**	**VO_{2max}**
iTRIMP:HID	r = 0.58 p = 0.08 (0.08 to 0.89) Moderate	r = 0.65* p = 0.04 (0.03 to 0.91) Moderate	r = 0.29 p = 0.41 (-0.08 to 0.78) Small
iTRIMP:TD	r = 0.69* p = 0.03 (0.11 to 0.92) Moderate	r = 0.58 p = 0.08 (0.08 to 0.89) Moderate	r = 0.07 p = 0.84 (-0.51 to 0.67) Trivial

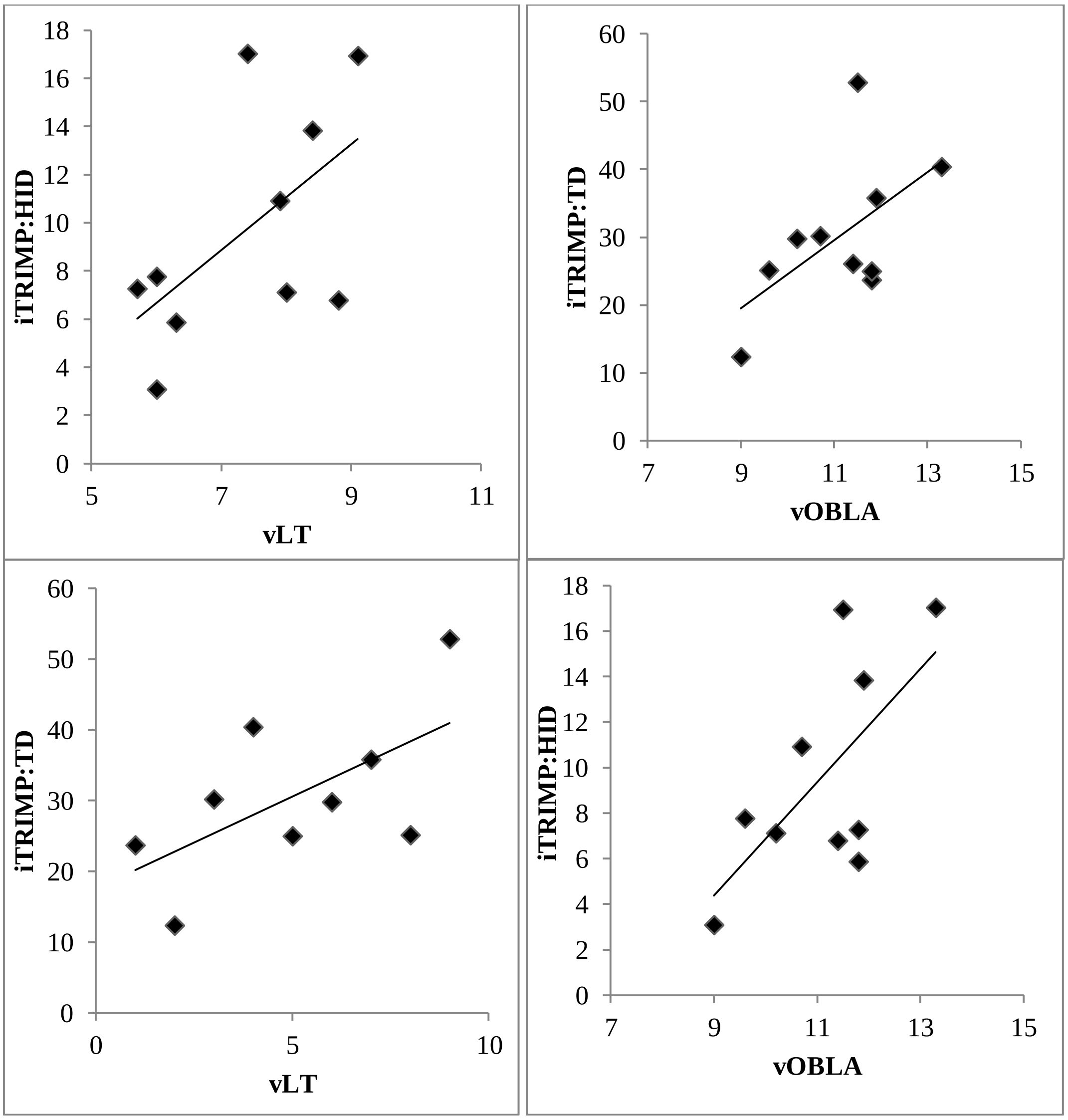

Figure 7.2. Correlations showing relationships between fitness measures and ratio's.

Pearson's correlation coefficients show that both ratio's showed moderate positive relationships with vLT and vOBLA, respectively. VO_{2max} showed a poor relationships with both ratios. This would suggest that improvements in fitness are associated with increases in the ratio (or the distance covered per iTRIMP), although the sensitivity of the ratio's cannot be proclaimed from this study. The change in ratios was correlated with the change in actual performance from $B_{90}M1$ to $B_{90}M2$. ΔiTRIMP:HID was not normally distributed therefore the Spearman rank coefficient was used as a non parametric analysis for this correlation.

Table 7.9. Correlation coefficients for changes in ratios vs changes in performance measures

Ratio	Performance (m)	
	ΔHID	**ΔTD**
ΔiTRIMP:HID	r = 0.61* p = 0.06 (-0.03 to 0.90) Large	
ΔiTRIMP:TD		r = - 0.04 ** p = 0.92 (-0.65 to 0.60) Trivial

**Spearman rank coefficient. **Pearson Coefficient*

The large relationship between the ΔiTRIMP:HID from B_{90}M1 to B_{90}M2 and ΔHID (considered a performance measure by many clubs) shows that change in performance may relate to a change in the iTRIMP:HID ratio. This would suggest that a decrease in the ratio would signal a decrease in performance, in the same way that a decrease in the ratio would also show a reduction in fitness.

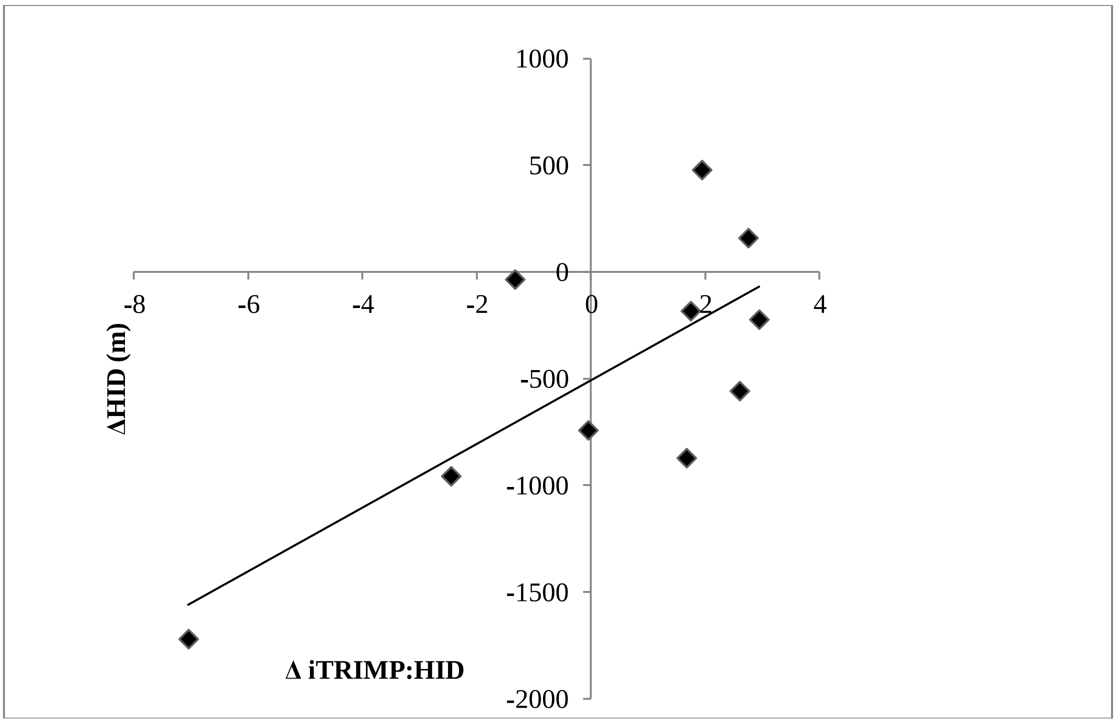

Figure 7.3. Relationship between change in ΔiTRIMP:HID and ΔHID (n=10)

Acute Performance Tests: Changes and Important Relationships

The APT consisted of sprints (10 m and 20 m), CMJ and isokinetic strength measures.

Table 7.10 below shows the sprint speeds for all players at all the testing points.

