THE UNIVERSITY OF HULL

The Dose-Response Validity of Measures of Training Load in Professional Soccer Players

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by

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ABSTRACT

Introduction: There is currently a lack of research into the physical demands of soccer training despite it contributing towards 75-80% of weekly training load. A particular area requiring more focus is the does-response relationship between training load and changes in fitness. *Purpose:* This study investigated the dose-response relationship between measures of training load and changes in fitness in elite academy soccer players. *Methods:* Six measures of training load (Internal: session rating of perceived exertion [sRPE], heart rate exertion; external: total distance, high-speed distance, Player Load^{TM}, total mean metabolic power [TMetAv]) were collected from 25 elite academy soccer players over the course of a 7-week pre-season period. A maximal YoYo Intermittent Recovery Test Level 1 (YYIR1) was performed prior to and following the 7-week pre-season period. The change in YYIR1 performance between weeks 1 and 8 was then correlated with the measures of training load collected during the 7-week pre-season period. *Results:* Mean change in YYIR1 (delta YoYo) was 195 m (95%CI: 160 m to 230 m; Cohen's *d:* 0.53 (95%CI: 0.44 to 0.63). No significant correlations were found between delta YoYo and any of the mean weekly training load measures. Significant correlations were present between a number of the measures of training load across the 7-week pre-season ($P < 0.01$), most notably between TMetAv and sRPE (r = 0.95; 95%CI = 0.89 to 0.98), total distance (r = 0.74; 95%CI = 0.49 to 0.88) and Player Load^{TM} (r = 0.76; 95%CI = 0.52 to 0.89) *Conclusions:* The results of this study confirm that many of the training load methods correlate with each other, in particular TMetAv with sRPE, total distance and Player Load^{TM}. Despite this, a dose-response relationship between changes in fitness and internal/external training-load measures was not established. Given this finding, it is suggested that the best practice for monitoring the training load of soccer players would be the use of a combination of TMetAv with total distance, sRPE and Player Load^{TM} in order to capture a more complete understanding of the physiological and psychological load experienced by elite soccer players.

Keywords: soccer, dose-response, GPS, YYIR1, sRPE, HR Exertion, total distance, high-speed distance, Player Load^{TM}, metabolic power

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Table of Contents

LIST OF FIGURES

LIST OF TABLES

1. GENERAL INTRODUCTION

1.1 Background

The activity patterns in soccer involve periods of high-intensity and low-intensity efforts which classify it as a complex intermittent-type sport. During a soccer match there is a high turnover of aerobic and anaerobic energy (Bangsbo, 1994). This combination of energy systems not only requires elite players to have a well-developed aerobic energy system to allow them to cope with the endurance requirements of the game (Hoff, Wisloff, Engen, Kemi, & Helgerud, 2002; Iaia, Rampinini, & Bangsbo, 2009; Impellizzeri et al., 2006) but also a well-developed anaerobic energy system to enable performance of repeated changes of direction, accelerations and maximal jumps (Buchheit, Bishop, Haydar, Nakamura, & Ahmaidi, 2010; Buchheit, Mendez-Villanueva, Simpson, & Bourdon, 2010; Rahnama, Reilly, Lees, & Graham-Smith, 2003). To further compound the physiological stress associated with training and match play there are independent factors such as tactical, technical and physiological elements which are all linked closely to soccer performance. For successful soccer performance at all levels specific match activity development is required meaning soccer requires players to be competent in an array of areas of technical abilities and physical fitness (Krustrup, Mohr, Ellingsgaard, & Bangsbo, 2005).

Due to the global popularity of soccer, significant interest in conducting scientific studies on the game has been shown by researchers over the past few decades. Although, the vast majority of research has been conducted with sub-elite players as there is often reluctance from professional clubs to grant researchers access to their working players and practices. Research conducted with elite players has generally been in the form of video-based time-motion analyses, meaning that the match play physical demands are reasonably well established. Despite this, within a weekly training load match play has been suggested to contribute approximately 20-25% (Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004).

Given the high-intensity and multidirectional nature of soccer, recent advances in technology have driven the development of new methods for quantifying the physiological and physical 'stress' imposed on the player during training and matches. One of these involves the use of the Global Positioning System (GPS). GPS devices allow distances covered and the speeds achieved during both matches and training to be quantified with reasonable accuracy and reliability (Castellano, Casamichana, Calleja-González, Román, & Ostojic, 2011; Varley, Fairweather, & Aughey, 2012). Previously, methods of training quantification relied upon subjective measures (Impellizzeri et al., 2004), cumulative scores which involved the training time and the cardiovascular training response (Jeong, Reilly, Morton, Bae, & Drust, 2011; Mallo & Navarro, 2008) due to team sports high-intensity multi-directional intermittent nature. The limitations of these methods are that they do not account for the physiological cost of the high-intensity multi-directional intermittent movements (Buchheit, Bishop, Haydar, Nakamura, & Ahmaidi , 2010; Buchheit, Haydar, Hader, Ufland, & Ahmaidi, 2011). These limitations underpin the need for further assessment of the physiological and physical demands placed on elite soccer players during training and competition in order to establish valid and reliable measures of training load.

The training process in soccer has previously been described as dividing the overall training load into two sub-sections classified as internal and external training load (Impellizzeri, Rampinini, & Marcora, 2005). The training prescribed by the coaches is referred to as external training load and the players physiological response to this is referred to as the internal load. External training load is usually classified using metrics such as total distance, high-speed distance and Player Load™ while internal training load metrics usually include heart rate measures or rating of perceived exertion.

It has been suggested that measures of training load should ultimately reflect the internal physiological response, such that a dose-response relationship exists between the training load measure and changes in fitness and/or physical performance (Manzi, Iellamo, Impellizzeri,

2

D'Ottavio, & Castagna, 2009; Stagno, Thatcher, & van Someren, 2007). The dose-response relationship between training and adaptation has been suggested to be an important training principle (Banister, 1991). To date, only measures of internal training load have shown dose-response relationships in team sports (Akubat et al., 2012; Manzi, Bovenzi, Impellizzeri, Carminati, & Castagna, 2013). However, because internal training load measures may not capture the entire physiological response during team sports such as soccer (Buchheit et al., 2010; Buchheit et al., 2011), it could be suggested that identifying a dose-response relationship between changes in fitness and external training load is also important. Despite high-speed distance being considered as a valid measure of physical performance due to it's ability to discriminate between levels of play (Mohr et al., 2003), the high variability means it does not allow meaningful inferences about fitness to be made (Gregson, Drust, Atkinson, & Salvo, 2010). With this in mind, it could be suggested that other external training load variables need to be investigated in relation to dose-response relationships. One measure which has received increased interest in recent years is metabolic power, which has been suggested to provide a more comprehensive assessment of overall energy cost and metabolic power output associated with activity at any given moment, when combined with traditional estimates of running speed (di Prampero, 2005; Gaudino, Iaia, Alberti, Hawkins, Strudwick & Gregson, 2013). This measure could be of particular use to soccer coaches if a dose-response relationship is identified.

1.2 Aims and Objectives

The primary objective of this thesis was to identify whether dose-response relationships were present in elite level academy soccer between changes in fitness and weekly training load during a pre-season period. The secondary objective of this thesis was to investigate the relationship between measures of training load during soccer training.

In summary, the aims of this thesis were:

3

- To compare the physiological response to a maximal aerobic exercise test prior to and following pre-season in elite level, academy soccer players.

- To investigate the dose-response relationship between the change in fitness and measures of training load in soccer players.

- To assess the relationship between measures of training load in relation to soccer training.

The completion of the above aims will enable a greater understanding of dose-response relationships in soccer and also the measurement of training load in soccer.

2. LITERATURE REVIEW

2.1. Overview of Soccer

There is an extensive body of research examining and describing the quantification of training demands in elite soccer. Examination of training demands is important because training accounts for a large proportion of the total weekly training load (Bangsbo, 1994; Bangsbo, Mohr, & Krustrup, 2006). As a consequence of this, it is important that practitioners appreciate the magnitude of both short-term and cumulative training load as this will allow for adaptations and game performance to be optimal (Gabbett, 2010; Hellard et al., 2005).

In team sports such as soccer the activity profile involves changes in exercise intensity that are intermittent in nature (Bangsbo, 1994). In comparison to sports with more continuous exercise profiles, soccer involves a much more complex physiological response to these intermittent activity bouts (Drust, Reilly, & Cable, 2000). Due to this, elite soccer can be classified as a 'high-intensity intermittent team sport' (Bangsbo, Iaia, & Krustrup, 2007; Bangsbo et al., 2006). Soccer-specific actions include kicking, tackling, dribbling and accelerations/decelerations (Bangsbo, 1994). During a soccer match, the typical total distance covered by an elite outfield player is around 10-13 km (Dellal et al., 2011; Di Salvo et al., 2007). Positional differences in

total distance have been previously reported with central defenders covering the least and central midfielders covering the most distance (Bradley et al., 2009; Carling, 2011; Di Salvo et al., 2007; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007; Mohr et al., 2003).

2.1.1 High-Intensity Distance

The distance covered at 'high-intensity' (high-speed) also appears to be position-dependent. Wide midfielders have been reported to cover more distance at high-intensity (>14.4 km·h^{-1}/19.1 km·h^{-1}) in comparison to other outfield positions, with central defenders again covering the least distance, as shown in Table 1 (Bradley et al., 2009; Di Salvo, Gregson, Atkinson, Tordoff, & Drust, 2009). In contrast to this, some studies have not classified wide midfielders as a position and have instead categorised central midfielders and wide midfielders together despite wide midfield being suggested to be the most demanding position in regards to high-intensity distance in soccer. Studies which had done this have provided contrasting findings. Despite Rampinini et al. (2007) suggesting midfielders (Central & Wide) to still cover the most high-intensity distance. Mohr, Krustrup & Bangsbo (2003) suggested when using this classification of positions, full-backs covered the most high-intensity running distance, again shown in Table 1 (Rampinini et al. 2007; Mohr et al., 2003). In addition to the distances covered, each player is required to perform roughly 1000-1400 activities of a short duration, changing intensity every 4-6 seconds during a match (Mohr et al., 2003). These include 30-40 jumps and tackles, 30-40 sprints (Bangsbo et al., 2006) and more than 700 turns (Bloomfield, Polman, & O'Donoghue, 2007). Differences in high-intensity activity have also been suggested to be affected by factors including competition period (Mohr et al., 2003; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007), training level (Krustrup & Bangsbo, 2001), competition level, environmental factors and game style (Reilly & Williams, 2003). A further factor which can account for the differences in high-intensity activity is that a number of studies have not provided a physiological justification for their use of a set threshold of absolute high-intensity

speed which would in turn effect the amount of high-intensity activity performed as highlighted by Abt and Lovell (2009).

Table 1: Comparison of match performance variables between positions and speed classifications (Bradley et al. 2009; Di Salvo et al. 2007; Mohr, Krustrup & Bangsbo, 2003; Rampinini et al. 2007)

		Central Defenders	Full Backs	Central Midfielders	Wide Midfielders	Attackers
Bradley et al. (2009)	Total Distance (M)	9885 ± 555	10710 ± 589	11450 ± 608[a]	11535 ± 933[a]	10314 ± 1175
	High Intensity Running (M)(>14.4 km·h^{-1})	1834 ± 256	2605 ± 387	2825 ± 473	3138 ± 565[b]	2341 ± 575
Di Salvo et al., (2007)	Total Distance (M)	10627 ± 1,016[b]	11410 ± 708	12027 ± 625[a]	11990 ± 776[a]	11254 ± 894
	High Intensity Running (M)(>19.1 km·h^{-1})	612 ± 214[b]	1054 ± 344	875 ± 300	1184 ± 335	1025 ± 301
Rampinini, et al. (2007)	Total Distance (M)	9995 ± 652	11223 ± 664	11748 ± 612		10233 ± 677
	High Intensity Running (M) (>14.4 km·h^{-1})	1885 ± 467	2892 ± 488	3051 ± 445		2259 ± 363
Mohr, Krustrup & Bangsbo (2003)	Total Distance (M)	9740 ± 220[b]	10980 ± 230	11000 ± 210		10480 ± 300
	High Intensity Running (M) (>18 km·h^{-1})	1690 ± 100[b]	2460 ± 130	2230 ± 150		2280 ± 140

Note: [a]Different from central defenders, full-backs, and attackers (P<0.05). [b]Different from all other playing positions (P<0.05).

From these studies the thresholds set to define the high-intensity zones ranged between 13 km·h^{-1} and 19.8 km·h^{-1} (Andersson, Ekblom, & Krustrup, 2008; Bangsbo, Nørregaard, & Thorsø, 1991; Bradley et al., 2009; Castagna & D'Ottavio, 2001; Di Salvo et al., 2007, 2007; D'Ottavio & Castagna, 2001; Mallo, Navarro, García-Aranda, Gilis, & Helsen, 2007; Mohr et al., 2003; Rampinini et al., 2007a; Rampinini, Coutts, Castagna, Sassi & Impellizzeri, 2007; Weston, Castagna, Impellizzeri, Rampinini, & Abt, 2007). These variances within soccer match play are highlighted in Table 1 and with such a large variation this could potentially be a major factor in the large errors for the measurement of high-intensity based running distance based upon absolute speed thresholds. This highlighted the need for individualised speed thresholds in relation to high-intensity activity in order to track individual players over time (Abt & Lovell, 2009). However, if absolute high-intensity speed thresholds are to be used, Abt and Lovell (2009) previously suggested the threshold of 15 km·h^{-1} to be the most appropriate of the many absolute high-intensity speed thresholds used in previous studies, as it was considerably closer to the players high-intensity speed threshold within this study in comparison to the default used by ProZone (19.8 km·h^{-1}).

The wide variety of actions outlined above results in heavy demands placed on different physiological energy-delivery systems. It also shows some of the discrepancies which can be found in studies investigating positional differences of players during match play. For example there appears to be some variability, especially in total distance, between the studies in Table 1 (Bradley et al. 2009; Di Salvo et al. 2007; Mohr, Krustrup & Bangsbo, 2003; Rampinini et al. 2007). This highlights variability within the data which further supports the need to employ accurate measurement systems in order to quantify training load.

2.1.2 Aerobic System

Despite the suggested importance of high intensity actions, it is suggested that during a soccer match, players depend mainly on aerobic metabolism (Stølen, Chamari, Castagna, & Wisløff, 2005), with more than 90% of total energy consumption being accounted for by aerobic

energy production during match play (Bangsbo, 1994). This is largely due to the duration of soccer matches. Maximal aerobic capacity has been reported to positively relate to match performance and team success (Helgerud, Engen, Wisloff, & Hoff, 2001; Hoff et al., 2002; Stølen et al., 2005; Wisloff, Helgerud, & Hoff, 1998). This reliance on the aerobic energy-delivery system is thought to be due to soccer consisting of large periods of activity of a moderate to low intensity (Di Salvo et al., 2007), usually between bouts of high intensity actions. Certainly, if the energy expenditure estimation is derived from measures of speed, the exercise intensity of these actions is considered moderate to low. However, the accelerations measured during match play would suggest that the exercise intensity and energetic demand of many of the brief actions performed is higher than previously thought (Bradley et al., 2009; di Prampero, 2005; Little & Williams, 2005; Osgnach, Poser, Bernardini, Rinaldo, & di Prampero, 2010). Despite the large dependence on aerobic metabolism, it has been reported that high-intensity actions such as sprints are crucial to the outcome of a match (Cometti, Maffiuletti, Pousson, Chatard, & Maffulli, 2001), such as assisting or scoring a goal (Faude, Koch, & Meyer, 2012). A high proportion of the energy required for these actions is supplied by phosphocreatine and anaerobic glycolysis (Cometti et al., 2001; Faude et al., 2012). High-speed actions during soccer competition can be categorised into actions requiring maximal speed (sprinting), acceleration or agility (Little & Williams, 2005).

2.1.3 Maximal Speed and Sprinting

Maximum speed is the maximal velocity at which a player can sprint (Little & Williams, 2005). Sprinting is a crucial component of performance and is arguably the most universally required fitness attribute for soccer success (Comfort, Haigh, & Matthews, 2012). Despite sprinting comprising only 1-4% of total distance during a soccer match, it typically occurs during significant moments related to the outcome of a match, such as goal-scoring opportunities (Di Salvo et al., 2009). The importance of sprinting has been highlighted by a number of studies reporting that teams who cover greater high-speed distances are more likely to win (Di Salvo

et al., 2009; Rampinini, Impellizzeri, Castagna, Coutts, & Wisløff, 2009). Although the most critical elements in a game are often determined by sprints, they rarely last longer than 10-22 m (Baker & Nance, 1999; Bangsbo et al., 2006). When combined within a game, these actions account for approximately 11% of game time. This equates to a 10-15 m sprint every 90 s (Baker & Nance, 1999; Withers, Maricic, Wasilewski, & Kelly, 1982). Stølen et al., (2005) reported 90% of sprint bouts to be 20 m or shorter, with 49% being 10 m or shorter.

