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Categorising repeated sprint activity in professional soccer

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Abstract

Limited information exists about repeated sprint activity in elite soccer. The purpose of this study was to investigate the repeated sprint demands in elite soccer throughout the game and to investigate if positional differences exist. Physical performance in official competition was analysed for players in a professional soccer team that competed in the English Championship in 2010/2011 season using a multi-camera computerised tracking system. Repeated sprint performance (defined as a minimum of three sprints with recovery duration between sprints of less than 21 seconds) was measured in 10 championship games. Wide midfielders had the highest number of bouts and were significantly greater than centre backs ($p<0.001$; effect size = 0.85) and centre forwards ($p<0.05$; effect size = 0.64). Time to next sprint was influenced by position with wide players having least recovery time and centre backs having the longest time to next sprint ($p<0.05$; effect size = 0.62). Wide players total bout distance was significantly higher than central midfielders total bout distance ($p<0.05$). The results demonstrate that repeated sprint performance may be an important physiological quality within elite level football and its relative importance particularly towards the end of games cannot be underestimated.

Keywords: Repeated Sprint, Physical performance, Fatigue, Position, Sprinting, Soccer

Categorising Repeated Sprint Activity in Professional Soccer

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Attestation

I understand the nature of plagiarism, and I am aware of the University’s policy on this. I certify that this thesis reports original work by me during my University project and all other material is appropriately referenced.

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1.0 Introduction

Field based team sports such as soccer have unpredictable movement patterns, where players are required to perform maximal or near maximal sprints of short duration interspersed with brief recovery periods throughout match play. These sprint type activities such as ‘sprinting down the wing to cross’ or a ‘last ditch tackle’ are widely considered to be a crucial element of performance but are only considered to be of a small proportion to the overall motion activity during games, quantified as being approx 10% (Carling *et al,*. 2008). The ability to recover and to reproduce performance in subsequent sprints is probably an important fitness requirement of athletes engaged in field based disciplines and has been termed repeated sprint ability (RSA) (Girard *et al.,* 2011). Consequently, it is fundamental that players develop the ability to repeatedly perform intense exercise for long periods of time (Iaia *et al*., 2009). Data from match analysis shows the demands placed on players are high and that temporary and permanent decrements occur in high intensity running (Bradley *et al.*, 2009). In addition, the frequency of high intensity bouts, with and without possession is affected by fatigue and the activity patterns vary between playing positions (Bradley *et al.,* 2009). Gabbet and Mulvey (2008) postulate that having the ability to recover and subsequently reproduce these efforts (RSA) is a critical component of soccer.

The modern day footballer plays approx 50 games per season and may be required to play up to three games per week and requires a high level of fitness to cope with the energy demands of the game (Iaia *et al*., 2009). Due to the high physiological demands placed upon players during a competitive season it is difficult to assess ‘fitness levels’ within this time frame. With the introduction of semi automatic computerised tracking systems to determine the work rate of elite players (Rampinini *et al.*, 2008) many sports scientist have began ‘monitoring’ players activity levels during games through systems such as Amisco and Pro Zone. There have been strong associations made between time motion analysis assessments of match performance and measures of fitness obtained via field and laboratory testing of soccer players (Carling *et al*., 2008). Bradley *et al*. (2009) postulate the need for a high anaerobic capacity when a large number of high intensity runs have to be performed within a 5 minute period. The amount of high intensity running in the most intense period of the game has been suggested to be related to the player’s physical capacity as evaluated by the Yo-yo IR2 Test (Randers *et al.,* 2007).

The match analysis literature to date has presented information regarding sprint distance means and total distances (Bradley *et al*., 2009; Di Salvo *et al*., 2009; Bradley *et al*., 2010) rather than the specific nature of high intensity or repeated sprints bouts performed. Although time motion analysis data reported throughout a game may provide valuable information on the overall physiological demands of team sport competition, it only provides a limited insight into the ‘physiology of repeated sprint ability' and patterns of repeated sprint ability (Spencer *et al*., 2004). There is limited information on the ability of soccer players to perform specific bouts of soccer activities where players repeat several intense running actions of short duration or 'repeated sprint bouts' over short time intervals (Carling *et al*., 2012). Furthermore, the relationship between match performance at the professional level for example total distance, high intensity distance and the results from tests of RSA have shown only moderate correlations (Rampinini *et al*., 2008). This is hardly surprising however as the association of match play measures related to RSA such as frequency of repeated sprint bouts with performance in RSA tests have also yet to be explored. It could be argued that RSA in elite soccer has not yet been categorised within elite match play thus it is difficult to develop field based RSA tests with ecological validity and the relevance to soccer match play. There may be instances in the game such as when teams are losing and chasing the game; or down to ten men having had a players sent off; or when games go into extra time, where players are required to perform sporadic but extreme sequences of repeated sprint activity therefore players must be highly conditioned to perform under these situations and these scenarios are difficult to replicate during game related training and field or laboratory based assessments.

Over the last 25 years, scientists have reported a plethora of tests of RSA (Dawson 2012) and RSA is widely accepted as a critical component of high intensity intermittent sports (eg soccer) (Gabbett, 2010) however scientists have yet to attain a 'gold standard' measurement of RSA and therefore its importance to match performance is not fully elucidated. Spencer *et al*. (2005) postulate the main reason it has been difficult to investigate the nature of RSA is because of the unpredictability of player movements performed during field based team sports. There have been methodological limitations in identifying repeated sprint performance however, with improvements in technology, motion analysis has allowed researchers to document the detailed movement patterns of elite team sport athletes. Carling *et al*. (2012) conclude the relative importance of RSA to team performance in professional soccer remains unexplored. Accordingly, there is a need for appropriate repeated sprint experimental protocols that match the movement pattern in order to replicate the most intense physiological demands of the game (Meckel *et al.*, 2009) as many tests have failed to take into account the most extreme demands of the sport (Gabbett, 2010).

Gabbett and Mulvey (2008) found international female football players performed repeated sprint bouts almost five times per game while Carling *et al*. (2012) found only one bout per player and suggests the fitness component of repeated high intensity bouts might not play as crucial a role in elite match performance as commonly believed. In the study of French Ligue 1 footballers, the authors investigated repeated high intensity demands and concluded doubts must be raised on the validity of laboratory repeated sprint based tests to predict physical performance. However, they did not investigate the possible occurrence of fatigue patterns in repeated high intensity performance as matches progressed and concluded the area warranted further research (Carling *et al*., 2012).

Clearly without an understanding of the most extreme demands of competition, the development of game specific conditioning programs to tolerate these demands becomes problematic (Gabbett and Mulvey, 208). Thus, in order to gain a detailed analysis of the distinct quality of RSA within the overall work rate profile, a full understanding of match analysis is required, as such information will provide important links to the specific testing, monitoring and conditioning of players (Di Salvo *et al.,* 2009) so that optimal training and preparation strategies can be constructed based upon the demands of match play. Individualising the data from time motion analysis into specific positional roles is required to further our understanding of the repeated sprint demands, in order to adequately assess repeated sprint ability in soccer through reliable and valid measurements.

Enhancing the understanding of RSA will have practical implications for practitioners to identify athletes' ability to perform RSA based on the demands of the individual role, information which is highly relevant for those who do not play ninety minutes every week such as substitutes or those left out of the team due to selection reasons.

Consequently, the study will investigate the repeated sprint demands in elite soccer across 90mins and investigate if positional differences of repeated sprint demands exist. The data will have implications for training regimes for position specific and have implications for the design and validity of repeated sprint tests in terms of frequency, distance and duration of repeated sprint assessments.

1.2 Aims, objectives and hypothesis

The aims of the study are twofold: (1) to investigate the repeated sprint performance in elite soccer across 90mins and (2) to investigate if positional differences of repeated sprint performance exist. In order to do this, repeated sprint performance will be assessed via the number of repeated sprint bouts, the number of repetitions per repeated sprint bout, the maximal distance per repetition, the bout total distance, average distance per repetition and maximal distance per repetition, mean bout duration, mean recovery time between repetitions, and the time to the next sprint.

It is hypothesised that there will be positional differences of repeated sprint performance and in addition, it is hypothesised that repeated sprint performance will decline over the 90 minutes.

2.0 Literature Review

2.1 Time motion analysis

In order to gain an insight into the physiological loads imposed on soccer players during competitive elite soccer, observations have to be made during real match-play. Motion analysis entails determining work-rate profiles of players within a team and classifying activities in terms of intensity, duration and frequency (Reilly, 1994). The application of motion analysis to soccer has enabled the objective recording and interpretation of match events, describing the characteristic patterns of activity in soccer (Strudwick and Reilly, 2001). Findings from time motion studies are useful for quantifying the physiological demands of soccer and can provide the conceptual framework for the development of specific performance tests and training regimes (Drust *et al*., 2000). Di Salvo *et al.* (2007) highlight the practical value of match analysis is that well chosen performance indictors can help coaches to identify good and bad performances of both individuals and teams.

Choosing to employ methodologies that evaluate overall exercise intensity associated with the game rather than any one specific element in great detail is probably a consequence of the time required to complete the extensive time motion analysis (Di Salvo *et al.,* 2009). Differentiating between movement activities such as striding and sprinting is somewhat difficult (Spencer *et al.,* 2004). Therefore, this has limited the available information in relation to high intensity running with general variables such as total distance covered, total time spent and the frequency of occurrence in various classification zones being reported. Semi automated computerised tracking systems have been recently introduced (Rampinini et al., 2007) enabling more detailed analysis of specific elements of individual's match performance to be investigated.

2.1.1 Distance Covered

Reilly and Thomas (1976) proposed the total distance covered provides information about the physiological load associated with soccer match-play. Several authors have determined the individual distance covered during a game, which can then be used as an indicator of the total work performed. Various methods have been used to quantify distance covered during a soccer game, including the use of hand notation systems, coded commentary (Reilly and Thomas, 1976), video recordings (Bangsbo *et al.,* 1991) and computerised techniques (Oshashi *et al.,* 1988). The different analysis techniques have meant that varying distances covered by players have been reported in the literature and make comparisons difficult. However, within the literature there is limited information of contemporary elite standard English League soccer players and Bradley *et al*. (2009) revealed total distances covered in the modern elite standard English League are much higher than 30 years ago reporting values of 9.5 – 11.5km. Nevertheless, there is a general consensus that elite players cover a distance of 9-12 km during match-play (Strudwick and Reilly, 2001). Several researchers have observed a reduction in total distance covered in the second half compared with the first (Reilly and Thomas, 1976; Bangsbo *et al*., 1991). Bangsbo (2003) postulate that the reduction may indicate the development of fatigue in the second half, although total distance covered appears not to be a perfect indicator of physical performance in a match. Carling *et al*. (2008) concluded sprint type activities accounted for approx 10% of the total distance covered in games in the English Leagues.

2.1.2 High Intensity Distance Covered

Semi automatic computerised tracking systems to enable the movement patterns of players has recently been introduced and has been used to determine the work rate of elite players (Rampinini *et al.*, 2008). This enables more complicated analytical evaluations of the specific elements of an individual player's match performance can be generated (Di Salvo *et al*., 2009). It is especially applicable to high intensity activities as more detailed information can be identified on the specifics of sprint activity enabling differential analysis of a key component of work rate to be collected (Di Salvo *et al*., 2009).

Some researchers have suggested that distances covered during high intensity running in matches are valid measures of physical performance in soccer because of their strong relationships with training status (Mohr *et al.,* 2003; Krustrup *et al.,* 2005) and are a distinguishing characteristic between different standards of player (Mohr *et al*., 2003). High intensity efforts are critical to the outcome of matches as they relate to activities that are key to the final match results such as movements to win the ball and actions with agility to go past defending players (Stolen, 2005).

Despite large positional differences in high intensity running, the pattern of high intensity running decreased after the most intense periods and towards the end of the game for players in all playing positions (Bradley *et al.,* 2009). A recent study by Rampinini *et al.* (2007) showed that players in the English Premier League that covered less distance at high intensity in the first half were able to cover more distance in the second half. Bradley *et al*. (2009) concluded the mean recovery time between very high intensity running bouts increased markedly over the duration of the game. These findings are similar to Krustrup *et al*. (2006) who reported both single and repeated sprint test performances are impaired after a high intensity period during as well as at the end of a game. Although it has been argued this may be due to the onset of fatigue (Krustrup *et al*., 2006; Bradley *et al*., 2009) it cannot be discounted that players have adopted a 'pacing strategy' whereby players reduce the amount of work they perform as this may be dependent on other external factors such as tactical system, the outcome of the match or their position on the pitch eg Centre Back when leading 3-0.

Furthermore, Bradley *et al*. (2009) attempted to examine 5 minute periods of High Intensity Running (HIR) by position in order to gain information regarding patterns of within game fatigue. The study was the first to report mean recovery times between very high intensity bouts and across the 5 min periods of the game, although these were on pre determined 5 min periods which potentially could mean the true temporary drop may have been even greater (Bradley *et al*., 2009). Bradley *et al*. (2009) categorised HIR as running, high speed running and sprinting (running speed >14.4km/h), while Very High Intensity Running (VHIR) consisted of high speed running and sprinting (running speed >19.8km/h.) VHIR is similar to Di Salvo *et al*. (2009) who categorised Total High Intensity Running (THIR) (running speed >19.8km/h) as high speed running and sprinting. Total Sprint Distance (TSD) consists of sprinting only (running speed >25.2km/h). The tactical relevance of High Speed Running and sprinting can be further illustrated by observation of positional differences in high intensity activity (Di Salvo *et al*., 2009). Tble 2.1 *below indicates the high intensity positional differences between Bradley et al. (2009) and Di Salvo et al. (2009) for running speed >19.8km/h and sprint distance > 25km/h*

Table 1.0 High Intensity Activity and Sprint Distance Comparisons of Positions (m)

	Full Backs	*Centre Backs*	*Wide Midfielders*	*Central Midfielders*	*Attackers*
VHIR (Bradley et al., 2009)	*984±195*	*603±132*	*1214±251*	*927±245*	*955±239*
THIR (Di Salvo et al.,2009)	*911±123*	*681±128*	*1049±106*	*928±124*	*968±143*
TSD (Bradley et al., 2009)	*287±98*	*152±50*	*346±115*	*204±89*	*264±87*
TSD (Di Salvo et al.,2009)	*238±55*	*167±53*	*260±47*	*217±46*	*262±63*

Bradley *et al*. (2009) suggest the amount of high intensity running is 10-15% higher in the English Premier League than in the Danish (Mohr *et al*., 2003) and Swedish league (Andersson *et al*., 2007). Tactical and differences in playing style may explain the increased intensity in the modern English game, where players are required to maintain a high level of activity in order to pressurise opponent or create space to receive passes (Bradley *et al*., 2009). Bradley *et al*. (2009) speculated, fitness levels of attackers are not sufficient to meet the demands of elite European Leagues. The authors (Bradley *et al*., 2009) concluded further studies are required to investigate the physical fitness of English FA Premier League attackers and its influence on team performance. This may be affected by tactics and formations however as some teams play a 'target man' attacker who does not press the opposition's defenders when his team are not in possession or a 'lone striker' in a team who choose to employ a defensive strategy.

The high intensity distance deficit (first 15min compared to last 15 min) was similar with and without possession of the ball indicating that all parts of play are affected by fatigue (Bradley *et al*., 2009). Differentiating between high intensity activity with and without the ball enables the relative effectiveness of high intensity efforts in relation to crucial match outcomes to be evaluated (Di Salvo *et al*., 2009). Di Salvo *et al*. (2009) indicate it is not the completion of THIR *per se* that is the most important indicator of team performance but rather the significance of this activity in relation to its function in the game. The authors evaluated the importance of high intensity running activity to overall team success and found that overall effectiveness of tactical and technical strategies rather than physical performance *per se* are more important in determining success in soccer (Di Salvo *et al*., 2009).

Di Salvo *et al*. (2009) proposed position specific activity is influenced by the success of the team. Players from less successful teams seem to require greater amounts of intense running from wide midfield positions while the amount of distance covered in position is increased for all positions in successful teams particularly wide midfielders except for central defenders and forwards. However, these demands may be a consequence of a specific tactical strategy employed by the team e.g. no pressing in the opposition's half.

2.1.3 Sprint Distance

Sprint type activities account for approximately 12% of the total distance covered with such efforts being short in terms of mean distance 16m (mean distance 16m) and duration (mean duration 2s; Rampinini *et al*., 2007). Total sprint distance observed by Di Salvo *et al*. (2009) was 229±71m with mean number of sprints 32±8m. Stolen *et al*. (2005) in their review have concluded large variations in both intense running and sprinting exist and the variability is partly due to methodological differences that exist between studies (Spencer *et al*., 2005). Di Salvo *et al*. (2009) argue there are difficulties in making comparison between studies sprinting as different definitions and analysis systems have been used.

Spencer *et al*. (2004) concluded the exercise intensities and sprint activities observed during elite level hockey competition are similar to those of elite soccer, rugby, and Australian Rules Football. In the first published study documenting the nature of repeated sprint activity, Spencer *et al*. (2004) identified sprint frequency (30 ±14) similar to those observed by Balsom *et al*. (1994) for elite level football although no sprint distance was reported. Bradley *et al*. (2009) and Di Salvo *et al*. (2009) both reported similar sprint distance and sprint frequency, however Di Salvo *et al*. (2009) stated 'positional sprint differences generally reflected differences in the number of sprints rather than a change in the pattern on sprint distance.' In addition, an interesting finding from was that maximal running speeds reached during games were 6-8% higher for wide midfielders and attackers than for central defenders. Although the reliability in the study was not determined, they concluded large differences in maximal running speeds were present between playing positions (Bradley *et al*., 2009). Di Salvo *et al*. (2009) were the first authors to differentiate between sprint activity i.e. explosive or leading according to their velocity profile. Players in central positions (central defenders and central midfielders) displayed a higher percentage of their sprint activity to be more explosive in nature while, significantly higher percentage of leading sprints were completed by players in wide positions and forward players. These findings could be explained by wide players waiting to receive passes when switching play and then running into open space whereas for central players the middle of the pitch is much more congested.

2.2 Repeated Sprint Ability

Both single and repeated sprint test performances are impaired after a high intensity period during as well as at the end of a game (see figure 1; Krustrup *et al*., 2006). The authors state it is unclear what causes the development of fatigue during a game and the cause of fatigue is likely to be multifactorial (Krustrup *et al*., 2006). In this study, sprint performance before and immediately after each half and after an intense period in each half was examined. Performance of the third, fourth and fifth sprints carried out after an intense period during the first half was reduced compared with before the game. In addition, sprint performance at the end of each half was the same as before the game and performance of all five sprints was reduced after an intense period in the second half suggesting temporary fatigue occurs during match play. This is in agreement with Mohr *et al.* (2003) who concluded temporary fatigue occurs during a game, and in the 5-min period following the most intense period of the game, the amount of high intensity exercise was reduced to levels below game average and towards the end of the game. Mohr *et al.* (2005) concluded the reduction in exercise intensity and sprint performance in the final phases of the game is independent of playing position, level of competition and gender, therefore indicating that most players utilize their physical potential during a game. Thus, assessing the ability of players to repeatedly sprint is considered a worthwhile performance measure for those involved in multiple sprint sports (Bishop *et al.*, 2001).