Table 7.10. 10m & 20m Sprint Times

Player	Sprints 10m (s)					Sprints 20m (s)				
	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
1	1.89	1.89	1.93	1.94	1.92	3.21	3.16	3.25	3.29	3.31
2	1.88	1.93	1.91	1.89	1.95	3.18	3.27	3.22	3.22	3.30
3	1.95	1.89	1.91	1.93	1.89	3.29	3.25	3.25	3.25	3.23
4	1.87	1.88	1.84	1.87	1.99	3.17	3.26	3.12	3.20	3.43
5	2.09	1.98	1.97	1.96	1.96	3.50	3.42	3.35	3.36	3.35
6	2.01	1.97	2.08	2.07	2.04	3.44	3.51	3.57	3.55	3.58
7	2.15	2.15	2.18	2.16	2.10	3.68	3.68	3.67	3.69	3.63
8	2.11	2.16	2.15	2.16	2.19	3.60	3.68	3.63	3.70	3.84
9	1.98	1.96	1.94	1.96	2.02	3.36	3.37	3.30	3.39	3.52
10	1.96	2.00	2.02	2.09	2.09	3.39	3.42	3.48	3.71	3.63
11	1.79	2.00	1.98	2.47	2.02	3.30	3.31	3.30	3.30	3.40
12	2.11	2.16	2.17	2.18	2.15	3.51	3.70	3.66	3.71	3.71
13	2.01	2.03	2.18	2.11	2.12	3.40	3.46	3.64	3.58	3.58
Mean	1.99	2.00	2.02	2.06	2.03	3.39	3.42	3.42	3.46	3.50
SD	0.11	0.10	0.12	0.16	0.09	0.16	0.18	0.20	0.20	0.18

A repeated measures ANOVA revealed no significant overall effect for 10m sprint times (F = 1.86; p = 0.19) after performing Greenhouse – Geisser correction as the assumption of sphericity was violated (Mauchlys; p = < 0.001). Twenty metre sprint performance showed a significant overall main effect (F = 5.140; p < 0.01). However post hoc analysis did not show a significant change. The difference between T1 and T5 20 m sprint time (mean change: -0.114; p = 0.07; CI:-0.235 to 0.007; ES: 0.67, moderate) was moderate.

Table 7.11. CMJ scores

Player	Counter Movement Jump (cm)				
	T1	**T2**	**T3**	**T4**	**T5**
1	42.69	44.29	40.69	41.84	37.90
2	33.52	28.79	29.54	29.33	32.09
3	35.83	38.20	37.30	33.42	34.65
4	39.15	41.19	38.60	36.50	32.60
5	37.44	36.04	36.16	35.64	35.76
6	32.22	38.59	31.98	34.00	36.56
7	28.00	27.85	29.27	30.05	34.06
8	32.22	35.11	33.16	31.96	34.00
9	39.08	40.27	38.07	37.52	40.29
10	36.91	36.30	32.48	33.61	32.67
11	37.77	36.76	37.72	35.49	33.31
12	32.09	35.18	33.36	34.26	32.59
13	38.05	37.37	36.83	37.64	36.50
Mean	35.77	36.61	35.01	34.71	34.84
SD	3.96	4.50	3.61	3.34	2.44

Table 7.11 above shows the CMJ scores. Analyses with a repeated measures ANOVA showed no main effect (F = 2.238; p = 0.08).

Table 7.12. Peak torque measurements for all muscle actions

Player	ConcQ					EccQ					ConcH					EccH				
	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
1	162.9	138.9	159.3	181.1	151.1	255.1	161.1	140.8	145.1	160.0	180.3	156.7	168.3	108.7	128.4	173.6	155.6	162.2	166.2	115.5
2	157.4	167.4	168.4	185.0	193.1	160.7	175.4	204.5	187.8	190.2	110.8	105.1	187.8	137.6	117.5	149.5	142.8	185.0	171.3	169.0
3	195.0	188.3	178.8	165.2	206.0	238.7	243.0	221.0	218.5	258.0	94.9	185.8	108.6	118.9	110.6	193.5	179.5	173.0	178.2	159.0
4	149.1	147.5	148.5	113.9	134.7	188.6	199.1	203.1	150.6	182.5	144.5	57.3	133.0	133.5	114.3	155.4	122.2	133.1	131.3	122.9
5	142.4	144.8	158.2	164.1	162.8	178.7	162.4	186.1	198.3	177.5	88.7	103.3	79.3	133.4	85.6	134.2	130.4	125.6	137.8	117.6
6	268.2	260.1	262.3	234.7	242.8	307.6	310.5	344.8	342.1	320.6	146.5	123.6	133.9	126.0	99.0	224.8	183.6	208.5	194.2	136.4
7	183.1	163.5	154.4	170.3	164.2	287.3	246.2	263.0	275.9	271.3	108.6	104.8	103.6	96.6	107.4	179.4	163.0	178.8	170.2	160.9
8	199.5	191.9	186.4	177.4	192.7	309.1	257.4	309.7	308.7	305.4	117.2	90.2	80.3	63.0	47.0	194.7	162.7	138.0	133.0	92.5
9	122.7	149.1	145.8	148.8	157.0	209.8	228.6	205.9	198.8	148.5	73.4	86.7	65.4	129.9	110.6	142.3	133.3	126.7	97.6	112.3
10	160.6	179.4	170.3	178.6	151.2	221.9	235.0	214.1	202.8	183.9	119.5	126.0	153.9	141.7	133.9	188.5	200.7	156.1	166.9	117.8
11	168.6	162.1	147.3	172.8	187.1	214.8	226.6	183.4	184.4	199.3	148.7	146.6	98.0	152.3	100.8	136.7	143.4	162.0	184.1	146.6
12	172.1	154.2	183.0	165.0	166.8	268.6	234.7	276.1	232.7	230.8	109.9	106.1	114.9	100.4	101.2	184.1	173.6	174.8	167.5	163.5
13	174.7	154.2	172.7	170.3	165.3	190.9	234.7	146.7	132.4	97.0	181.2	167.0	97.6	X	91.2	162.7	122.8	131.1	X	137.8
Mean	173.6	169.3	172.0	171.3	175.0	233.2	224.2	223.0	213.7	209.6	124.9	119.9	117.3	120.2	103.7	170.7	154.9	158.1	158.2	134.8
SD	35.2	31.8	30.4	26.3	28.7	49.2	41.4	60.1	62.7	64.5	33.3	35.9	36.5	24.5	21.7	26.8	24.9	25.9	27.6	23.8

Table 7.12 shows the peak torques for all muscle actions through the study. A repeated measures ANOVA showed that ConcQ ($F = 0.35$; $p = 0.84$), EccQ ($F = 1.63$; $p = 0.18$), ConcH ($F = 0.791$; $p = 0.53$) showed no significant main effects.

EccH ($F = 6.961$; $p < 0.01$) showed a significant main effect. The data did not satisfy the assumption of sphericity (Mauchlys: $p = 0.02$) therefore the results presented are those using the Greenhouse-Geisser correction. Sidak post hoc analysis showed that EccH had been significantly higher at T3 ($p = 0.01$; CI: -46.08 to -5.56; ES: 0.92, moderate) and T4 ($p = 0.04$; CI: -46.88 to -0.5; ES: 0.96, moderate) when compared to T5 and showed trends towards significance with T1 ($p = 0.052$; CI: -74.13 to 0.34 ES: 1.45, large). The results suggest that EccH recovers after $B_{90}M1$ as there is no significant difference between T1 and T2, however, the exercise during $B_{90}M2$ appears to have a greater effect on EccH resulting in a significant decrease at T5. There appears to be an accumulated fatigue.

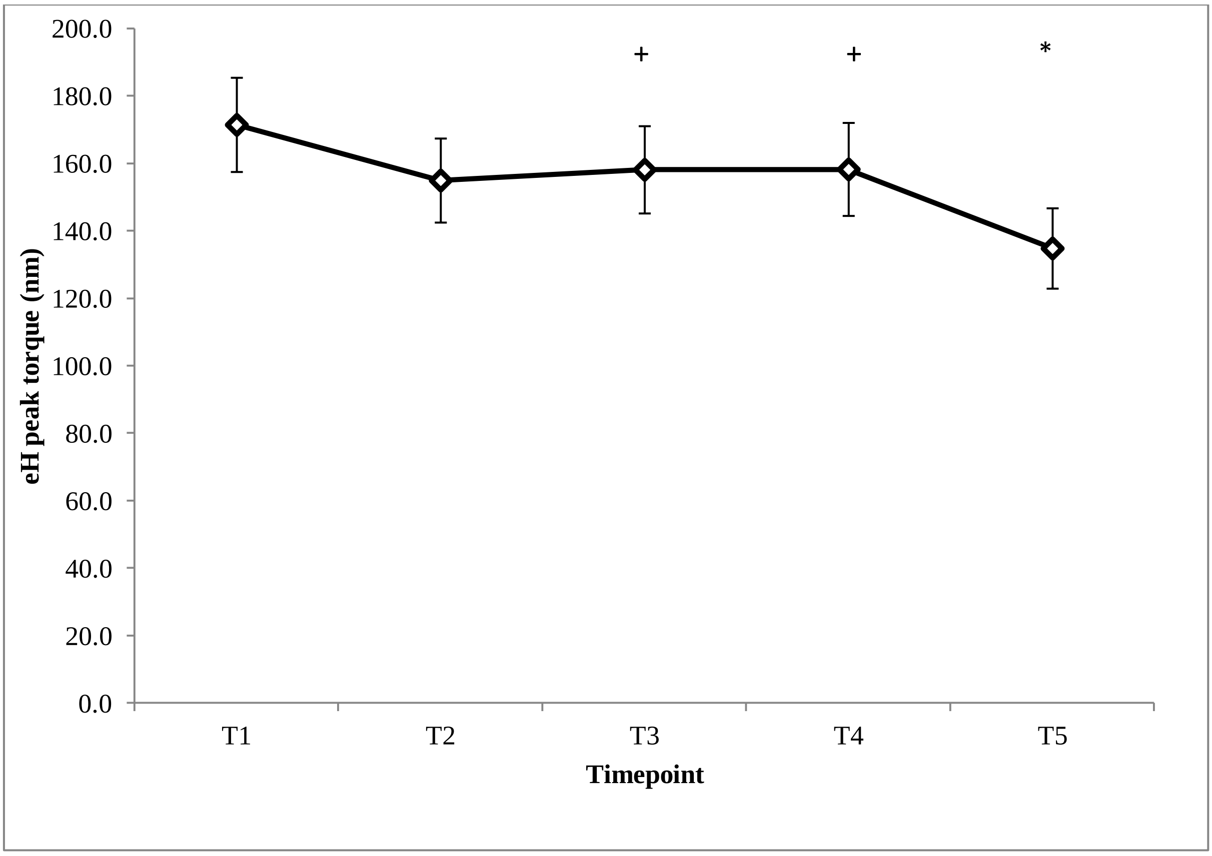

Figure 7.4. Change in EccH peak torque. *+significantly higher than T5 *Significantly lower than all other time points*

The significant decrease at T5 for EccH coincided with a significant main effect for the functional ratio ($F = 7.253$; $p < 0.001$) with T5 being significantly lower when compared to T1 ($p < 0.01$; CI: -38.86 to -5.72; ES: 5.97, very large), T2 ($p = 0.03$; CI: -30.46 to -1.26; ES: 4.13, very large), T3 ($p = <0.01$; CI: -27.53 to-5.70; ES: 4.13, very large) and T4 ($p = 0.01$; CI: -27.53 to -3.07; ES: 3.76, very large) (Figure 7.5).