2.1.3.1 Sprint Distance

As with high-speed running, positional differences in peak speed and acceleration profiles have been reported, with full backs and attackers frequently being faster than other positions (Haugen, Tønnessen, Hisdal, & Seiler, 2014; Sporis, Jukic, Ostojic, & Milanovic, 2009; Taskin, 2008). Peak speeds of 9 $m·s^{-1}$ have been reported (Rampinini et al., 2007a; Rampinini et al., 2007b) with Haugen et al. (2014) reporting the fastest elite player to reach 9.7 $m·s^{-1}$. As mentioned previously regarding the variation in 'high-intensity' speed bandings within studies (Abt & Lovell, 2009), this variance has also occurred when characterising sprint actions in previous studies. In these studies, the thresholds used to define sprinting actions has been 18 $km·h^{-1}$ (Javier Mallo et al., 2007), 23 $km·h^{-1}$ (Di Salvo et al., 2007), 24 $km·h^{-1}$ (Castagna & D'Ottavio, 2001; D'Ottavio & Castagna, 2001), 25.1 $km·h^{-1}$ (Barnes, Archer, Hogg, Bush, & Bradley, 2014), 25.2 $km·h^{-1}$ (Gregson et al., 2010; Rampinini, Bishop, et al., 2007b; Rampinini, Coutts, et al., 2007) and 30 $km·h^{-1}$ (Andersson et al., 2008). Again, with such a large variation between studies this could be a decisive factor in the large errors for the measurement of sprinting distance, due to a lack of universal agreement on the classification of sprint speed. Moreover, sprint distance has been found to have the largest between match variability, which suggests that players do not always produce their maximal sprint efforts during a match (Gregson et al., 2010). This could be said to be largely effected by a team's playing style and tactical organisation, which subsequently influences the work rate of players (Reilly & Williams, 2003). The match variability of sprint actions begin to question its use as an indicator

of performance within a single observation, this is further supported by Gregson et al. (2010) who suggested it does not provide the most accurate indication of an individual's capacity to perform activities at a high speed when based on a single observation. With this in mind, it could be suggested that there are more effective actions within a match which provide more reliable measures. For example Akenhead, Hayes, Thompson and French (2013) suggested accelerations and decelerations appear to have a greater reliability than that of high-speed and sprint running. This could be of use to practitioners as they could potentially use these measures as performance monitoring variables.

2.1.4 Accelerative and Decelerative Actions

Acceleration is the rate of change in velocity that allows a player to reach maximal velocity in the minimum time duration (Little & Williams, 2005). Within team sports, decelerations are just as common as accelerations (Akenhead et al., 2013; Osgnach et al., 2010; Spencer et al., 2004), with a rapid acceleration usually preceded by a rapid deceleration (Hewit, Cronin, & Hume, 2013). Decelerations are suggested to be critical to the success of many movements (Hewit et al., 2013) and can place significant mechanical stress upon the body (Thompson, Nicholas, & Williams, 1999). Decelerating requires eccentric muscle actions, which can lead to exercise-induced muscle damage, ultimately limiting an athlete's physical performance (Howatson & Milak, 2009).

Although sprints are associated with important events during a match, recent studies have reported that maximal accelerations (>2.78 m·s^{-1}) occur more frequently than sprint bouts (>6.94 m·s^{-1}) with maximal accelerations occurring on average 57±15 times during a match, compared with sprint bouts occurring 7±4 times in a 90 minute match (Varley & Aughey, 2013). Despite this, the acceleration of athletes during matches has not been investigated extensively (Aughey, 2010; Bradley et al., 2009; Osgnach et al., 2010). The ability to accelerate or change speed (Little & Williams, 2005) is decisive in crucial match activities such as moving into space before an opponent, being first to the ball and in stopping or creating goal-scoring

opportunities (Carling, Bloomfield, Nelsen, & Reilly, 2008; Reilly, Bangsbo, & Franks, 2000). When taking these factors into consideration it is important for a greater emphasis to be placed upon accelerations and decelerations within training and matches. The average duration of sprint actions in soccer do not provide sufficient time and distance for maximal running speed to be obtained. This supports the suggestion that a player's ability to accelerate is of greater importance as it will enable them to obtain the peak speed achievable before their opponent.

Acceleration and deceleration are more energetically demanding movements than movement of a constant speed (Osgnach et al., 2010). During a maximal 5 s sprint, 50% of the total work is achieved within the first 1.5 s (Cavagna, Komarek, & Mazzoleni, 1971) with peak power output (W$^.$kg^{-1}) 40% greater than the average power output achieved after just ~0.5 s (di Prampero, 2005). This would suggest that from a standing start the greatest work is performed before the sprinting threshold is achieved. Additionally, despite the power output required for constant speed running at 4.17 m·s^{-1} being 54% greater than the constant speed of 2.5 m·s^{-1}, an acceleration performed from a lower speed can match or even exceed the required power output to maintain the higher speed (Osgnach et al., 2010). Consequently, accelerating and decelerating are not only tasks with high metabolic demands but also ones that can be challenging even when not occurring at high speeds. This supports previous suggestions by Abt and Lovell (2009) that the term 'high-intensity' running should be referred to as 'high-speed' instead, as the term 'intensity' incorrectly implies that the player is moving at an individualised intensity. In more recent match analysis literature there has been a shift in terminology with the term 'intensity' being replaced by 'speed' (Gregson et al., 2010; Osgnach et al., 2010).

Current match analysis could potentially underestimate the number of high intensity actions that occur, due to the exclusion of accelerations and decelerations, as during team sports players are required to frequently accelerate and decelerate (Aughey, 2010; Bradley et al., 2009; Osgnach et al., 2010). Despite this, Buchheit et al. (2014) suggested that with

acceleration and deceleration data practitioners should apply care when comparing data collected from different models and when attempting to compare with historical data. This highlights the need for further validations and also potentially another measure which can capture both high-speed and acceleration/deceleration events as one, due to both measures having high metabolic demand.

2.1.5 Agility and Changes of Direction

Agility is often recognised as the ability to change direction and start and stop quickly (Little & Williams, 2005). Sheppard and Young (2006: 919) propose agility to be 'a rapid, whole-body, change of direction or speed in response to a sport-specific stimulus'. Subsequently there is often difficulty in discovering an agility definition that is accepted by everyone due to multiple factors (Sheppard & Young, 2006). Agility is considered to be dependent upon 2 sub-components: a) perceptual and decision making factors, and b) factors related to the change of direction mechanics (Sheppard & Young, 2006; Young et al., 2002; Young & Farrow, 2006). With a number of components contributing towards an individual's agility it would be deemed more appropriate to measure 'change of direction speed' components rather than 'agility' as a whole when attempting to improve agility through physical training programme interventions.

Agility and change of direction ability has been extensively researched in soccer players (Haugen et al., 2014; Sheppard & Young, 2006). The primary physical action in most agility tasks is changing direction and deceleration (Sheppard & Young, 2006). Particularly in team sports such as soccer a clear determinant of overall performance is an individual's change of direction speed (Keogh, Weber, & Dalton, 2003). The ability to accelerate, decelerate and change direction is a component providing the foundation for overall agility performance (Sheppard & Young, 2006). Change of direction speed further highlights the prominence of acceleration as a vital component during soccer performance as mentioned previously. The acceleration-deceleration dynamics associated with repeated change of directions require high levels of metabolic and mechanical (e.g eccentric contractions) load (Osgnach et al., 2010).

These requirements can be reflected by increases in muscular damage markers following soccer training (Silva et al., 2014) and matches (Silva et al., 2013). Frequent cutting actions and changes of direction contribute towards neuromuscular fatigue, which can adversely affect future sprint performance (Lakomy & Haydon, 2004). Scientific and empirical evidence suggests that the energy demands of human locomotion are increased when running with changes of direction. In comparison to straight-line runs, greater heart rate (Buchheit, Bishop, et al., 2010; Dellal et al., 2010), oxygen uptake (Buchheit et al., 2010) and blood lactate concentrations have been reported in both submaximal and supramaximal running exercises involving a change of direction component (Buchheitet al., 2010; Dellal et al., 2010).

It has been suggested that when reacting, performance in agility tasks can be influenced by the nature of the stimulus (timing or location), due to this, significant factors in agility performance are perceptual (Chelladurai & Yuhasz, 1977). During a field sport game such as soccer, there is a requirement for players to perform sprints with rapid change of direction and deceleration throughout (Keogh et al., 2003; Reilly, Williams, Nevill, & Franks, 2000) with lateral changes in direction and rapid changes in direction often being required to pursue or evade an opponent, or react to a moving ball (Young et al., 2002). Therefore there is a large reliance on the player's reactive agility. Despite this, most research literature investigating agility has involved pre-planned changes of direction. Some athletes may be identified as outstanding in on-field agility tasks but only possess average change of direction speed based upon their athleticism in testing. Contrary to this, an athlete may have outstanding athleticism in testing but lack the skills required to react to opponents in match situations. The underlying factor for this is likely to be due to the athlete being highly skilled in the decision making and perceptual factors (Young & Farrow, 2006).

Research which has investigated the perceptual components of agility (Farrow, Young, & Bruce, 2005; Gabbett, Rubinoff, Thorburn, & Farrow, 2007; Sheppard, Young, Doyle, Sheppard, & Newton, 2006; Sheppard et al., 2006) has suggested reactive agility to be able to successfully

discriminate higher and lesser skilled Australian soccer players, something which pre-planned change of direction tests did not. Similar results have also been reported in softball (Gabbett et al., 2007) and netball (Farrow et al., 2005) players. Despite the lack of research investigating reactive agility response time in a true sport-specific setting, Mendez-Villanueva, Hamer, and Bishop (2008) showed agility performance to decrease with fatigue. It could be suggested that perceptual factors may further increase metabolic demand associated with change of direction tasks as mentioned previously (Osgnach et al., 2010). Due to the unpredictable nature of reactive agility tasks, athletes may have to work harder to produce force when fatigued, than when not in a fatigued state. This could also support the case for a quantifiable measure of metabolic demand to be identified. However to date, practitioners have struggled to identify a valid and reliable measure of this (Buchheit, Manouvrier, Cassirame, & Morin, 2015).

2.1.6 Summary

Due to similar biochemical and morphological determinants of maximal speed, acceleration and agility, this has led to the assumption that there is a considerable relationship between these qualities (Gabbett et al., 2008; Little & Williams, 2005; Pauole et al., 2000; Sayers, 2000; Sheppard et al., 2006; Spaniol et al., 2010). A finding of particular interest which supports discussion regarding classification of 'reactive agility' and 'change of direction speed' as separate components of agility is the work of Sheppard et al. (2006) and Gabbett et al. (2008). These researchers investigated the relationship between 'reactive agility' and 'change of direction speed' in the same athlete, as separate variables, within Australian Rules footballers and rugby league players respectively. The correlation between sprint performances was stronger with 'change of direction speed' than with 'reactive agility' in both studies.

In contrast, other research has suggested change of direction speed and sprinting to be separate physical qualities (Young, Hawken, & McDonald, 1996) with a number of studies suggesting athletes who are quick sprinters do not necessarily have a quick change of direction speed (Pauole et al., 2000; Sheppard et al., 2006). Young, McDowell and Scarlett (2001) also

suggested straight line speed did not improve sprints involving a change of direction and vice versa, with change of direction speed being found to have minimal transferability to straight line speed. Despite this, acceleration and sprint speed could still be underpinning components of change of direction speed as in any change of direction these qualities are involved (Sheppard & Young, 2006).

With this in mind, and due to the physiological demands of soccer, which require players to effectively complete all these actions repeatedly within the duration of a match, it is vital that separate measures of external load are identified for sprinting and changes of direction allowing these to be viewed in isolation due to the different facets involved when executing these movements.

2.2. Training Load in Soccer

Given the ever-increasing demands placed on players due to congested playing schedules, match-intensity and the demands of training (Barnes et al., 2014), it is no surprise that researchers are interested in the relationships between training load and performance (Akubat & Abt, 2011; Gabbett & Domrow, 2007; Gabbett, 2010; Hayes & Quinn, 2009; Manzi et al., 2013, 2009; Midgley, McNaughton, & Jones, 2007). Early studies examined the basic variables involved in training - frequency, duration, and intensity (Bangsbo et al., 2006). More recently, 'training load' has been determined by a combination of these factors (Impellizzeri et al., 2005).

Providing an accurate evaluation of training load is vital for the planning and periodization of training, which is particularly important in the prevention of overtraining or undertraining in order for athletes to be in optimum condition for competition (Little & Williams, 2005). When not exposed to an appropriate stimulus, player's fitness will usually deteriorate or not develop as it should. However, an inappropriate or excessive overload can result in injuries or an overtraining state (Impellizzeri et al., 2005). A major component of finding the balance

between overtraining or undertraining is the principle of progressive overload (Pearson, Faigenbaum, Conley, & Kraemer, 2000). When using progressive overload, there is a systematic and logical method to building up an athlete's work capacity, strength, and conditioning. This practice leads to a maximised workout potential in a safe manner for the individual.

Within team sports such as soccer, it can be particularly difficult to provide an evaluation of training load due to specific conditioning drills associated with soccer being affected by pitch dimensions, number of players involved, presence of goalkeepers, number of touches, amount of coaching involvement and player-specific tactical roles. Due to the various physical demands associated with soccer, it is vital that each of these actions can be measured in terms of the 'load' players have been subjected to during these conditioning drills. Training load measurement is also encouraged for the understanding of dose-response relationships (Manzi et al., 2009; Stagno et al., 2007). Dose-response relationships between training and adaptation have been supported as an important training principle (Banister, 1991). It is important to discover dose-response relationships for both 'internal' and 'external' measures of training load in soccer for both fitness and fatigue, as this could allow predictions of how both components respond to a specific 'dose'.

Training load is usually subdivided into sub-sections of 'internal' and 'external' training load (Impellizzeri et al., 2005). Internal training load refers to the physiological stress incurred by the player in response to training or match play (Eniseler, 2005; Mallo & Navarro, 2008; Wrigley, Drust, Stratton, Scott, & Gregson, 2012). Internal training load is the component which ultimately effects the training outcome (Impellizzeri et al., 2005). The training-induced adaptations produced are stimulated by these stressors (Booth & Thomason, 1991). External load refers to measures external to the body, including distance, work, speed and accelerations. It has been suggested that the internal response to the given external stimulus

can be influenced by factors including previous training experience and genetic background (Bouchard & Rankinen, 2001).

2.3. Monitoring within Soccer

With the optimization of physical performance being paramount within soccer, including the ability to consistently perform over a competitive season, it is vital that the prescribed training load suits the needs of each player (Alexiou & Coutts, 2008). Inappropriate training loads can increase the risk of injury incidence (Dupont et al., 2010), affect subjective recovery measures (Brink, Visscher, Coutts, & Lemmink, 2012) and increase risk of illness (Foster, 1998). In soccer, the most frequently used technologies to monitor training load are global positioning systems (GPS) (including accelerometers), heart rate (HR), and session rating of perceived exertion (sRPE) (Akenhead & Nassis, 2015; Casamichana, Castellano, Calleja-Gonzalez, San Román, & Castagna, 2013).

Data derived from measures of training load, regardless of the method used, should be both valid and reliable in the context of training load. Validity refers to the ability of a method of monitoring training load to measure either the acute and/or chronic stress imposed on the player (Atkinson & Nevill, 1998). A common method of quantifying this is by comparing the measure of training load with a criterion measure of training load, which is often perceived as the 'gold standard' for the specific measurement (Hopkins, 2004). However, there are a number of problems with this approach. First, there is no 'gold standard' measure of training load that has been identified (Paulson, Mason, Rhodes, & Goosey-Tolfrey, 2015; Weaving, Marshall, Earle, Nevill, & Abt, 2014). Second, it has been suggested that training load measures should be sensitive to changes in fitness and physical performance, rather than simply being correlated with other measures of training load (Akubat et al., 2012; Manzi et al., 2009). Reliability relates to the repeatability of the measure across multiple assessments (Hopkins, 2000). This can be calculated through various statistical approaches that aim to quantify the

within-subject variation, test-retest correlation and change in the mean (Hopkins, Hawley, & Burke, 1999). It is clear for soccer practitioners that the quantification of both the validity and reliability of commonly used methods of training load monitoring are of significant importance, especially within their own group of players.

2.3.1. Session Rating of Perceived Exertion (sRPE)

sRPE is a metric used for internal training load quantification. It is calculated by multiplying session duration and session intensity, with the session intensity measured with the category-ratio Borg scale (Foster et al., 1995; Foster et al., 2001) (Figure 1). The use of sRPE as a training load quantification method has undergone extensive research. Foster et al. (1995) assessed the relationship between sRPE and known measures of physiological intensity including blood lactate accumulation and heart rate reserve. sRPE was found to be a useful tool for determining intensity. Following on from this, research by Foster et al. (2001) compared sRPE to heart rate based training scores, where time in various heart rate zones (50%-100% in 10% increments) were then multiplied by a weighting value (1-5). sRPE scores from this tended to overestimate training loads but despite this the correlations with the HR scores were consistent across methods of training.

Classification	Descriptor
0	Rest
1	Very, very easy
2	Easy
3	Moderate
4	Somewhat hard
5	Hard
6	-
7	Very hard
8	-
9	-
10	Maximum

Figure 1: The Borg CR10 scale (1982) modified by Foster et al. (2001)

sRPE has also been found to be an acceptable measure of training loads within resistance training (Day, McGuigan, Brice, & Foster, 2004; McGuigan, Egan, & Foster, 2004; Sweet, Foster, McGuigan, & Brice, 2004) which allows the accumulation and comparison of training loads across cycles or modalities.