A

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FIGURE 1—Time of five 30-m sprints before the game (filled circles), after the first half (open circles), and after the game (filled triangles) (A, N = 11) as well as time of five 30-m sprints before the game (filled circles) and after intense exercise periods during the first (open circles) and second halves (filled triangles) (B, N = 20). The sprints were separated by 25-s periods of active recovery. Data are means ± SEM. Krustrup *et al*. (2006)

Mohr *et al.* (2005) indicated that most players utilise their physical potential during a game, however, Krustrup *et al.* (2006) sampling from blood and muscle lactate reported that changes in muscle metabolites (ATP, PCr, Lactate etc) during a soccer match are quite small, therefore perhaps questioning whether players are playing within their physiological limits. This leads to the question as to whether or not "pacing strategies" are adopted throughout the game. It is also a possibility that the variability of repeated sprint performance differs against different levels of opposition (Di Salvo *et al*., 2009), and during stages of the season. In addition, the assessment of repeated sprint performance in games may be based on tactical implications and game demands, not necessarily repeated sprint ability or capacity.

2.2.1 Repeated Sprint Demands in match play

Gabbett and Mulvey (2008) was the first study to investigate the repeated sprint demands of soccer with respect to duration of sprints, number of sprint repetitions, recovery duration and recovery intensity in their analysis of small sided training games and competition in elite women soccer players. Interestingly, Gabbett and Mulvey (2008) found similar repeated sprint demands for different playing positions with midfielders performing more repeated sprint bouts in a match; and the number of sprints and sprinting duration were similar among the different playing positions However, it must be stipulated that although position specific, the positions were only categorised into defenders, midfielders and forwards. Recovery duration between sprints was the only repeated sprint variable to differ considerably between defenders (4.3 seconds), midfielders (6.6 seconds) and attackers (6.7 seconds). Gabbett and Mulvey (2008) demonstrated players performed an average of 4.8 repeated sprint bouts per player per match (n = 12), with each bout comprising three to six sprints with mean recovery time of 5.8 seconds between sprints in comparison to Spencer *et al*. (2004) who found a mean recovery time of 14.9 seconds between sprints. This demonstrates quite different repeated sprint demands between soccer and field hockey suggesting training and testing of repeated sprint ability should differ between the two sports. In addition, Spencer *et al*.'s (2004) classification of the motion categories was coded according to the authors individual interpretation, and Gabbett & Mulvey (2008) reported logging frequency of activities, distance covered and duration of movement was performed by only one experienced observer questioning the external validity and reliability of the observational analysis. Test-retest reliability for the activities of standing, walking, jogging, striding and sprinting were 0.6%, 0.3%, 2.4% 4.6% and 3.5% respectively.

2.1.2 Repeated Sprint Ability and Performance Measures

The ability to perform repeated sprints with minimal recovery between sprint bouts is termed repeat sprint ability (RSA) and is an important attribute for team sport athletes and associated with playing at higher competitive levels (Rampinini *et al*., 2007*a;* Rampinini *et al*., 2007*b).* The link between performance in a brief RSA test and match performance, where a player will have to repeatedly sprint over the duration of the match is not well established (Oliver *et al*., 2009). Establishing relationships between fitness measures and match performance is problematic given the random pattern of activity and varying tactical influences throughout games (Oliver *et al*., 2009).

Spencer *et al*. (2005) argue due to the unpredictability of player movements performed during field based team sports, it has been difficult to investigate the nature of Repeated Sprint Ability (RSA). Although time motion analysis data reported throughout a game may provide valuable information on the overall physiological demands of team sport competition, it only provides a limited insight into the physiology of 'repeated sprint ability' (Spencer *et al*., 2004).

Spencer *et al*. (2004) defined repeated sprint bouts as a minimum of three sprints with mean recovery duration between sprints of less than 21s and stated this occurred on 17 occasions throughout an international field hockey match. Approximately 95% of the recovery between sprints was active in nature. The authors (Spencer *et al*., 2004) claimed this criteria appropriate as nearly 25% of recovery period between sprints were less than 21 seconds duration and would thus represent a typical period of intense repeated sprint activity, however they fail to acknowledge the rationale of this choice as the average mean time in the study for repeated sprint bouts was 14.9±5.5 seconds. It is also interesting to note the mean number of sprints within a repeated sprint bout was 4±1, however the maximal number of sprints within a repeated sprint bout was 7 with a mean recovery of 15 seconds. Spencer *et al*. (2004) concluded this 'intense' but 'realistic' protocol for assessing RSA within field hockey players could be modified to suit the specific requirements of other team sports such as soccer and rugby. However, the repeated sprint analysis conducted by Spencer *et al*. (2004) only incorporated one game whereas Gregson *et al*. (2010) states match to match variability of high speed activities in premier league soccer is high and research requires large samples in order to detect systematic performance characteristics. In addition, the field hockey game studied was the first game in an international tournament and had interchangeable substitutes with mean player game time of 48mins (range 23 - 71min) (Spencer *et al*., 2004) which is not a true reflection of elite soccer match play played over a 90 minute period.

2.3 Testing soccer players

Few laboratory studies to date have employed exercise protocols that have attempted to replicate the demands of soccer match-play (Thatcher and Batterham, 2004; Drust *et al*., 2002; Nicholas *et al*., 2000). Describing performance via motion analysis is problematic, given the irregular pattern of play inherent in a match and the possibility of tactics influencing performance parameters (Oliver *et al*., 2007).

2.3.1 Laboratory Testing

Several tests have been designed either to be part of an overall physiological assessment or to measure specific components of soccer specific fitness (Svensson and Drust, 2005). Laboratory tests provide a means for coaches and sports scientists to establish the general fitness of players, as these tests are not necessarily specific to soccer. Indeed, through the use of specialised equipment in the laboratory, accurate test results can be obtained in isolated fitness components (Svensson and Drust, 2005).

VO_{2max} is a useful tool in the assessment of soccer players (Svensson and Drust, 2005), however VO_{2max} does not always appear to be a sensitive measure of performance in important aspects of soccer match play (Bangsbo and Lindqvist, 1992) or in the detection of detraining (Bangsbo and Mizuno, 1988). Svensson and Drust (2005) concluded that VO_{2max} may not be a sensitive enough indicator of the ability to perform soccer specific exercise despite observations of a positive relationship with standard of play and distance covered in a match.

Lactate threshold does not appear to be strongly related to physical performance during match play or performance during an intermittent field test for soccer (Bangsbo and Lindqvist, 1992). Evidence for the usefulness of the lactate threshold as a predictor of intermittent performance during a match is therefore unclear (Svensson and Drust, 2005). It is probably advisable to use the lactate threshold as an objective indicator of a player's endurance capacity following training interventions rather than as a predictor of physical performance during a match (Grant and McMillan, 2001). Svensson and Drust (2005) concludes its failure to be sensitive enough to be related to specific indications of match performance suggests that lactate threshold is at best a general descriptor of fitness rather than a specific indicator of physiological potential for match performance.

2.3.2 Soccer Specific Laboratory Protocols

Nicholas *et al*. (2000) devised a free running test, performed indoors that simulates the activity patterns common to soccer, without any contact. The Loughborough Intermittent Shuttle Test (LIST) comprises two parts, Part A and Part B. Part A is of a fixed duration and consists of five 15-min exercise periods separated by 3 min of recovery. The exercise periods consist of a set pattern of intermittent high-intensity running. Part B is an open-ended period of intermittent shuttle running, designed to exhaust the participants within approximately 10-min. Participants are required to run at speeds corresponding to 55% and 95% of predicted VO_{2max}, the speed alternating every 20-m. Magalhaes *et al.* (2010) recently analysed the impact of the LIST versus a soccer match on physiological, biomechanical and neuromuscular parameters and found the impact of both exercises did not differ regarding the observed muscle damage markers and some neuromuscular parameters, although soccer had a much higher physiological demand.

Drust *et al.* (2000) developed an intermittent protocol representative of the work-rates involved in soccer match-play. The soccer-specific intermittent protocol designed by Drust *et al*. (2000) is performed on a non-motorised treadmill (Woodway, Vor Dem, Auf Schrauben, Germany). Such apparatus has the benefits of almost instantaneous acceleration and deceleration. The combination of speeds and activity changes are designed to mimic the activity pattern typically recorded for soccer match-play (Reilly and Thomas, 1976) and consist of four movement categories: walking, jogging, cruising and sprinting. Static periods are also included in the protocol in which the subjects are stationary on the treadmill. Due to the technical limitations of the equipment, utility movements (backwards and sideways) are not included. The protocol is arranged around a 15-min activity cycle. This cycle is performed six times in total to make up a 90 min protocol. The 15-min cycle is further sub-divided into 3-separate 5-min cycles. Each section of 5-min cycles consisted of 3 discrete bouts of walking, 3 bouts of jogging, 3 bouts of cruising, 3-static pauses and one maximal sprint. The time spent in each category is designed to replicate the physiological stresses of match-play. Treadmill speeds for each activity are: walking 4 $km.h^{-1}$, jogging 8 $km.h^{-1}$, and cruising 12 $km.h^{-1}$. No speed restrictions are placed on the sprinting category as subjects are instructed to produce a maximal effort. The physiological and metabolic responses to the intermittent protocol are similar to those reported in the literature for soccer match-play (Drust *et al.*, 2000). Therefore, the protocol is deemed suitable for the examination of soccer-related performance. However, although the protocol of Drust *et al.* (2000) did allow for maximal sprints, the observation that blood lactate did not significantly increase during the test suggests that the requirement to complete one 3-second sprint every 5 minutes was not sufficiently demanding (Oliver *et al.*, 2007).

2.3.3 Field Based Testing

While laboratory-based tests have an advantage of controlled environments and superior forms of assessment, field-based tests enhance the specificity of the evaluation (Svensson and Drust, 2005). Indirect field-based tests have been employed to provide an estimation of VO_{2max}. One such test that has become popular with the soccer playing population is the 20-m multistage shuttle test (20-MST) (Ramsbottom *et al.,* 1988). The 20m shuttle run has the advantage of evaluating more than one individual at a time and can be performed with relative ease and minimal costing (Svensson and Drust, 2005). However, performance on the test only provides an indirect measurement of VO_{2max} while Svensson and Drust (2005) concluded the continuous activity pattern of the 20m shuttle run does not truly represent the intermittent activity profile of soccer or soccer specific endurance *per se*.

Bangsbo (2003) developed a more soccer specific assessment designed to measure the ability to perform bouts of repeated intense intermittent exercise (Yo-Yo Intermittent Endurance test) and the ability to recover from intense exercise (Yo-Yo Intermittent Recovery test). Svensson and Drust (2005) concluded the Yo-Yo Intermittent Recovery (IR) test provides a more valid indication of soccer specific aerobic fitness and activity patterns during a match than direct assessment or field predictions of VO_{2max}. In a study by Krustrup *et al.* (2005) performance of elite females in YoYo IR Test was significantly correlated ($r= 0.81, p <0.05; n =14$) with the amount of high intensity running performed at the end of each half. Bangsbo (2008) also reported a significant correlation between high intensity running in a game and YoYo IR Test 1 performance ($r= 0.70, p <0.05; n =61$). A significant relationship between YoYo IR Test 2 performance and the highest distance covered over a 5 min period during a game was observed ($r=0.72, p <0.05$ $n = 16$) (Bangsbo, 2008). The yoyo tests are sensitive to training interventions and can differentiate between different standards of play and between playing positions (Svensson and Drust, 2005). However, to date it is not known if this applies to Repeated Sprint Performance.

2.3.4 Assessing Repeated Sprint Ability

Assessment of various physiological and performance parameters during tests of RSA have increased over the years (Spencer *et al.*, 2005). Comparisons between studies are difficult to evaluate due to differences in exercise mode, sprint duration, number of sprint repetitions, type of recovery and training status of subjects (see table 1). The duration of sprints in Table 1 has a range from 3seconds - 7 seconds with a maximum distance of 40m. The energy system contribution during repeated sprints also appears to be heavily influenced by the duration of sprints, recovery duration and sprint number (Spencer *et al.*, 2005).

Speed is a very important component in soccer, as the ability to accelerate can decide important outcomes of the game such as sprinting past a defender to have an attempt on goal. The use of tests consisting of several sprints interspersed with brief recovery periods, instead of a single sprint, ensures physiological responses similar to those occurring during actual soccer matches (Rampinini *et al.,* 2007a).

Bishop *et al.* (2001) observed significant correlation between performance in running circuit replicating typical movement during motion analysis of field hockey match play with several performance indices in a repeated sprint test (r= -0.88 to -0.77, p <0.05), however the authors concluded it needed to be modified to reflect common sprint distance and recovery periods found in specific sports (Bishop *et al.,* 2001). In addition, the subjects involved were only recreationally active and the mode of test used in the study was cycling rather than running, therefore limiting the application to well trained athletes. In a recent study, Rampinini *et al.* (2008) found players running repeated sprint ability was moderately correlated with the distance covered for very high intensity running and sprinting during a match (r= -0.60 to -0.65, p<0.01). According to Aziz *et al.* (2008) assessing the validity of the RSA performance in a team sport athlete is complex because RSA contributes rather than being a primary determinant of the player's overall match performance during a match.

Table 1: Repeated Sprint Tests used to measure Repeated Sprint Ability in soccer players

Study	Mode	Subjects	Reps & Distance	Sprint Duration	Total Sprint Distance	Recovery Duration / mode
Aziz *et al.* (2000)	Run Track	Hockey / soccer players	8 x 40m	5 s	320m	30s stretching
Aziz *et al.* (2008)	Run Track (rRSA)	Pro soccer players	6 – 8 x 20m	3.10s	160m	20s active jogging
Bangsbo (1994)	Run Track	Professional players	7 x 35m	7.5s	245m	25s active recovery
Barbero Alverez *et al.* (2010)	Run Track (RSAT)	Junior recreational soccer players	7 x 30m	N.R.	210m	30s active jogging
Buchheit *et al.* (2010)	Run Track	Elite male adolescents	6 x 30m(15 +15)	6s	180m	14s passive stand
Ferrari Bravo *et al.* (2007)	Run Track	Top levels, professional and amateur players	6 x 40m (20 +20)	7.4	240m	20s active recovery
Gabbett (2010)	Run track	Elite women (national) & non elite (state)	6 x 20m	N.R.	80m	15s active recovery
Hill Haas *et al.* (2009)	Run track	Junior elite	12 x 20m	N.R.	240m	20s active recovery
Impellezzeri *et al.* (2008)	Run Track	Male soccer players	6 x 40m (20 + 20)	6.9	240m	20s active recovery
Meckel *et al.* (2009)	Run track	Elite male adolescents	12 x20m 6 x 40m	3.1s 5.6s	240m 240m	20s passive recovery 30s passive recovery
Mujika *et al.* (2009)	Run track	Pro club academy players	6 x 30m	N.R	180m	20s active recovery
Oliver *et al.* (2009)	NM Treadmill	School boys	7 x 5s	5s	N.R.	20s active recovery
Rampinini *et al.* 2007a)	Run Track	Pro soccer players	6 x 40m (20 +20)	6.9	240m	20s active recovery
Rampinini *et al.* (2009)	Run track	D3 Pro Soccer players / D6 Amateur players	6 x 40m (20 +20)	7.4	240m	20s active recovery
Wragg et al. (2000)	Run Track	Male games players	7 x35m	7.5s	245m	25s active recovery

N.R. illustrates the information was not reported in the study.

2.3.5 Validitiy and Reliability of Assessing Repeated Sprint Ability

The validity of most currently used repeated sprint ability tests is predominantly based on their intrinsic characteristics (logical validity). However the use of these tests often assumes that they actually measure match related physical performance (construct validity; Impellizzeri *et al.*, 2008). Aziz *et a*l. (2008) suggest assessing the athletes RSA is now a common practice in multi team sport but the validity of the RSA test as a criterion measure has not been fully elucidated. Bishop *et al.* (2001) observed significant correlation between performance in running circuit replicating typical movement during motion analysis of field hockey match play with several performance indices in a repeated sprint test (r= -0.88 to -0.77, p <0.05), however the authors concluded it needed to be modified to reflect common sprint distance and recovery periods found in specific sports (Bishop *et al.*, 2001). In addition, the subjects involved were only recreationally active and the mode of test used in the study was cycling rather than running, therefore limiting the application to well trained athletes.

Rampinini *et al.* (2007a) recently established the construct validity, as indicated by match related physical performance of a repeated sprint ability test for soccer players. Rampinini *et al*. (2007a) identified that physical performance in an incremental running test to exhaustion and a repeated sprint ability test were related to match specific physical performance. Peak velocity at exhaustion in the incremental speed test was related to total distance covered, high intensity running and very high intensity running. Rampinini *et al.* (2007a) demonstrated moderate but significant correlations between sprinting (r = -0.65) and high intensity running (r = -0.60) completed during official match play and the mean performance during an RSA shuttle running test (six 40m shuttle sprints interspersed with 20s of passive recovery). The protocols were also able to distinguish between ability levels suggesting they have good construct validity (Currell and Jeukendrup, 2008). However, Rampinini *et al.* (2007a) did not find any significant relationship between $RSA_{Decrement}$ and any match related performance which may be as a result of the initial sprint performance as this has consistently been reported to be positively correlated with performance decrement over subsequent sprints (Girard *et al.*, 2011). The strength of the correlation does not support the predictive validity of the test for which r values above 0.90 are necessary (Impellizzeri *et al.*, 2008).

The strength of relationship reported by Rampinini *et al.* (2007a) although significant, suggests that RSA is not a general quality reflected in overall match performance (Oliver *et al*, 2007). Oliver *et al.* (2007) hypothesised that measuring a player's ability to repeatedly sprint over a prolonged period of time, as is required during a soccer match, might represent a more specific measure of RSA and developed the Soccer Specific Intermittent Endurance Test (SSIET), a laboratory protocol used to measure prolonged repeated sprint ability (RSA) during soccer specific exercise. Oliver *et al.* (2007)

suggested the prolonged nature of the SSIET provided a more ecologically valid measure of RSA than traditional RSA tests, which are brief in nature (≤ 3 minutes). The authors concluded the protocol provided a suitable method to measure soccer specific prolonged RSA in the laboratory with acceptable levels of reliability (Oliver *et al.*, 2007). Locomotion categories during the SSIET were the same as those previously used in the soccer specific protocol of Drust *et al.* (2000), although the study was carried out by a youth population therefore results may not be extended to adult populations. Furthermore, Oliver *et al.* (2009) in a recent study found the ability to reproduce speed during a brief repeated sprint ability test is not well related to the ability to reproduce sprints over a more prolonged duration.