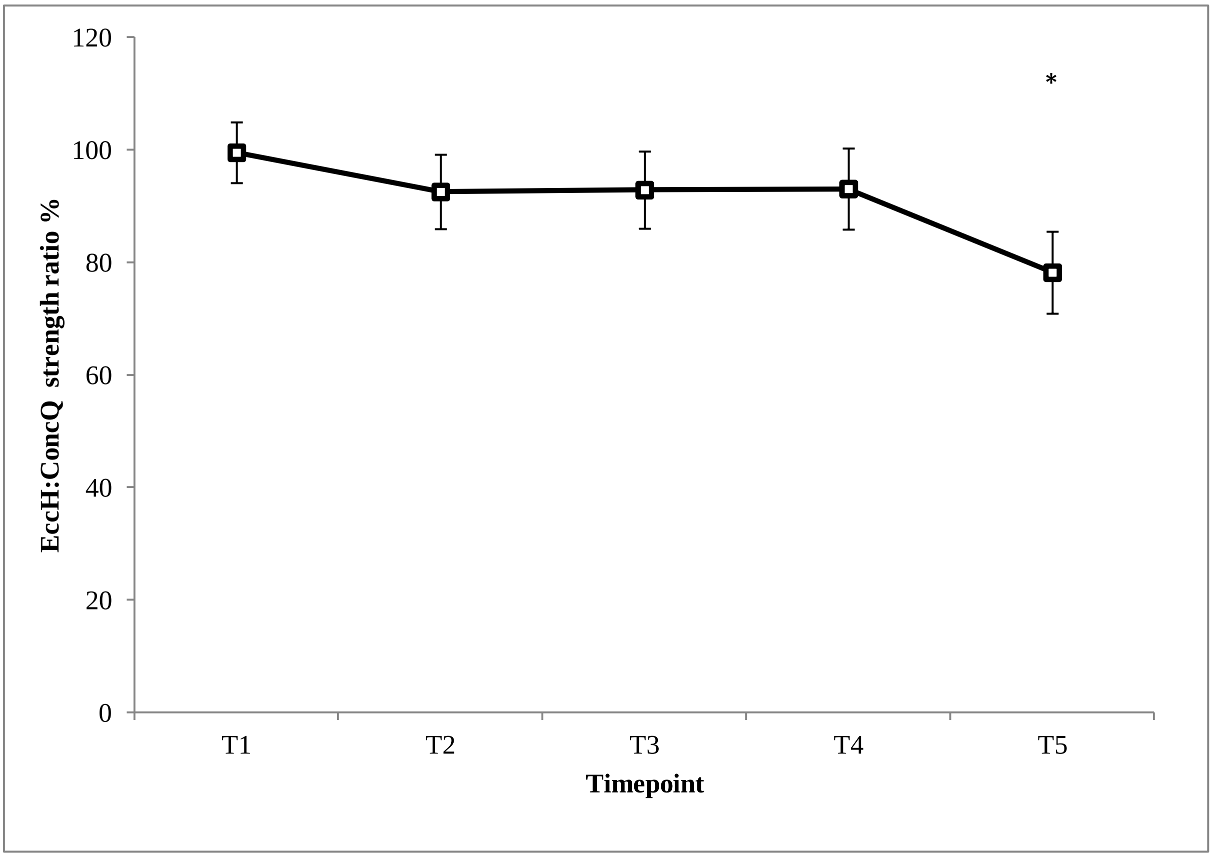

Figure 7.5. Change in functional strength ratio. **denotes significantly lower than all other timepoints.*

The results suggest that $B_{90}M2$ causes a significant drop in the ratio potentially showing the effect of accumulated fatigue given that TD covered didn't change across both matches and HID decreased. The decrease in HID could potentially be attributed a decrease in EccH and the power producing capability of the muscle. However isokinetic strength measurements are not always practical in a field setting. Therefore relationships with TL measures and the change in the functional ratio either as a result of exercise or during recovery may prove useful as TL can be measured. Therefore the relationships below were analyzed;

1) The change between T1 and T2 and TL in B_{90}M1 (iTRIMP,sRPE, TD and HID)
2) The change at T3 and T4 from baseline (T1) with TL (iTRIMP,sRPE, TD and HID) in B_{90}M1
3) The change in the functional ratio from T1 and T4 and the change in performance

This allows assessment of how TL may help to identify potential fatigue post match and during the recovery process.

Table 7.13. Correlations of Training Load with changes in EccH:ConQ ratio

Training Load	**N**	**ΔT1-T2**	**ΔT1-T3**	**ΔT1-T4**
iTRIMP	12	r = 0.68* p = 0.02 (0.17 to 0.90) Large	r = 0.48 p = 0.12 (- 0.13 to 0.83) Moderate	r = 0.41 p = 0.21 (- 0.21 to 0.80) Small
HID	10	r = -0.24 p = 0.50 (- 0.76 to 0.46) Small	r = -0.43 p = 0.21 (- 0.83 to 0.27) Moderate	r = -0.21 p = 0.59 (-0.74 to 0.48) Small
TD	10	r = 0.57 p = 0.09 (- 0.09 to 0.88) Large	r = -0.06 p = 0.87 (- 0.66 to 0.59) Trivial	r = 0.04 p = 0.91 (-0.60 to 0.65) Trivial
sRPE	13	r = 0.06 p = 0.84 (-0.51 to 0.59) Trivial	r = 0.04 p = 0.90 (-0.52 to 0.58) Trivial	r = -0.01 p = 0.99 (-0.56 to 0.54) Trivial

**significant at 0.05*

The results in the above table show that iTRIMP significantly correlates to changes in the functional ratio immediately after the match at T2. Similarly TD also shows a good relationship with the change in ratio at T2. However, positive correlations suggests that those with a higher TL show less of a reduction in the ratio and hence less fatigue. A negative correlation is what would have been expected and made any relationship meaningful. HID does show small to moderate negative correlations with the change in the functional ratio. Analysis of the %change from T1 – T4 of the functional ratio (T1 and T4) and change in TD (r = 0.53; p = 0.11; CI: -0.14 to 0.87; Large) and HID (r = -0.19; p = 0.59; CI: -0.73 to 0.50; Small) revealed non-significant correlations (n=10). Again a negative correlation would be expected to show a greater reduction in performance with an increase of fatigue. HID showed a small negative correlation.

Biochemical Measures: Changes and Important Relationships

At T2 one participant could not provide a blood sample therefore the mean for blood measures at T2 has been calculated excluding this data. This participant's data will also be excluded from any repeated measures ANOVA. Correlation analyses involving data at T2 will be conducted excluding the participants data.

Figures 7.6 to 7.9 below show how testosterone, cortisol and the T:C ratio changed over time points.