A more specific relation to this thesis is the use of sRPE for soccer-specific training quantification. This has been demonstrated as being a worthwhile internal load measure in soccer (Casamichana et al., 2013; Impellizzeri et al., 2004, 2005; Scott, Lockie, Knight, Clark, & De Jonge, 2013) and also in other field and intermittent sports (Lupo, Capranica, & Tessitore, 2014; Manzi et al., 2010; Scanlan, Wen, Tucker, Borges, & Dalbo, 2014; Waldron, Twist, Highton, Worsfold, & Daniels, 2011). Casamichana et al. (2013) compared sRPE with the internal training load calculation method proposed by Edwards, Clark and Macfadyen (2003), based on heart rate data. In that study a strong correlation (r=0.50 to 0.85) between sRPE and the Edwards et al. (2003) method was reported. In a study by Impellizzeri et al. (2004) similar results were reported when comparing sRPE with multiple heart rate based internal training load scores. A large relationship has also been observed between sRPE and external training load indices such as total distance covered during elite rugby league (Lovell, Sirotic, Impellizzeri, & Coutts, 2013) and soccer (Scott et al., 2013) training. Despite this, more recently, only a small relationship between overall match RPE and GPS-derived measures of external load in Australian League Football was reported by Weston, Siegler, Bahnert, McBrien and Lovell (2015).

Although sRPE has been reported to correlate with other measures of training load, there is very little evidence for its dose-response validity. Only two studies have reported a dose-response relationship between sRPE and changes in fitness (Coutts et al. 2007; Gil-Rey et al. 2015). Coutts et al (2007) reported a significant correlation between the change in multi-stage fitness test performance and the change in training load, as measured by sRPE ($r = -0.84$; $P <$

0.001) in elite rugby league players. However, there are two issues with this study that must be addressed. First, a negative correlation suggests that as sRPE increased the change in fitness decreased. This suggests those players experiencing the highest training loads improved their fitness the least, and vice versa. This is the opposite of what would be expected and might suggest regression towards the mean. Second, Coutts et al (2007) didn't report the confidence interval for the correlation, but based on the number of participants and r, the 95% confidence interval for r = -0.84 are -0.98 to -0.24. Such a wide confidence interval shows that the true relationship could almost be anything, and strongly suggests that more research with high sample sizes is required if a dose-response relationship between sRPE and changes in fitness is to be established.

A more recent study by Gil-Rey et al (2015) examined the relationship between the time to exhaustion in the Léger and Boucher's (1980) Université de Montreal endurance test and differential sRPE (sRPEres-TL and sRPEmus-TL). These authors reported correlations of r = 0.71 (95%CI: 0.42 to 0.87) and r = 0.69 (95%CI: 0.4 to 0.85) for sRPEres-TL and sRPEmus-TL, respectively. Again, there are a number of issue with this study. First, the use of a continuous endurance test as a measure of soccer fitness is probably not appropriate. Second, the wide confidence intervals show that there is considerable uncertainty in these relationships. In a worse-case scenario, only about 16% of the variance between sRPEres-TL/sRPEmus-TL and fitness is shared between them. Based on this research, it would be assumed that across training modalities, there are still discrepancies regarding the utilisation of sRPE as an internal training load measure.

2.3.2. Global Positioning Systems (GPS)

In recent years GPS technology has advanced rapidly to become a common method for assessing the physical demands of competition and training in field based team sports such as soccer, hockey, rugby league and Australian football (Aughey, 2011; Buchheit, Mendez-

Villanueva, et al., 2010; Gabbett, Jenkins, & Abernethy, 2012; Macutkiewicz & Sunderland, 2011). GPS designed as a tracking tool for team-sports first became commercially available in 2003 (Edgecomb & Norton, 2006). GPS relies on space-based navigation which provides an individual's location through radio-based calculations between a GPS receiver on earth and the satellites. In order for an accurate location to be triangulated and speed-based calculations derived the GPS receiver is required to be connected to four separate signals (Larsson, 2003).

GPS technology is now commonly used by elite soccer clubs as the devices are portable and although still relatively expensive, they are a cheaper alternative to semi-automated tracking systems, without the ongoing costs apart from servicing which is usually included within the warranty. GPS tracking has predominately been used for the monitoring of training due to previous regulations of international governing bodies preventing players from wearing external devices during high level competitive match play. As of August 2015, FIFA and the FA in England announced that GPS would be allowed to be used in competitive match play, opening up further avenues for analysis within soccer (FIFA, 2015 – Letter – Appendix 4).

GPS is now a key tool used to monitor external training loads during training sessions for individual players (Casamichana et al., 2013) and is now commonplace during match play and training with team-sport athletes (Aughey, 2010; Aughey, 2011; Brewer, Dawson, Heasman, Stewart, & Cormack, 2010; Duffield, Reid, Baker, & Spratford, 2010; Jennings, Cormack, Coutts, Boyd, & Aughey, 2010). An area of particular focus is the speed of player movement, for which a range of variables are recorded including distance covered in various speed zones (Harley, Lovell, Barnes, Portas, & Weston, 2011). The quantification of low, moderate and high-speed running is enabled through the differentiation of speed thresholds. The common bands used often include high-intensity running and sprinting (Harley et al., 2011). The classification of high-intensity running is usually in line with the 'default' thresholds used by the Prozone semi-automatic camera system which classifies it as the distance covered above 5.5 $m \cdot s^{-1}$ (19.8 $km \cdot h^{-1}$), although some studies have used varying high-intensity zones between 13 $km \cdot h^{-1}$

and 19.8 km·h^{-1} as mentioned earlier in this thesis (Andersson et al., 2008; Bangsbo et al., 1991; Castagna & D'Ottavio, 2001; Di Salvo et al., 2007; D'Ottavio & Castagna, 2001; Javier Mallo et al., 2007; Rampinini, Bishop, et al., 2007a; Rampinini, Coutts, et al., 2007; Weston et al., 2007).

Previous research has investigated the distance covered in various speed zones in both matches and training. Bradley et al. (2009) investigated high-intensity running (>14.4 km·h^{-1}) values from 28 Premier League soccer matches and reported values to range between 1834-3138 m throughout all positions. Total distance was found to range between 9885-11535 m throughout positions in the same study. These data showed the total distances in elite standard English league soccer to be much higher than 30 years ago (Reilly & Thomas, 1976) and also revealed the amount of high-intensity running to be similar to that of other European leagues (Di Salvo, et al., 2007; Mohr et al., 2003). To further add to this, more recently, Barnes et al. (2014) investigated the evolution of Premier League soccer between 2006-07 and 2012-13, in terms of total distance and high-intensity running (19.8 km·h^{-1}) it was found that although total distance had increased significantly ($P < 0.001$; ES: 0.01-0.22) in this time (10679 ± 956 vs. 10881 ± 885 m) it was of a trivial magnitude. With regards to high-intensity distance the increase between 2006-07 and 2012-13 were of a much greater magnitude (890 ± 29 vs 1151 ± 337 m; $P < 0.001$; ES: 0.82) highlighting an increased in high-intensity movements within the modern game.

Dellal et al. (2012) examined the proportion of distance covered in various speed zones during small sided training games (SSG) in elite players. From this study, mean distances for high-intensity running (>14.4 km·h^{-1}) and sprinting (>25.1 km·h^{-1}) were 483 m and 382 m, respectively. Mean total distance was 2664 m during the training drill, which consisted of 4x4 min games (30 m x 20 m area) with 3 minutes passive recovery and in possession free-play rules being applied. These results show that a technical training drill produces both high intensity and volume values for total distance and high-intensity running, it was also suggested

that the technical demands placed upon elite soccer players during SSGs are linked with their playing positions. These findings support the implementation of SSG as part of elite level professional soccer training programmes as they can influence more than one fundamental component of the game simultaneously. These findings emphasise the importance of speed zone banding to allow training drill contribution to training session intensity and volume to be determined.

Despite the notable advantages of using GPS to analyse external training load there is a lack of any in-house reliability or validity research readily available to the consumer (Edgecomb & Norton, 2006). With any measurement system accuracy is critical in the application of its information, and due to this reliability and validity assessments have been performed by the researchers themselves (Coutts & Duffield, 2010; Duffield et al., 2010; Jennings et al., 2010). Consequently, the interpretation of this data should be viewed with the limitations associated with the technology currently identified in mind, which include aspects such as sampling frequency and quality of satellite coverage. Sampling frequency refers to the speed at which data is gathered within the unit (Cummins, Orr, O'Connor, & West, 2013). Previous studies have used devices of varying sampling frequencies between 1 Hz-15 Hz when investigating the validity and reliability of GPS devices for team sport movement measurement (Barbero-Alvarez, Coutts, Granda, Barbero-Alvarez, & Castagna, 2010; Coutts & Duffield, 2010; Jennings et al., 2010; Johnston, Watsford, Kelly, Pine, & Spurrs, 2014; Portas, Harley, Barnes, & Rush, 2010; Varley et al., 2012). Logically, the precision of the unit should improve with an increased sample rate when measuring short, rapid movements such as acceleration and deceleration efforts and sprints, with these efforts often being of a minimal duration (Mohr et al., 2003).

When comparing the 1 Hz GPS unit with the 5 Hz unit for multidirectional courses Portas et al. (2010) identified a large range of error in the 1 Hz units compared to the 5 Hz. 1 Hz units have a standard error of the estimate (SEE) between 1.8-6.0% in comparison with 2.2-4.4% within the 5 Hz devices when performing running tasks (mean speed: 3.58 m·s^{-1}) within a linear and

multidirectional course. Jennings et al. (2010a) also found the SEE to be 1.2% lower in 5 Hz units in comparison to 1 Hz during walking and jogging tasks over 20 m. However the SEE was 5.3% lower during sprinting tasks. When comparing the typical error of measurement between walking (0-6 km·h^{-1}) and sprinting (>25 km·h^{-1}) Johnston et al. (2012) reported the typical error measurement to increase from 3.3% to 123.2% using 5 Hz GPS units. Research using the 10 Hz GPS units has suggested that they are up to 6 times more reliable when measuring constant speed in comparison to the 5 Hz units (Varley et al., 2012). These units also displayed lower coefficient of variation (CV) % values during different starting speeds (1-8 m·s^{-1}), 2.0-5.3% in comparison to 6.3%-12.4% in the 5 Hz units. The data suggests that as the sampling frequency of the GPS units is reduced, the magnitude of measurement error increases. Despite this, regardless of sampling frequency, the accuracy of measurement is decreased when movement speed and multidirectional motion is increased (Coutts & Duffield, 2010; Jennings et al., 2010; Petersen, Pyne, Portus, & Dawson, 2009).

An increase in SEE% has been reported across varying multi-directional courses with turning actions ranging from 45-180 degrees (Portas et al., 2010), with the SEE% between 2.4-6.8% during the multidirectional courses in comparison to 2.6% during straight line running. This finding is of notable importance when working to quantify soccer-specific movement as during match play soccer players are required to perform a large number of changes in direction (Bloomfield et al., 2007). Despite the limitations of quantifying soccer play using GPS technology, the devices still provide objective data in relation to training load which provide more insight than using subjective interpretations alone. For sport scientists using GPS it is vital to quantify the degree of error present in the specific GPS device in use, and these measurements must be incorporated into any implemented decision-making process. In order to limit the degree of error it is important that practitioners follow the instructions from the GPS manufacturer. These include leaving the devices on 30 minutes prior to activity in order

for satellite lock-on to be maximised. The number of signals to the surrounding satellites can also be increased by conducting activity in an open space.

Despite the use of GPS metrics as a measure of external training load, there are currently no studies which have investigated the dose-response relationship between GPS measures and changes in fitness or performance. Therefore, despite its suggested importance within training load monitoring, there is no evidence for dose-response validity of external training load derived from the GPS. Despite its lack of validity with regards to dose-response, more recently there has been a focus on the dose-response relationship between external training load and injury incidence in athletes (Blanch & Gabbett, 2015; Gabbett, 2016) with the outcome of this being the development of a training-injury relationship model. With this in mind, it could be suggested that it is vital for dose-response relationships to be identified in regards to physical improvement alongside the dose-response relationship of injury incidence.

2.3.3. Metabolic Power

Until recently, the use of GPS technologies has focused on evaluating the distance covered or time spent within specific speed zones with a large emphasis being placed on the volume of high-speed activities due to its importance in match play (Di Salvo et al., 2009; Iaia et al., 2009; Vigne, Gaudino, Rogowski, Alloatti, & Hautier, 2010). A potential problem with this approach is that it does not account for the additional energy demands which are usually associated with accelerations and decelerations, changes of direction and non-linear movements which arise frequently during soccer (Akenhead, French, Thompson, & Hayes, 2013; Akenhead, Hayes, et al., 2013; Osgnach et al., 2010; Serpiello, McKenna, Stepto, Bishop, & Aughey, 2011; Varley & Aughey, 2013; Varley et al., 2012). Due to this, a combined use of speed data and accelerations/decelerations elicits a greater holistic representation of physical demands (Coutts et al., 2014). This method is supported by Dwyer and Gabbett (2012), who reported the importance of measuring both acceleration and speed data to understand the demands

placed on field sport players. If high-speed distance is the only metric used there is likely to be an underestimation of the true energy cost of the activity (Cavagna et al., 1971; di Prampero, 2005; Gaudino, Iaia, Alberti, Hawkins, et al., 2013; Osgnach et al., 2010). Despite this, there has been limited focus on acceleration and deceleration activity in elite soccer players (Di Salvo et al., 2009), meaning the contribution of these activities to external load estimates incurred by players are minimal. As an example of this, a ~2 s maximal acceleration produces a 90-100 $W \cdot kg^{-1}$ power output, which would not be detected if using common speed category distances (Cavagna et al., 1971; di Prampero, 2005; Gaudino, Gaudino, Alberti, & Minetti, 2013).

In an attempt to address this issue di Prampero (2005) developed a mathematical approach allowing the quantification of the estimated energy cost of accelerated and decelerated running. The model considers accelerated running on a flat surface as being metabolically equivalent to constant velocity incline running, in which the incline angle is equal to the extent of forward acceleration. By doing this, an 'equivalent slope' is provided which is used to calculate an instantaneous measure of the energy cost of accelerated running and an estimate of metabolic power output. This method has been suggested to provide a more comprehensive assessment of overall energy cost and metabolic power output associated with activity at any given moment when combined with traditional estimates of running speed (di Prampero, 2005; Gaudino, Iaia, Alberti, Hawkins, et al., 2013). Coutts et al. (2014) highlighted potential limitations within this approach. This included a number of assumptions derived from within the equations (di Prampero, 2005) including the centre of mass location, the effects of air resistance and the influence of limb movement on running energetics (Aughey & Varley, 2013; Manzi et al., 2013).

Despite the limitations highlighted, research has used this approach reporting that energy costs associated with high-intensity activity were 2 to 3 times greater than estimates based on running speed alone during training and match play (Gaudino, Iaia, Alberti, Strudwick, et al., 2013; Osgnach et al., 2010). This early research using metabolic power suggests that estimated

metabolic power is a better measure for the coach as it relates to the true demands of soccer activity (Gaudino, Iaia, Alberti, Hawkins, et al., 2013). Despite this approach being reported to provide energy cost estimates similar to 'directly' determined measures (Osgnach et al., 2010), there has been little research that has validated this method for metabolic power and energy cost estimates during soccer practices against a gold standard method (e.g., indirect calorimetry). Stevens et al. (2015) reported locomotor-related metabolic power to be much lower (-15%) than actual net energy demands (VO_2 measures) during shuttle runs at low speed (7.5-10.0 $km \cdot h^{-1}$). Despite this, these results may not be generalised due to shuttle runs not being representative enough of soccer practice. Moreover, players were not required to pass a ball or shoot and the protocol used by Stevens et al. (2015) did not include rest periods which are usually present between efforts in soccer. Recent research by Buchheit et al. (2015) investigated the validity and reliability of metabolic power during soccer specific drills using 4 Hz GPS units with oxygen uptake (VO_2) being measured with a portable gas analyser. This study suggested locomotor-related metabolic power to very largely underestimate the actual net metabolic demands, especially during rest periods. Despite this, there has been a response to this in a recent paper by Osgnach, Paolini, Roberti, Vettor, and di Prampero (2016). The authors suggest that actual energy consumption (VO_2) and metabolic power are not directly comparable due to the inherent time lag present in VO_2 during soccer specific drills. Also, it was concluded that when dealing with accelerations, any sampling frequency below 10 Hz is highly questionable, with the sampling frequency of the GPS units in the Buchheit et al. (2015) study being 4 Hz.

Another contributing factor towards this underestimation could potentially be due to the equations derived by di Prampero (2005) and Osgnach et al. (2010) assuming linear running. Within team sports such as soccer there is a significant portion of non-linear running involved, which is metabolically demanding action which would not be included within the output derived from the GPS. The original method for calculating metabolic power is based on a

modelling of speed-time curves based on maximal sprint acceleration (from zero to maximal running speed). It could be suggested that this may not be the case within soccer-specific drills, with athletes commonly performing accelerations when already moving and therefore they rarely accelerate from zero. This notion is highlighted by Buchheit et al. (2015) in showing that both the duration and magnitude of accelerations occurring during a soccer specific circuit were shorter and lower than that during a maximal sprint (Figure 2), which could be an explanation as to why metabolic power derived from GPS provided inconsistent values. The equations only consider the running performance during a match, many of the other typical activities involved within soccer are neglected including dribbling or turning and also jumping, kicking the ball, tackling and controlling of the ball in which non-locomotor muscles are likely to be highly activated (Buchheit et al., 2015; Osgnach et al., 2010). Findings from metabolic power studies should also be interpreted with caution due to the 10 Hz GPS devices commonly used to accurately measure accelerations and movement at higher speeds, being shown to have considerable error (Buchheit et al., 2014). Moreover, game specific actions such as jumping and tackling are not accounted for in all time-motion analyses, therefore, metabolic power production estimates provided in previous studies underestimate these actions' contributions to overall energy expenditure. To add to this, this model does not consider the effects of eccentric actions and although the actual metabolic costs of these actions are low, eccentric actions may contribute to the onset of muscular fatigue during exercise. Due to this, the true cost of these actions may be neglected by the metabolic power approach (Coutts et al., 2014).