It has been difficult to assess Repeated sprint performance in the field setting using conventional methods (Barbero Alvarez *et al.*, 2010). Fitzsimons *et al.* (1993; cited by Barbero Alvarez *et al.*, 2010) proposed the most common method used to assess RSA in the field setting is with electronic timing gates, however this assessment method limits the number of athletes or teams that can be tested simultaneously, is time consuming and may well be difficult to implement in a team environment (Barbero Alvarez *et al.*, 2010). GPS devices provide a practical alternative in assessing repeated sprint performance characteristics in team sport athletes and the most appropriate measure of RSA for longitudinal monitoring of athletes is RSA mean sprint time or total sprint time rather than fatigue index measures (Barbero Alvarez *et al*,. 2010). This is in agreement with Oliver (2009) who queried the use of a fatigue index given both the reliability of the measurement and also the difficulty in practically interpreting a fatigue index. A better fatigue index does not necessarily indicate better repeated sprint ability, as this is reflected by mean or total sprint time (Oliver, 2009). Total sprint time or mean sprint time may be influenced by pacing strategies, therefore any repeated sprint protocol should be designed to be sport specific and to minimise the possibility of pacing (Oliver, 2009). Conversely, Glaister *et al.*, (2008) in evaluating eight different approaches of reliability and validity of fatigue measures in repeated sprint performance found that the percentage sprint decrement (S_{dec}) calculation was the most valid and reliable method to quantify fatigue in Repeated sprint performance. The percentage decrement score attempts to quantify fatigue by comparing actual performance to a best of fastest “ideal performance” (i.e. where the best effort would be replicated in each sprint). one possible advantage of the percentage sprint decrement score is that it takes into consideration all sprints, whereas the fatigue index will be influenced more by a particularly good or bad first or last sprint.

Wragg *et al.* (2000) in evaluating the reliability and validity of the Bangbso Sprint Test (Bangsbo, 1994), also indicated a higher number of sprints in a RSA protocol may result in the increasing predominance of aerobic energy production and a “pacing” of sprint efforts thus conceding some of its validity as a measure of RSA. Wragg *et al.* (2000) through adopting a multiple trials design and comparing it to a laboratory repeated sprint test and found the energetic of the two tests not to be closely related; however the test demonstrated high reliability. Impellizzeri *et al.* (2008) investigated the reliability and validity of the repeated shuttle sprint ability (Rampinini *et al.,* 2007b) test and found the only parameter showing an absolute and relative reliability acceptable for monitoring players is $RSA_{mean,}$ time and only RSA_{mean} time can be useful to quantify large changes induced by specific training regimes. It is therefore necessary to contextualise fatigue indices when evaluating RSA as less or greater fatigue does not always equate to a worse or better performance (Girard *et al.*,2011).

2.3.6 Improving Repeated Sprint Ability

Anecdotally, repeated sprint training is used to improve RSA, however very few studies have actually compared such specific training to generic training (interval training) in team sport athletes therefore only tentative conclusions can be drawn regarding its potential application (Bishop *et al.,* 2011). Repeated sprint training is able to improve $VO_{2\ max}$ (Ferrari Bravo *et al.,* 2008) however the increases in $VO_{2\ max}$ were 5.0-6.1% whereas Helgured *et al*. (2001) utilising interval training reported more than 10% increases. Bishop *et al.* (2011) reveals compared with repeated sprint training, interval training produces superior increases in both intracellular buffering (Schneiker and Bishop, 2008)and Na^+/K^+ pump isoform content (Mohr *et al.,* 2007). Interval training also appears to be superior to repeated sprint training to decrease (i.e. improve) the sprint decrement (or the fatigue index; Mohr *et al*., 2007; Schneiker and Bishop, 2008).

With regards to RSA, repeated sprint training compared with interval training has been reported to demonstrate greater improvements in mean sprint time (Ferrari Bravo *et al.*, 2008; Mohr *et al*., 2007; Schneiker and Bishop, 2008; Bucheitt *et al*., 2010) and produce greater improvements in best sprint time (Mohr *et al.,* 2007; Schneiker and Bishop, 2008; Bucheitt *et al.,* 2010).

Although Bishop *et al*. (2011) proposes that repeated sprint training is superior to improving the performance of individual sprint, interval training may be superior at minimising the decrement during repeated sprints (due to greater physiological adaptations) (Bishop *et al.*, 2011). The authors conclude, a combination of the two (i.e. repeated sprint training to improve sprint performance plus interval training to improve the recovery between sprints) may be the best strategy to improve RSA (Bishop *et al.,* 2011).

Bishop *et al.* (2011) also advocates the use of traditional sprint training (i.e. short sprints interspersed with complete recovery periods) and suggests that there is good evidence to support the use of resistance training on single sprint performance, the impact on RSA is less clear (Newman *et al.*, 2004).

The two key recommendations based on the existing literature from the review of Bishop *et al*. (2011) were:

1. It is important to include some training to improve single sprint performance This should include (I) specific sprint training (ii) strength / power training (iii) occasional high intensity (>$VO_{2\ max}$ training (e.g. repeated 30 second, all out efforts separated by 10 minutes recovery) to increase the anaerobic capacity.

2. It is also important to include some interval training to best improve the ability to recover between sprints (if the goal is to improve fatigue resistance). High intensity (80-90% $VO_{2\ max}$) interval training, interspersed with rest periods (eg 1 minute) that are shorter than the work periods (2 minutes) is efficient at improving the ability to recover between sprints by increasing aerobic fitness ($VO_{2\ max}$ and the lactate threshold), the rate of phosphocreatine resynthesis and blood buffering capacity.

2.3.7 Improving RSA in Football

It is important to establish the physiological characteristics associated with improved RSA and high intensity, intermittent exercise because it could be useful for guiding the development of specific training interventions for high standard soccer players (Rampinini *et al.*, 2009). Findings from Rampinini *et al.* (2009) suggest that in order to improve RSA, trained soccer players could benefit from training for better VO_2 kinetics and improving the ability to tolerate metabolic acidosis during intense intermittent exercise, rather than training for greater $VO_{2\ max}$.

During repeated sprint training the relative contribution of anaerobic glycogenolysis is reduced when subsequent sprints are performed, which is partially explained by an increase in aerobic metabolism (Spencer *et al.*, 2005). In addition, the degradation and resynthesis rate of PCr is related to performance decrement and loss of muscle purine nucleotides may also occur during subsequent sprints (Spencer *et al.*, 2005)

Meckel *et al.* (2010) examined the relationships among aerobic fitness, anaerobic capacity and two different repeated sprint test (RST) protocols. They found that despite the identical total work, RSTs of different repetition and rest intervals demonstrate different physiological implications (Meckel *et al.*, 2010). Meckel *et al.* (2010) emphasised the need for the selection of an appropriate RST protocol that will match the work –rest pattern and physiological demands of the relative sports, as well as the age and gender of the participants.

Iaia *et al*. (2009) suggests the match analysis characteristics and intermittent nature of the game should be taken into account when designing training programs for football. Aerobic and football related training should be football related and preferably performed with a ball (Iaia *et al*., 2009). This may be achieved by through playing small sided games and football related drills (Little and Williams, 2007) consisting of repeated exercise bouts involving change of directions, speed and specific movement patterns observed during match play.

Few studies have examined the effect of repeated sprint and speed endurance training on football players during the competitive season (Iaia *et al.*, 2009). Dupont (2004) compared the effects of a specific training protocol based on sprint repetitions and high intensity intermittent runs in comparison with a control period. They reported that 2 interval sessions per week for 10 weeks consisting of 12-15 x 15 s runs at 120% velocity of VO_{2max} ($vVO_{2\,max}$) with 15 s rest, and 12-15 all-out 40 m sprints with 30 s rest, improved vVO_{2max} speed by 8.1%. However, there are a number of issues related to this study which need to be highlighted, Dupont *et al.* (2004) stated the VO_{2max} (60.1 +-3.4 $ml.kg^{-1}.min$) at the beginning of the study, however no data are reported following the completion of the training period. In addition, team performance was evaluated by results i.e. wins and losses which raises questions regarding the reliability as opposed to similar training studies (Hoff, 2004; Impellezzerri, 2006).

Ferrari Bravo *et al.* (2008) compared the effect of two sessions per week of Repeated Sprint Training (three sets of six 40m maximal shuttle sprints with 20s of rest between sets and 4 mins recovery between sets) versus aerobic high intensity running training (4 x 4 mins at 90 -95% HR_{max} 3 mins recovery) on YoYo IR performance and repeated sprint performance. Football specific endurance, as measured with the YoYo IR Test improved in both groups but the RSA based training induced a greater increase (28.1% vs 12.5%). This corresponds with similar findings (22% improvement YoYo IR Test) from Hill Haas *et al.* (2009) after an intense RST intervention. Mohr *et al*. (2007) reported greater improvements in YoYo IR2 Test performance (28% vs 10%) when comparing speed endurance training with repeated sprint training in moderately trained subjects.

A study by Helgured *et al.* (2001) has shown that high intensity aerobic interval training is an effective training strategy for improving the aerobic fitness of football players with no negative effect on strength, power or sprint performance. Physiological adaptations reported were an increase in VO_{2max} levels of 11% and a 21% increase in speed at lactate threshold. Moreover, this study is of significant importance because the improvements in endurance capacities led to improvements in soccer performance, such as increasing distance covered by 20%, number of sprints by 100%, number of involvements with the ball by 24%, and average work intensity from 82.7 ± 3.4% to 85.6 ± 3.1% HR_{max}. Despite certain problems with methodology, such as the analysis of only 1 game pre and post treatment, these results suggest VO_{2max} training will be of great benefit to soccer performance. Stolen (2005) suggest that players with VO_{2max} of 60ml/kg/min require one VO_{2max} interval training session (4 x 4 mins) to maintain VO_{2max} levels, while players above 70ml/kg/min require 2 sessions. Two VO_{2max} sessions per week have been shown to be extremely effective in elite adult (Helgerud *et al.*, 2001), and youth soccer players (McMillan *et al.*, 2005).Conversely, Rampinini *et al*. (2010) suggested that in order to improve RSA, trained soccer players could benefit from training for better VO_2 kinetics and improving the ability to tolerate metabolic acidosis during intense intermittent exercise, rather than training for greater VO_{2max}.

2.4 Summary

Although Di Salvo *et al.* (2009) and Bradley *et al.* (2009) provide a much needed overview of general physical demands of high intensity performance, the data does not categorise or characterise the specific nature of repeated sprint activity movement patterns which would enable RSA test variables to be tailored to performance. Clearly assessing RSA performance is complex because repeated sprinting activity contributes to rather than being a primary determinant of the player's overall performance during a match (Aziz *et al.*, 2008). Additionally, field tests and laboratory assessments should never be used to predict on field performance because of the complex and mulitfactorial nature of soccer performance itself (Svensson and Drust, 2005). However, validated field tests can be used to assess specific physiological components of soccer performance and in the prescription of individualized physical training for soccer players (Rampinini *et al*., 2007a).

Bishop *et al.* (2001) conclude that RSA appears to be specific to the test protocol rather than a general quality and there was no "gold standard" test available to measure RSA. This is in agreement with Green (1995; cited by Aziz *et al.* 2008), who found running repeated sprint ability (rRSA) is an anaerobic type of performance test and currently there is no established "gold standard" anaerobic test that can be used for comparison.

3.0 Methods

3.1 Match sample

Physical performance in official competition was analysed for players in a professional soccer team that competed in the English Championship in 2008/2009 season using a multi-camera computerised tracking system (ProZone Version 3.0, Pro Zone Sports Ltd®, Leeds, UK).While approval for the study was obtained from the present club, and Prozone (see appendix) the data arose as a condition of employment in which player performance is routinely measured over the course of the competitive season (Winter & Maughan, 2009). Therefore, usual appropriate ethics committee was not required, however due to data confidentiality for player and team, all physical performance data was anomalized before analysis and game information was in public domain.

Data on performance of 10 English Championship games were used in 2008/2009 season. Ten games were selected as the team played a 4-4-2 (two full back, two centre backs, two wide midfielders, two central midfielders and two centre forwards) formation for the duration of each game with only the home team's data being analysed. The 10 games were the team's first ten home league games of the season. Following the first ten games, the team frequently changed their formation to 4-3-3 (playing with three central midfielders and one centre forward) and playing 3-5-2 (three centre backs, two wing backs, three centre midfielders and two centre forwards) during the game and therefore comparisons between positions would not have been able to take place. Each game sample included 10 outfield players with a total of two players for each positional roles, full backs, centre backs, centre midfielders, wide midfielders and centre forwards.

A total of 125 observations (manual analysis of players repeated sprint performance via prozone) were recorded of which 74 players completed 90 mins. Goalkeepers and players who failed to complete the 90 minutes were excluded from the study. Please see below total observations for each position.

Position	90 mins	75mins or more	15mins or less	Total Observations
Full Backs	18	2	2	22
Centre Backs	20	0	0	20
Wide Midfielders	7	13	12	32
Centre Midfielders	20	0	1	21
Centre Forwards	9	13	8	30

3.2 Data Collection procedures and measures of competitive performance

Match performance data were produced using a computerized semi automated multi-camera image recognition system (Prozone Version 3.0, Pro Zone Sports Ltd, Leeds, UK) as previously independently validated by Di Salvo and Colleagues (2006) in order to verify the capture process and subsequent accuracy of the data. Di Salvo *et al.* (2009) determined the reliability and objectivity of the system. Reliability and objectivity CVs increased significantly as velocity increased across the various movement categories. The highest CV that was obtained was 6.5% for the variability between observers in measuring time spent sprinting (Di Salvo *et al.*, 2009).

3.3 Movement categories and Speed Thresholds of Prozone

Players' activities were coded into the following categories and speed thresholds: standing (0-0.60km·h^{-1}), walking(0.7-7.1 km·h^{-1}), jogging (7.2 -14.3 km·h^{-1}), running (14.4 – 19.7 km·h^{-1}), high speed running (19.8 – 25.1km km·h^{-1}) and sprinting (>25.2 km·h^{-1}). The speed threshold used for the analysis of 'sprint' actions in professional soccer match play refers to 0.5s runs performed at velocities above 25.2 km·h^{-1} , this value was the same as those in the recent literature and generated as automatic output (Bradley *et al.,* 2009; Di Salvo *et al.,* 2009; Gregson *et al.*, 2010).

3.4 Repeated Sprint Performance

The extreme physical demands of team sport match play can be examined using information from analysis of 'repeated sprint bouts' (Spencer *et al.,* 2005). The definition of a repeated sprint bout was the same as that employed by Gabbett and Mulvey (2008) in an international soccer match and Spencer *et al.* (2004) in an international field hockey competition: a minimum of three sprints, with recovery duration of less than 21 seconds between sprints.

The number of repeated sprint bouts were examined, the number of repeated sprint repetitions per bout were examined., maximal sprint distance of each repeated sprint repetition, the bout total Distance, average distance per repeated sprint repetition, mean bout duration, mean recovery time between repeated sprint repetitions and the time to the next single sprint were all recorded for assessment of repeated sprint performance.

3.5 Data Capture.

Data collection was obtained from the Pro Zone system's post event analysis. This is an automatically generated output. Identification for Repeated Sprint Bout was available from the software through manual analysis of repeated sprint bouts. Sprints were automatically identified by the system and then categorised as repeated sprint bouts if they attain the specific criteria identified by Spencer *et al.* (2004) (see figure 1.0 for an example of repeated sprint bout).

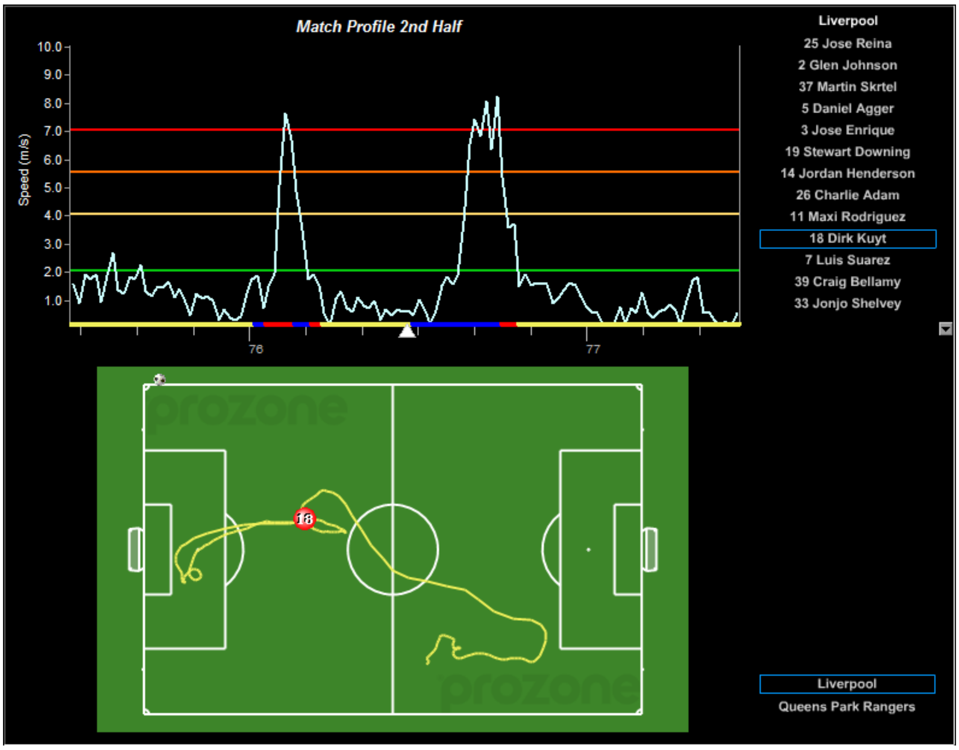
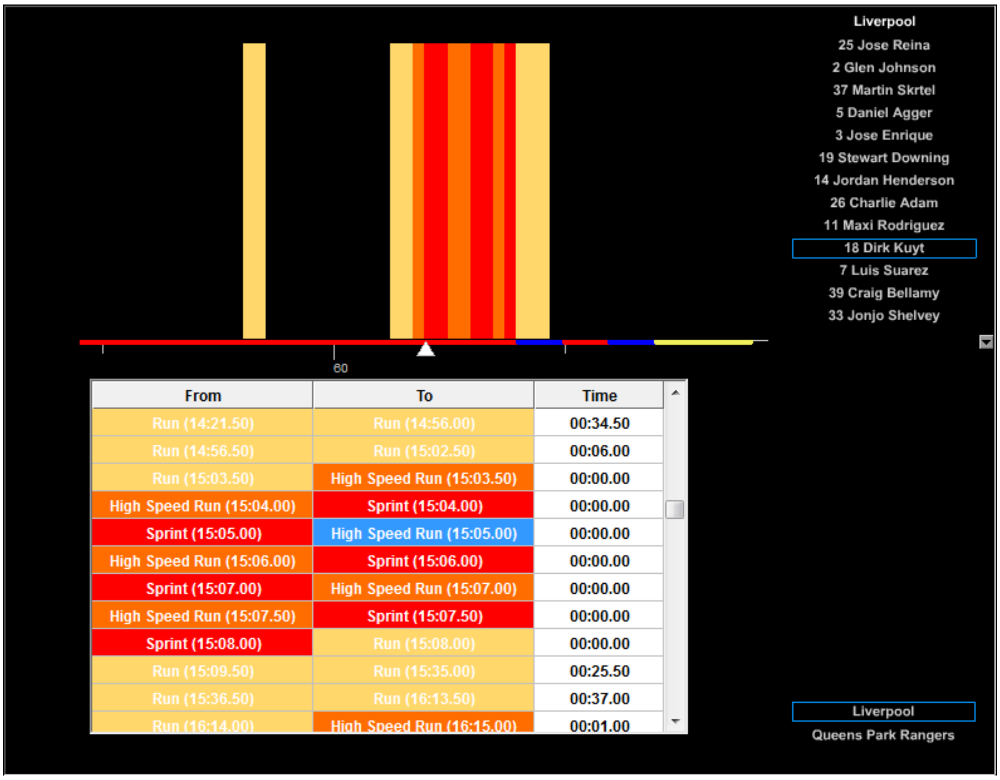


Figure 1.0 – Example of a repeated sprint bout from match profile.