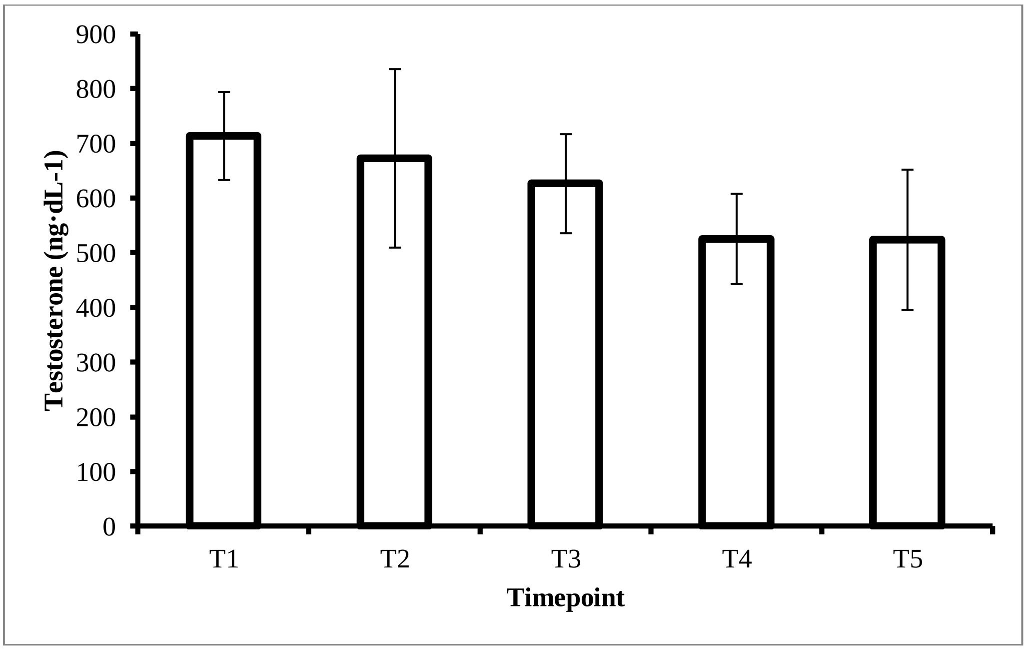

Figure. 7.6. Testosterone levels across time points

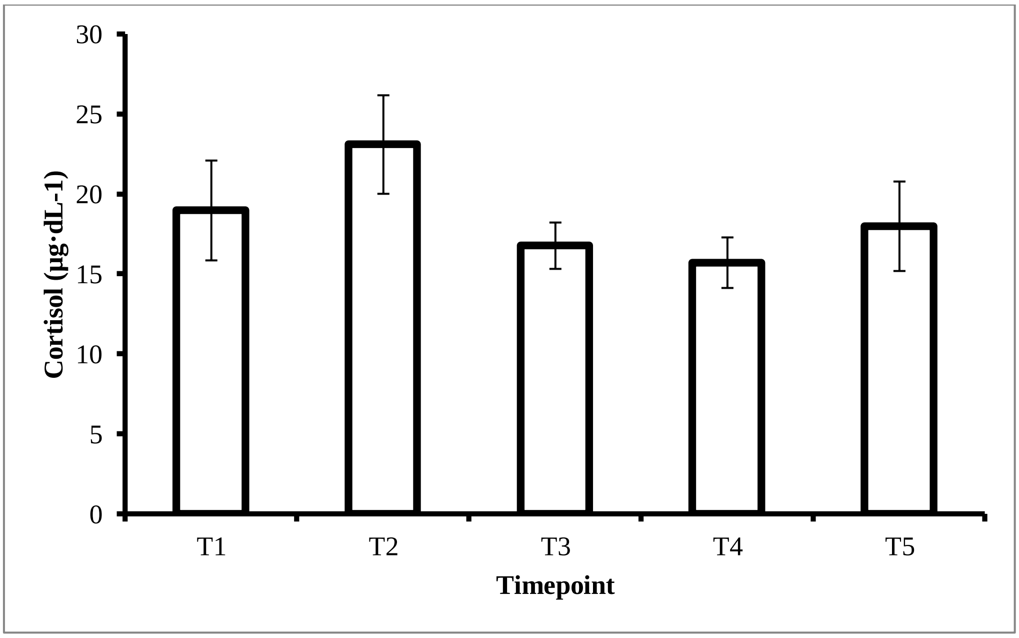

Figure.7.7. Cortisol levels across time points

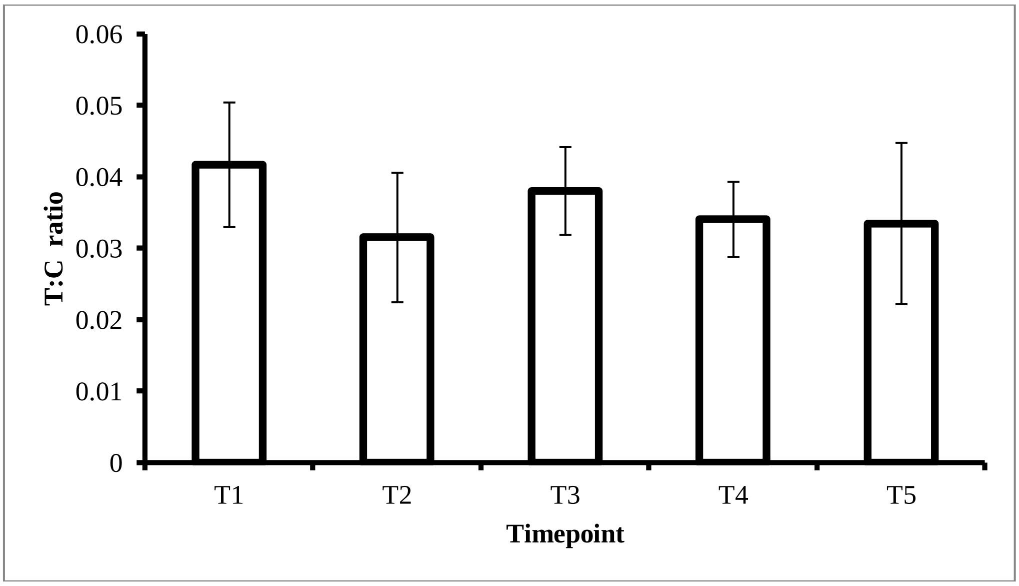

Figure.7.8. T:C across time points

A repeated measures ANOVA was performed with the Greenhouse-Geisser correction as there was a lack of sphericity (Mauchlys: $p = 0.004$). This showed there was a significant main effect for testosterone ($F= 7.416$; $p <0.01$). Sidak post hoc analysis showed that T4 ($p < 0.001$; CI: 100 to 302; ES: 1.19, moderate) and T5 ($p = 0.02$; CI: 24 to 379; ES: 0.93, moderate) were significantly lower than T1. T4 was also significantly lower than T3 ($p = 0.03$; CI: 10 – 220; ES: 0.60, moderate).

Cortisol also lacked sphericity (Mauchlys: $p = 0.04$). The repeated measures ANOVA with the Greenhouse-Geisser correction showed there was a significant main effect for testosterone ($F= 5.837$; $p <0.01$). Sidak post hoc analysis showed that T5 was significantly lower that T1 ($p=0.02$; CI: 24-379; ES: 1.43, large). Finally the T:C ratio also lacked sphericity (Mauchlys; $p = 0.02$). The RM ANOVA with the Greenhouse-Geisser correction showed there was no significant main effect ($F = 1.277$; $p = 0.30$).

Testosterone showed no significant relationships with percentage changes from baseline (T1) for any TL measures apart from ΔsRPE from T1-T3 (see Table 7.14). However inverse relationships suggest a decrease in testosterone with increased load.

Table 7.14. Correlations of Training Load with %changes in Testosterone

Training Load	N	ΔT1-T2	ΔT1-T3	ΔT1-T4
iTRIMP	12	r = 0.19 p = 0.59 (-0.43 to 0.69) Small	r = 0.30 p = 0.35 (-0.33 to 0.75) Moderate	r = -0.03 p = 0.93 (-0.59 to 0.55) Trivial
HID	10	r = -0.39 p = 0.30 (-0.82 to 0.32) Moderate	r = -0.56 p = 0.10 (-0.88 to 0.11) Large	r = -0.08 p = 0.84 (-0.68 to 0.58) Trivial
TD	10	r = -0.01 p = 0.98 (-0.68 to 0.58) Trivial	r = 0.05 p = 0.88 (-0.60 to 0.66) Trivial	r = 0.16 p = 0.60 (-0.52 to 0.72) Small
sRPE	13	r = -0.47 p = 0.12 (-0.81 to 0.11) Moderate	r = -0.58* p = 0.04 (0.04 to 0.86) Large	r = -0.44 p = 0.13 (-0.80 to 0.15) Moderate

**significant at 0.05*

Changes in cortisol showed some relationships with iTRIMP during the recovery phase with the percentage change at T3 (r = -0.57; p = 0.04; CI = -0.87 to -0.02) and T4 (r = -0.61;p =0.03; CI = -0.88 to -0.06) showing large significant correlations.

Table 7.15. Correlations of Training Load with %changes in Cortisol

Training Load	N	ΔT1-T2	ΔT1-T3	ΔT1-T4
iTRIMP	12	r = -0.11 p = 0.74 (-0.64 to 0.50) Small	r = -0.57* p = 0.04 (-0.87 to -0.02) Large	r = -0.61* p = 0.03 (-0.88 to -0.06) Large
HID	10	r =-0.49 p = 0.17 (-0.63 to 0.63) Moderate	r = 0.12 p = 0.73 (-0.55 to 0.7) Small	r = 0.16 p = 0.67 (-0.52 to 0.72) Small
TD	10	r = 0.25 p = 0.43 (-0.45 to 0.76) Small	r = -0.26 p = 0.39 (-0.76 to 0.44) Small	r = -0.33 p = 0.28 (-0.79 to 0.38) Moderate
sRPE	13	r = -0.49 p = 0.10 (-0.82 to 0.08) Moderate	r = -0.34 p = 0.24 (-0.75 to 0.26) Moderate	r = -0.28 p = 0.35 (-0.72 to 0.32) Small

**significant at 0.05*

However the change in cortisol was not normally distributed (Shapiro-Wilk: T3 < 0.01; T4 < 0.001) and the correlations the removal of an extreme data point resulted in correlation coefficients of 0.00 for T3 and 0.01 for T4, respectively.

Given the highly individual nature of the hormonal response the T:C ratio has previously been used to assess the anabolic or catabolic state of the body. The change in T:C ratio showed significant correlations at T3 and T4 with iTRIMP, where TD, HID and sRPE didn't show any.