Despite this most recent literature there is still a lack of research in the field of metabolic power, in particular when examining its validity and reliability. Due to the limitations previously mentioned in this section including the limitations of the 10 Hz devices and also frequent soccer actions which are not captured in the measurement of metabolic power, this highlights a need for further research. Research focusing particularly on the quantification and

validity of this measure could be potentially useful. A further advancement could be to assess

the measurement of metabolic power in relation to dose-response.
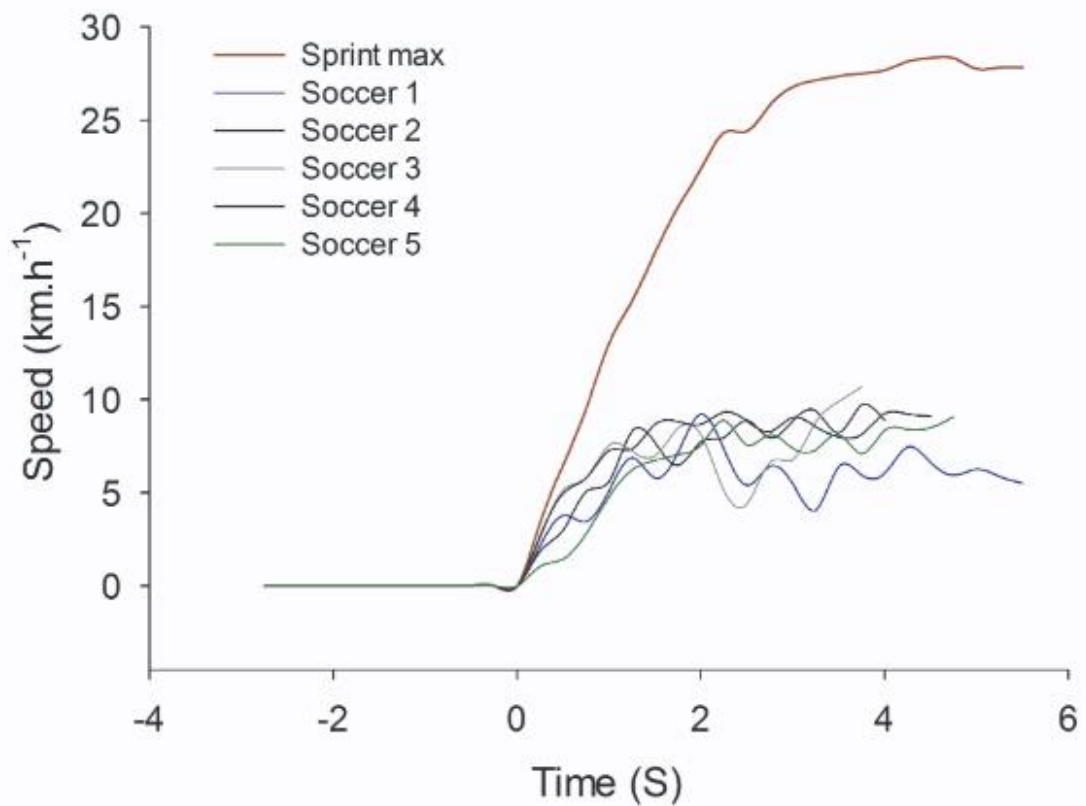
Figure 2: Comparison of acceleration patterns during soccer-specific drills and a standardised maximal sprint initiated from a standing start without a ball (Buchheit et al. 2015).

2.3.4 Accelerometry

Generally running distances at high speeds derived from GPS have been utilised as a key

external-load measure, although, this is limited due to it disregarding changes in running speed

which can be energetically demanding (Osgnach et al., 2010; Varley & Aughey, 2013) and can

also be highly variable between team-sport matches (Gregson et al., 2010; Kempton, Sirotic, &

Coutts, 2014). In order to account for the changes in running speed, the metabolic power

model as discussed in the previous section has been adopted for the quantification of the

metabolic cost of acceleration and deceleration activities during training sessions (Gaudino,

Iaia, Alberti, Hawkins, et al., 2013) and team-sport matches (Coutts et al., 2014; Osgnach et al.,

2010). Despite being suggested as a valuable monitoring addition for practitioners (Barrett et al., 2016), the metabolic-power approach is limited by its measurement accuracy in tracking high accelerations and decelerations from GPS (Akenhead, French, et al., 2013; Varley et al., 2012). The metabolic power model is also unable to quantify other taxing activities such as changes of direction, impacts and jumps, which are all key features of team sports.

With this in mind, high-resolution triaxial accelerometers have been incorporated with devices containing GPS. Usually housed within the same device as the GPS is the triaxial accelerometer, which measures the magnitude and frequency of movement in three axes (Anterior-Posterior, Mediolateral & Longitudinal) (Krasnoff et al. 2008). An accelerometer calculates acceleration in G-forces (g) or metres per second squared ($m \cdot s^{-1}$). Accelerometers only measure accelerative and decelarative events, once these actions become constant they would be recorded on the device as zero. In context, when a player achieves maximum velocity, though they may be still moving at above 30 $km \cdot h^{-1}$, their forward acceleration may potentially read as zero. This is important to consider when assessing the use of accelerometry, as data is produced by the triaxial accelerometer by recording the total number of accelerations in the three perpendicular axes. From measuring the magnitude and frequency of these movements, the total G-forces an athlete is exposed too can be calculated (Chambers, Gabbett, Cole, & Beard, 2015; Waldron et al., 2011).

Devices with this technology offer a higher sampling frequency than GPS as the accelerometers typically have 100 Hz sampling rate compared to 10 Hz for the latest GPS systems (Boyd, Ball, & Aughey, 2011). The devices that house both the GPS receiver and triaxial accelerometers have previously been referred to as MEMS (micromechanical electrical systems) devices (Barrett et al., 2016), and this is what the devices will be referred to as within the current thesis.

The integration of GPS and accelerometers in a MEMS device has enabled the measurement of a greater number of movements, with the total mechanical stress experienced by the athlete being recorded during quick changes of direction, collisions and jumping (Barrett, Midgley, & Lovell, 2014). Accelerometers typically sample at 100 times per second (100 Hz) and therefore display excellent accuracy and reliability (Boyd et al., 2011). With regards to accelerometry derived data, some sporting microtechnology companies have attempted to quantify the 'load' imposed on the athlete from this. The quantification of this load has varied in name based on the manufacturer of the MEMS device. The main manufacturers of MEMS devices are Catapult, StatSports and GPSports. Both StatSports and GPSports refer to this load as Body Load whereas the most common accelerometer load within the research and applicable to this study is Player Load,[TM] calculated within the Catapult software. Player Load[TM] is an arbitary unit which is defined as an 'instantaneous rate of change of acceleration in each of the three vectors (X,Y and Z axis) and divided by 100' which utilises the highly responsive accelerometers within the three movement planes to enable movement intensity quantification (Boyd et al., 2011, p. 313). This load quantification for inertial data can provide a different perspective to athlete demands in comparison to other technologies such as GPS (Boyd et al., 2011; Cummins et al., 2013), with Boyd et al. (2011) suggesting that there is the potential to characterise gross fatiguing movements from using accelerometry alongside the conventional GPS output.

Recent studies have measured physical activity through the use of Player Load[TM] to describe the physical demands of sports including Australian Rules football (Boyd et al., 2011), basketball (Montgomery, Pyne, & Minahan, 2010), netball (Chandler, Pinder, Curran, & Gabbett, 2014; Cormack, Smith, Mooney, Young, & O'Brien, 2014) and soccer (Barrett et al., 2016). Boyd et al. (2011) reported when testing the reliability of accelerometers in sport, coefficients of variance of 1% for static reliability, 0.9-1.4% for dynamic reliability and 1.9% in team sport settings. From this it was concluded accelerometry in team sports has an acceptable level of reliability and capability in measuring non-running movement. Despite this,

it has been suggested that the accelerometer and Player Load^{TM} fail to account for contact based and skill activities such as: tackling, blocking, jumping, kicking and passing, which may lead to underestimated actual workloads. Due to this, the Player Load^{TM} derived from accelerometer data remains questionable as it potentially underestimates total workload (Chambers et al., 2015; Cunniffe, Proctor, Baker, & Davies, 2009). Moreover, no dose-response study for Player Load^{TM} has been published.

2.4. Summary

In summary, the importance of monitoring tools in order to accurately quantify both internal and external training load is apparent. It is also paramount for dose-response relationships to be identified between a change in fitness and measures of training load in order to better inform soccer training practices.

3. Methods

3.1 Participants

25 elite academy male soccer players (two squads) from the same Premier League club participated in the study. The participants had the following characteristics: age 18±1.2 years, height 181.9±5.9 cm, mass 75.8±7.5 kg. Data was collected during the pre-season phase with all players continuing to participate in normal team training and fixtures as prescribed and in-line with the periodised training plan and fixture schedule. The study was granted ethics approval by the Department of Sport, Health and Exercise Science Human Research Ethics Committee at The University of Hull and was conducted in accordance with the Declaration of Helsinki. All the participants were fully informed of all aspects of the study and any risks were highlighted. Prospective participants were required to provide written consent and also complete a pre-exercise medical questionnaire. All participants were also required to be free

from injury and illness and to be deemed eligible to participate by the club's medical staff, to be included within the study.

3.2 Experimental Design

Data collection for the study was performed on a daily basis throughout the pre-season of the 2015/2016 season and included a maximal Yo-Yo Intermittent Recovery Test Level 1 (YYIR1) on the first day of pre-season and in week 8, which was following the final week of pre-season. The maximal YYIR1 test was performed as has been described in previous studies (Bangsbo, Iaia, & Krustrup, 2008; Krustrup et al., 2003; Mohr & Krustrup, 2014). Both testing sessions were conducted on an outdoor UEFA standard 3G surface. All players wore Minimax S4 devices with in-built accelerometer (GPS), heart rate (HR) monitor (Polar T31-Coded, Polar Electro, Kempele, Finland) that was compatible with and recorded via the Minimax S4 device and also provided a rating of perceived exertion (RPE) using the category-ratio scale of Foster et al. (2001) following every training session conducted in the pre-season period. The players were familiarised with all procedures prior to the beginning of the study data collection. Each of the pre-season training session's content was determined by the team's coaches and sport scientist in accordance with the technical, tactical and physical objectives for each session. Devices were always turned on 30 minutes before the data collection to allow acquisition of satellite signals (Maddison & Ni Mhurchu, 2009). In order to avoid inter-unit error players wore the same GPS device for every training session (Buchheit et al., 2014).

3.3 Procedures

The player's training load measures during the YYIR1 and each training session were monitored using Minimax S4 devices (Catapult Innovations, Scoresby, Victoria) which provided GPS, accelerometry and HR data. This device provided position, distance and velocity data at 10 Hz. Each player wore a custom made vest supplied by the manufacturer (Catapult Innovations,

Scoresby, Victoria). The device was positioned across the upper back between the right and left scapula. The positioning of the device across the upper back enabled the GPS device to receive a clear satellite reception. Participants were also required to provide a sRPE following each training session. During the study period, 4 training sessions (Monday, Tuesday, Thursday & Friday) were performed followed by 1 match for each player during a typical training week. The typical weekly training plan is outlined in Table 2. Players were progressed from 45 minutes up to 90 minutes in matches during pre-season.

Table 2: Typical training week during pre-season

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Session	Light Tactical	Conditioning	OFF	Moderate Tactical	Light Tactical	Game	OFF
Duration – minutes (approximate)	60	90		75	60	90	

3.3.1 Internal Training Load

Session Rating of Perceived Exertion (sRPE)

sRPE was calculated for each player using the method of Foster et al. (2001). The sRPE exercise intensity was determined using the Borg CR-10 scale, which was collected ~30 minutes following the completion of each training session. sRPE was collected from players individually and would usually be provided once participants had eaten lunch following training. sRPE training load was calculated into arbitrary units by multiplying sRPE by training-session duration. All participants in the study had been familiarised with the sRPE scale in a presentation prior to pre-season training beginning, including the exertion interpretation in relation to visual anchors placed on the scale.

Heart Rate

HR exertion index was measured using the Minimax S4. This process involved the players wearing a Polar HR strap (T31 coded, Polar, Oy, Finland), which then synchronised with the player's GPS device and provided a HR trace for the session. From the software provided by the manufacturer (Catapult Sprint software, Version 5.1.7; Firmware 6.108), a HR exertion index was provided. HR exertion measures the total load for a session based on weighted heart rate values. Each 5 s heart rate is assigned a weighting based on the heart rate reserve ($HR_{exercise} - HR_{rest}$)/($HR_{max} - HR_{rest}$).

3.3.2 External Training Load

Measures of external training-load including metabolic power, total distance, high speed distance (>15 km·h^{-1}) and Player Load^{TM} were collected concurrently during each session using the MEMS devices (Catapult Innovations, Scoresby, Victoria). The specific unit was the Minimax S4. The size of this unit is similar to that of a small mobile telephone, it weighs 66 g and is approximately 18 mm x 40 mm x 85 mm. GPS devices have been shown to provide an acceptable level of reliability and accuracy for speed and distance measures during intermittent high-intensity exercises (Coutts & Duffield, 2010; MacLeod, Morris, Nevill, & Sunderland, 2009). In regard to the metabolic power parameters, the total of Mean Metabolic Power (TMetAv) in each band (Zone 1: 0-10 W/kg; Zone 2: 10-20 W/kg; Zone 3: 20-35 W/kg; Zone 4: 35-55 W/kg; Zone 5: 55-100 W/kg) was calculated using the algorithm included in the software provided by the manufacturer (Catapult Sprint software, Version 5.1.7; Firmware 6.108) which was adapted and calculated based on formulas proposed by di Prampero (2005) and adapted by Osgnach et al. (2010).

For the collection of Player Load^{TM} the GPS-housed tri-axial accelerometer data displayed in g force and sampling at 100 Hz were used. Player Load^{TM} is an arbitrary measure and is the

instantaneous rate of change of acceleration divided by a scaling factor. Player Load^{TM} is calculated using the algorithm included in the software provided by the manufacturer (Catapult Sprint software, Version 5.1.7; Firmware 6.108). Player Load^{TM} is a modified vector magnitude expressed as the square root of the sum of the squared instantaneous rates of change in acceleration in each of the 3 planes divided by 100.17. The vector magnitude of Player Load^{TM} and individual component planes of Player Load^{TM} (anteroposterior, mediolateral and vertical) were recorded, expressed in arbitrary units (au).

3.4 Statistical Analysis

Descriptive results are reported as mean ± SD. To determine the statistical analysis type, normality criteria were verified for distance, sRPE and each MEMS device measure during the YYIR1 and also the weekly mean load for sRPE and each MEMS device measure (Kolmogorov-Smirnov or Shapiro-Wilk). Relationships between measures of training load and the change in YYIR1 distance (delta YoYo) are reported as Pearson correlation coefficients including 95% confidence intervals.

During initial analysis of the results from the pre and post YYIR1, regression towards the mean was identified. We explored regression toward the mean by plotting (see Figure 3) and correlating the change scores (post score - pre score) and the sum of both scores (post score + pre score). The resulting negative relationship (r = -0.68) provided evidence for regression toward the mean (Nevill, Holder, Atkinson, & Copas, 2004). To remove the effect of this artifact, we applied a correction to post scores using the following formula:

$Y'=M_y + b_{yx}+(X-M_x)$

Where Y′ is the predicted post scores minus the artifact, M_y is the mean of the post score, b_{yx} the regression coefficient in which the post score is predicted by the pre score, X is the pre-test score and M_x the mean of the pre-test score (Campbell & Kenny, 1991). These modified scores were then used in subsequent analyses.
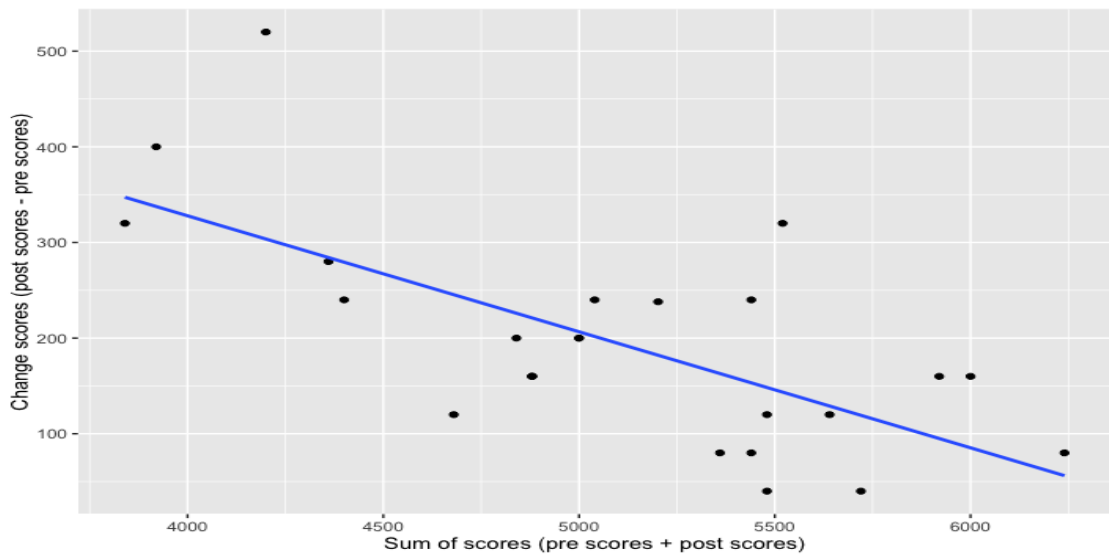
Figure 3: Scatter plot with fit line relating raw change score and sum of scores

Standardised mean differences (effect sizes [ES]) and magnitude based inferences (MBI) were calculated to assess the practical significance of changes (Cohen, 1988, p. 1) in the pre and post YYIR1 distance scores. ES between <0.2, 0.2-0.59, 0.6-1.19, 1.2-1.99 and 2.0-4.0 were considered to be trivial, small, moderate, large and very large respectively.