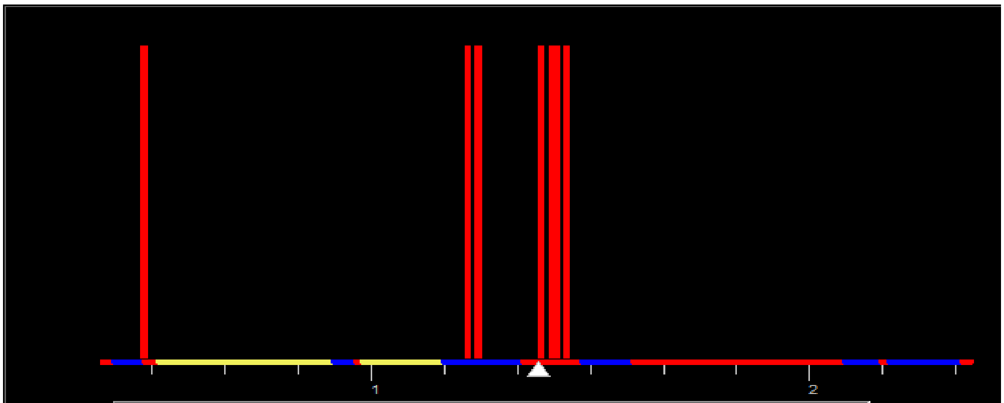
Under the fitness section, upon manually selecting the speed endurance, recovery time is highlighted between various activities (Figure 2.0).



From	To	Time
Run (14:21.50)	Run (14:56.00)	00:34.50
Run (14:56.50)	Run (15:02.50)	00:06.00
Run (15:03.50)	High Speed Run (15:03.50)	00:00.00
High Speed Run (15:04.00)	Sprint (15:04.00)	00:00.00
Sprint (15:05.00)	High Speed Run (15:05.00)	00:00.00
High Speed Run (15:06.00)	Sprint (15:06.00)	00:00.00
Sprint (15:07.00)	High Speed Run (15:07.00)	00:00.00
High Speed Run (15:07.50)	Sprint (15:07.50)	00:00.00
Sprint (15:08.00)	Run (15:08.00)	00:00.00
Run (15:09.50)	Run (15:35.00)	00:25.50
Run (15:36.50)	Run (16:13.50)	00:37.00
Run (16:14.00)	High Speed Run (16:15.00)	00:01.00

Figure 2.0 Pro zone activity profile representing recovery times between activities.

Running and high speed running were then deselected to represent sprints only (figure 3.0). Each sprint is documented (see overleaf) from recovery time of end of the last sprint to the beginning of the next. If recovery time between sprints was 00:21:00 it was not used for repeated sprint performance. Each individual sprint is then identified (figure 3) with information consisting of when the sprint occurred i.e. time period in the game



From	To	Time
Sprint (01:13.50)	Sprint (01:14.50)	00:01.00
Sprint (01:15.00)	Sprint (01:23.00)	00:08.00
Sprint (01:23.50)	Sprint (01:24.50)	00:01.00
Sprint (01:26.00)	Sprint (01:26.50)	00:00.50
Sprint (01:27.00)	Sprint (02:41.00)	01:14.00
Sprint (02:42.00)	Sprint (04:30.50)	01:48.50
Sprint (04:32.00)	Sprint (05:19.50)	00:47.50
Sprint (05:20.00)	Sprint (07:39.50)	02:19.50
Sprint (07:40.00)	Sprint (09:49.50)	02:09.50
Sprint (09:50.00)	Sprint (09:52.50)	00:02.50
Sprint (09:53.50)	Sprint (09:58.50)	00:05.00
Sprint (09:59.00)	Sprint (10:02.50)	00:03.50

Figure 3: Identification of Sprint Recovery times.

From Figure 3.0, we can see an example of a repeated sprint bout consisting of 5 sprints with recovery duration under the time section and time to the next sprint.

Once identification of bout repetitions, figure 4.0 was used to identify start of sprint, end of sprint, time taken and sprint distance covered.

Figure 4.0 – Identification of sprint variables for Sprint Repetitions

This data are then exported into excel for further analysis (figure 5.0 and figure 6.0).

Bout No	Start Time	End Time	Time Take	Sprint Distance	Time to next sprint
1	05.24.5	05.25.0	0.00.5	3.7	0.01.5
1	05.26.5	05.27.0	0.00.5	4.1	0.10.0
1	05.37.0	05.37.5	0.00.5	3.5	0.06.0
1	05.43.5	05.44.0	0.00.5	3.6	0.46.5
2	07.31.0	07.31.5	0.00.5	3.6	0.20.0
2	07.51.5	07.52.0	0.00.5	4	0.01.0
2	07.53.0	07.54.0	0.01.0	8.4	0.29.0
3	27.14.0	27.14.5	0.00.5	3.5	0.08.5
3	27.23.0	27.23.5	0.00.5	3.6	0.16.5
3	27.40.0	27.40.5	0.00.5	3.6	0.27.0
4	37.03.5	37.04.5	0.01.0	7.7	0.14.5
4	37.19.0	37.19.5	0.00.5	3.5	0.15.0
4	37.34.5	37.35.0	0.00.5	3.5	1.08.5
5	73.12.5	73.13.0	0.00.5	3.8	0.03.5
5	73.16.5	73.18.0	0.01.5	12.3	0.02.5
5	73.20.5	73.22.5	0.02.0	16.3	1.13.0

Figure 5.0 Excel sheet for recording information of sprints.

Time Period	Bout Number	No of Reps	Sprint Duration	Max Sprint Duration	Av Recovery b/w b/w sprints	Time to next sprint	Bout Duration	Maximal Sprint Distance	Sprint T. Distance	Sprint Av Distance
1	1	4	00:02.5	00:00.5	00:04.3	00:46.5	00:19.5	4.1	14.9	3.7
1	2	3	00:02.0	00:01.0	00:07.0	00:29.0	00:23.0	8.4	16	5.3
2	3	3	00:01.5	00:00.5	00:08.3	00:27.0	00:26.5	3.6	10.7	3.6
3	4	3	00:02.0	00:01.0	00:10.0	01:08.0	00:32.5	7.7	14.7	4.9
5	5	3	00:04.0	00:02.0	00:02.0	01:13.0	00:10.0	16.3	32.4	10.8

Figure 6.0 Management of Excel data for repeated sprint performance.

3.6 Reliability of Repeated sprint performance assessment

Post event analysis is automatically generated via Prozone. One game was analysed twice for intra observer reliability purposes for all outfield players with no differences observed.

3.7 Statistical Analyses

Statistical analyses were conducted using SPSS for Windows v.17.0 (SPSS Inc., Chicago, IL, USA). Results are reported as means and standard deviations (means ±) unless otherwise stated. Data was checked for normality. A two way analysis of variance (ANOVA) was used to test for differences in means in match performance measures across positional roles and time. In the event of statistical differences, Bonferroni *post-hoc* Analysis were carried out. Statistical significance was set at $P < 0.05$. Effect sizes were calculated as the difference between the means divided by the pooled standard deviation, with the following quantitative criteria for effect sizes used to explain the practical significane of the findings: trivial <0.2, small 0.21-0.6, moderate 0.61 -1.2, large 1.21 – 1.99, and very large > 2.0 (Hopkins, 2006).

4.0 Results

Table 4.1. Match performance variables in relation to playing position (Games, n = 10).

Match Performance Variables	Full Backs (n = 18)	Central Defenders (n = 20)	Central Midfielders (n = 20)	Wide Midfielders (n = 7)	Centre Forwards (n = 9)
Distances Covered					
Total (m)	11582 ± 384	10958 ± 453	11896 ± 1562	11076 ± 1013	9629 ± 2199 [a]
Sprint Distance	453 ± 80[b]	275 ± 66[c]	352 ± 89	480 ± 90 [b]	323 ± 97
Number of Sprints	60 ± 4	43 ± 11[d]	55 ± 13	65 ± 12	47 ± 14[d]
High Intensity Distance	1393 ± 131	1056 ± 153[e]	1381 ± 277	1515 ± 1382	1089 ± 236[e]

Notes: [a] Different from all other positions ($p<0.05$). [b] Different from central defenders, wide midfielders and centre forwards ($p<0.05$). [c] Different from all other positions($p<0.05$). [d] Different from full backs, central midfielders and wide midfielders($p<0.05$). [e] Different from full backs central midfielders and wide midfielders ($p<0.05$).

Total Distance was influenced by position. Central midfielders and full backs completed the greatest total distance followed by wide midfielders, centre backs and centre forwards respectively. Centre forwards covered less distance than all other positions ($p<0.05$). Sprint distance was influenced by playing position. Full backs and wide midfielders completed similar sprint distance however wide midfielders and full backs were significantly higher than all other positions ($p<0.05$). Sprint distance for centre backs was lower than in all other positions ($p<0.05$). Number of sprints was similar between full backs, centre midfielders and wide midfielders but greater than that for centre backs and centre forwards ($p<0.05$). Wide midfielders and centre backs completing the highest and lowest respectively ($p<0.05$). Similarly, there were no significant differences observed between high intensity distance for full backs, centre midfielders and wide midfielders however centre backs and centre forwards covered less distance ($p<0.05$). Wide midfielders and centre backs completed the highest and lowest high intensity distances respectively ($p<0.05$).

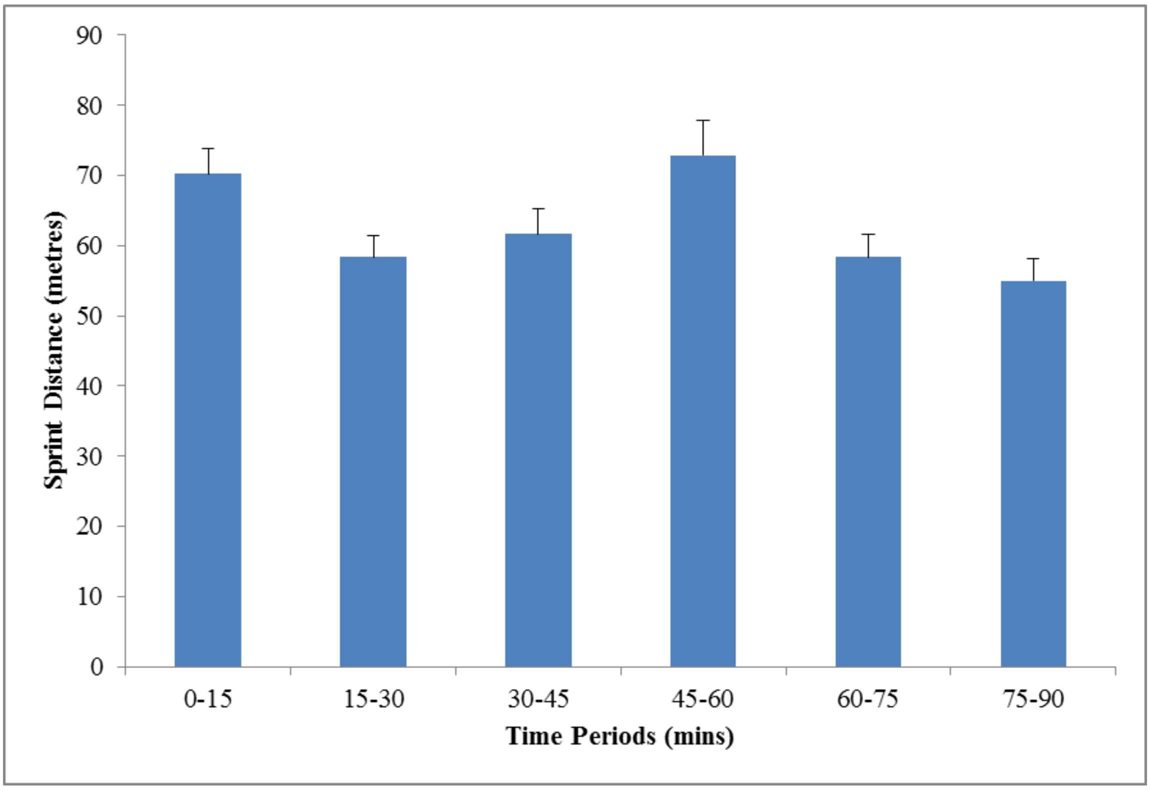


Figure 4.1 Sprint Distance covered during the 90 minutes (mean ±sd).

Sprint distance was greater in the first 15 min compared to the last 15 min of a game ($P<0.05$) with a 27% reduction. There was also a 33% reduction in Total Sprint distance from the first 15 min of the 2nd half to the last 15 min of the game ($P<0.05$). Values are means and standard deviations.

4.1 Repeated Sprint Activity

Repeated sprint activity (defined as a minimum of three or more sprints with a mean recovery duration between sprints of less than 21s) was identified during the ten games and there was a range of Total Bouts per game from 37- 56. The mean number of RSA bouts per game was 45.9 (±7.1).

Table 4.2. Frequency and characteristics of Repeated Sprint Bouts(mean ±s in relation to positional role (mean ±s). n = (464) total number of sprint bouts per position for all players across the ten games; composed of two full backs, two centre backs, two centre midfielders, two wide midfielders, two centre forwards).

Repeated Sprint Bouts	All Players (n = 464)	Full Backs (n = 102)	Centre Backs (n = 48)	Central Midfielders (n = 81)	Wide Midfielders (n =145)	Centre Forwards (n = 78)
No. of RS Bouts	4.6 ± 0.4	5.1 ± 0.6	2.5 ± 0.3	4.4 ± 0.4	7.2± 0.5*	4.1 ± 0.4
No of RS Reps per Bout	3.5 ± 0.1	3.5 ± 0.1	3.4 ± 0.2#	3.4 ± 0.1	3.6 ± 0.2	3.5 ± 0.3
Maximal Sprint Distance (m)	11.2 ± 1.3	12.4 ± 1.7 >	10.3 ± 1.7	9.1 ± 1.3	11.9 ± 2.4	11.2 ± 2.7
Bout Total Distance (m)	23 ± 2.1	24.6 ± 2.6	20.9 ± 3.3	20.1 ± 1.7	24.7 ± 2.9	21.9 ± 3
Sprint Average Distance (m)	6.7 ± 0.5	6.9 ± 0.6	6.3 ± 0.9	5.9 ± 0.7	7.0 ± 0.9	6.8 ± 0.8
Mean Bout Duration (s)	15 ± 1.0	16 ± 1.0	14 ± 2	16 ± 3	16 ± 3	13 ± 4
Mean Recovery Between RS (s)	3 ± 1.0	3 ± 1.0	4 ± 1.0	4 ± 1	4 ± 1	3 ± 1
Time to Next Repeaeted Sprint (s)	133 ± 27	129 ± 28	184 ± 40	134 ± 14	113 ± 12+	145 ± 42

Notes: * Difference between centre backs and centre forwards. + Difference between centre back and wide midfielders. > Difference between full backs and central midfielders. { Difference between wide midfielders and central midfielders

Note: RS = Repeated Sprints

The number of repeated sprint bouts varied between position (p<0.05). Wide midfielders had the highest number of bouts and were significantly greater than centre backs (p<0.001; effect size = 0.85) and centre forwards (p<0.05; effect size = 0.64). There were no significant differences in the number of repeated sprint repetitions per bout or mean recovery duration between sprints within a single bout (p<0.05) across all positions. Time to next sprint was influenced by position with wide players having least recovery time and centre backs having the longest time to next sprint (p<0.05; effect size = 0.62) Differences were observed between Centre backs and full backs (p=0.092) although non-significant. Maximal Sprint Distance was highest in full backs and lowest in central midfielders (p<0.05) however there was no significant differences observed between positions for sprint average distance with wide midfielders the highest and central midfielders the lowest. Wide players total bout distance was significantly higher than central midfielders total bout distance (p<0.05).

The positional profile of repeated sprint performance of full backs and wide midfielders displaying higher sprint distance and lowest recovery time is very similar to that seen with the patterns observed in single sprint distance (Bradley *et al*, 2009; Di Salvo *et al.*,2009).

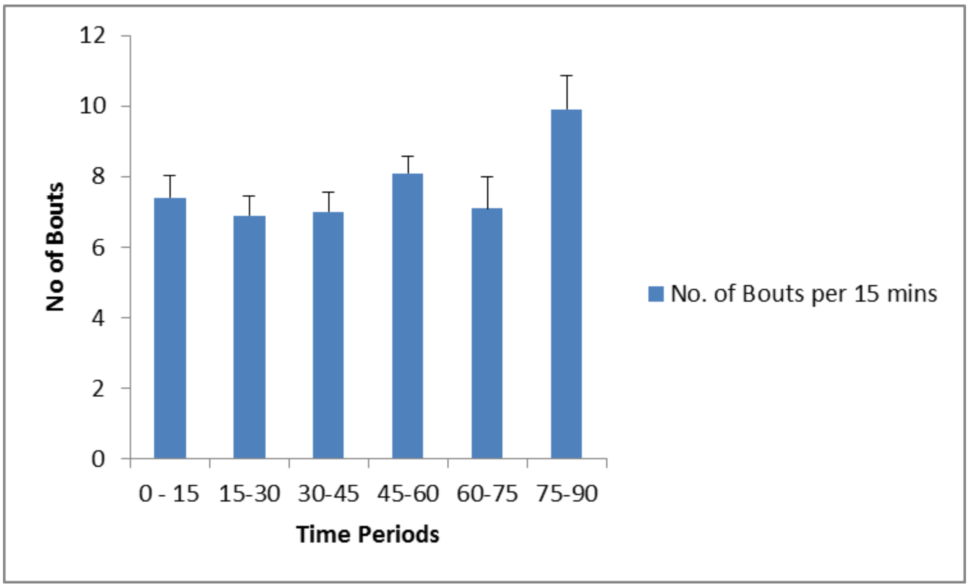


Figure 4.2 shows the Mean Number of Bouts in each of the 15min periods of the game for all players (mean ±sd).