Table 7.16. Correlations of Training Load with %changes in T:C ratio

Training Load	N	ΔT1-T2	ΔT1-T3	ΔT1-T4
iTRIMP	12	r = 0.20 p = 0.56 (-0.02 to 0.86) Small	r = 0.62* p = 0.03 (-0.88 to -0.07) Large	r = 0.67* p = 0.02 (-0.90 to -0.16) Large
HID	10	r = -0.06 p = 0.87 (-0.66 to 0.59) Trivial	r = -0.29 p = 0.40 (-0.78 to 0.42) Small	r = -0.10 p = 0.79 (-0.69 to 0.57) Small
TD	10	r = 0.09 p = 0.99 (-0.57 to 0.68) Trivial	r = 0.28 p = 0.36 (-0.42 to 0.77) Small	r= 0.50 p = 0.08 (-0.19 to 0.86) Large
sRPE	13	r = 0.01 p =0.99 (-0.54 to 0.56) Trivial	r = 0.11 p = 0.72 (-0.47 to 0.62) Small	r = 0.12 p = 0.71 (-0.46 to 0.63) Small

**significant at 0.05*

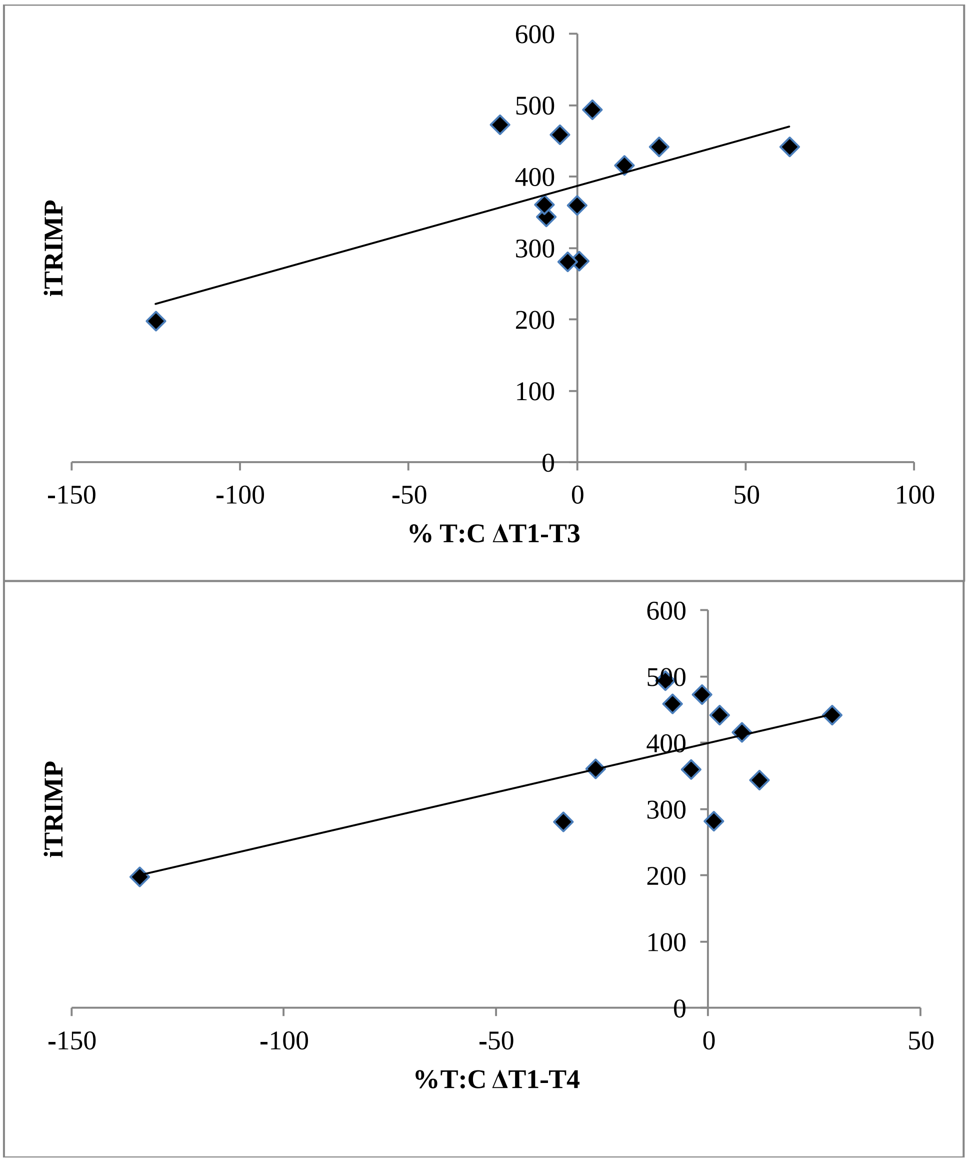

Figure 7.9. Correlations showing change in T:C vs iTRIMP with extreme value

Again the correlations show the effect of an extreme value, which when removed again shows different relationships (r = 0.02 and r = 0.31 respectively).

Table 7.17. Correlations of %**H**ormones and %Δ performance

Performance	N	%ΔTestosterone	%ΔCortisol	%ΔT:C
%ΔHID	10	r = - 0.74* p = 0.02 (-0.93 to -0.21) Very large	r = -0.76* p = 0.01 (-0.94 to -0.25) Very Large	r = 0.49 p = 0.15 (-0.20 to 0.86) Moderate
%ΔTD	10	r = -0.48 p = 0.15 (-0.85 to 0.21) Moderate	r = -0.49 p = 0.15 (-0.86 to 0.20) Moderate	r = 0.45 p = 0.19 (-0.25 to 0.84) Moderate

The %Δcortisol was shown not to be normally distributed (Shapiro-Wilk: $p < 0.01$). Removal of the outliers changes the correlations coefficients to - 0.39 and -0.40 for TD and HID, respectively. There was a significant negative correlation between the change in testosterone levels and change in HID. This suggest a decrease in testosterone relates to increases or limits the performance decline in soccer matches.

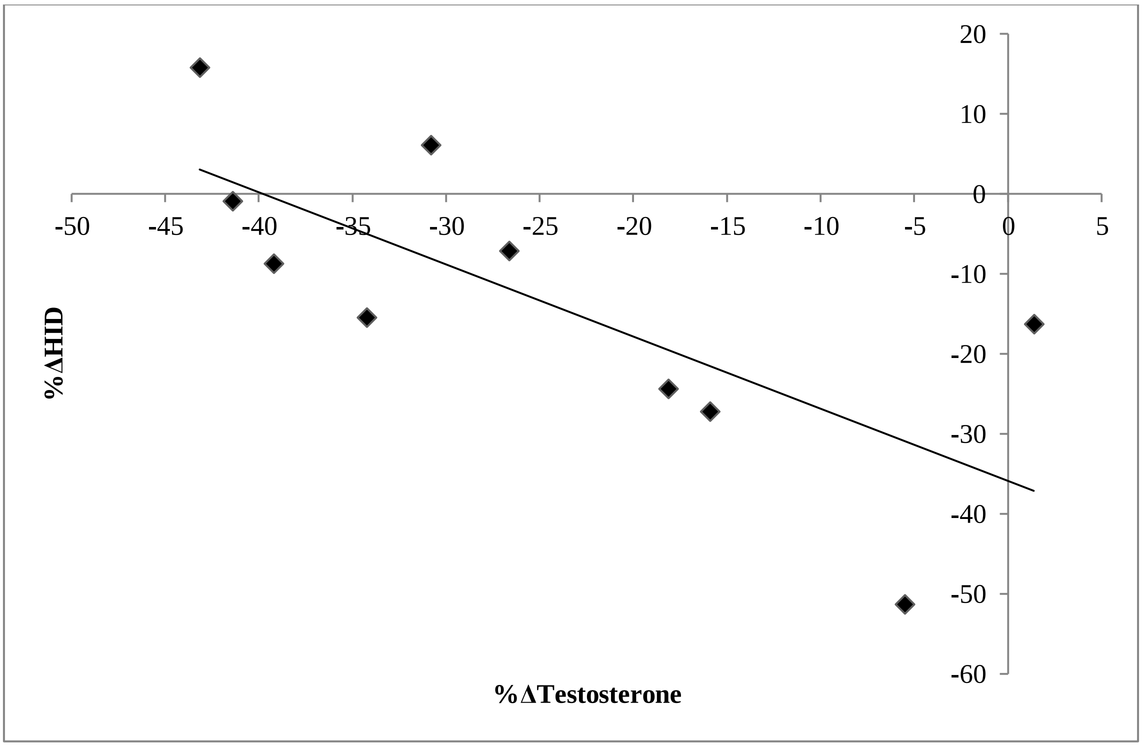

Figure 7.10. Correlations showing %ΔTestosterone vs %ΔHID

The variability in total CK measurements have previously been identified in section 2.4. While assessing underlying assumptions for an ANOVA the data were found to have unequal variances between groups (Mauchlys: $p < 0.001$), despite log transformation. Therefore no parametric analyses could be conducted.

Table 7.18. Raw values for CK for each player at each time point.