The data were analysed using a modified Microsoft Excel spreadsheet (Hopkins, 2006, 2007) and SPSS statistical software (Version 23.0, IBM SPSS Statistics, Chicago, IL, USA).

4. Results

The team mean YYIR1 distance and MEMS device metrics for the maximal YYIR1 in weeks 1 and 8 are shown in Table 3. Figure 4 shows team mean ± SD for YYIR1 distance in week 1 and week 8 alongside each individual's scores. Weekly mean training loads over the 7 weeks are shown as follows; Figure 5: Total Distance, Figure 6: Session RPE, Figure 7: High Speed Distance, Figure 8: Player Load^{TM}, Figure 9: HR Exertion, Figure 10: Total Mean Metabolic Power (TMetAv).

Pearson correlations including 95% confidence intervals and r^2 values between the weekly mean loads for MEMS device metrics are presented in Table 4. Correlations between changes in maximal YYIR1 distance (Delta YoYo) and each weekly mean load for MEMS device metrics are presented in scattergraphs with Pearson correlations and r^2 values and *P* values in Figure 11.

After the 7-week period, the mean change in YYIR1 distance was 195 m (95%CI: 160 m to 230 m), with the mean change expressed as Cohen's *d* being 0.53 (95%CI: 0.44 to 0.63). The % chance of this change being substantially positive, trivial, or negative is 100/0/0. Qualitative interference: Most likely small.

Table 3: YoYo Distance and Training Load Measures for the Pre and Post YYIR1, Mean ± SD

Measure	Pre (Week 1)	Post (Week 8)
YoYo Distance (m)	2450 ± 355	2645 ± 269
Total Distance (m)	2864 ± 457	2957 ± 315
High Speed Distance (m)	1121 ± 314	1318 ± 503
Player Load™ (AU)	269 ± 52	287 ± 43
Heart Rate Exertion (AU)	33 ± 5.9	30 ± 8.5
Total Metabolic Power Mean (AU)	153 ± 1.9	155 ± 19.5
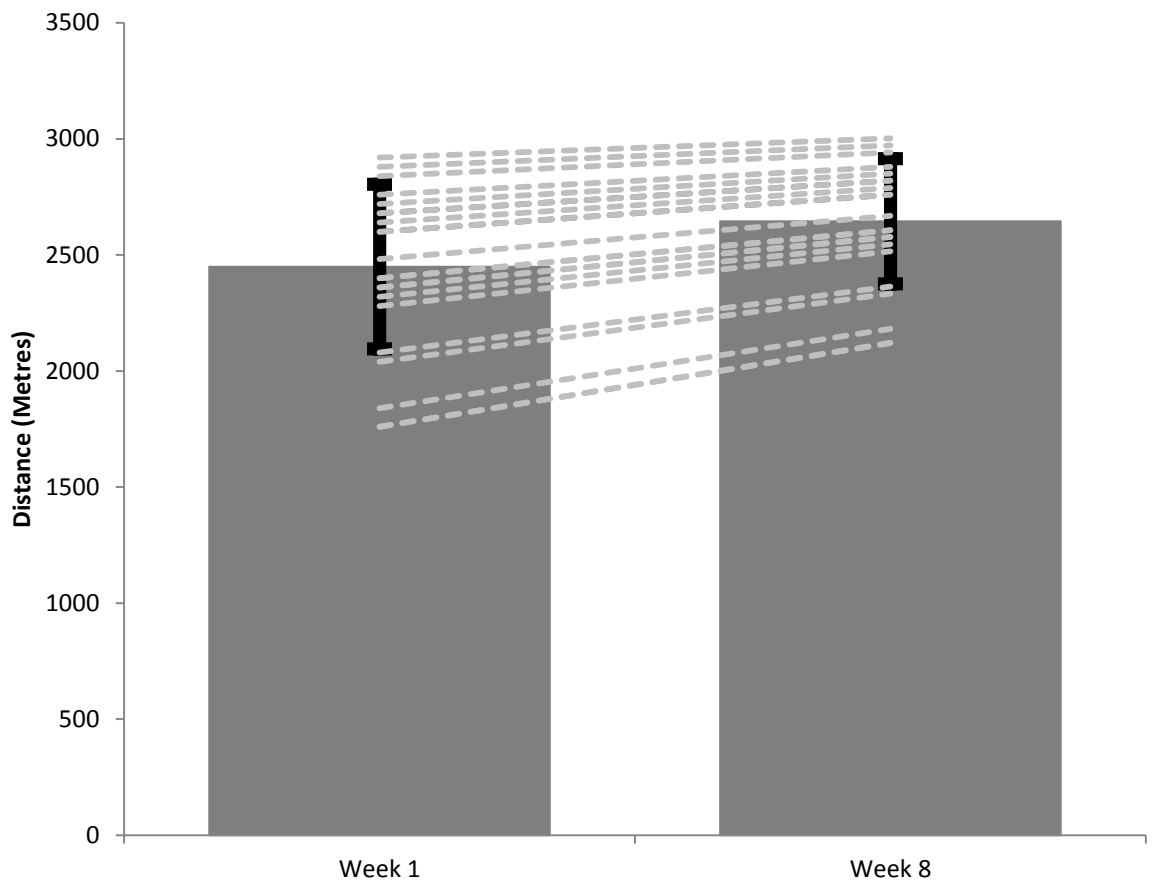
Figure 4: Mean ± SD maximal YYIR1 distance during Week 1 and Week 8 of Pre-season. Each individual's Week 1 and Week 8 distance is represented by each line.
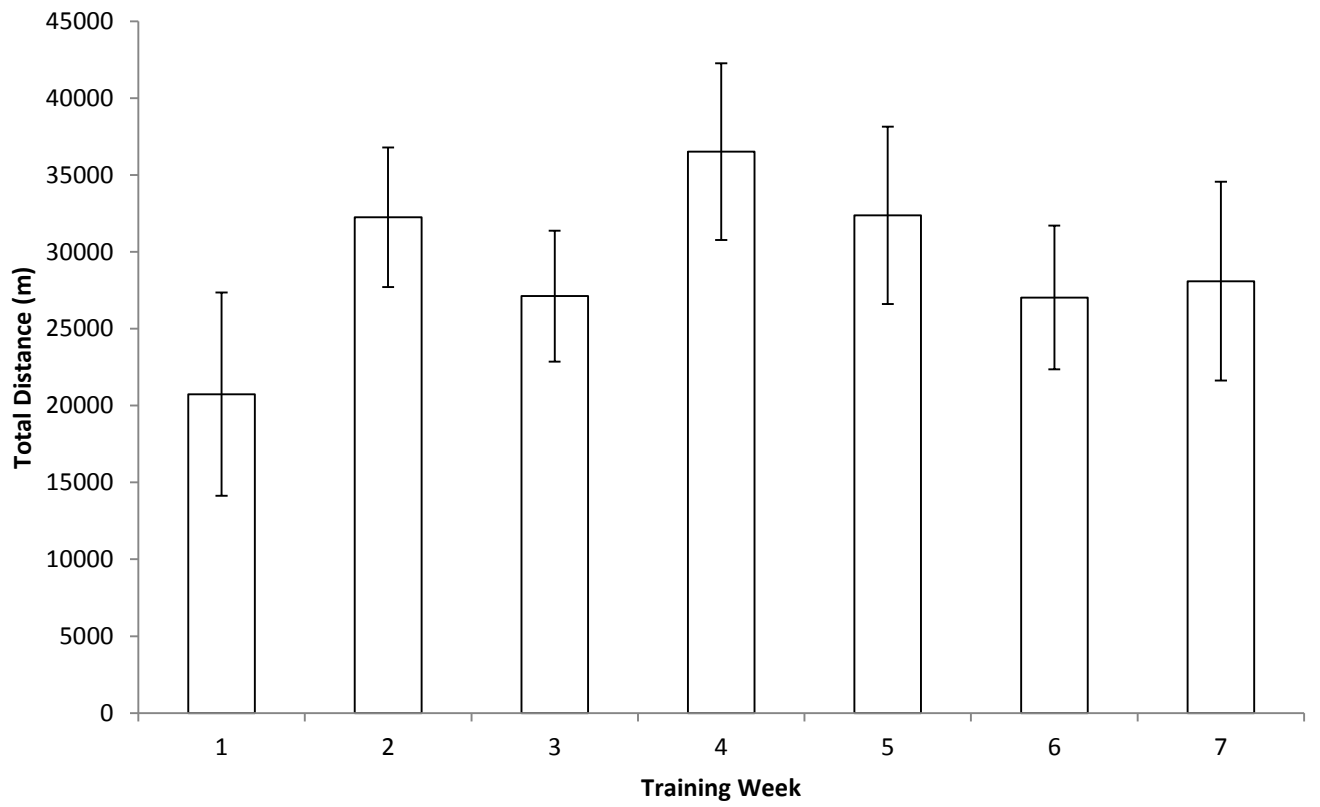
Figure 5: Mean ± SD weekly total distance across the 7 weeks of pre-season.

Figure 6: Mean ± SD weekly sRPE across the 7 weeks of pre-season.

Figure 7: Mean ± SD weekly high speed distance across the 7 weeks of pre-season.

Figure 8: Mean ± SD weekly Player Load™ across 7 weeks of pre-season.

Figure 9: Mean ± SD weekly heart rate exertion across the 7 weeks of pre-season.