No significant statistical differences existed ($p<0.05$). The data shows there was a 26% increase in the number of bouts in the last 15mins compared to the first 15 mins.

Table 4.3 shows RSA Analysis Per 15 minute period per Player (n = number of bouts per time period).

Mins **Repeated Sprint Bouts**	0- 15 (n=74)	15-30 (n= 67)	30-45 (n= 68)	45-60 (n=77)	60-75 (n= 69)	75-90 (n= 96)
No. of Bouts	0.7 ± 0.3	0.7 ± 0.3	0.7 ± 0.3	0.8 ± 0.2	0.7 ± 0.5	1.0 ± 0.5
No of Reps per Bout	3.5 ± 0.7	3.5 ± 0.9	3.4 ± 0.7	3.4 ± 0.7	3.5 ± 0.7	3.5 ± 1.1
Maximal Sprint Distance (m)	12.6 ± 8.9	9.4 ± 5.8	12.4 ± 8.3	12.1 ± 10.2	10.0 ± 5.8	10.8 ± 6.8
Bout Total Distance (m)	24± 12	20.3 ± 8.9	24.5 ± 10.6	23.1 ± 12.6	21.5 ± 8.3	23.9 ± 12.1
Sprint Average Distance (m)	7.2 ± 3.6	5.9 ± 2.4	7.2 ± 3.1	6.9 ± 3.9	6.1 ± 2.2	6.7 ± 2.5
Mean Bout Duration (s)	14 ± 9	16 ± 10	17 ± 11	13 ± 9	15 ± 12	18 ± 15
Mean Recovery Between Sprints (s)	3 ± 3	4 ± 2	4 ± 3	3 ± 3	3 ± 3	4 ± 3
Time to Next Sprint (s)	113 ± 79	145 ± 116	144 ± 134	126 ± 131	135 ± 162	124 ± 110

There were no significant differences in the number of bouts per player throughout the 90 minutes however the last 15 minutes had the highest total number of bouts. There were no significant differences ($p<0.05$) observed in the number of reps per bout.. The 0-15 minutes period had the highest maximal sprint distance with the 15-30 period being the lowest for maximal sprint distance although not reaching significance ($p=0.052$). In addition, sprint average distance was highest for the 0-15min and lowest for 15-30min ($p=0.070$) however no significant differences were observed. Bout total distance was lowest between 15-30min although not significantly different throughout the 90 minutes. Time to next sprint was lowest for 0-15min and highest for 15-30min although not significant. Mean bout duration was highest for the last 15 minutes of the game however no significant differences were observed throughout the 90 minutes ($p<0.05$). There was a significant difference observed for Mean recovery between sprints ($p<0.05$; main effect).

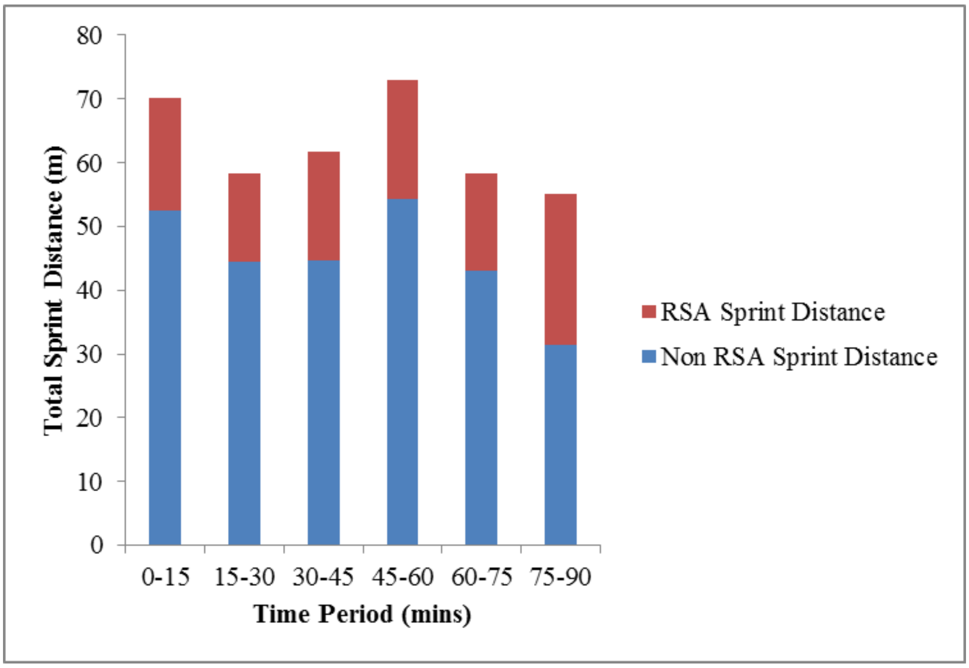


Figure 4.3. The contribution of Repeated Sprint Distance to Total Sprint Distance for 15 min time periods.

The mean contribution of repeated sprint distance to total sprint distance for each 15min period was 28.7%. The last 15 min period had the highest proportion of RSA sprint distance to total sprint distance (43%). The % contribution for the first 15 min was 25.4% and 43% in the last 15 min an increase of 17.4%.

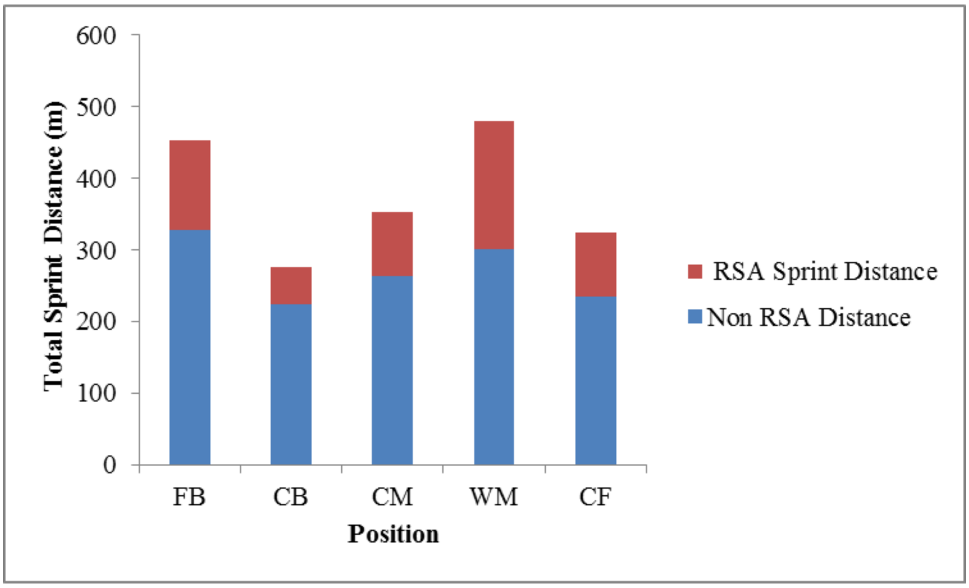


Figure 4.4. The shows the contribution of Repeated Sprint Distance to overall Total Sprint Distance for positional role.

Wide midfielders had the highest contribution (35%) with full backs (27%), central midfielders (25%) and centre forwards (27%) displaying similar % contributions. Centre backs had the lowest contribution of 18%.

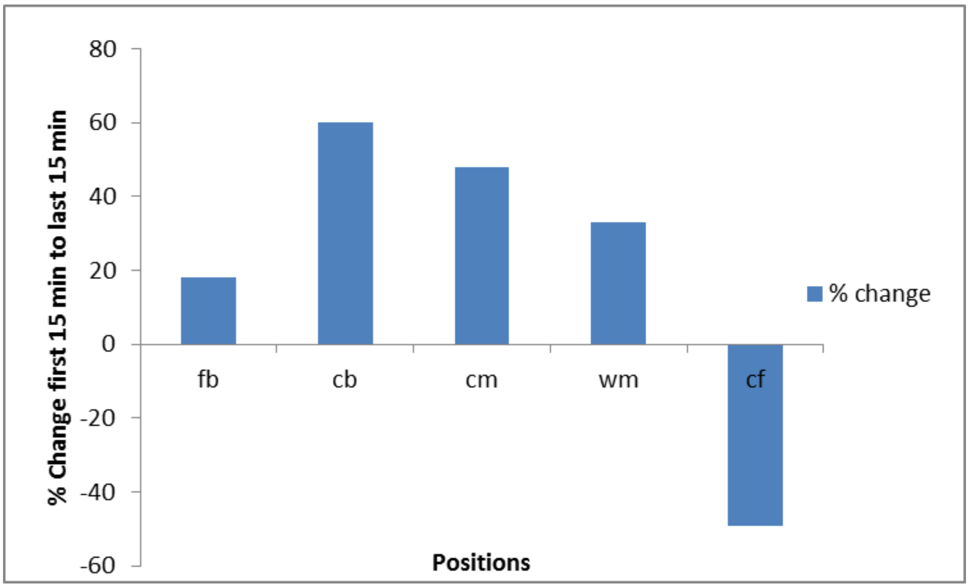


Figure 4.5 % Difference in the Number of Bouts for 0-15 min and 75-90min for each position.

Centre backs had the highest increase in number of bouts from 0-15min to 75-90min of all positions with an increase of 60% (9 bouts) while full backs (4 bouts), centre midfielders (6 bouts) and wide midfielders all increasing the total number of bouts in the final 15 mins while centre forwards had a 49% decrease in the number of bouts in the last 15 minutes of the game compared to the first 15 minutes. No significant differences were observed.

5.0 Discussion

The data presented has enabled us to gain a better understanding and importance of repeated sprint performance in soccer. Increasing knowledge of football specific movement demands provide good scientific rationale for testing and training purposes. The compelling questions regarding RSA are does it relate to overall performance and what type of training will improve it in a football specific context. RSA tests are designed to replicate a highly stressful period of play during a match and measure the ability to resist fatigue (Carling *et al.*2012). Ideally tests will incorporate 'worst case scenarios' in s occer where players are physiologically taxed and have to maintain performance levels and thus categorising RSA enable conditioning coaches to measure, assess and ultimately improve player work rate and football performance.

To the authors knowledge this study is the first to investigate in detail the characteristics of repeated sprint ability in elite professional football throughout the 90 minutes and the demands specific to positional role. The data illustrates that RSA, similar to high intensity distance and sprint distance (Bradley *et al.*, 2009; Di Salvo *et al*., 2009) is affected by playing position with the frequency demands highest in wide midfielders although this finding is in contrast to Carling *et al.* (2012) who found the frequency of repeated high intensity bouts varied across positional role but was highest in full backs. This difference may have been as a result of the tactics employed by the individual teams. For example, Carling *et al.* (2012) investigated a French Division One Team who play in European competitions and had been National Champions, while the players in the current study were playing in the English Championship. The players analysed in the sudy of Carling *et al.* (2012) may therefore employ a 'possession based' tactical strategy and have the ball for longer periods of time thus allowing their full backs to join in the attack, while a 'high intensity press out of possession tactic' may increase physical output. In agreement with this, Di Salvo *et al.* (2009) postulate players from less successful teams seem to require greater amounts intense running from wide midfield positions Di Salvo *et al.*, 2009).

The major findings were despite a reduction in sprint distance throughout the 90 minutes in the current study, as observed by others (Bradley *et al*., 2009; Di Salvo *et al*., 2009; Mohr *et al*., 2003) there was no decline in repeated sprint performance and although not significant the mean number of repeated sprint bouts were highest in the last 15 minutes of each match.

It is important for conditioning coaches and practitioners to consider the repeated sprint demands when prescribing repeated sprint training for players with regards to number of sprint repetitions, number of bouts, recovery duration between repeated sprint repetitions and time between bouts however there are various limitations of the study which need to be taken into consideration.

The lack of a decline in repeated sprint performance may have been a result of the teams conditioning levels therefore it may be difficult to apply this to football matches at the elite level. The team may have performed repeated sprint ability or high intensity work in training and this then would have implications on match day performance. As the sample only performed the first ten home games of the season and not a full season, there may have been seasonal variation in fitness levels. Mohr *et al*., 2003) observed a CV of around 24% in the distance covered in high speed running in elite professional players at different stages of the season.

The small number of games sampled may also be a limitation of the study. Match to match variability in performance characteristics of elite soccer players is high and in order to detect real systematic changes in performance characteristics the inherent variability requires large sample sizes (Gregson *et al*. (2010). Although Gregson *et al*. (2010) reported the effect of the time of the competitive season was low, the data was collected at the early part of the season and pre-season conditioning levels may have affected performance. Other factors such as playing away, changes in opposition formation were also said to be responsible for inherent variation in high speed distances (Gregson *et al*.,2010). Within the current study, all ten games by were home games and tactics employed at home games may have been different to those performed away from home. Within the study,

An additional limitation of the study was no fitness testing data was available therefore it is difficult to state if the lack of repeated sprint performance was a result of the training employed by that particular team or game demands of repeated sprint performance Additional research is required to determine the applicability of the data to professional soccer and evaluate repeated sprint performance in a larger and wider sample of professional teams to verify the present findings.

To the authors knowledge this study is the first to investigate in detail the characteristics of repeated sprint ability in elite professional football throughout the 90 minutes and the demands specific to positional role. The data illustrates that RSA, similar to high intensity distance and sprint distance (Bradley *et al.,* 2009; Di Salvo *et al*., 2009) is affected by playing position with the frequency demands highest in wide midfielders although this finding is in contrast to Carling *et al.* (2012) who found the frequency of repeated high intensity bouts varied across positional role but was highest in full backs. The major findings were despite a reduction in sprint distance throughout the 90 minutes in the current study, as observed by others (Bradley *et al*., 2009; Di Salvo *et al*., 2009; Mohr *et al*., 2003) there was no decline in repeated sprint performance and although not significant the mean number of repeated sprint bouts were highest in the last 15 minutes of each match. Additional research is required to determine the applicability of the data to professional soccer and evaluate repeated sprint performance in a larger and wider sample of professional teams to verify the present findings.

The findings of a lack of decline in repeated sprint performance indicate that fatigue in football may not be a physical decline such as that observed by Bradley *et al*. (2009) and Di Salvo *et al*. (2009) for total distance, high speed distance and sprint distance, rather than a case of how 'fatigue' is measured. Clearly players respond to the demands of the game. Anecdotally, commentators refer to games 'opening up' where managers may make tactical changes as they figure out strategies employed by their counterparts and players began to work out how to create or nullify space through movement. This may be assessed through physical decline however assessment of skills and decision making may also be pertinent to determine the effect this has on overall match performance rather than simply repeated sprint performance, high intensity distance and sprint distance.

Bradley *et al.* (2009) identified the distance deficit for high intensity running was most pronounced in the last 15 min of the game for all five positions. However, the relative contribution of repeated sprint distance increased in the last 15 mins to 43% from 25% in the first half in the present study. Edwards and Noakes (2009) postulate that despite a reduction in high intensity efforts in the last 15 min of the second half, players retain sufficient energy reserves to respond to match demands until the final whistle, thus refuting the presence of progressive fatigue towards a situation which would induce the immediate cessation of exercise. The authors (Edwards and Noakes, 2009) proposed that in order for players to reach the conclusion of the game they adopt a multi-level pacing plan. This level corresponds to the maintenance of tolerable physical discomfort (exercise homeostasis) that the player is prepared to endure for the game. Players need to respond to the demands of the game and if there was no pacing, no one would reach the end of the match and no player would have reserves of energy for short term sprints in the latter stages (Edwards and Noakes, 2009). In a practical sense, this can be observed in players' tactical decisions for example a central midfielder choosing to cover an opposition player's movement rather than initiating a long run forward into the opposition's penalty area or a full back opting to pass the ball to a team mate and support from behind the ball instead of dribbling into space or performing an overlapping run forward into the oppositions half. This would also be affected by extrinsic factors such as specific match considerations for example score line of the game, importance of the game or current levels of fitness. In the current study, it is plausible that players adapted a pacing strategy based upon the demands of the game as within 90% of the games studied the score line was ± 1 goal and the final result was still unknown. Therefore, players may well have adopted a dynamic pacing strategy (Edwards and Noakes, 2009) in the last 15 minutes of the match reducing the total high intensity distance and sprint distance yet still be able to complete an increased number of repeated sprint bouts based as they are 'necessity type sprints' which may be required in order to defend when your team are winning by tracking back or to create a goal scoring opportunity if your team are losing by performing an additional sprint.

5.1 RSA vs Single Sprint

The contribution of Repeated Sprint Distance to Total Sprint Distance varied from 18% in Central Defenders to 35% in Wide Midfielder highlighting the different RSA positional demands and different implications this may have on training for those positions. In addition, the contribution of Repeated Sprint Distance to Total distance was 25% in the first 15mins compared to 43% in the last 15mins. This information demonstrates the importance of RSA as a fitness requirement of footballers and ultimately understanding training strategies that can improve this component. Carling *et al.* (2012) questioned the relative importance of RSA, however these findings highlight the value of RSA particularly towards the end of the game where the outcome of the game is generally decided (Armatas *et al.*, 2007). The anaerobic ATP production during single sprints for example a centre forward pressing the goalkeeper to kick long followd by a long recovery period of inactivity is provided by contributions from both PCr degradation and anaerobic glycolysis. The importance of anaerobic glycolysis is supported by the fact that PCr are only partly depleted during short duration sprinting (Spencer *et al.*, 2005). The relative contribution of anaerobic glycogenolyses is reduced during the performance of repeated sprints which is partially explained by an increase in aerobic metabolism. For example if the centre forward presses the goalkeeper and recovers to position followed by pressing the full back, winning the ball and sprinting towards goal the degradation and resynthesis rate of PCr would be much higher. The greater the degradation, the greater the time required for complete repletion. Energy system contribution during repeated sprint exercise is clearly influenced by variables such as sprint duration, sprint number and recovery duration (Spencer *et al.*, 2005). While previous studies have looked at repeated sprint activity in field hockey (Spencer *et al.*, 2004) and women's soccer (Gabbett and Mulvey, 2008) and Carling *et al*. (2012) looked at repeated high intensity activity, this is the first study to document the nature of repeated sprint performance in elite soccer.