	Creatine Kinase ($u \cdot L^{-1}$)				
Player	**T1**	**T2**	**T3**	**T4**	**T5**
1	103	400	585	501	763
2	350	614	725	636	1017
3	179	583	827	533	1425
4	110	547	1061	548	2443
5	119	410	1427	736	937
6	470	958	2389	1408	1810
7	145	367	938	565	917
8	101	361	858	515	666
9	81	542	775	322	615
10	126	1712	2811	1788	5633
11	130	253	407	277	448
12	196	650	1427	973	2679
13	123	X	1223	597	918
Mean	172	616	1189	723	1559
SD	113	391	699	431	1408
Median	126	545	938	565	937

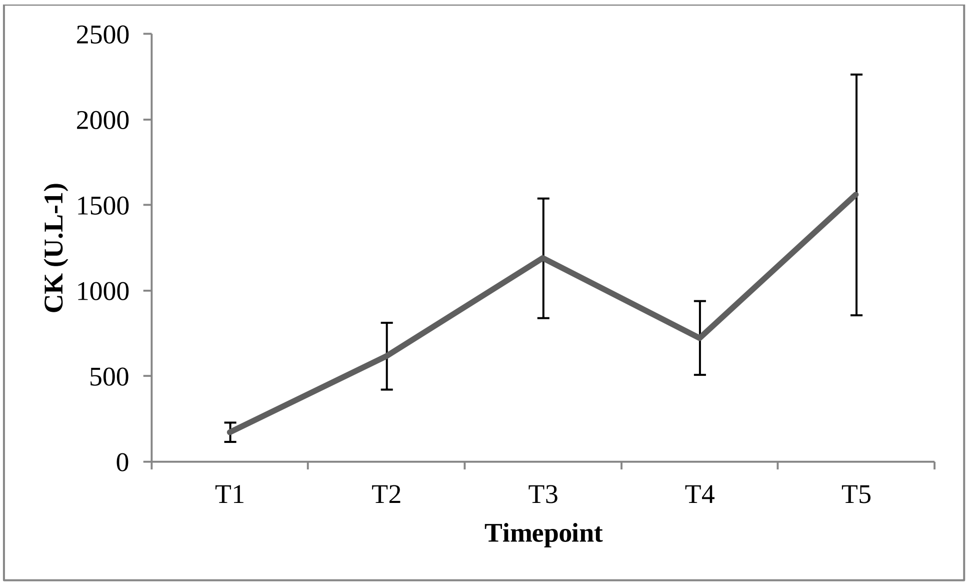

Figure 7.11. CK changes and variability across time points

The results showed that CK peaked at T3 before starting to recover, however $B_{90}M2$ increased CK again to its highest levels. The error bars also shows the variability in responses to exercise.

Table 7.19. Urea and Uric Acid raw data

Player	Urea (mmol·L^{-1})					Uric Acid (μmol·L^{-1})				
	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
1	5.42	6.51	6.05	5.74	5.98	333	370	358	344	334
2	4.01	5.47	5.79	5.46	6.51	403	454	450	440	460
3	5.58	6.37	6.41	5.48	6.8	325	353	362	369	379
4	4.78	5.47	5.06	3.86	5.07	353	381	359	345	350
5	6.27	7.46	6.65	5.76	6.35	325	367	344	347	337
6	6.05	6.40	5.63	7.04	7.33	347	381	344	296	307
7	5.92	6.76	6.56	6.30	6.55	192	247	231	229	253
8	4.77	5.13	5.00	4.58	4.44	321	332	370	343	333
9	5.10	5.87	5.93	5.30	5.71	299	316	340	269	273
10	4.00	4.79	4.84	3.81	3.92	314	337	387	341	348
11	3.68	4.37	3.96	3.7	4.01	352	348	373	352	341
12	5.29	6.11	6.00	5.83	6.06	215	255	245	212	973
13	3.98	X	4.60	3.48	3.66	334	X	368	357	340
Mean	4.99	5.89	5.58	5.10	5.57	316	345	349	326	387
SD	0.87	0.88	0.82	1.12	1.22	56	56	56	61	183
Median						325	351	359	344	340

A repeated measures ANOVA with the Greenhouse-Geisser correction showed a significant main effect for urea (F = 8.415; p < 0.001). T2 (p <0.001; CI: -1.14 to – 0.50; ES:0.94, Moderate) and T3 (p = 0.02; CI: -1.11 to – 0.06; ES:0.72, Moderate) were significantly higher than T1. T4 was significantly lower than T2 (p <0.04; CI: 0.01 to – 1.30; ES: 0.68, Moderate) and T5 significantly higher than T4 (p = 0.04; CI: -0.94 to – 0.03; ES: 0.46, Small).

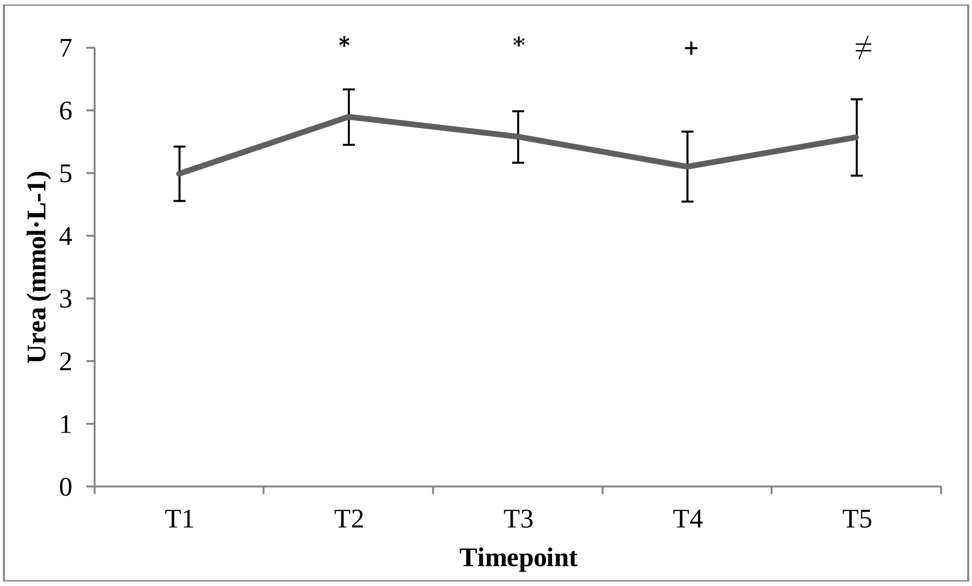

Figure 7.12. Changes in Urea across time points **significantly higher than T1,+ significantly lower than T2, ≠ significantly higher than T4(p < 0.05).*

Analysis of the %Δ in urea against TL measures revealed no significant relationships showing that changes in urea during the recovery process could not be attributed to the measures of TL alone.

Table 7.20. Correlations between changes in urea and TL.

Training Load	**N**	**ΔT1-T2**	**ΔT1-T3**	**ΔT1-T4**
iTRIMP	12	r = 0.36 p = 0.25 (-0.27 to 0.77) Moderate	r = 0.22 p = 0.49 (-0.41 to 0.70) Small	r = 0.45 p = 0.14 (-0.17 to 0.81) Moderate
HID	10	r = -0.08 p = 0.82 (-0.68 to 0.58) Trivial	r = -0.40 p = 0.25 (-0.82 to 0.31) Moderate	r = -0.49 p = 0.16 (-0.86 to 0.20) Moderate
TD	10	r = 0.42 p = 0.22 (-0.28 to 0.83) Moderate	r = -0.34 p = 0.33 (-0.80 to 0.37) Moderate	r = -0.50 p = 0.14 (-0.82 to 0.07) Moderate
sRPE	13	r = -0.39 p = 0.18 (-0.77 to 0.21) Moderate	r = -0.22 p = 0.47 (-0.69 to 0.38) Small	r = -0.13 p = 0.67 (-0.64 to 0.45) Small

The results in table 7.20 show that measures of TL present no significant relationships with changes in urea through the recovery process. However there a number of moderate correlations. Analysis of the %Δurea from T1 to T4 against ΔTD/HID from $B_{90}M1$ to $B_{90}M2$ revealed no significant correlations (TD: $r = 0.21$, $p = 0.56$; HID: $r = 0.63$, $p = 0.05$). The relationship with HID was very close to significance. However a positive relationship would represent an increase in performance with an increase in urea, whereas urea levels above baseline is usually indicative of incomplete recovery and inverse relationships would be more meaningful.

Analysis of UA data showed that it lacked sphericity (Mauchlys: $p <0.001$) and showed that it wasn't normally distributed despite log transformation (Shapiro-Wilk: $p < 0.05$ at T1, T3 and T5) and therefore no parametric analysis was conducted. Figure 7.13 below shows that Uric Acid levels remain constant, however $B_{90}M2$ causes a notable and highly varied increase. Median values are also presented in Table 7.19.

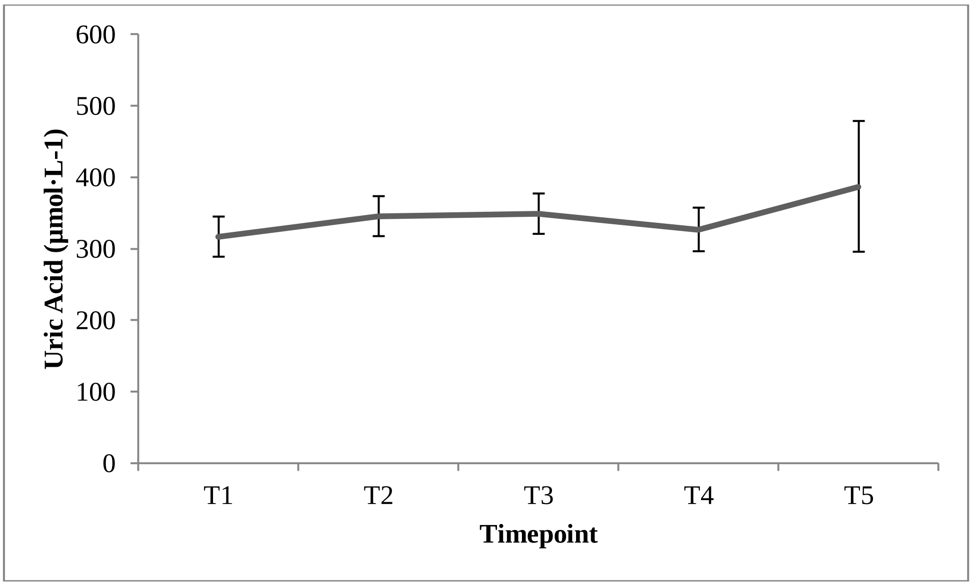

Figure 7.13. UA changes and variability across time points

7.4 Discussion

Performance and Training Load

The mean TD covered in $B_{90}M1$ was in the range previously reported in section 1 (10-12 km) with Mohr, *et al.*, (2003) reporting that international players covered ~2.5 km at high-intensity (>15 $km \cdot h^{-1}$). However in this study the mean HID was closer to 3.3 km and given the difference in the caliber of the players used in this study compared to international level players by Mohr, *et al.*,(2003) it is tempting to suggest that the conditions of a match actually limit the players to maximally perform physiologically. This could explain the wide range of distances covered that have been reported previously. This means that assessing fitness using just the distance covered has major limitations. Coaches are interested in the ability of the individual. The wide ranges reported even within this controlled study for TD and HID suggest that there has to be a more valid assessment of fitness, fatigue and the related exertion. The assessment of fitness and fatigue have been identified (Banister 1991; Busso, 2003) as components in the modeling of exercise performance. Therefore assessment of these two components is essential in making an informed judgment about a player's ability to perform.