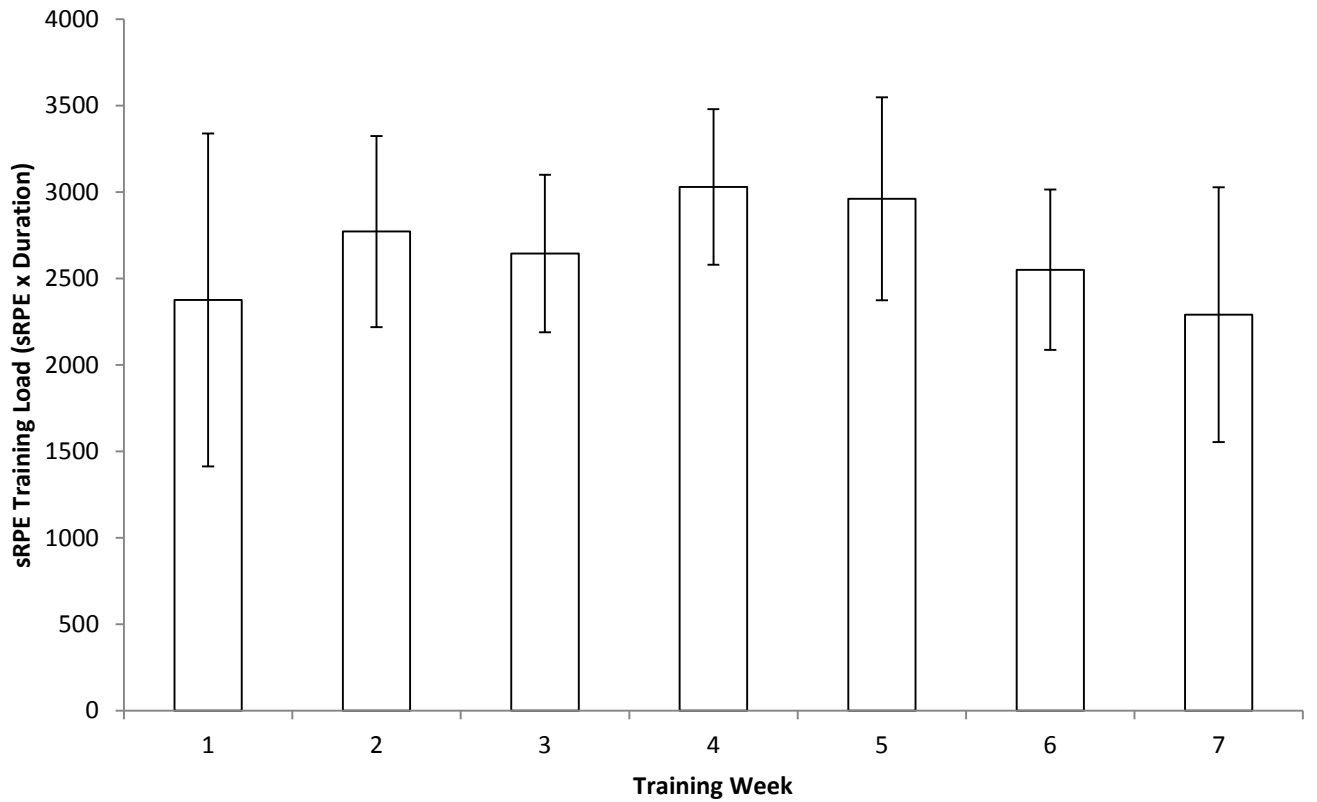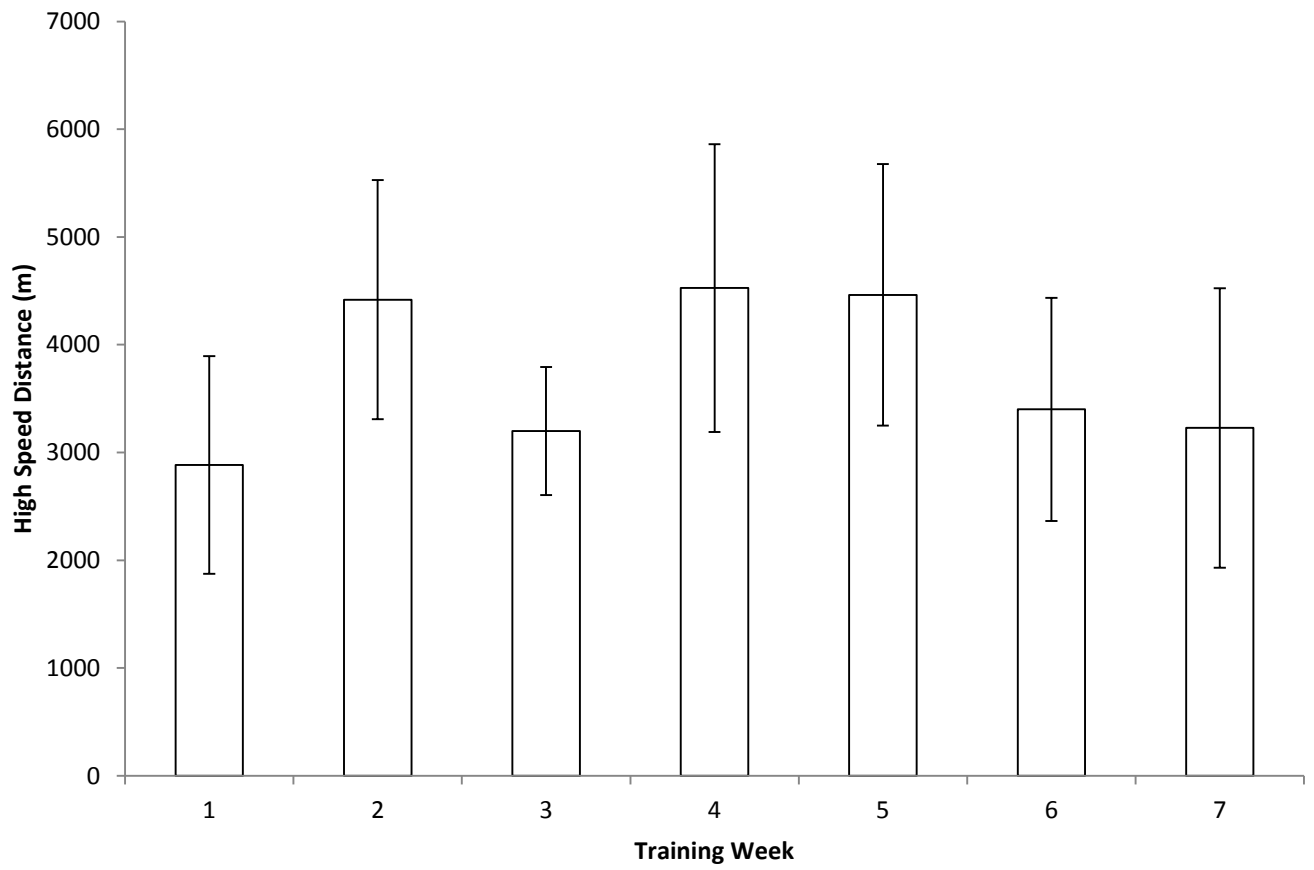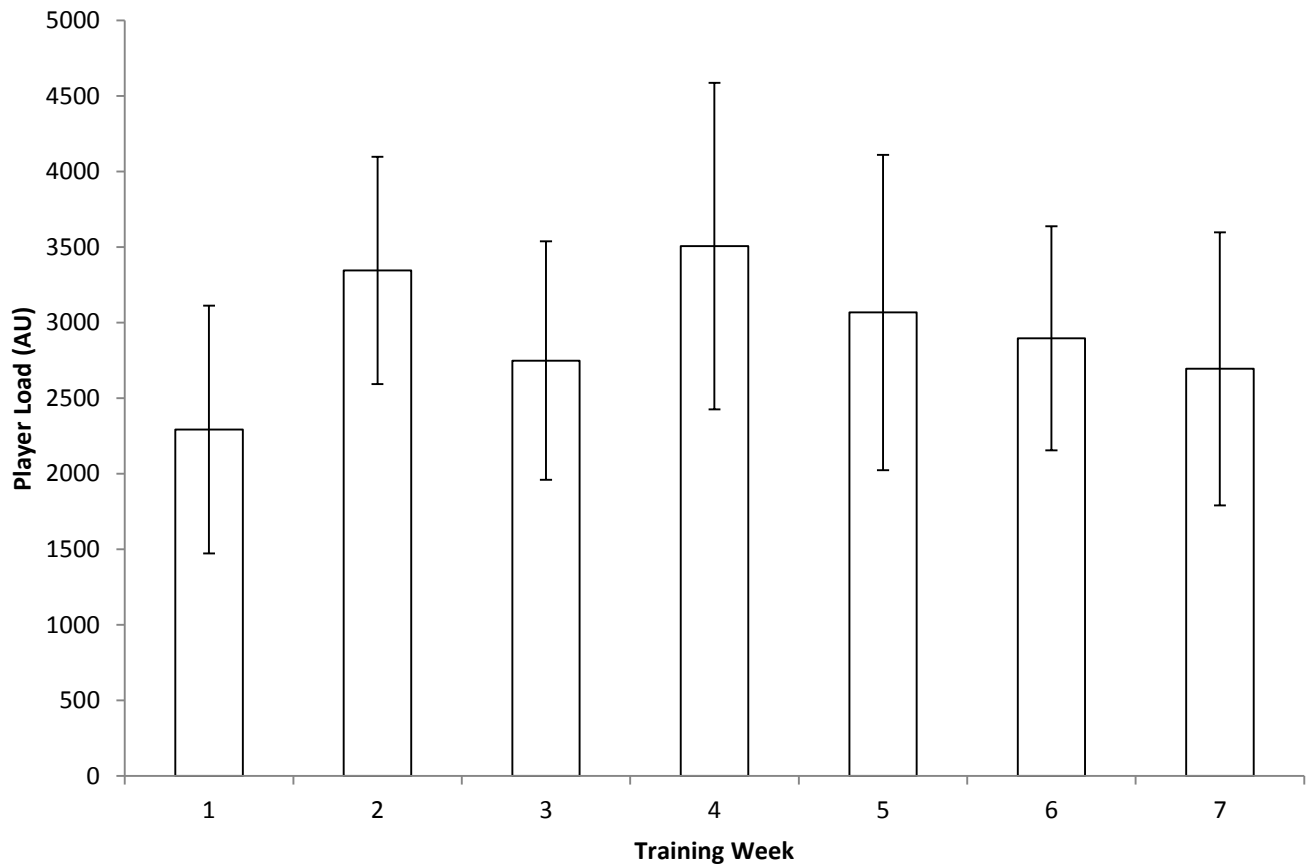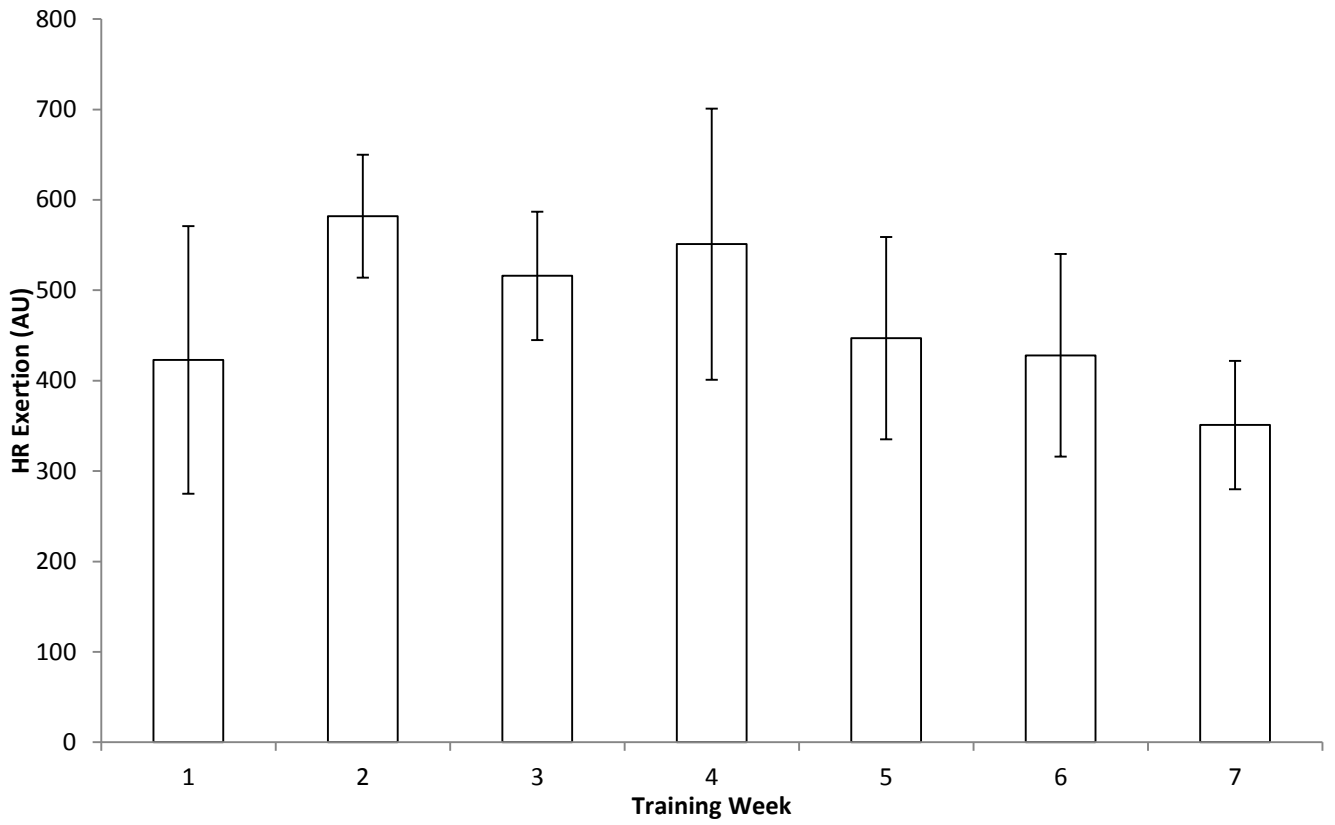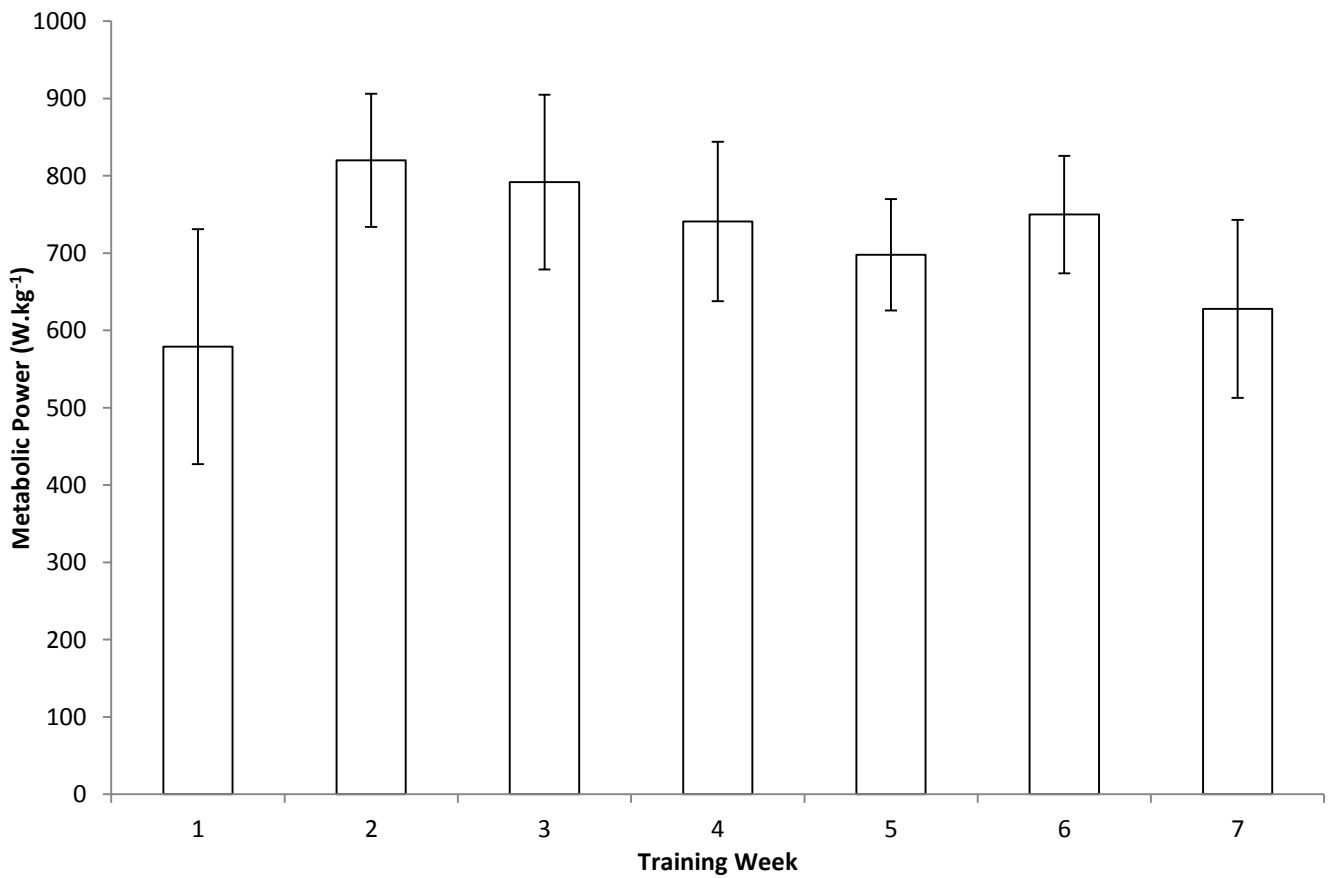**Figure 10: Mean ± SD weekly metabolic power across the 7 weeks of pre-season.**

Significant correlations were present between a number of the measures of training load across the 7-week pre-season (P < 0.01) (Table 4: Pearson correlations (r) for the relationship between delta YoYo and the weekly mean for each training load measure, including 95% confidence intervals and $r2$ values.. Most notable were the relationships between TMetAv and sRPE (r = 0.95; 95%CI = 0.89 to 0.98), total distance (r = 0.74; 95%CI = 0.49 to 0.88) and Player Load[TM] (r = 0.76; 95%CI = 0.52 to 0.89). Further strong correlations included sRPE and Total Distance (r=0.76; 95%CI =0.52-0.89) and Player Load[TM] (r=0.73; 95%CI =0.47-0.87), Total distance and High Speed Distance (r=0.62; 95%CI =0.3-0.82) and Player Load[TM] (r=0.83; 95%CI =0.65-0.92) (Table 4). There was a moderate correlation (P < 0.05) between High Speed Distance and Player Load[TM] (r=0.45, 95%CI =0.07-0.72). No correlations were found between HR Exertion and any of the other measures of training load (Table 4).

No significant correlations were found between delta YoYo and any of the mean weekly training load measures following the 7 week pre-season period (Figure 11).

In Summary, a small improvement (ES = 0.53) in maximal YYIR1 distance between week 1 and week 8 was found. There was found to be no significant correlation between delta YoYo and any mean weekly training load measures (sRPE, Total Distance, High Speed Distance, Player Load[TM], HR Exertion and Total Mean Metabolic Power) following a 7 week pre-season period (Figure 11) although a number of these weekly training load measurers correlated strongly with each other over the 7 week pre-season period (Table 4).

Table 4: Pearson correlations (*r*) for the relationship between delta YoYo and the weekly mean for each training load measure, including 95% confidence intervals and r^2 values.

	sRPE			Total Distance			High Speed Distance			Player Load™			Heart Rate Exertion			Total Mean Metabolic Power		
	r	95%	r^2	r	95%	r^2	r	95%	r^2	r	95%	r^2	r	95%	r^2	r	95%	r^2
sRPE	1.0			.76**	[.52 - .89]	58% [27%-79%]	.35			.73**	[.47 - .87]	53% [22% - 76%]	.18			.95**	[.89 - .98]	90% [79% - 96%
Total Distance	.76**	[.52 - .89]	58% [27%-79%]	1			.62**	[.3 - .82]	38% [9%-67%]	.83**	[.65 - .92]	69% [42%-85%]	.27			.74**	[.49 - .88]	55% [24%-77%]
High Speed Distance	.35			.62**	[.3 - .82]	38% [9%-67%]	1.0			.45*	[.07-.72]	20% [1%-52%]	.21			.29		
Player Load™	.73**	[.47 - .87]	53% [22% - 76%]	.83**	[.65 - .92]	69% [42%-85%]	.45*	[.07-.72]	20% [1%-52%]	1			-.02			.76**	[.52-.89]	58% [27%-79%]
Heart Rate Exertion	.18			.27			.21			-.15			1.0			.15		
Total Mean Metabolic Power	.95**	[.89 - .98]	90% [79% - 96%	.74**	[.49 - .88]	55% [24%-77%]	.29			.76**	[.52-.89]	58% [27%-79%]	.15			1		

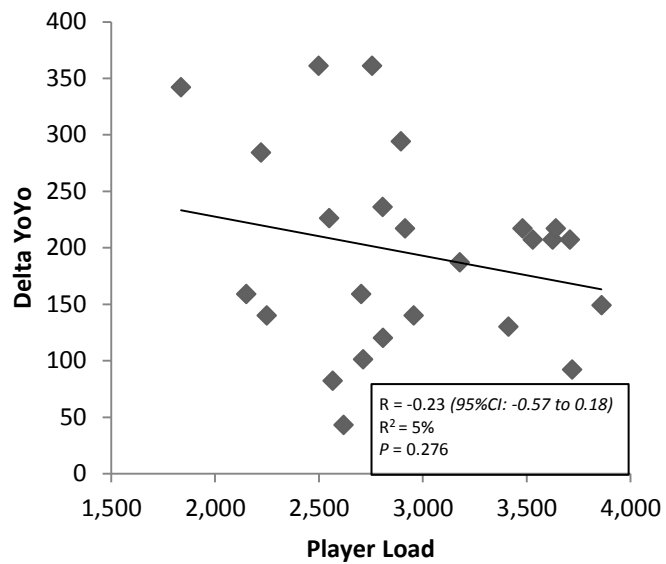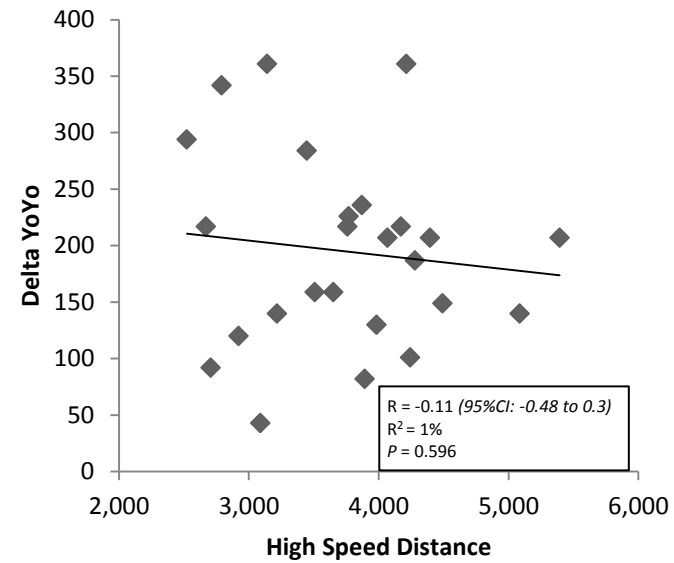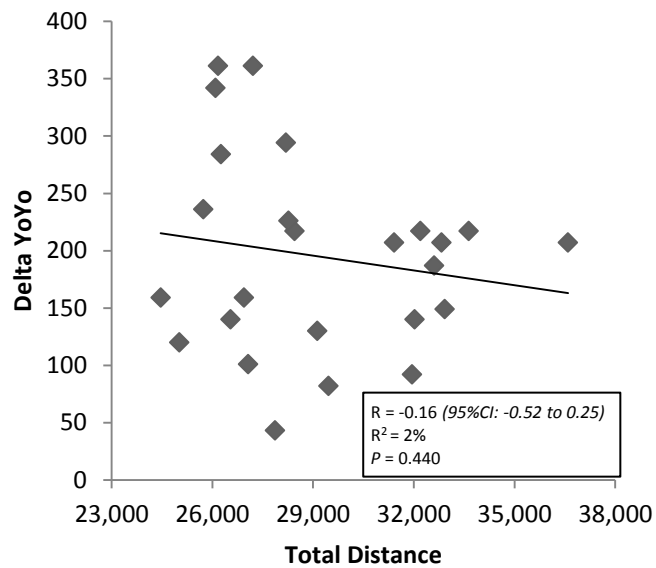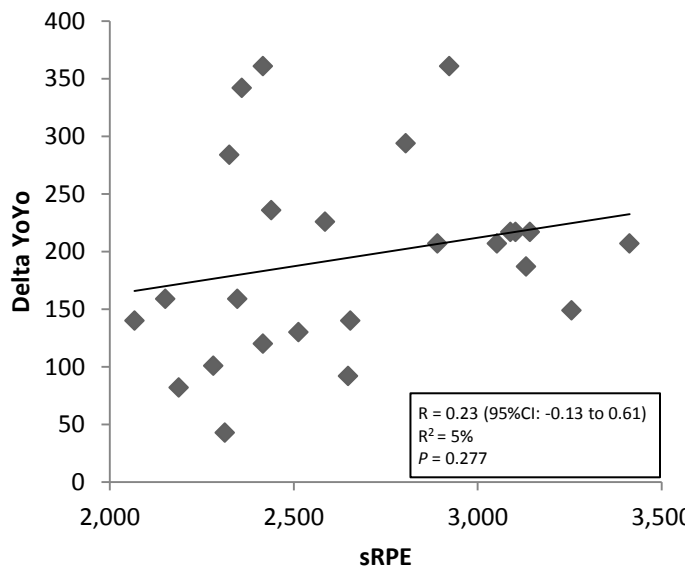* Significant at the .05 level. **Significant at the .01 level
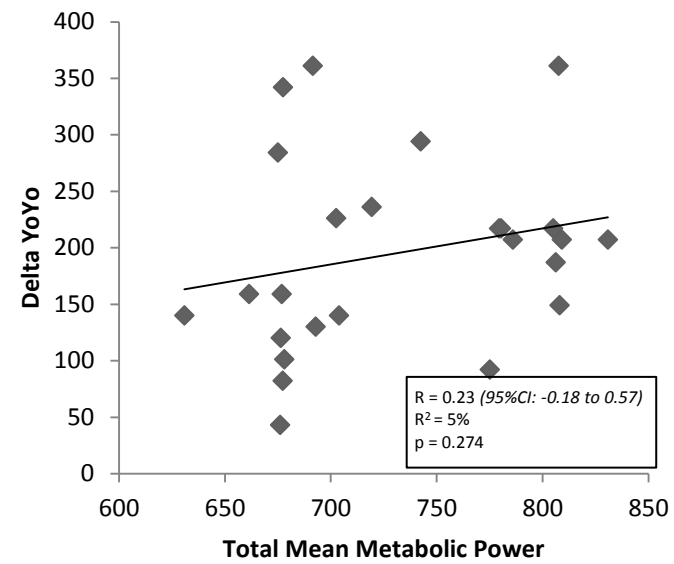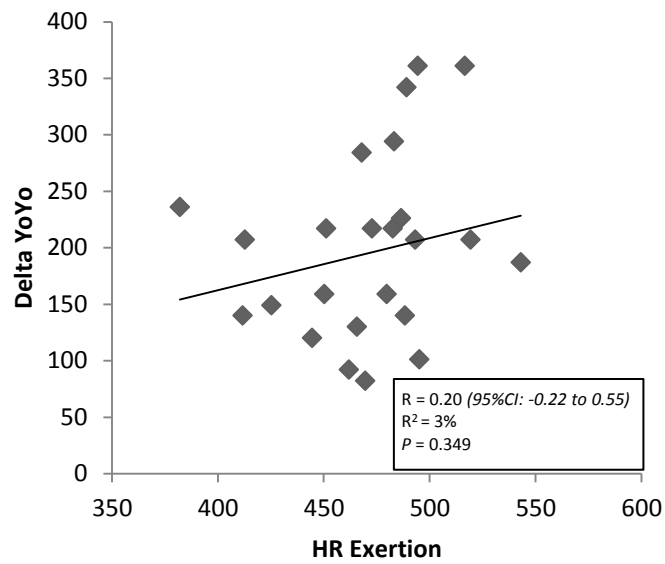
Figure 11: Scattergraphs showing the correlation between delta YoYo and mean weekly load for each MEMS device training load variable