5.2 Total Number of Bouts per game

The total number of Repeated Sprint Bouts that met the criteria for Repeated Sprint Activity per game was 45.9 (±7.1) which is much higher than the data reported by Spencer *et al.* (2004) who identified Repeated Sprint Bouts on 17 occasions in an international hockey match. Spencer *et al.* (2004) suggested the results from this one off hockey game were similar to exercise intensities and sprint activities observed in other sports such as elite soccer. However, it must be stipulated that this game was the first game in an international tournament where roll on – roll off subs were utilised thus substitutions may have reduced the effects of temporary fatigue identified by Bradley *et al.* (2009) and thus causing a reduced pace and intensity of the game (Bradley *et al*., 2009). In addition, players self -regulating match play efforts according to numerous intrinsic and extrinsic factors such as current fitness levels, importance of the game i.e. first game in a tournament as well as positional and tactical considerations (Edwards and Noakes, 2009). The figure reported in the present study is also much higher than data presented by Gabbett and Mulvey (2008) who identified Repeated Sprint Activity on 58 occasions during women's international soccer matches (n=12) (Gabbett and Mulvey, 2008). Conversely, Gabbett and Mulvey (2008) identified RSA as 4.8 (±2.8) bouts per player per match which raises questions to the reader of the ambiguity of this information as it appears more likely to be 4.8 RSA bouts per game. Nonetheless, the data presented in the present study found 4.6 (±1.7) bouts per player per game, similar to the findings of Gabbett and Mulvey (2008). In a similar investigation of Repeated High Intensity running (movement at velocities >19.8kmph for a minimum duration of 1s) performed in French professional soccer, players performed 1.1 repeated high intensity bouts per match (Carling *et al*., 2012) postulate the discrepancy may be explained by differences in respective methods employed to collect the movement data as manual coding techniques tend to overestimate high intensity running performance (Carling *et al.*, 2008). In addition, Carling *et al.* (2012) used a different semi-automatic computerised player tracking system from the current study. This system' identification of high intensity actions are >19.8 kph for a minimum 1s duration as other studies using Prozone (Bradley *et al*., 2009; Di Salvo *et al.*, 2009) define high intensity actions as >19.8 kph for a minimum 0.5s duration and sprinting as >25.2 kph for a minimum 0.5s duration. The author therefore echoes the sentiments of Carling *et al.* (2012) in the need for consensus to ensure standardisation in the classification of movement thresholds with regards to speed and duration for time motion analyses of professional soccer match play.

5.3 Number of Bouts per player

In the present study, wide midfielders (7.2) had the highest mean number of bouts per game, full backs performed the second highest mean number of RS bouts (5.1) while centre back had the lowest mean number of repeated sprint bouts (2.5) per player. This trend is supported by previous research on the high intensity activity pattern identified by Bradley *et al.* (2009) and Di Salvo *et al.* (2009) and the differences may be a consequence of the tactical role of the positions within the team (Reilly, 2003). These figures are similar to those presented by Gabbett and Mulvey (2008), however they categorised players into three positional groups (defenders, midfielders and attackers) and found defenders to be the lowest group (n=4). In contrast, Carling *et al.* (2012) found despite the low frequency of repeated high intensity bouts, performance demands differed significantly across positional roles with full backs performing the most bouts. It could be argued, the tactics of the team may have an effect on the results as well as success of the team (Di Salvo *et al.*, 2009) as in the four seasons analysed the French team achieved European qualification each season. Tactically, the role of wingers in a typical English 4-4-2 high pressing system where they defensively ‘help out’ may well be very different from wingers in a European 4-3-3 system where the wide attackers are seen more as creative forwards with little defensive responsibility, while the full backs have to support the wingers and overlap in order to penetrate from wide areas, although Carling *et al* (2012) did not stipulate the actual tactical formation strategy utilised.

Interestingly in the current study, the most RSA bouts occurred in the last 15 minutes of the game for all positions except for Centre Forwards although this was not statistically significant. This finding is in direct contrast to other literature which states that fatigue generally manifests over the course of the game and high intensity running decreased after the most intense periods and decreased markedly towards the end of the game suggesting a more permanent form of fatigue (Mohr *et al*, 2003; Di Salvo *et al*. 2009). This data also challenges Di Salvo *et al.* (2009) findings who concluded that technical and tactical effectiveness of the team rather than high levels of physical performance *per se* are more important in determining success in soccer and the ability to perform repeated intense efforts is not as crucial to match outcome as previously thought. Di Salvo *et al.* (2009) however only looked at total and mean high intensity data therefore they may not have identified the last 15 mins of games when the outcome of most games is effectively decided (Armatas *et al*., 2007) or that it may not take into account repeated sprint activity.

The present results displayed centre backs to have the largest increase in repeated sprint bouts from first 15 min (6 bouts) to the last 15 min (15 bouts) an increase of 60%. This finding may be due to a number of factors such as changes in tactical organisation where teams are attempting to defend a lead or a tactical pacing strategy. Surprisingly, the current study shows the centre forwards have a 43% reduction in the total number of bouts compared to the first 15min period. Bradley *et al* (2009) speculated that the fitness levels of attackers are not sufficient to meet the demands of elite standard European leagues. Bradley *et al*. (2009) highlighted that further studies were required to investigate the physical fitness of attackers and their influence on game performance. In support of this notion, Krustrup *et al.* (2003; 2006) found attackers performed more poorly than all other positions including central defenders in a game specific Yoyo Intermittent Recovery Test 1 and 2 Test. This reduction of Repeated Sprint Activity may well be due to tactical changes or levels of conditioning and a manifestation of fatigue. Glaister (2005) concluded there is still no clear explanation for the mechanisms that limit RSA. In team sports such as soccer where performance may be dominated by other factors such as technical and tactical abilities, fatigue development has been linked with the inability to reproduce sprints (Krustrup *et al.* 2006). Fatigue may be caused by a variety of factors such as generation of inadequate motor command in the motor cortex (neural factors) or an accumulation of metabolites in the muscle fibres (muscular factors) however there is no global mechanism responsible for all manifestations of fatigue (Girard *et al.* 2011).

A limiting factor regarding the aetiology of fatigue during the game may be the metabolite accumulation (Girard *et al*. 2011). Increases in muscle, blood and hydrogen ion (H+) accumulation that occur during Repeated sprint exercise (RSE) may affect sprint performance via adverse effects on the contractile machinery and /or through the inhibition of ATP derived from glycolysis. In support of this, significant correlations have been observed between sprint decrement and both changes in blood pH and muscle buffer capacity (Bishop *et al.*,2003; Bishop *et al.*,2004; Bishop *et al.*,2006). Therefore, RSA may be improved by interventions that can increase the removal of H+ from the muscle. The removal of intracellular H^+ during intense skeletal muscle contractions (such as repeated sprints) occurs via intracellular buffering and a number of different membrane transporter systems, especially the monocarboxylate transporters (MCTs) (Juel, 1998; cited by Bishop *et al.,* 2011). However, in the only field based study to date investigating muscle and blood metabolites during a soccer match and relating to sprint performance, it has been reported that changes in muscle metabolites were quite small with a decline in sprint performance during the game not correlated with muscle lactate, muscle pH or total glycogen content (Krustrup *et al*, 2006) although it must be stipulated the analysis was not position specific.

Laboratory and field based protocols have demonstrated that fatigue manifests as a decline in maximal / mean sprint speed or as a decrease in peak power or total work over sprint repetitions (Girard *et al.* 2011). Girard *et al.* (2011) proposed the manifestations of fatigue during repeated sprint exercise are dependent upon factors such as the measurements indices, influence of initial sprint performance and task dependency with much of the studies being carried out in a controlled laboratory environment. However within football, activity patterns are random and self-selected based on tactical patterns and intensity of the game for example attacking players when they are winning may well do less sprinting when pressing out of possession in order to win the ball back and instead stay compact and invite pressure in order to counter attack. Fatigue occurring during intense periods of the game has been suggested to be related to the accumulation of potassium in muscle interstitium (Krustrup *et al*., 2006). Billaut and Bishop (2009) concluded sprint exercises results in important ionic pertubations that may contribute to fatigue during sprint exercise. Juel *et al*. (2000; cited in Girard *et al.,* 2011) state in some cases following dynamic contractions at a skeletal level, the Sodium (Na^+) / Potassium K^+ pump cannot readily accumulate the K+ efflux out of the muscle cells, inducing at least a doubling of muscular extra-cellular K+ concentration which impair cell membranes excitability and thus depresses force development.

5.4 Sprints Repetitions per Bout and Recovery Duration

Reps per bout in the current study did not differ significantly between playing position or over the 90 mins. The values were similar to those reported by Spencer *et al.* (2004) and Gabbett and Mulvey (2008) with a range of 3-7 reps. Spencer *et al* (2004) postulated a test protocol designed to elicit an overload stimulus of repeated sprint activity specific to field hockey may be applied to football consisting of 6-7 sprints however the recovery duration of 14.9 seconds may not be adequate for elite soccer. Gabbett and Mulvey (2008) suggested training and testing repeated sprint demands for soccer and field hockey should differ between the two sports. They identified recovery duration of 5.8 seconds between sprints while the present study identified mean recovery duration of 3-4 seconds which did not change according to position or over the 90 minutes. When rest periods are below 30s in duration, subsequent sprint performance can deteriorate due to decreases in Adenosine triphosphate concentration and intra-muscular pH slowing phosphoscreatine resynthesis (Spencer *et al.*, 2005). Bishop *et al.* (2011) propose that an increase in the rate of phosphocreatine resynthesis may be improved by certain training interventions. The limited research to date suggest that while the optimal training intensity has need yet been established, improvements in aerobic fitness may be required to improve phosphocreatine resynthesis (Bishop *et al*., 2011).

McGawley and Bishop (2008) postulate the contribution of oxidative phosphorylation to total energy expenditure during a single short sprint is limited (<10%) however as sprints are repeated there is an increase in the aerobic contribution to individual sprint in the final stages of RSE of up to 40%. Girard *et al. (*2011) suggests the aerobic contribution during RSE may be limited by VO_{2max} and that increasing $VO_{2\ max}$ via appropriate training or ergonenic aids may allow for greater aerobic contribution during the latter sprints and potentially minimising fatigue. $V0_{2max}$ has been reported to be moderately correlated (0.62<r<0.68;p,0.05) with RSA (both mean sprint time and performance decrement) (Rampinini *et al.*, 2010). Bishop and Edge (2006) suggest that subjects with a greater $VO_{2\ max}$ have a superior ability to resist fatigue during RSE, furthermore McGawley and Bishop (2008) stipulate the ability to resist fatigue is especially prevalent during the latter stages of a repeated sprint test when subjects may reach their $VO_{2\ max}$. Therefore improving $VO_{2\ max}$ may allow for a greater contribution to repeated sprints and thus potentially improving RSA (Bishop et al., 2011) however research also indicates there is not a linear relationship between $VO_{2\ max}$ and the various fatigue indices of RSA (Bishop *et al*., 2006). In order to increase the aerobic fitness of team sport athletes one should utilise high intensity interval training (80-90% of $VO_{2\ max}$) interspersed with rest periods (e.g. 1 minute) that are shorter than the work periods (e.g. 2 minutes) (Bishop *et al*., 2011). Another advantage of this high intensity interval training is it may concurrently develop other factors such as the rate of phosphocreatine resynthesis (Bishop *et al.*, 2008) and muscle buffer capacity (Edge *et al*., 2006).

5.5 Time to Next Sprint

The present study was the first to report the mean recovery between sprints and the time to the next sprint following an RSA Bout. Centre Backs had the largest recovery time until the next sprint (3 minutes 4 seconds) as expected with Wide Midfielders having the lowest recovery time to the next sprint (1 minute 53 seconds). A 120s recovery period between short bouts of high intensity activity has been shown not to lead to a decrement in running performance even when 15 sprints were completed in succession (Balsom *et al.,* 1992). players in wide positions such as full backs and wingers may potentially experience transient fatigue during certain phases of match play (Carling *et al.,* 2012). The limitations in energy supply may be a limiting factor in Repeated Sprint Exercise (RSE). Phosphocreatine (PCr) represents the most immediate reserve for the rephosphorylation of adenosine triphosphate (ATP). Therefore PCr is very important within repeated sprint exercise where a high rate of ATP utilisation and resysnthesis is required (Girard *et al.,* 2011). Stores of PCr can be reduced to around 35-55% of resting levels (Gaitanos *et al.,* 1993) and may take up to five minutes for complete recovery of phosphocreatine stores (Tomlin and Wenger, 2001) and this would have important implications during the game whereby successive sprint performance may be compromised as within the results shown, time to next sprint was only 2min 13secs on average. The ability to resynthesise phosphocreatine may be an important determinant of the ability to reproduce sprint performance as brief recovery times between sprints will only lead to a partial restoration of phosphocreatine stores (Bogdanis *et al.,* 1996; Dawson *et al*., 1997). During a single 6 second sprint in cycling, Anaerobic glycolysis supplies approximately 40% of the total energy with a progressive inhibition of glycolysis as sprints are repeated. However it is unclear whether increasing the maximal anaerobic glycogenolytic and glycolytic rate will lead to improvements in RSA (Girard *et al.,* 2011). Increasing the anaerobic contribution is likely to improve both initial and mean sprint performance and thus the ability to perform repeated sprints (Bishop *et al.,* 2011). Intriguingly, as centre backs had a much longer recovery time than full backs following repeated sprint bouts until the next sprint, thus potentially allowing adequate PCr replenishment, this may have enabled more RSA bouts to take place towards the end of the 90 minutes

5.6 Maximal Sprint Distance / Total Sprint Distance / Average Sprint Distance

A novel approach of this study was the quantification of Sprint Distance within repeated sprint bouts which has important consequences for conditioning coaches. Carling *et al* (2012) had previously identified high intensity actions to have a Total bout distance of 16.5m (±4.9), lower than the current study values of sprint distance of 22.87m (±1.7). These values did not differ significantly over time, however wide midfielders were significantly higher than centre midfielders (p<0.0.5). This may be attributed to wide midfielders who are involved in attacking and defending and have more of a freedom to dictate their own activity profile as a consequence of the need to create attacking opportunities while centre midfielders may have to counter the movements of opposition players (Di Salvo *et al*., 2009).

Sprinting involves considerable amounts of neural activation (Ross *et al.* 2001). Although not as extensively studied, Neural mechanisms are also factors which may critically affect fatigue resistance in repeated sprint activity, such as failure to fully activate the contracting muscle (Ross *et al.,* 2001) assessed via surface electromyogram (EMG) and changes in inter muscular recruitment strategies (Billaut *et al*. 2005) will theoretically decrease force production and therefore reduce RSA. Ross *et al*. (2001) also identified changes in mechanical behaviour (stiffness regulation) may also indirectly alter fatigue resistance during repeated sprints while environmental perturbations will determine the relative contribution of the underlying mechanisms to fatigue (Girard *et al*. 2011).

In elite soccer, coaches refer to the game 'settling down' after an opening period of 15 minutes with lots of transitions between teams in possession and teams beginning to 'familiarise' themselves with the game and external environment. From Figure 2 sprint distance is most pronounced during the opening 15 min period of each half. In addition, with regards to the repeated sprint activity variables, 0-15 time period had the highest maximum sprint distance, second highest bout total distance, the highest average sprint distance and shortest recovery time to next sprint. Interestingly, in relation to key repeated sprint variables although significant differences were not observed, the 15-30mins time period was the shortest maximum sprint distance, lowest bout total distance, the shortest sprint average duration and had the longest recovery time to next sprint. This reduction may be as a result of players taking longer to recovery between sprints. In agreement with this theory, Bradley *et al.* (2009) advocated that although the amount of high intensity running in the most intense 5 min period of the game varied between playing position, the subsequent 5 min period showed a 50% reduction in high intensity distance. Anecdotally, players will often refer to 'getting a second wind' after about 20 – 30 minutes of the game which may be as a result of a prolonged recovery period allowing adequate PCr replenishment (Girard *et al.*, 2011) which enables them to continue through the rest of the game.

6.0 Practical Implications

The present study is the first study to investigate repeated sprint performance in elite soccer players. The results of the study demonstrate that repeated sprint performance differs between position however it does not decline across the ninety minutes. To ensure the construct validity of repeated sprint tests is respected protocols must measure match related performance (Meckel *et al.*, 2009). The present study therefore suggests fitness personnel might employ repeated sprint tests that are position specific with a maximum of four reps per bout with varying recovery times between bouts (see Table 5). Additionally, changes in positional profile have identified the need for position specific repeated sprint training to be implemented. Table 6 provides examples of how these may be performed practically. Further studies need to be carried out in order to assess whether training induced changes in RSA also produce changes in match physical performance. The increased emphasis on the use of small sided games conditioning to improve team sport fitness and technical abilities must also be investigated further in order to ensure repeated sprint performance is identified and improved or if additional repeated sprint training needs to take place.

6.1 Implications for Repeated Sprint Testing in football

The present study reports the total sprint distance in the bout, average sprint distance per repeated sprint and maximum sprint distance in each of the bouts may have important implications for the design and validity of RSA in terms of frequency, duration and distances of RSA bouts. Tests of RSA in team sports are designed in order to replicate a highly stressful period during the game and measure the ability to maintain performance whilst resisting fatigue (Oliver *et al.*, 2007). Results from this study contrast with those of Carling *et al.* (2012) and Spencer *et al.* (2004) who suggested fitness personnel might employ RSA tests with a maximum duration of 15s recovery between consecutive efforts however the present study demonstrates average recovery durations of 3s. This discrepancy may be due to the classification of sprints (>25.2 kph for a minimum 0.5s duration) which may have increased the frequency of sprints in comparison to Carling *et al.* (2012) (>19.8 kph for a minimum 0.5s duration).

Carling *et al.* (2012) postulated an RSA test should take into account various running activities at low and moderate intensities due to the large oscillations within extreme bouts of repeated sprint exercise and recovery durations. Therefore, due to different tactical demands of each position, perhaps future tests should take into account variations in recovery duration, number of bouts, effort lengths and be positional based to provide a more ecologically valid assessment of players ability to perform repeated sprints (see table 5). Furthermore, it may be argued field and laboratory assessments should distinguish between repeated sprint capacity and repeated sprint activity as players may not be working at their maximal physiological limits. Future research is required to identify if repeated sprint capacity and repeated sprint activity need to be differentiated. Table 5 provides examples of tests which may be used to provide more ecologically valid tests.

Table 5 – Examples of Field Based Repeated Sprint Ability Testing incorporating position specific data.