The variation in match performance has previously been outlined (Gregson, *et al.*, 2010). This (as discussed before) could be a result of numerous external factors, such as tactics, playing position and the match situation. Therefore playing performance measured from a match as a distance measurement may not be a manifestation of their maximum physiological capacity. The simulation used in this study reduces many of these potential sources of variation. However we still cannot account for the motivation of the player to perform maximally.

Few studies have examined performance in back-to-back matches over a short period of time for the purpose of assessing fatigue. Andersson, *et al.*, (2008) reported distance data (HID and TD) for female players was not significantly different in two matches 72 hours apart. Similarly Odeteyinbo, *et al.*, (2007) also didn't find significant differences in TD or HID when players who played three matches in 5 days were analyzed, although there were trends towards decreases in HID. In comparison the results of this study show a significant decrease in HID in B_{90}M2. However as mentioned earlier the B_{90}M appeared to allow players to manifest their ability to cover distance at high-intensity to a greater extent than in match situations. Given this observation and that the level of participants in this study are of a much lower standard, the decrease in HID is feasible. Previous studies (Bradley, *et al.*, 2009; Krustrup, *et al.*, 2006; Mohr, *et al.*, 2003; Mohr, Krustrup, Nybo, Nielsen & Bangsbo, 2004) have documented within match changes in HID potentially decreasing. These results are also subject to the sources of variations previously mentioned. The results of this study show that HID was lower in the 2^{nd} half of the 2^{nd} B_{90}M and showed trends towards significance. More importantly this study and some previous studies show the extent to which performance as a distance varies between individuals. Hence, the novel findings of this study are not the change in distance but being able to use this information in conjunction with internal load to provide information on a players' ability to perform.

The measurement of internal training load in previous studies has been limited to the measurement of intensity expressed as $\%HR_{max}$. However this is imperative to understanding to what extent players are exerting themselves. This could help explain if any performance decrement is a manifestation of fatigue or a response to other sources of variance. The results of this study showed that although players perceived (RPE) they were working significantly harder in the 2^{nd} match, the iTRIMP was significantly lower. However there were poor relationships between iTRIMP and TD or HID showing that they are largely independent of each other. However, there was a significant inverse relationship between the iTRIMP in B_{90}M1 and the change in iTRIMP from B_{90}M1 to

$B_{90}M2$, showing that those who worked harder in $B_{90}M1$ didn't or couldn't work as hard in $B_{90}M2$. If they couldn't work harder this may be evidence of central fatigue (St Clair Gibson and Noakes, 2004), where the brain limits the ability of the heart to provide the necessary oxygen to the muscle, which may lead to the performance decline evident in terms of HID.

Therefore integrating the internal and external TL would give us an economy measurement which tells us how much distance players are capable of covering per unit of internal training load. As you would expect those with better economy would be the fitter individuals. The results in Table 7.8 show that the ratios demonstrate strong relationships with fitness measures, confirming this theory. Interestingly iTRIMP:TD showed better relationships with vLT and iTRIMP:HID better relationships with vOBLA. This may well be a reflection of the intensity continuum at which the external load contributing to the particular ratio's cover. The HID is around and above vOBLA whereas a greater contribution of TD would be around vLT than vOBLA. This ratio gives a particularly useful surrogate measure of fitness from information potentially readily available from matches. Further analysis of these ratios showed that the ΔiTRIMP:HID from $B_{90}M1$ to $B_{90}M2$ also related to the ΔHID (Figure 7.5). HID has been widely considered an important performance measure by clubs. However with just distance data we are unable to judge if a decline in HID is a manifestation of fatigue or a change in the match situation. This relationship could potentially help us identify fatigue. There was no relationship between ΔiTRIMP:TD and ΔTD. This could partly be explained by the lack of change in these parameters or them being not as sensitive to fatigue. If fatigue is to manifest itself it is more likely to manifest itself as a reduction in higher intensity activities as previous studies have suggested (Bradley, *et al.*, 2009; Krustrup, *et al.*, 2006; Mohr, *et al.*, 2003; Mohr, *et al.*, 2004). Given that we have now integrated the internal TL into a measurement where the distance covered per iTRIMP gives us more information about the players exertion we can be more confident in our judgments regarding performance decline and if this is actually a manifestation of fatigue. Notational evidence has often been used to monitor performance and also imply fatigue. The limitations of implying fatigue from notational evidence alone has been discussed earlier (section 2.2). These results show that two measurable variables (HR and distance) can be integrated to potentially provide useful information on a players fatigue and fitness, as both components are used in the modeling of endurance performance as discussed in section 2. This may in future reduce the need for specific fitness testing sessions in team sports. Future research should now focus on assessing the reliability of the iTRIMP method and ratio's in addition to relating changes in fitness to changes in these ratio's and potential modeling of intermittent exercise performance capabilities. However as previously outlined with the correlation between vLT and weekly iTRIMP (Figure 6.3) there is still considerable between subject variation. This may well be a reflection of the small sample size used and results should be treated with caution. Therefore the results of this study should be seen as somewhat preliminary but also as a new direction for research in training load monitoring.

Acute Performance Tests

Studies examining the recovery process in soccer have focused on describing this process using either APT and/or biochemical measures. The applicability of APT to test fatigue has to be questioned and the results of this study show the maintenance in the results of such tests despite the lower HID in B_{90}M2.2. This can partly be explained by the fact that these tests rely mainly on ATP resynthesis using phosphocreatine (PCr) as an energy source and as mentioned in section 1 PCr can be replenished with adequate rest within minutes. However in a match situation players are rarely afforded such rest and it may lead to incomplete replenishment thereby reducing sprint performance gradually during a match (Abt, *et al.*, 2003). Furthermore sprinting equates for <2% of time during a match and the rest of the performance relies mainly on the other energy systems (Bangsbo, 1994; Mohr*, et al.*, 2003). Hence drawing conclusions on recovery from such measures cannot be deemed to be valid. The results from sprints and CMJ and many of the isokinetic actions showed that there was no significant change, although an overall effect was found for 20 m sprints. This is in contrast to previous studies that have shown significant decreases after matches and through the recovery period (Andersson*, et al.*, 2008; Ascensao*, et al.*, 2008; Fatouros*, et al.*, 2010; Reilly & Rigby, 2002)

These studies have reported decreases in APT post match in contrast to what has been found in the current study (section 1). This may be due to the differences in muscle temperature potentially affecting performance. The muscle temperature of the players was likely to be much higher post match compared to after the modest pre match warm up as described in the methods. Mohr, et al., (2004) have previously shown how a reduction in muscle temperature can affect sprint speed in soccer players. Therefore any potential decline in these measures may be negated by the increased force production capabilities due to increased muscle temperature after a match compared to bespoke testing points at T1, T3 and T4.

EccH showed a significant decrease at T5 compared to other time points, which also resulted in the EccH:ConQ ratio which is used as an indicator of hamstring injury being significantly reduced. It was significantly lower at T5, after the same half where HID was notably lower than B_{90}M1.1, potentially showing some neuromuscular fatigue as the reason for the performance decline. Despite the limitation posed by the varying muscle temperature, the significant decrease in EccH and the functional ratio showed that there was neuromuscular fatigue at T5, which the other tests were not sensitive enough to assess. Assessing the EccH:ConQ ratio requires specialist equipment and expertise. Therefore a surrogate measure would be useful however we found no significant relationships with any load measure.

Biochemical Response

Biochemical measures have been used as measures of muscle damage (CK), oxidative stress (UA) and as a way of assessing anabolic/catabolic state of the body (testosterone and cortisol). Although the time course for recovery of such measures has previously been studied their implications on performance and on an athlete's ability to perform are relatively unknown. One study has outlined a potentially useful method of using CK to monitor potential injury risk, but huge variation between individuals have also been noted (Lazarim, *et al.*, 2008; Mougios, 2007). Similar results were found in this study where the variability in CK, cortisol and UA responses violated assumptions for parametric analyses. One possible explanation for such variability is that increases in some biochemical measures do not necessarily have a detrimental effect on performance but are a process of adaptation and some organisms may up-regulate to defend against such increases (Nikolaidis, *et al.*, 2008). This maybe evident in athletic populations where they have been found to have significantly higher levels of CK than sedentary people (Koutedakis, Raafat, Sharp, Rosmarin, Beard & Robbins, 1993a; Mougios, 2007). However this also may just be an indication of athletes who are consistently training and performing (Brancaccio, *et al.*, 2007). CK in this study appears to peak at T3, which is 24 hours after the 1st match. This is in contrast to what has previously been reported for males with CK peaking at 48 h post match (Ascensao, *et al.*, 2008; Ispirlidis, *et al.*, 2008). CK then started to recover but then increases beyond its initial peak after the 2nd match with greater variance. However the individual response is varied and could be explained by numerous factors such as age, training status, other sports played and there is also the possibility of there being high and low responders (Brancaccio, *et al.*, 2007; Mougios, 2007).