5. Discussion

The primary aim of this study was to investigate whether dose-response relationships were present between the change in maximal YYIR1 and mean weekly training load as measured by a variety of methods. There was a small improvement (ES = 0.53) in maximal YYIR1 distance between week 1 and week 8 which would be expected with the implemented overload followed by a taper (Pearson et al., 2000). This supports previous research suggesting YYIR1 to be sensitive to training adaptations (Bishop & Spencer, 2004; Bishop, Spencer, Duffield, & Lawrence, 2001; Krustrup & Bangsbo, 2001; Krustrup et al., 2003).

Despite the significant improvement in maximal YYIR1 performance between the beginning and end of the 7-week pre-season there was found to be no significant dose-response relationship between delta YoYo and any measure of training load (Figure 11). This finding is in contrast to previous studies that have reported a relationship between individualised HR-based training load and changes in aerobic fitness in professional soccer players (Akubat et al., 2012; Castagna, Impellizzeri, Chaouachi, Bordon, & Manzi, 2011; Castagna, Impellizzeri, Chaouachi, & Manzi, 2013; Manzi et al., 2013). It is also in contrast to the findings of Akubat et al. (2012) who reported mean weekly iTRIMP over a 6-week training period to correlate with velocity at 2 mM·L^{-1} during a modified lactate threshold test on a motorised treadmill and those of Gil-Rey, Lezaun and Los Arcos (2015). Gil-Rey et al (2015) reported strong positive correlations between changes in an aerobic fitness test (Leger and Boucher's 1980 Université de Montreal endurance) and sRPE for respiratory and sRPE for leg musculature over a 9 week period, with players that accumulated a higher perceived load after 9 weeks of training being more likely to improve in the aerobic fitness test. However, the limitations of that study as outlined in the literature review must be taken into consideration when interpreting the results of their study.

One possible reason for differing results in the current study compared to the previous studies conducted by Akubat et al. (2012) and Gil-Rey et al. (2015) could be due to testing periods being at differing points of the season. The current study was performed during the pre-season period where baseline fitness generally has a much greater variance. The study by Gil-Rey et al. (2015) was performed during an in-season competitive period at which point it would be expected that the variance in baseline fitness would be much less, although the study by Akubat et al. (2012) doesn't specify the stage of season. Due to the mentioned weekly training structure it could be assumed that this study was also performed in-season and therefore, as with the Gil-Rey et al. (2015) study, baseline fitness may have had much less variance. Along with this, the tests of aerobic fitness differed in each of the studies with a modified lactate threshold on a motorised treadmill used by Akubat et al. (2012), a Leger and Boucher's 1980 Université de Montreal endurance test used by Gil-Rey et al. (2015) and a maximal YYIR1 used in the current study. It could be suggested these tests may elicit differing physiological or psychological effects. Finally, despite iTRIMP being suggested to significantly correlate with the change in the modified lactate threshold on a motorised treadmill test in the study by Akubat et al. (2012), these findings should be viewed with caution due to the number of the participants within the study. Although a significant correlation was reported ($P < 0.05$), the confidence interval was large (r = 0.67; 95%CI: 0.01 to 0.92) as would be expected with the given sample size of 9.

A potential limitation of the YYIR1 in the current study is that it has been suggested to correlate predominantly with VO_2max (Bangsbo et al., 2008; Rampinini et al., 2010) compared to the YoYo Intermittent Recovery Test Level 2 (YYIR2). YYIR2 has also been suggested to elicit a high rate of blood lactate accumulation in comparison to YYIR1 (Krustrup et al., 2006) and higher peak blood lactate concentration, lower muscle pH and lower levels of creatine phosphate in comparison to YYIR1 (Bangsbo et al., 2008; Krustrup et al., 2006), suggesting a greater anaerobic contribution in YYIR2. Despite the suggested importance of both tests in the

fitness monitoring of soccer players (Rampinini et al., 2010), with performance in each test being influenced by different adaptations to training, it could be suggested that players who performed to a high level in the pre YYIR1 had less scope to improve in the post testing as they had potentially reached their 'ceiling' of aerobic improvement. Therefore the magnitude of improvement may not have been as great. In this case it could be suggested that the YYIR2 would have been more appropriate when evaluating anaerobic adaptations (Rampinini et al., 2010). In contrast, players who performed to a lesser extent in the pre YYIR1 potentially had a large scope for improvement aerobically due to them not being as close to their 'ceiling' of aerobic performance. Furthermore, as mentioned previously, soccer involves frequent anaerobic actions within key moments of a match (Cometti et al., 2001; Faude et al., 2012). With this in mind the pre-season training may have had more focus on performing these anaerobically taxing actions, an adaptation which will not have been fully captured within the YYIR1.

With reference back to the primary aim of this study, the dose-response relationship between change in YYIR1 performance and mean weekly training load had no significant correlations between any training load method and the change in YYIR1 (Figure 11). Therefore, to date, there is still little research regarding the dose-response training effect. As previously suggested the YYIR2 could be a more applicable test for soccer and future research would be suggested to investigate this. It is also important to note that, although a number of training load measures have been found to significantly correlate, this doesn't necessarily result in a change in fitness. This suggests that either better methods of monitoring training load are required, or that a combination of existing methods are required to capture all of the variety of training stress imposed on players (Weaving et al, 2014).

The secondary aim of this study was to determine the relationship between measures of training load across a 7 week pre-season. This study found significant correlations between a number of training load metrics (Table 4), with sRPE and TMetAv displaying the strongest

correlations ($P < 0.01$) with the other measures of training load. The large correlations between sRPE and measures of external load including total distance (r = 0.76) and Player Load[TM] (r = 0.73) support previous findings (Scott et al., 2013). Of particular interest is the strong correlation between sRPE and TMetAv (r = 0.95), despite previous studies reporting a moderate correlation (r = 0.37, $P < 0.001$) between sRPE and the number of accelerations (Gaudino et al., 2015), which is a component of metabolic power. No other studies have reported a correlation between sRPE and external load derived from metabolic power. TMetAv also had strong correlations with total distance (r = 0.74) and Player Load[TM] (r = 0.76), further highlighting that these measures of external training load are probably measuring very similar aspects of training.

Total distance was found to correlate with all measures of training load other than HR Exertion (sRPE, r = 0.76; high-speed distance, r = 0.62; Player Load[TM], r = 0.73; TMetAv, r = 0.74). The significant correlations with sRPE and Player Load[TM] supports previous findings regarding the correlation between total distance and these measures of training load (Casamichana et al., 2013). Despite total distance being previously found to correlate strongly with measures of heart rate (Casamichana et al., 2013), no correlation was found in this study between total distance and HR exertion (r = 0.27). A potential reason for this discrepancy could be due to different methods of HR analysis being used. Within the current study HR exertion was used as the heart rate measure of internal load. However, in previous studies that have reported significant correlations with total distance the Edward TRIMP method for HR was used. A further potential reason for the lack of correlation between HR exertion and other measures of training load (Table 4) may be due to the increased contribution of anaerobic metabolism associated with high-intensity activities which frequently occur within soccer sessions. HR measures have been suggested to respond slowly to these short bouts of anaerobic work, resulting in these measures being underestimated (Achten & Jeukendrup, 2003).

As with previous studies, Player Load[TM] was found to correlate strongly with sRPE (r = 0.73) (Scott et al., 2013) along with total distance (r = 0.83) and TMetAv (r = 0.76) and also correlated moderately with high-speed distance (r = 0.45). Despite Player Load[TM] previously correlating largely with measures of HR (Banister's TRIMP and Edwards' TRIMP), there was no significant correlation between Player Load[TM] and HR exertion within this study.

High-speed distance was found to correlate with total distance (r = 0.62) and Player Load[TM] (r = 0.83), but despite previous studies also suggesting a significant correlation between sRPE and high-speed distance (Gaudino et al., 2015; Scott et al., 2013), this was not present within the current study.

An unusual finding from this study is the highly significant correlations between TMetAv and sRPE (r = 0.95; 95%CI = 0.89 to 0.98), total distance (r = 0.74; 95%CI = 0.49 to 0.88) and Player Load[TM] (r = 0.76; 95%CI = 0.52 to 0.89). No previous studies to date have found correlations between these metrics.

Furthermore, the use of running speed based metrics to analyse the intensity of soccer training and matches are considered to underestimate the strain players experience metabolically, with running speed based approaches being suggested to underestimate the intensity of Rugby Sevens compared to metrics derived from metabolic power (Furlan et al., 2015). A further support of the use of metabolic power as a measure of training load within soccer is that high-speed running metrics could be suggested to be largely opportunity dependant (i.e players may possess the physical capacity to perform a greater amount of running but are not able to due to a lack of opportunities to do so), with a player's high-speed distance previously being highlighted as depending largely on playing position (Bradley et al., 2009; Di Salvo et al., 2009). TMetAv is suggested to continue accumulating during periods of low activity such as walking and jogging and therefore would appear to contain less positional bias and also less sensitivity to transient fluctuations in intensity. Despite the promising signs of the use of TMetAv as an external training load measure, further research is required to continue to

validate this method of measurement as it has been suggested that this metric should be used with caution (Buchheit et al., 2015).

It is important to consider, although the results from the current study have shown promise regarding the correlations between training load measures, a limitation of this study is the sample size. Despite a number of significant correlations being found, the confidence intervals for some of these are very wide (Table 4), suggesting low precision. With this in mind, further studies with larger sample sizes are required for corroboration. It should also be considered that the athletes within this study were all from one team, therefore the physical outputs within the training week may have reflected the team's style of play rather than the individual's physical capacity. The same research may have produced different findings with another team.

5.1 Practical Applications

Due to the number of soccer teams now monitoring internal and external training loads and the recent change in rules allowing MEMS devices to be worn during matches, the findings from this study could be of some use to practitioners in soccer. With regards to the measurement of training load the findings from this study show that a number of training load measures are related to each other, suggesting that they could possibly be used interchangeably. However, the finding that no training load method correlated with the change in YYIR1 suggests that the best practice for monitoring the training load of soccer players would be the use of a combination of training load measures in order to capture a complete understanding of the physiological and psychological requirements of soccer training.

6. Conclusion

This study is one of the first to investigate the dose-response relationships between a number of common measures of training load and changes in fitness in professional soccer players. In addition, this study has provided further insight into the relationships between both internal and external training load measures within soccer training and matches. The results of this study confirm that many of these training load methods correlate with others. Despite this, a dose-response relationship between changes in fitness and internal/external training-load measures was not established and further research is required.

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APPENDICES

1. EC2 – U18

Department of Sport, Health & Exercise Science	UNIVERSITY OF **Hull**

Parent/Guardian Letter of Invitation ⓘ

Project title	The validity of metabolic power in quantifying training load in professional soccer players
Principal investigator	**Name**: Dr Grant Abt **Email address**: g.abt@hull.ac.uk **Contact telephone number**: 01482 463397
Student investigator **(if applicable)**	**Name**: Robert Svenson **Email address**: R.P.Svenson@2012.hull.ac.uk **Contact telephone number**: 07956468440

01/09/2015

Dear Parent or Guardian

This is a letter of invitation to enquire if you would like your child to take part in a research project at Stoke City Football Club

Before you decide if you would like your child to take part it is important for you to understand why the project is being done and what it will involve. Please take time to carefully read the Parent/Guardian Information Sheet on the following pages and discuss it with your child and others if you wish. Ask me if there is anything that is not clear, or if you would like more information.

If you would like your child to take part please complete the Informed Consent Declaration form and return it in the envelope provided.

Please do not hesitate to contact us if you have any questions.

Yours faithfully

Robert Svenson

Parent/Guardian Information Sheet ⓘ

1. **Project title** ⓘ	The validity of metabolic power in quantifying training load in professional soccer players
2. **Principal investigator** ⓘ	**Name**: Dr Grant Abt **Email address**: g.abt@hull.ac.uk **Contact telephone number**: 01482 463397
3. **Student investigator** **(if applicable)** ⓘ	**Name**: Robert Svenson **Email address**: R.P.Svenson@2012.hull.ac.uk **Contact telephone number**: 07956468440

4. **What is the purpose of this study?** ⓘ
The purpose of this project is to assess the validity of the Metabolic Power metric from the GPS by relating the changes in metabolic power across the pre-season to the changes in fitness following pre-season. In order to attempt to quantify the training and match load for soccer players, practitioners use a number of performance measures including locomotor variables such as Total Distance, High Speed Running Distance and Sprint Distance and variables which are often classified as mechanical including player load. With all the variables listed above, research has validated each variable to varying degrees. Another variable which has increased in popularity over recent years is 'metabolic power'. To date, there has been very little research validating this as measure of training load.

5. **Why has my child been chosen?** ⓘ
The study is seeking to recruit professional soccer players who train and play on a regular basis and make use of GPS data throughout those training sessions and matches. You have been chosen because you meet the inclusion criteria for the study.

6. **Does my child have to take part?** ⓘ
It is up to you and your child to decide whether or not to take part. If you do decide to allow your child to take part you will be given this Parent/Guardian Information Sheet to keep and asked to sign the Informed Consent Declaration form at the back. If you decide to allow your child to take part you are free to withdraw your child at any time without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect the standard of

care your child receives.

7.   What will my child have to do if he or she takes part? ⓘ
Your child will be required to complete a Yo Yo Intermittent Recovery Test (Level 1) before and after the pre-season period. This test requires your child to run back and forth between two cones spaced 20m apart. At the completion of each 40m shuttle (Up & Back) they will receive a 10s recovery. The test is incremental, which means that the test will require them to gradually increase their speed over the course of the test. Their running speed is dictated by a series of audio beeps which will gradually get closer and closer together, meaning that they will need to run faster and faster in order to keep up. They will continue to follow the beeps until they reach volitional exhaustion.   Throughout all testing, training sessions and matches they will be required to wear a GPS monitor that will be provided by the Academy. During training sessions and matches, other than wearing the GPS monitor, they will be required to train and play as they would normally do.   All of the above procedures represent standard practice at the club and do not represent any additional activity for your child.   Following the pre-season period you will be provided with a debrief document explaining the outcomes of the study and a copy of your child's fitness test data.