Test	Number of Bouts	Number of Reps per Bout	Sprint Repetition Distance (m)	Total Sprint Distance (m)	Recovery Duration between Sprints (s)	Recovery Duration between Bouts (S)
Repeated Sprint Capacity	1	7	12	84	3	n/a
Repeated Sprint Activity	FB – 5 CB – 3 CM - 5 WM -7 CF - 4	3	7	21 x 5 = 105 21 x 3 = 63 21 x 5 = 105 21 x 7 = 147 21 x 4 = 84	3	FB – 120 CB – 180 CM – 120 WM – 120 CF - 150

Overall, RSA performance assessment is complex because RSA contributes to rather than being a primary determinant of the player's overall performance during a match (Aziz *et al.*, 2008). Establishing relationships between RSA performance measures and match performance is problematic and doubts must be raised on the ecological validity of laboratory based RSA tests to predict physical performance in match play.

6.2 Improving Repeated Sprint Ability in Football

Anecdotally, repeated sprint training is used to improve RSA, however very few studies have actually compared such specific training to generic training (interval training) in team sport athletes therefore only tentative conclusions can be drawn regarding its potential application (Bishop *et al.*, 2011).

During repeated sprint training the relative contribution of anaerobic glycogenolysis is reduced when subsequent sprints are performed, which is partially explained by an increase in aerobic metabolism (Spencer *et al.,* 2005). In addition, the degradation and resynthesis rate of PCr is related to performance decrement and loss of muscle purine nucleotides may also occur during subsequent sprints (Spencer *et al.,* 2005).

With regards to RSA, repeated sprint training compared with interval training has been reported to demonstrate greater improvements in mean sprint time (Ferrari Bravo *et al.,* 2008; Mohr *et al*., 2007; Schneiker and Bishop, 2008; Bucheitt *et al*., 2010) and produce greater improvements in best sprint time (Mohr *et al.,* 2007; Schneiker and Bishop, 2008; Bucheitt *et al.,* 2010).

Bishop *et al.* (2011) reveals compared with repeated sprint training, interval training produces superior increases in both intracellular buffering (Schneiker and Bishop, 2008)and Na^+/K^+ pump isoform content (Mohr *et al.,* 2007). Interval training also appears to be superior to repeated sprint training to decrease (i.e. improve) the sprint decrement (or the fatigue index; Mohr *et al*., 2007; Schneiker and Bishop, 2008). Although Bishop *et al.* (2011) proposes that repeated sprint training is superior to improving the performance of individual sprint, interval training may be superior at minimising the decrement during repeated sprints (due to greater physiological adaptations) (Bishop *et al.,* 2011). The authors conclude, a combination of the two (i.e. repeated sprint training to improve sprint performance plus interval training to improve the recovery between sprints) may be the best strategy to improve RSA (Bishop *et al.,* 2011).

It is important to establish the physiological characteristics associated with improved RSA and high intensity, intermittent exercise because it could be useful for guiding the development of specific training interventions for high standard soccer players (Rampinini *et al.,* 2009). Bishop (2009) states surprisingly little research exists about the best methods to improve "physical performance" (e.g. number of sprints) during actual team sport competition. One of the major reasons for this is the difficulty in conducting training studies and in measuring "physical performance" during team sports. One concept that has emerged due to the absence of scientific evidence is "train as you play" however, we should ask does this concept better improve physiological qualities important for team sport performance than other types of training (Bishop, 2009)? Match analysis studies have demonstrated football requires participants to repeatedly produce maximal or near maximal actions of short duration with brief recovery therefore football training should commonly include football exercises aimed to enhance both aerobic fitness and RSA (Ferrari Bravo *et al.,* 2008). The use of soccer specific endurance training involving the ball may increase technical and tactical development. In addition, Rampinini *et al.* (2009) found that technical skills also decreased during a game and match related fatigue may influence a player's technical ability. They conclude it is not only the ability to compete at high intensity during a match, but also the ability to have greater involvements with the ball and complete more skill related activities which are the determinants for successful teams in elite soccer (Rampinini *et al*. 2009). Therefore, performing ball related high intensity training may improve technical and tactical skills under fatiguing conditions which replicate game demands.

6.3 RSA and Position Specific Training

Recent match analysis studies (Bradley *et al*., 2009; Di Salvo *et al*., (2009) have given us an insight into game demands and indicated positional differences exist and thus it may be pertinent to design specific game related training for different positions based on their physical, tactical and technical needs. For example central defenders cover less high intensity running than any other position and perform more explosive sprints than other positions except central midfielders, while wide midfielders perform the most high intensity running with attackers performing the highest sprint distance and leading sprints (Di Salvo *et al*., 2009). The match analysis literature to date however, has presented information regarding means and total distances, rather than the specific nature of high intensity or repeated sprints bouts performed and when the physiological system is highly taxed. Spencer *et al*. (2004) stated match analysis provides a limited insight into the 'patterns of repeated sprint ability' and its influence and importance has yet to be investigated (Spencer *et al*., 2004). The information in the current study gives us the opportunity to design specific position based training based on the repeated sprint demands of the game. There may be instances in the game such as when teams are losing and chasing the game; or down to ten men having had a player sent off; or when games go into extra time, consequently players must be highly conditioned to perform under these situations and these scenarios are difficult to replicate during game related training. The present study therefore identifies that these 'patterns of repeated sprint ability' may well occur late in the game, specifically for central defenders hence conditioning coaches must ensure their players are appropriately conditioned to perform these bouts.

Practitioners may employ position specific data for testing and conditioning purposes based upon the current study. In light of the findings observed, the importance of RSA and the requirement to train for it and the positional differences that exist ensure assessment training, and conditioning can be position specific. The type and amount of training should be game related and specific to the technical, tactical and physical demands imposed on the players (Iaia *et al*, 2009). The present findings enable us to design specific game related training drills. For example, during repeated sprint training the number of sprint bouts may vary between position with wide midfielders performing seven bouts and the centre backs performing three. In addition, wide midfielders may have less recovery time between bouts (120 seconds) compared to centre backs (180 seconds). In addition, wide midfielders may have a higher total bout distance than centre midfielders. An example of a position specific drill is presented in Table 6 below. The variables are those used in the categorisation of repeated sprint performance in the study. Each bout consists of one maximum repeated sprint repetition per bout for distance and the remainder are average repetition per bout. For example, a full back will complete four repeated sprint repetitions per bout, three of which will be average and one maximum..

Table 6 – Examples of Field Based Repeated Sprint Ability Training incorporating position specific data.

Position	Number of Repeated Sprint Bouts	Number of Repeated Sprint Reps per Bout	Maximum Repeated Sprint Repetition Distance (m)	Average Repeated Sprint Repetition Distance (m)	Total Repeated Sprint Distance (m) per Bout	Recovery Duration between Repeated Sprints (s)	Bout Duration (s)	Recovery Duration between Bouts (S)
Full Back	5	4	1 x 13	3 x 7	34	3	16	120
Centre Back	3	3	1 x 10	2 x 6	22	4	14	180
Centre Midfield	4	3	1 x 9	2 x 6	21	4	16	120
Wide Midfielder	7	4	1 x 12	3 x 7	33	4	16	120
Centre Forward	4	4	1 x 11	3 x 7	32	3	14	150

This information has important implications for practitioners for example those players not playing 90 minutes every week may be able to perform additional repeated sprint training ensuring substitutes and injured players returning to play can tolerate game demands when required.

This information is of value to practitioners as for example RSA was not found to be present in the study of Gabbett and Mulvey (2008) who compared the time motion characteristics within small sided games (i.e. 3v3 and 5v5) domestic and international matches with special reference to high intensity activities and repeated sprint demands. The authors reported the matches do not simulate the high intensity, repeated sprint demands of international women's competitions, suggesting small sided games should be supplemented with game specific training that stimulates high intensity, repeated sprint demands of international competition (Gabbett and Mulvey, 2008). A combination of RSA and small sided games may help ensure players develop the repeatedly perform intense exercise for long periods (Iaia *et al*, 2009).

Proponents of 'training as you play' however need to provide more scientific evidence that this is a superior method of training for team sport athletes (Bishop, 2009). Sports scientists and conditioning coaches may need to utilize a combination of aerobic high intensity and speed endurance or repeated sprint training specific to the technical, tactical and physical demands of the game and positions such as that highlighted in table 6.. This type of training will 'provoke the metabolic perturbations required to stimulate adaptations' (Bishop, 2009) and ultimately improve the capacity to perform repeated maximal bouts of maximal or near maximal efforts interspersed with short recovery within the context of game demands ultimately improving 'physical performance'

6.4 RSA and Small sided Games

The effect of performing high intensity training through football specific exercises such as small sided games, has also been examined (Impellizzerri *et al.,* 2006; McMillan *et al.,* 2005; Hill-Haas *et al.*, 2009). Impellizzerri *et al.* (2006) compared the effect of training (using small sided games) and generic without the ball (interval) training and found both were equally effective in improving a number of physiological measures (VO_{2max}, speed at lactate threshold and running economy) and physical performance in a game (total distance and high intensity activity during a match). Although physical performances during the game were not different between general and specific training, it cannot be ruled out differences may have existed (Iaia *et al.* (2009). Only one game was analysed before and after the training period, technical aspects were not taken into consideration (Iaia *et al.,* 2009). Hill Haas *et al.* (2009) in a similar study comparing the two exercise modalities in junior elite players found 17% performance improvements in the YoYo IR1 with no change in VO_{2max}. Iaia *et al.* (2009) postulated the overall effect of training with small sided games is greater for football specific performance.

Small sided training games as a means of concurrently developing a players technical, physical and tactical abilities are well documented (Dellal *et al.,* 2012; Hill Haas *et al.,* 2011) however only two studies have investigated the effects of small sided games training on RSA (Buchheit *et al*.,2009; Hill Haas *et al.,* 2009) and both have reported small non significant differences in RSA performance enhancement compared with generic training (Buchheit *et al.*,2009; Hill Haas *et al.,* 2009). In addition, Gabbett and Mulvey (2008) have compared the time motion characteristics within small sided games (i.e. 3v3 and 5v5) domestic and international matches with special reference to high intensity activities and repeated sprint demands. The authors reported the matches do not simulate the high intensity, repeated sprint demands of international women's competitions, suggesting small sided games should be supplemented with game specific training that stimulates high intensity, repeated sprint demands of international competition (Gabbett and Mulvey, 2008). When carrying out football related high intensity training, it is important to make sure players are performing at the desired intensity. Exercise intensity may be manipulated by various factors during small sided games. These include pitch sizes, number of players, coach's encouragement and specific conditions. Little and Williams (2007) suggest that heart rate is a generally valid method of monitoring intensity in soccer games but may have limited usefulness in shorter, more intense drills. They conclude a combination of Heart Rate and Borg RPE appears to be valid markers of exercise intensity over a range of training drills (Little and Williams, 2007).

Only two studies to date (Impellezzeri et al., 2006; Gabbett 2006) have investigated the effects of small sided games training on RSA, both reporting small, non-significant changes in terms of RSA performance enhancement. Further research is required comparing small sided games training with other types of training in order to establish if small sided games induces repeated sprint demands and if small sided games can actually improve RSA.

7.0 Limitations

A methodological limitation of the study was the relatively small number of players included for analysis and that they came from one club. Therefore the patterns observed may not be representative of the league in which it competes. Tactics employed by the team such as a high pressing 'out of possession' strategy may have influenced the data. There are various factors such as tactics and formations utilized, stage of the season and home fixtures may have influenced the results. A small number of players included for analysis may also be a limitation due to the match to match variability of High speed running which requires large sample sizes in order to detect systematic changes in performance characteristics (Gregson *et al.*, 2010). In the present study, there was no ability to differentiate between types of sprints such as leading or explosive. Di Salvo *et al.* (2009) in the analysis of three seasons' data reported that sprints had become more frequent, shorter and explosive in nature. Another limitation of note in the current findings is there is no indication if the repeated sprint bouts were with or without possession. This differentiation between high intensity activity with and without the ball allows the value of high intensity efforts in relation to crucial match outcomes to be assessed (Di Salvo *et al*., 2009).

8.0 Conclusion

In summary, the present study is the first to investigate the repeated sprint demands of elite level football. The major new finding from the study was the increased number of RSA bouts in the last 15mins of the end of the game for all positions except for centre forwards. This interesting finding may be due to a number of factors such as the fitness level of the various positions, manifestations of fatigue or a pacing strategy based upon internal and external factors. Furthermore, fatigue may occur throughout the game particularly after the first 15 minute period potentially causing a 'second wind phenomena' as well as towards the end of the game. The results demonstrate that RS performance may be an important physiological quality within elite level football and its relative importance particularly towards the end of games cannot be underestimated. Further in-depth scientific research of categorizing repeated sprint performance in elite match play needs to be carried out particularly with specific reference to match outcomes over a large sample size to inform our training and testing protocols and procedures. Future research into the possible occurrence of fatigue patterns in repeated sprint performance is required in order to facilitate an objective framework for the design and validity of repeated sprint ability tests and enhance our understanding of how best to improve RSA. The importance of RSA performance measures to improved game performance must be further explored. It may also be pertinent to investigate the repeated sprint demands of small sided games in elite soccer to examine if they elicit repeated sprint performance and if this can be used as a valuable training tool. Further research is also required in order to investigate position specific repeated sprint training and how it may also be used to replicate game demands based upon technical, tactical and physical requirements.

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Tests of Between-Subjects Effects

Dependent Variable: Averecovery

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	950074.099[a]	29	32761.176	1.150	.273
Intercept	11948086.810	1	11948086.810	419.395	.000
Position	98783.781	4	24695.945	.867	.484
Timeperiod	326436.493	5	65287.299	2.292	.045
Position * Timeperiod	519744.410	20	25987.220	.912	.572
Error	12221725.683	429	28488.871		
Total	28715384.000	459			
Corrected Total	13171799.782	458			

a. R Squared = .072 (Adjusted R Squared = .009)

Multiple Comparisons

Dependent Variable: Averecovery

Bonferroni

(I) Timeperiod	(J) Timeperiod	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	-0:00:16.65	0:00:28.263	1.000	-0:01:40.07	0:01:06.78
	3.00	-0:00:34.98	0:00:28.156	1.000	-0:01:58.09	0:00:48.12
	4.00	0:00:41.97	0:00:27.296	1.000	-0:00:38.60	0:02:02.54
	5.00	0:00:13.85	0:00:28.051	1.000	-0:01:08.95	0:01:36.65
	6.00	-0:00:28.91	0:00:25.838	1.000	-0:01:45.17	0:00:47.36
2.00	1.00	0:00:16.65	0:00:28.263	1.000	-0:01:06.78	0:01:40.07
	3.00	-0:00:18.33	0:00:28.842	1.000	-0:01:43.47	0:01:06.80
	4.00	0:00:58.62	0:00:28.003	.554	-0:00:24.04	0:02:21.28
	5.00	0:00:30.50	0:00:28.739	1.000	-0:00:54.33	0:01:55.33
	6.00	-0:00:12.26	0:00:26.584	1.000	-0:01:30.73	0:01:06.21
3.00	1.00	0:00:34.98	0:00:28.156	1.000	-0:00:48.12	0:01:58.09
	2.00	0:00:18.33	0:00:28.842	1.000	-0:01:06.80	0:01:43.47
	4.00	0:01:16.96	0:00:27.895	.091	-0:00:05.38	0:02:39.29
	5.00	0:00:48.83	0:00:28.633	1.000	-0:00:35.69	0:02:13.35
	6.00	0:00:06.08	0:00:26.470	1.000	-0:01:12.05	0:01:24.21
4.00	1.00	-0:00:41.97	0:00:27.296	1.000	-0:02:02.54	0:00:38.60
	2.00	-0:00:58.62	0:00:28.003	.554	-0:02:21.28	0:00:24.04
	3.00	-0:01:16.96	0:00:27.895	.091	-0:02:39.29	0:00:05.38
	5.00	-0:00:28.12	0:00:27.789	1.000	-0:01:50.15	0:00:53.90
	6.00	-0:01:10.88	0:00:25.554	.087	-0:02:26.31	0:00:04.55
5.00	1.00	-0:00:13.85	0:00:28.051	1.000	-0:01:36.65	0:01:08.95

	2.00	-0:00:30.50	0:00:28.739	1.000	-0:01:55.33	0:00:54.33
	3.00	-0:00:48.83	0:00:28.633	1.000	-0:02:13.35	0:00:35.69
	4.00	0:00:28.12	0:00:27.789	1.000	-0:00:53.90	0:01:50.15
	6.00	-0:00:42.75	0:00:26.358	1.000	-0:02:00.56	0:00:35.05
	1.00	0:00:28.91	0:00:25.838	1.000	-0:00:47.36	0:01:45.17
	2.00	0:00:12.26	0:00:26.584	1.000	-0:01:06.21	0:01:30.73
6.00	3.00	-0:00:06.08	0:00:26.470	1.000	-0:01:24.21	0:01:12.05
	4.00	0:01:10.88	0:00:25.554	.087	-0:00:04.55	0:02:26.31
	5.00	0:00:42.75	0:00:26.358	1.000	-0:00:35.05	0:02:00.56

Based on observed means.

The error term is Mean Square(Error) = 28488.871.

Tests of Between-Subjects Effects

Dependent Variable: Timetonextsprint

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1814785185.329[a]	29	62578799.494	1.150	.274
Intercept	26627515676.747	1	26627515676.747	489.155	.000
Position	754697825.821	4	188674456.455	3.466	.008
Timeperiod	254151009.250	5	50830201.850	.934	.459
Position * Timeperiod	745562442.355	20	37278122.118	.685	.842
Error	23352927154.976	429	54435727.634		
Total	54482943800.000	459			
Corrected Total	25167712340.305	458			

a. R Squared = .072 (Adjusted R Squared = .009)

Multiple Comparisons

Dependent Variable: Timetonextsprint

Bonferroni

(I) Position	(J) Position	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
	2.00	-0:55:32.27	0:21:20.404	.096	-1:55:45.10	0:04:40.55
1.00	3.00	-0:05:15.33	0:18:11.949	1.000	-0:56:36.41	0:46:05.74
	4.00	0:15:43.70	0:15:49.394	1.000	-0:28:55.14	1:00:22.54

	5.00	-0:16:23.34	0:18:23.432	1.000	-1:08:16.82	0:35:30.13
2.00	1.00	0:55:32.27	0:21:20.404	.096	-0:04:40.55	1:55:45.10
	3.00	0:50:16.94	0:22:12.210	.240	-0:12:22.06	1:52:55.94
	4.00	1:11:15.97*	0:20:18.105	.005	0:13:58.93	2:08:33.01
	5.00	0:39:08.93	0:22:21.638	.807	-0:23:56.67	1:42:14.54
3.00	1.00	0:05:15.33	0:18:11.949	1.000	-0:46:05.74	0:56:36.41
	2.00	-0:50:16.94	0:22:12.210	.240	-1:52:55.94	0:12:22.06
	4.00	0:20:59.03	0:16:58.184	1.000	-0:26:53.91	1:08:51.97
	5.00	-0:11:08.01	0:19:23.147	1.000	-1:05:49.98	0:43:33.96
4.00	1.00	-0:15:43.70	0:15:49.394	1.000	-1:00:22.54	0:28:55.14
	2.00	-1:11:15.97*	0:20:18.105	.005	-2:08:33.01	-0:13:58.93
	3.00	-0:20:59.03	0:16:58.184	1.000	-1:08:51.97	0:26:53.91
	5.00	-0:32:07.04	0:17:10.489	.622	-1:20:34.70	0:16:20.62
5.00	1.00	0:16:23.34	0:18:23.432	1.000	-0:35:30.13	1:08:16.82
	2.00	-0:39:08.93	0:22:21.638	.807	-1:42:14.54	0:23:56.67
	3.00	0:11:08.01	0:19:23.147	1.000	-0:43:33.96	1:05:49.98
	4.00	0:32:07.04	0:17:10.489	.622	-0:16:20.62	1:20:34.70

Based on observed means.