UA showed a similar pattern to CK, peaking at T3 before beginning to recover only to increase beyond its initial peak with greater variability in its response to $B_{90}M2$. Previous studies have reported UA to remain elevated post match peaking at 72 hours (Ascensao, *et al.*, 2008; Ispirlidis, *et al.*, 2008). This is in contrast to this study, which provided a peak at 48 hours and to that of Andersson, *et al.*, (2008) who reported full recovery at 69 h post match. Some of the difference in reported values between this study and others may be due to the non-contact nature of the simulation, which prevents muscular contusions that may add to muscle damage and oxidative stress. Urea showed no significant difference across time points again contrasting with the Andersson, et al., (2008) study, who reported a significant increase post match. The increase in UA at T5 due to $B_{90}M2$ is maybe due to increased purine metabolism as energy substrates depleted. This may be the cause of the reduction in HID.

Several studies have reported increases in cortisol post match (Haneishi, *et al.*, 2007; Ispirlidis, *et al.*, 2008; Malm, *et al.*, 2004), which recovered by 24 hours (Ispirlidis, *et al.*, 2008; Malm, *et al.*, 2004). Malm, *et al.*, (2004) also reported testosterone to decrease at 6 h post match only to recover at 24 h. They also reported no significant change in the T:C ratio. The increase (although not statistically tested) was also seen in this study with regard to cortisol and it appears to recover at 24 h (T3). The results of this study also show that there was no significant difference across time points in testosterone or T:C. Given this, the decrease in testosterone may happen between the end of the match and 24 h post match the protocol used in this study may have missed any potential change. However Table 7.14 shows that sRPE shows a significant moderate relationship with changes in testosterone. Although the T:C did not violate any parametric assumptions an extreme data point has a similar effect on its relationship with iTRIMP. However given the relatively small dataset this could indicate the potential for a significant relationship with a larger dataset. The finding of greatest interest in relation to hormones was the significant correlation between the changes in testosterone and change in HID. Although Malm et al., (2004) had shown as acute decrease, the results in this study suggest a prolonged suppression and the correlation between the change in testosterone levels and change in HID suggests that those with greatest suppression of testosterone show a lesser reduction in performance. This is the first time to our knowledge that such a relationship has been identified in soccer and warrants further investigation. Direct measurement of hormones is now more easily accessible with saliva kits. The change in hormone levels only showed a moderate relationship with one measure of TL (sRPE), hence direct measurement is probably more appropriate. Testosterone is also the only biochemical measure of those used in this study and those previously reported that actually relates to changes in performance, which raises questions about the validity of the other measures used to assess recovery status. Despite the growing body of research on the biochemical responses to soccer match play, it largely remains descriptive and its influence on performance relatively unknown. However the acute inflammatory response is thought to be an essential part of adaptation (Barnett, 2006) and sufficient time for adaptation to occur has long been championed for effective training but also the prevention of injury (Bompa & Carrera, 2005). However measurement still remains highly variable, in need of expertise and can be expensive.

7.5 Conclusions

- The integration of the internal and external training load and the relationship of the ratio with measures of aerobic fitness is a novel finding in this study.
- The relationship of iTRIMP in $B_{90}M1$ with the change in iTRIMP from $B_{90}M1$ to $B_{90}M2$ could be evidence of central governance of physical exertion.
- The dose-response relationship with measures of stress, recovery and fatigue was not evident with the measures of TL used in this study apart from the moderate to large relationships sRPE presented with changes in testosterone.
- The relationships between changes in soccer specific performance and changes in measures of stress, fatigue and recovery also only presented one significant correlation with the relationship changes in testosterone levels exhibited with changes in the high intensity distance covered.

8 – Overall Summary and Practical Applications

The studies for this thesis were conducted in an attempt to fulfill the aims presented in section 1.2. The purpose of this final section is to summarize to what extent these aims have been fulfilled, highlight the limitations of the studies and the directions for future research in the area as a result of the findings of this thesis.

The main aim of the thesis was to better understand the dose-response relationship with respect to recovery in soccer. Having reviewed the literature in sections 1 and 2 the following aims were identified to help progress the research in the area. These were;

- To systematically analyze how match frequency and recovery time between matches has changed over time.
- To assess if an individualised measure of training load relates to changes in fitness in soccer players.
- To assess if an individualised measure of TL relates to measures of recovery/fatigue in soccer player.
- To compare the blood lactate and heart rate responses in continuous and intermittent exercise.

The results in section 3 showed that for a successful team current demands meant approximately a third of matches were played with approximately three days of recovery or less. Given the performance (Odetoyinbo, *et al.*, 2007) and injury implications (Dupont, *et al.*, 2010) with recovery periods of this duration the study of the recovery process was justified. The results from the studies by Odetoyinbo, *et al*., (2007) and Dupont, *et al.*, (2010) showed that the implications for performance and increases in injury rates were based on accumulated physical load or exertion.

The quantification of physical exertion was imperative to understand the dose-response relationship for recovery in soccer. However a valid measure of dose was not yet available as section 2.1 identified. The iTRIMP method originally proposed by Manzi, *et al.*, (2010) was the only method to have been validated with respect to the dose-response relationship with fitness and performance. The comparative study of a number of the methods used to measure TL was conducted and reveled that the iTRIMP method was the only method to significantly relate to changes in fitness in soccer players (section 4). However the relationships were not as strong as those reported by Manzi, *et al.*, (2010). One such reason for this may be a potential underestimation of the TL given the intermittent nature of soccer. Section 6 showed the higher blood lactate response to intermittent exercise at the high intensities, which could potentially lead to this underestimation. Although sample size was larger than the previous studies of Manzi, *et al.*, (2010) and Stagno, *et al*., (2007), a sample size of nine participants is also regarded as low for correlation analysis. This is a fate suffered by many training studies, due to factors such as participant motivation for a prolonged period of time, technical loss of data and injury. Finally the study of Manzi, *et al.*, (2010) used partially detrained recreational runners. If participants have similar levels of fitness and a controlled training programme the chances of showing relationships with certain variables relatively controlled are perhaps greater than with our sample, who were youth soccer player at the start of a competitive season. Our sample consisted of players with different playing and training requirements and also a mixture of players that were well conditioned and those who were less so as a result of injury. Future studies need to consider larger sample sizes and also the development of an intermittent protocol for the assessment of the HR-Bla relationship. Given the limitations of the study the results of this thesis require further corroboration. However given the limitations applied equally to all the measures of TL the superiority of the iTRIMP method can be proposed.

Extending the dose-response relationship to recovery proved to be less successful. One of the primary reasons for this maybe because the advocated biochemical and physiological measures of stress, fatigue and recovery actually do not relate to changes in soccer performance with the exception of testosterone. Therefore the question must be asked as to whether the measurement of jumps, sprints, CK, urea, uric acid and cortisol are appropriate for the measurement of recovery, especially as some biochemical markers upregulate. Given the apparent inadequacies of such measurements the major novel finding of this thesis which will also inform future research has to be the integrated internal and external load ratio (iTRIMP:TD/iTRIMP:HID).

The results in section 7 suggest that the ratios relate to measures of fitness and changes in performance from B_{90}M1 to B_{90}M2. Hence, a potential use for the ratios in the prediction of fitness and fatigue. A closer look at these correlations and the correlation in section 6 looking at the relationship between iTRIMP and change in vLT shows that although significant relationships exist there seems to be inter-subject variation, where some players with similar iTRIMP or ratio scores exhibit quite different responses for the similar score in one variable. Therefore future studies in the area need to address two major points. Firstly the reliability of both the iTRIMP measurement and ratio's need to be assessed so meaningful changes can be identified and appropriate inferences made. Secondly if the ratio's can be used as a surrogate measure of fitness the sensitivity of the ratio's need to be assessed and compared to other measures of fitness used in soccer.

At the beginning of the thesis recovery in soccer had been examined in relation to biochemical measures and/or acute performance tests. The measurement of load in soccer had been described with external measurements. The valid measurement of internal load hadn't been adequately scrutinized with respect to the dose-response relationship. Finally despite the measurement tools such as heart rate monitors and GPS/Video systems (distance measurement) being available at professional levels of the match there was no research examining how these systems can be used constructively to aid sports scientists and coaches to make judgments on a player's capability to perform.

The research presented in this thesis highlighted;

- the severity of the short recovery periods between matches,
- a valid measure of internal training load in soccer,
- the lack of a relationship between many measures considered as measurements of stress, recovery and fatigue and soccer specific performance and questions their use.
- the potential uses of a novel internal:external load ratio in the assessment of fitness and fatigue.

In conclusion, the studies presented in this thesis will considerably add to the body of research in the area and shift the research focus to new areas that will allow sports scientists, coaches and practitioners to make greater use of the data routinely collected.

9- References

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