8.   Will participation involve any physical discomfort or psychological stress? ⓘ
The study will involve mild levels of physical discomfort associated with high-intensity exercise, but nothing that your child is not accustomed to when training and playing soccer. The study involves procedures that are very common in sport science and generally most people tolerate the tests well. Throughout the study the safety of each participant is paramount and you and your child are encouraged to communicate with the project team if they have any concerns.

9.   Are there any possible benefits of participation? ⓘ
Your child's participation in this study will help the coaches and sport scientists at the Academy better understand the use of a relatively new GPS metric in detecting change in fitness. This increased understanding will hopefully lead to better physical performance and/or reduce injury rates. As a participant your child will undergo a number of tests and procedures that can be used to provide an understanding of their current fitness.

| **10. What happens when my child has completed all that has been asked?** ⓘ |
| --- |
| Once the study is finished you and your child will be provided with a debrief form and a copy of the fitness test data. Once data collection is finished, all data will be anonymised thereby ensuring all personal and identifying information is removed. The results will then be analysed and shared with the Academy coaches and sport scientists. |

11. How will my child taking part in this project be kept confidential? ⓘ

All personal information will be kept securely and only members of the research team will have access to this information. The privacy of your child is of upmost important throughout the study and every effort will be made to ensure their involvement and personal information remains secure. All hardcopies of documentation will be kept in a secure location within the Department of Sport, Health and Exercise Science or in a secure off-site location. Any electronic information will be stored on password-protected computers.

12. How will my child's data be used? ⓘ

Data collected from the study will be used to establish (or not) the validity of the new indicator of change in fitness. All data analysed will be anonymous and after analysis the results will be shared with the Academy coaches and sport scientists. No personal identifying information will be made public and only members of the research team will have access to this data during the data collection phase of the study. Your child's data will contribute to the completion of a masters degree thesis and may also contribute to publication/s relating to this project.

13. Who is organising and funding the research? ⓘ

The study is organised by Robert Svenson who is a Masters degree student in the Department of Sport, Health and Exercise Science at the University of Hull.

14. What if my child or I are unhappy during my child's participation in the project? ⓘ

You are free to withdraw your child at any time. During the study itself, if you decide that you do not wish your child to take any further part then please inform the person named in Section 15 and he or she will facilitate your withdrawal. You do not have to give a reason for withdrawing your child. Any information or data relating to your child (both paper and electronic) will be destroyed or deleted as soon as possible after your child's withdrawal. After your child has completed the research you can still withdraw your child's personal information and data by contacting the person named in Section 15. If you are concerned that regulations are being infringed, or that you or your child's interests are otherwise being ignored, neglected or denied, you should inform Dr Andrew Garrett, Chair of the Department of Sport, Health and Exercise Research Ethics Committee, who will investigate your complaint (Tel: 01482 463866; Email: a.garrett@hull.ac.uk).

15. How can my child take part? ⓘ

If you decide to allow your child to take part in the study then you are asked to complete and return the Informed Consent Declaration form found on the next page. You should retain this Parent/Guardian Information Sheet for your information. If you have any queries please contact the investigator using the details given below. He or she will answer any queries and explain

how your child can get involved.

Name: Robert Svenson **Email:** R.P.Svenson@2012.hull.ac.uk   **Phone:** 07956 468440

Informed Consent Declaration ⓘ

Project title	The validity of metabolic power in quantifying training load in professional soccer players
Principal investigator	**Name**: Dr Grant Abt **Email address**: g.abt@hull.ac.uk **Contact telephone number**: 01482 463397
Student investigator **(if applicable)**	**Name**: Robert Svenson **Email address**: R.P.Svenson@2012.hull.ac.uk **Contact telephone number**: 07956 468440

Please Initial

- I confirm that I have read and understand all the information provided in the Parent/Guardian Information Sheet (EC2-U18) relating to the above project and I have had the opportunity to ask questions.

- I understand this project is designed to further scientific knowledge and that all procedures have been risk assessed and approved by the Department of Sport, Health and Exercise Science Ethics Committee (University of Hull). Questions I have about my child's participation in this project have been answered to my satisfaction.

- I fully understand my child's participation is voluntary and that I am free to withdraw my child from this project at any time and at any stage, without giving any reason. I have read and fully understand this consent form.

- I agree for my child to take part in the above project.

....

Parent/Guardian name   **Date**   **Signature**

....

Child's name and date of birth   **Date**   **Signature of Assent (child's signature)**

....

Person taking consent   **Date**   **Signature**

2. EC2

UNIVERSITY OF **Hull**

Participant Letter of Invitation ⓘ

Project title	The validity of metabolic power in quantifying training load in professional soccer players
Principal investigator	Name: Dr Grant Abt Email address: g.abt@hull.ac.uk Contact telephone number: 01482 463397
Student investigator (if applicable)	Name: Robert Svenson Email address: R.P.Svenson@2012.hull.ac.uk Contact telephone number: 07956468440

01/09/2015

Dear Sir or Madam

This is a letter of invitation to enquire if you would like to take part in a research project at Stoke City Football Club

Before you decide if you would like to take part it is important for you to understand why the project is being done and what it will involve. Please take time to carefully read the Participant Information Sheet on the following pages and discuss it with others if you wish. Ask me if there is anything that is not clear, or if you would like more information.

If you would like to take part please complete and return the Informed Consent Declaration form.

Please do not hesitate to contact me if you have any questions.

Yours faithfully,

Robert Svenson

Department of Sport, Health & Exercise Science

Participant Information Sheet

Project title ⓘ	The validity of metabolic power in quantifying training load in professional soccer players
Principal investigator ⓘ	Name: Dr Grant Abt Email address: g.abt@hull.ac.uk Contact telephone number: 01482 463397
Student investigator (if applicable) ⓘ	Name: Robert Svenson Email address: R.P.Svenson@2012.hull.ac.uk Contact telephone number: 07956468440

What is the purpose of this project? ⓘ

The purpose of this project is to assess the validity of the Metabolic Power metric from the GPS by relating the changes in metabolic power across the pre-season to the changes in fitness following pre-season. In order to attempt to quantify the training and match load for soccer players, practitioners use a number of performance measures including locomotor variables such as Total Distance, High Speed Running Distance and Sprint Distance and variables which are often classified as mechanical including player load. With all the variables listed above, research has validated each variable to varying degrees. Another variable which has increased in popularity over recent years is 'metabolic power'. To date, there has been very little research validating this as measure of training load.

Why have I been chosen? ⓘ

The study is seeking to recruit professional soccer players who train and play on a regular basis and make use of GPS data throughout those training sessions and matches. You have been chosen because you meet the inclusion criteria for the study.

What happens if I volunteer to take part in this project? ⓘ

First, it is up to you to decide whether or not to take part. If you decide to take part you will be given this Participant Information Sheet to keep and asked to complete the Informed Consent

Declaration at the back. You should give the Informed Consent Declaration to the investigator at the earliest opportunity. You will also have the opportunity to ask any questions you may have about the project. If you decide to take part you are still free to withdraw at any time and without needing to give a reason.

What will I have to do?

You will be required to complete a Yo Yo Intermittent Recovery Test (Level 1) before and after the pre-season period. This test requires you to run back and forth between two cones spaced 20m apart. At the completion of each 40m shuttle (Up & Back) you will receive a 10s recovery. The test is incremental, which means that the test will require you to gradually increase your speed over the course of the test. Their running speed is dictated by a series of audio beeps which will gradually get closer and closer together, meaning you will need to run faster and faster in order to keep up. You will continue to follow the beeps until you reach volitional exhaustion.

Throughout all testing, training sessions and matches you will be required to wear a GPS monitor that will be provided by the Academy. During training sessions and matches, other than wearing the GPS monitor, you will be required to train and play as you would normally do.

All of the above procedures represent standard practice at the club and do not represent any additional activity yourself.

Following the pre-season period you will be provided with a debrief document explaining the outcomes of the study and a copy of your fitness test data.

Will I receive any financial reward or travel expenses for taking part?

No financial reward or travel expense reimbursement will be provided.

Are there any other benefits of taking part?

Your participation in this study will help the coaches and sport scientists at the Academy better understand the use of a relatively new GPS metric in detecting change in fitness. This increased understanding will hopefully lead to better physical performance and/or reduce injury rates. As a participant you will undergo a number of tests and procedures that can be used to provide an understanding of your current fitness.

Will participation involve any physical discomfort or harm?

The study will involve mild levels of physical discomfort associated with high-intensity exercise,

but nothing that you are not accustomed to when training and playing soccer. The study involves procedures that are very common in sport science and generally most people tolerate the tests well. Throughout the study the safety of each participant is paramount and you are encouraged to communicate with the project team if you have any concerns.

Will I have to provide any bodily samples (e.g. blood or saliva)? ⓘ

No

Will participation involve any embarrassment or other psychological stress? ⓘ

No

What will happen once I have completed all that is asked of me? ⓘ

Once the study is finished you will be provided with a debrief form and a copy of the fitness test data. Once data collection is finished, all data will be anonymised thereby ensuring all personal and identifying information is removed. The results will then be analysed and shared with the Academy coaches and sport scientists

How will my taking part in this project be kept confidential? ⓘ

All personal information will be kept securely and only members of the research team will have access to this information. Your privacy is of upmost important throughout the study and every effort will be made to ensure your involvement and personal information remains secure. All hardcopies of documentation will be kept in a secure location within the Department of Sport, Health and Exercise Science or in a secure off-site location. Any electronic information will be stored on password-protected computers

How will my data be used? ⓘ

Data collected from the study will be used to establish (or not) the validity of the new indicator of change in fitness. All data analysed will be anonymous and after analysis the results will be submitted to a peer-reviewed scientific journal. No personal identifying information will be made public and only members of the research team will have access to this data during the data collection phase of the study.Your data will contribute to the completion of a masters degree thesis and may also contribute to publication/s relating to this project.

Who has reviewed this study? ⓘ

This project has undergone full ethical scrutiny and all procedures have been risk assessed and approved by the Department of Sport, Health and Exercise Science Ethics Committee at the University of Hull.

What if I am unhappy during my participation in the project? ⓘ

You are free to withdraw from the project at any time. During the study itself, if you decide that you do not wish to take any further part then please inform the person named in Section 18 and they will facilitate your withdrawal. You do not have to give a reason for your withdrawal. Any personal information or data that you have provided (both paper and electronic) will be destroyed or deleted as soon as possible after your withdrawal. After you have completed the research you can still withdraw your personal information and data by contacting the person named in Section 18. If you are concerned that regulations are being infringed, or that your interests are otherwise being ignored, neglected or denied, you should inform Dr Andrew Garrett, Chair of the Department of Sport, Health and Exercise Research Ethics Committee, who will investigate your complaint (Tel: 01482 463866; Email: a.garrett@hull.ac.uk

How do I take part? ⓘ

Contact the investigator using the contact details given below. He or she will answer any queries and explain how you can get involved.

Name: Robert Svenson Email: R.P.Svenson@2012.hull.ac.uk Phone: 07956468440

Informed Consent Declaration ⓘ

Project title	The validity of metabolic power in quantifying training load in professional soccer players
Principal investigator	Name: Dr Grant Abt Email address: g.abt@hull.ac.uk Contact telephone number: 01482 463397
Student investigator (if applicable)	Name: Robert Svenson Email address: R.P.Svenson@2012.hull.ac.uk Contact telephone number: 07956468440

Please Initial

I confirm that I have read and understood all the information provided in the Informed Consent Form (EC2) relating to the above project and I have had the opportunity to ask questions.

I understand this project is designed to further scientific knowledge and that all procedures have been risk assessed and approved by the Department of Sport, Health and Exercise Science Research Ethics Committee at the University of Hull. Any questions I have about my participation in this project have been answered to my satisfaction.

I fully understand my participation is voluntary and that I am free to withdraw from this project at any time and at any stage, without giving any reason. I have read and fully understand this consent form.

I agree to take part in this project.

....

Name of participant   Date   Signature

....

Person taking consent   Date   Signature

3. EC5 – Participant Debrief Form

Participant Debrief Form

1. **Project title** ⓘ	The validity of metabolic power in quantifying training load in professional soccer players
2. **Principal investigator** ⓘ	**Name**: Dr Grant Abt **Email address**: g.abt@hull.ac.uk **Contact telephone number**: 01482 463397
3. **Student investigator** **(if applicable)** ⓘ	**Name**: Robert Svenson **Email address**: R.P.Svenson@2012.hull.ac.uk **Contact telephone number**: 07956468440

4. What was the purpose of the project? ⓘ

The purpose of this project was to assess the validity of Metabolic Power metric from the GPS by relating the changes in metabolic power across the pre-season to the changes in fitness following pre-season. In order to attempt to quantify the training and match load for soccer players, practitioners use a number of performance measures including locomotor variables such as Total Distance, High Speed Running Distance and Sprint Distance and variables which are often classified as mechanical including player load. With all the variables listed above, research has validated each variable to varying degrees. Another variable which has increased in popularity over recent years is 'metabolic power'. To date, very has been very little research validating this as measure of training load.

5. How will I find out about the results? ⓘ

The results of the research project will contribute to an MSc thesis. Information about the outcome of the study will be made available to each participant once analysis of the results is complete.

6. Will I receive any individual feedback? ⓘ

Individual feedback will be made available to every participant; this information will involve details regarding performance during all exercise tests and track the improvement over the

training period. Participants will be able to opt-out from receiving this information if they so wish.

7. What will happen to the information I have provided? ⓘ

Any information provided in confidence will be made anonymous and stored for a period of five years after the data collection of the project concludes. After five years of storage, hard copies of documents will be destroyed.

8. How will the results be disseminated? ⓘ

The results from this study will be part of an MSc thesis; this will be available in print and

electronic form and will be stored in the University of Hull library.

9. Have I been deceived in any way during the project? ⓘ

No

10. If I change my mind and wish to withdraw the information I have provided, how do I do this? ⓘ

If you would like to withdraw your information from the project please contact Robert Svenson by email (Robert.svenson@stokecityfc.com) or in person.

11. What if I am unhappy about my participation in the project? ⓘ

If you have any concerns or worries concerning the way in which this research has been conducted, or if you have requested, but did not receive feedback from the investigator regarding your results within the time specified in the Participant Debrief Form, then please contact Dr Andrew Garrett, Chair of the Department of Sport, Health and Exercise Ethics Committee, who will investigate your complaint (Tel: 01482 463141; Email: a.garrett@hull.ac.uk).

4. Letter from Fifa regarding the use of GPS in competative gameplay

FIFA®
For the Game. For the World.

TO THE MEMBERS OF FIFA

Circular no. 1494

Zurich, 8 July 2015
SG/sco/ovo

Approval of Electronic Performance and Tracking System (EPTS) devices

Dear Sir or Madam,

Technology is advancing at a great pace in all aspects of our daily life, and of course, our beautiful game is not an exception. One example of this is the use of electronic devices aimed at monitoring, tracking and storing data about the performance of players on the field of play.

Requests have been made to The IFAB to permit players to wear such devices during matches. Although the permission to wear EPTS devices was given in principle by The IFAB, the final decision as to whether or not EPTS devices may be used lies with the respective association, league or competition (according to The IFAB Circular No. 1, sent to the member associations in May this year).

FIFA has put in place a process to control the use of these tools for its own final competitions. For instance, for the FIFA U-20 World Cup New Zealand 2015 and the FIFA Women's World Cup Canada 2015™, the teams were requested to send these electronic performance and tracking system devices to be inspected by FIFA.

In general terms, the approval of such tools are subject to the following principles:

- All devices will be inspected (including those devices already inspected) at the Team Arrival Meeting by the FIFA referee instructor or another occasion as considered appropriate by FIFA. If there are any concerns, the devices will be presented to the FIFA Medical Officer for further inspection and a joint final decision with either the match commissioner or general coordinator.

- The data to be collected by an approved electronic performance or tracking system device, or any interpretation of it, may only be used by the respective participating team and/or the individual player for performance monitoring purposes (including physical, technical and tactical data) and by no means for any commercial purpose and/or in association with any third party.

- In order to protect the integrity of, and FIFA's rights in, the competition, FIFA may impose further restrictions on the use of the data collected by an approved electronic performance or tracking system device.

Fédération Internationale de Football Association
FIFA-Strasse 20   P.O. Box   8044 Zurich   Switzerland   T: +41 (0)43 222 7777   F: +41 (0)43 222 7878   www.FIFA.com

- According to art. 25 of the FIFA Equipment Regulations, the device shall not display the branding of its manufacturer or any third party with the exception of one tonal identification of its manufacturer which is not visible whilst such device is used.

- No technical devices will be allowed in the technical area, nor may any data/information collected through such devices be transmitted to the technical area during the match.

Furthermore, according to Law 4 of the Laws of the Game, such devices shall not cause any danger to the player himself/herself or any opposing player.

Participating member associations shall ensure that all team delegation members fully comply with the above requirements. The responsibility for failing to do so will be borne by the member association.

FIFA would like to emphasise that any device worn is at the risk and responsibility of the player and/or member association concerned.

Thank you for your cooperation with the above.

Yours faithfully,

FÉDÉRATION INTERNATIONALE
DE FOOTBALL ASSOCIATION

Jérôme Valcke
Secretary General

cc: FIFA Executive Committee
        - Confederations

CMP