The error term is Mean Square(Error) = 54435727.634.

*. The mean difference is significant at the 0.05 level.

Tests of Between-Subjects Effects

Dependent Variable: Boutduration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	12834838.604[a]	29	442580.642	.934	.567
Intercept	290265903.624	1	290265903.624	612.774	.000
Position	1229500.866	4	307375.217	.649	.628
Timeperiod	3094428.941	5	618885.788	1.307	.260
Position * Timeperiod	6110933.177	20	305546.659	.645	.878
Error	203213811.832	429	473691.869		
Total	592623950.000	459			
Corrected Total	216048650.436	458			

a. R Squared = .059 (Adjusted R Squared = -.004)

Multiple Comparisons

Dependent Variable: Boutduration

Bonferroni

(I) Position	(J) Position	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound

1.00	2.00	0:01:15.33	0:01:59.441	1.000	-0:04:21.69	0:06:52.35
	3.00	-0:00:19.34	0:01:41.861	1.000	-0:05:06.76	0:04:28.07
	4.00	-0:00:22.55	0:01:28.563	1.000	-0:04:32.44	0:03:47.34
	5.00	0:02:38.89	0:01:42.932	1.000	-0:02:11.55	0:07:29.33
2.00	1.00	-0:01:15.33	0:01:59.441	1.000	-0:06:52.35	0:04:21.69
	3.00	-0:01:34.67	0:02:04.274	1.000	-0:07:25.33	0:04:15.98
	4.00	-0:01:37.88	0:01:53.629	1.000	-0:06:58.50	0:03:42.74
	5.00	0:01:23.56	0:02:05.153	1.000	-0:04:29.58	0:07:16.69
3.00	1.00	0:00:19.34	0:01:41.861	1.000	-0:04:28.07	0:05:06.76
	2.00	0:01:34.67	0:02:04.274	1.000	-0:04:15.98	0:07:25.33
	4.00	-0:00:03.20	0:01:34.980	1.000	-0:04:31.20	0:04:24.79
	5.00	0:02:58.23	0:01:48.503	1.000	-0:02:07.92	0:08:04.39
4.00	1.00	0:00:22.55	0:01:28.563	1.000	-0:03:47.34	0:04:32.44
	2.00	0:01:37.88	0:01:53.629	1.000	-0:03:42.74	0:06:58.50
	3.00	0:00:03.20	0:01:34.980	1.000	-0:04:24.79	0:04:31.20
	5.00	0:03:01.44	0:01:36.128	.598	-0:01:29.80	0:07:32.67
5.00	1.00	-0:02:38.89	0:01:42.932	1.000	-0:07:29.33	0:02:11.55
	2.00	-0:01:23.56	0:02:05.153	1.000	-0:07:16.69	0:04:29.58
	3.00	-0:02:58.23	0:01:48.503	1.000	-0:08:04.39	0:02:07.92
	4.00	-0:03:01.44	0:01:36.128	.598	-0:07:32.67	0:01:29.80

Based on observed means.

The error term is Mean Square(Error) = 473691.869.

Tests of Between-Subjects Effects

Dependent Variable: Maxsprintduration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	106362.250[a]	29	3667.664	1.161	.261
Intercept	1826941.463	1	1826941.463	578.457	.000
Position	23300.937	4	5825.234	1.844	.119
Timeperiod	26610.117	5	5322.023	1.685	.137
Position * Timeperiod	48480.341	20	2424.017	.768	.753
Error	1354912.260	429	3158.304		
Total	3816600.000	459			
Corrected Total	1461274.510	458			

a. R Squared = .073 (Adjusted R Squared = .010)

Multiple Comparisons

Dependent Variable: Maxsprintduration

Bonferroni

(I) Position	(J) Position	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	0:00:10.08	0:00:09.753	1.000	-0:00:17.44	0:00:37.59
	3.00	0:00:19.48	0:00:08.317	.197	-0:00:03.99	0:00:42.94
	4.00	-0:00:01.52	0:00:07.232	1.000	-0:00:21.92	0:00:18.89
	5.00	0:00:10.56	0:00:08.405	1.000	-0:00:13.15	0:00:34.28
2.00	1.00	-0:00:10.08	0:00:09.753	1.000	-0:00:37.59	0:00:17.44
	3.00	0:00:09.40	0:00:10.147	1.000	-0:00:19.23	0:00:38.03
	4.00	-0:00:11.59	0:00:09.278	1.000	-0:00:37.77	0:00:14.59
	5.00	0:00:00.49	0:00:10.219	1.000	-0:00:28.35	0:00:29.32
3.00	1.00	-0:00:19.48	0:00:08.317	.197	-0:00:42.94	0:00:03.99
	2.00	-0:00:09.40	0:00:10.147	1.000	-0:00:38.03	0:00:19.23
	4.00	-0:00:20.99	0:00:07.756	.071	-0:00:42.88	0:00:00.89
	5.00	-0:00:08.91	0:00:08.860	1.000	-0:00:33.91	0:00:16.09
4.00	1.00	0:00:01.52	0:00:07.232	1.000	-0:00:18.89	0:00:21.92
	2.00	0:00:11.59	0:00:09.278	1.000	-0:00:14.59	0:00:37.77
	3.00	0:00:20.99	0:00:07.756	.071	-0:00:00.89	0:00:42.88
	5.00	0:00:12.08	0:00:07.849	1.000	-0:00:10.07	0:00:34.23
5.00	1.00	-0:00:10.56	0:00:08.405	1.000	-0:00:34.28	0:00:13.15
	2.00	-0:00:00.49	0:00:10.219	1.000	-0:00:29.32	0:00:28.35
	3.00	0:00:08.91	0:00:08.860	1.000	-0:00:16.09	0:00:33.91
	4.00	-0:00:12.08	0:00:07.849	1.000	-0:00:34.23	0:00:10.07

Based on observed means.

The error term is Mean Square(Error) = 3158.304.

Tests of Between-Subjects Effects

Dependent Variable: sprintduration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	195449.876[a]	29	6739.651	.972	.509
Intercept	9341880.939	1	9341880.939	1347.953	.000
Position	69095.588	4	17273.897	2.492	.043
Timeperiod	36455.347	5	7291.069	1.052	.387
Position * Timeperiod	66904.322	20	3345.216	.483	.973
Error	2973151.105	429	6930.422		
Total	15379425.000	459			
Corrected Total	3168600.980	458			

a. R Squared = .062 (Adjusted R Squared = -.002)

Multiple Comparisons

Dependent Variable: sprintduration

Bonferroni

(I) Position	(J) Position	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	0:00:20.20	0:00:14.447	1.000	-0:00:20.57	0:01:00.96
	3.00	0:00:28.46	0:00:12.321	.214	-0:00:06.30	0:01:03.23
	4.00	-0:00:03.66	0:00:10.712	1.000	-0:00:33.89	0:00:26.57
	5.00	0:00:23.09	0:00:12.450	.643	-0:00:12.04	0:00:58.22
2.00	1.00	-0:00:20.20	0:00:14.447	1.000	-0:01:00.96	0:00:20.57
	3.00	0:00:08.26	0:00:15.032	1.000	-0:00:34.15	0:00:50.68
	4.00	-0:00:23.86	0:00:13.744	.833	-0:01:02.64	0:00:14.93
	5.00	0:00:02.90	0:00:15.138	1.000	-0:00:39.82	0:00:45.61
3.00	1.00	-0:00:28.46	0:00:12.321	.214	-0:01:03.23	0:00:06.30
	2.00	-0:00:08.26	0:00:15.032	1.000	-0:00:50.68	0:00:34.15
	4.00	-0:00:32.12	0:00:11.489	.054	-0:01:04.54	0:00:00.30
	5.00	-0:00:05.37	0:00:13.124	1.000	-0:00:42.40	0:00:31.66
4.00	1.00	0:00:03.66	0:00:10.712	1.000	-0:00:26.57	0:00:33.89
	2.00	0:00:23.86	0:00:13.744	.833	-0:00:14.93	0:01:02.64
	3.00	0:00:32.12	0:00:11.489	.054	-0:00:00.30	0:01:04.54
	5.00	0:00:26.75	0:00:11.627	.219	-0:00:06.06	0:00:59.56
5.00	1.00	-0:00:23.09	0:00:12.450	.643	-0:00:58.22	0:00:12.04
	2.00	-0:00:02.90	0:00:15.138	1.000	-0:00:45.61	0:00:39.82
	3.00	0:00:05.37	0:00:13.124	1.000	-0:00:31.66	0:00:42.40
	4.00	-0:00:26.75	0:00:11.627	.219	-0:00:59.56	0:00:06.06

Based on observed means.

The error term is Mean Square(Error) = 6930.422.

Tests of Between-Subjects Effects

Dependent Variable: Maximalsprintdist

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2240.470[a]	29	77.258	1.276	.157
Intercept	44775.992	1	44775.992	739.519	.000
Position	584.728	4	146.182	2.414	.048
Timeperiod	460.865	5	92.173	1.522	.182
Position * Timeperiod	1037.213	20	51.861	.857	.643
Error	25974.867	429	60.547		
Total	86162.490	459			
Corrected Total	28215.337	458			

a. R Squared = .079 (Adjusted R Squared = .017)

Multiple Comparisons

Dependent Variable: Maximalsprintdist

Bonferroni

(I) Position	(J) Position	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	2.1187	1.35037	1.000	-1.6916	5.9289
	3.00	3.2552*	1.15162	.049	.0057	6.5046
	4.00	.4476	1.00127	1.000	-2.3776	3.2728
	5.00	1.2094	1.16373	1.000	-2.0742	4.4930
2.00	1.00	-2.1187	1.35037	1.000	-5.9289	1.6916
	3.00	1.1365	1.40501	1.000	-2.8279	5.1009
	4.00	-1.6711	1.28467	1.000	-5.2959	1.9538
	5.00	-.9093	1.41495	1.000	-4.9018	3.0832
3.00	1.00	-3.2552*	1.15162	.049	-6.5046	-.0057
	2.00	-1.1365	1.40501	1.000	-5.1009	2.8279
	4.00	-2.8076	1.07382	.092	-5.8375	.2224
	5.00	-2.0458	1.22671	.961	-5.5071	1.4155
4.00	1.00	-.4476	1.00127	1.000	-3.2728	2.3776
	2.00	1.6711	1.28467	1.000	-1.9538	5.2959
	3.00	2.8076	1.07382	.092	-.2224	5.8375
	5.00	.7618	1.08680	1.000	-2.3048	3.8283
5.00	1.00	-1.2094	1.16373	1.000	-4.4930	2.0742
	2.00	.9093	1.41495	1.000	-3.0832	4.9018
	3.00	2.0458	1.22671	.961	-1.4155	5.5071
	4.00	-.7618	1.08680	1.000	-3.8283	2.3048

Based on observed means.

The error term is Mean Square(Error) = 60.547.

*. The mean difference is significant at the 0.05 level.

Tests of Between-Subjects Effects

Dependent Variable: Sprintavedist

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	312.427[a]	29	10.773	1.168	.253
Intercept	15873.418	1	15873.418	1721.515	.000
Position	71.001	4	17.750	1.925	.105
Timeperiod	87.585	5	17.517	1.900	.093

Position * Timeperiod	130.359	20	6.518	.707	.820
Error	3955.641	429	9.221		
Total	24707.154	459			
Corrected Total	4268.068	458			

a. R Squared = .073 (Adjusted R Squared = .011)

Multiple Comparisons

Dependent Variable: Sprintavedist

Bonferroni

(I) Position	(J) Position	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	.6043	.52697	1.000	-.8826	2.0912
	3.00	.9342	.44941	.382	-.3338	2.2023
	4.00	-.1823	.39074	1.000	-1.2848	.9202
	5.00	.0989	.45413	1.000	-1.1825	1.3803
2.00	1.00	-.6043	.52697	1.000	-2.0912	.8826
	3.00	.3299	.54829	1.000	-1.2172	1.8770
	4.00	-.7866	.50133	1.000	-2.2012	.6279
	5.00	-.5054	.55217	1.000	-2.0634	1.0526
3.00	1.00	-.9342	.44941	.382	-2.2023	.3338
	2.00	-.3299	.54829	1.000	-1.8770	1.2172
	4.00	-1.1166	.41905	.080	-2.2990	.0658
	5.00	-.8353	.47871	.817	-2.1860	.5155
4.00	1.00	.1823	.39074	1.000	-.9202	1.2848
	2.00	.7866	.50133	1.000	-.6279	2.2012
	3.00	1.1166	.41905	.080	-.0658	2.2990
	5.00	.2813	.42411	1.000	-.9154	1.4780
5.00	1.00	-.0989	.45413	1.000	-1.3803	1.1825
	2.00	.5054	.55217	1.000	-1.0526	2.0634
	3.00	.8353	.47871	.817	-.5155	2.1860
	4.00	-.2813	.42411	1.000	-1.4780	.9154

Based on observed means.

The error term is Mean Square(Error) = 9.221.

Tests of Between-Subjects Effects

Dependent Variable: Sprinttotaldist

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4485.396[a]	29	154.669	1.293	.144

Intercept	183004.571	1	183004.571	1530.395	.000
Position	1518.113	4	379.528	3.174	.014
Timeperiod	758.548	5	151.710	1.269	.276
Position * Timeperiod	1856.495	20	92.825	.776	.743
Error	51299.792	429	119.580		
Total	297736.750	459			
Corrected Total	55785.188	458			

a. R Squared = .080 (Adjusted R Squared = .018)

Multiple Comparisons

Dependent Variable: Sprinttotaldist

Bonferroni

(I) Position	(J) Position	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	3.6287	1.89773	.565	-1.7260	8.9834
	3.00	4.4865	1.61841	.058	-.0800	9.0531
	4.00	-.1770	1.40713	1.000	-4.1474	3.7934
	5.00	2.7041	1.63543	.990	-1.9105	7.3187
2.00	1.00	-3.6287	1.89773	.565	-8.9834	1.7260
	3.00	.8578	1.97451	1.000	-4.7135	6.4292
	4.00	-3.8057	1.80539	.356	-8.8998	1.2885
	5.00	-.9246	1.98849	1.000	-6.5354	4.6862
3.00	1.00	-4.4865	1.61841	.058	-9.0531	.0800
	2.00	-.8578	1.97451	1.000	-6.4292	4.7135
	4.00	-4.6635*	1.50908	.021	-8.9216	-.4054
	5.00	-1.7824	1.72394	1.000	-6.6467	3.0819
4.00	1.00	.1770	1.40713	1.000	-3.7934	4.1474
	2.00	3.8057	1.80539	.356	-1.2885	8.8998
	3.00	4.6635*	1.50908	.021	.4054	8.9216
	5.00	2.8811	1.52732	.599	-1.4285	7.1906
5.00	1.00	-2.7041	1.63543	.990	-7.3187	1.9105
	2.00	.9246	1.98849	1.000	-4.6862	6.5354
	3.00	1.7824	1.72394	1.000	-3.0819	6.6467
	4.00	-2.8811	1.52732	.599	-7.1906	1.4285

Based on observed means.

The error term is Mean Square(Error) = 119.580.

*. The mean difference is significant at the 0.05 level.

Tests of Between-Subjects Effects

Dependent Variable: Repsperbout

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	14.547[a]	29	.502	.737	.840
Intercept	4390.733	1	4390.733	6447.744	.000
Position	2.439	4	.610	.896	.466
Timeperiod	.728	5	.146	.214	.957
Position * Timeperiod	10.115	20	.506	.743	.782
Error	292.137	429	.681		
Total	5891.000	459			
Corrected Total	306.684	458			

a. R Squared = .047 (Adjusted R Squared = -.017)

Tests of Between-Subjects Effects

Dependent Variable: Numofbouts

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	60.029[a]	29	2.070	1.504	.056
Intercept	857.993	1	857.993	623.314	.000
Time	8.572	5	1.714	1.245	.289
Position	25.721	4	6.430	4.671	.001
Time * Position	21.496	20	1.075	.781	.735
Error	262.912	191	1.377		
Total	1314.000	221			
Corrected Total	322.941	220			

a. R Squared = .186 (Adjusted R Squared = .062)

Multiple Comparisons

Dependent Variable: Numofbouts
Bonferroni

(I) Position		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	.6277	.27033	.213	-.1401	1.3954
	3.00	.1618	.24635	1.000	-.5378	.8615
	4.00	-.4098	.23174	.786	-1.0680	.2483
	5.00	.3674	.24487	1.000	-.3280	1.0629
2.00	1.00	-.6277	.27033	.213	-1.3954	.1401
	3.00	-.4659	.27643	.936	-1.2509	.3192
	4.00	-1.0375*	.26350	.001	-1.7859	-.2892
	5.00	-.2603	.27511	1.000	-1.0416	.5211
3.00	1.00	-.1618	.24635	1.000	-.8615	.5378
	2.00	.4659	.27643	.936	-.3192	1.2509
	4.00	-.5717	.23883	.177	-1.2499	.1066

	5.00	.2056	.25159	1.000	-.5089	.9201
4.00	1.00	.4098	.23174	.786	-.2483	1.0680
	2.00	1.0375*	.26350	.001	.2892	1.7859
	3.00	.5717	.23883	.177	-.1066	1.2499
	5.00	.7773*	.23730	.013	.1033	1.4512
5.00	1.00	-.3674	.24487	1.000	-1.0629	.3280
	2.00	.2603	.27511	1.000	-.5211	1.0416
	3.00	-.2056	.25159	1.000	-.9201	.5089
	4.00	-.7773*	.23730	.013	-1.4512	-.1033

Based on observed means.
The error term is Mean Square(Error) = 1.377.