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Christopher Carling [a,b], Franck Le Gall [a] & Gregory Dupont [a,c]

[a] LOSC Lille Métropole Football Club, Camphin-en-Pévèle, France

[b] Institute of Coaching and Performance, University of Central Lancashire, Preston, United Kingdom

[c] Univ Lille Nord de France, UArtois, EA4488, 59000 Lille, France

Abstract

The aims of this study conducted in a professional soccer team were two-fold: to characterise repeated high-intensity movement activity profiles in official match-play; b) to inform and verify the construct validity of tests commonly used to determine repeated-sprint ability in soccer by investigating the relationship between the results from a test of repeated-sprint ability and repeated high-intensity performance in competition. High-intensity running performance (movement at velocities >19.8 km/h for a minimum of 1-s duration) in 20 players was measured using computerised time motion analysis. Performance in 80 French League 1 matches was analysed. In addition, 12 out of the 20 players performed a repeated-sprint test on a non-motorized treadmill consisting of 6 consecutive 6s sprints separated by 20s passive recovery intervals. In all players, the majority of consecutive high-intensity actions in competition were performed after recovery durations ≥61s, recovery activity separating these efforts was generally active in nature with the major part of this spent walking, and players performed 1.1±1.1 repeated high-intensity bouts (a minimum of 3 consecutive high-intensity with a mean recovery time ≤20s separating efforts) per game. Players reporting lowest performance decrements in the repeated-sprint ability test performed more high-intensity actions interspersed by short recovery times (≤20s, $p<0.01$ and ≤30s, $p<0.05$) compared to those with higher decrements. Across positional roles, central-midfielders performed a greater number of high-intensity actions separated by short recovery times (≤20s) and spent a larger proportion of time running at higher intensities during recovery periods while fullbacks performed the most repeated high-intensity bouts (statistical differences across positional roles from $p<0.05$ to $p<0.001$). These findings have implications for repeated high-intensity testing and physical conditioning regimens.

Key terms: locomotor activity, physical performance, sprinting, football

Introduction

The physical preparation of the elite player has become an indispensable part of contemporary professional soccer due to the high fitness levels required to cope with the ever-increasing energy demands of match-play (Iaia, Rampinini, & Bangsbo, 2009). Sprint-type activities in particular, are widely considered to be a crucial element of performance but only contribute a small proportion to the overall motion activity during competition; accounting for approximately 10% of the total distance covered over the course of matches (Carling, Bloomfield, Nelsen, & Reilly, 2008). However, evidence shows that per game, top-class soccer players perform 150 to 250 intense actions (Mohr, Krustrup, & Bangsbo, 2003) and perform a run at high intensities (>19.8km/h) every 72s (Bradley et al., 2009). Analyses of physical performance during short periods in match-play also show that players transiently perform substantially higher amounts of high-intensity running than the game average (Carling & Dupont, 2011). Consequently, short recovery intervals between consecutive intense actions occur on several occasions throughout competition. The ability to recover and subsequently reproduce these efforts (termed repeated-sprint ability) is widely accepted as a critical component of the high-intensity intermittent sport that is soccer (Gabbet & Mulvey, 2008).

The design of the conditioning elements of fitness training programmes requires detailed information on repeated high-intensity exercise profiles and the intensity and duration of recovery periods that occur during competition (O'Donoghue, 2002). However, there is limited information on the ability of soccer players to perform specific bouts of exercise during which players repeat several intense running actions of short duration or 'repeated-sprint bouts' over short time intervals. Research in amateur male (Orenduff et al., 2010), international youth male (Buchheit, Mendez-villanueva, Simpson, & Bourdon, 2010) and international female (Gabbett & Mulvey, 2008) soccer match-play has provided varying levels of information on the frequency and characteristics of repeated-sprint bouts. Gabbett & Mulvey (2008) found that international female players performed repeated-sprint bouts (defined in their study as a minimum of three consecutive sprints, with recovery of less than 21 seconds between actions) almost 5 times per game and that recovery between sprints was generally active in nature (~93% of time). However, the specific nature and composition of repeated-sprint bouts performed in male professional soccer match-play are unclear. The frequency of bouts and the mean number of sprints and the duration and intensity of recovery periods between sprints within these bouts warrant investigation. Furthermore, no information is available on the capacity of players in competition to maintain performance in consecutive sprints within repeated-sprint bouts (e.g., progressive decline in maximal and/or mean velocity across sprinting actions).

Measures of fitness obtained via field and laboratory testing of soccer players can be strongly associated to time motion analysis assessments of match performance (Carling et al., 2008). Somewhat surprisingly though, there is limited information on the relationship between match performance at professional levels and the results from tests of repeated-sprint ability. In a group of professional players, the total distance run and that covered in high-intensity movement were significantly associated to performance in a field test of repeated-sprint ability (Rampinini et al., 2007). However, the association between performance in tests measuring repeated-sprint ability and other pertinent match-play measures such as the frequency of sprint efforts and recovery times separating these actions, the frequency of repeated-sprint bouts and changes in mean velocity of individual sprints within these bouts has yet to be explored. Furthermore, there is a need for appropriate repeated-sprint experimental protocols - ones that match the movement pattern in order to replicate the most intense physiological demands of the game (Meckel, Machnai, & Eliakim, 2009). To ensure that the construct validity of repeated-sprint tests is respected, protocols must measure match-related physical performance. However, many tests have inadequately assessed the repeated-sprint demands of competition in a game-specific manner by failing to take into account the most extreme demands of the sport (Gabbett, 2010). Additional information obtained from recent and more detailed analyses of repeated sprint exercise in professional soccer match-play could provide a more objective framework for the design of valid tests of repeated-sprint ability by determining the frequency and duration of sprints, their duration, and the intensity of recovery between these actions.

Consequently, the aims of this study in a professional soccer team were two-fold: to characterise repeated high-intensity movement activity profiles in official competition and determine the demands specific to positional role; b) to inform and verify the construct validity of tests commonly used to determine repeated-sprint ability in soccer by investigating the relationship between the results from a repeated-sprint ability test and repeated high-intensity running performance in match-play.

Methods

Participants and match sample

Physical performance in official competition was analysed for players in a professional soccer team that competed in the French League 1. While approval for the study was obtained from the present club, these 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 clearance was not required. Nevertheless, to ensure team and player confidentiality, all physical performance data were anonymised before analysis.

Data on performance in 80 French League 1 games played over 4 seasons (2007/2008, 2008/2009, 2009/2010 and 2010/11) were collected for analyses. The sample included 20 players with a total of 4 players in each of 5 positional roles: fullback (FB), central-defender (CD), central- and wide-midfielder (CM & WM) and centre-forward (CF). Over the 4-season study period, a total of 9 players participated in every season, 7 in 3 seasons, 3 in 2 seasons and 1 in a single season.

A total of 80 observations of physical performance for games in which players participated in at least 90-minutes of play were obtained for fullbacks and wide-midfielders, 73 for central-defenders and 70 for central-midfielders respectively. In centre-forwards, 50 observations of performance were obtained of which 25 were for at least 90-minutes of play. The remaining observations (n=25) were obtained from games in which the players completed a minimum of 75-minutes play. On average, centre-forwards were substituted after approximately 83-minutes of play.

Data collection procedures and measures of competitive performance

A semi-automatic computerised player tracking system (AMISCO Pro®, Sport-Universal Process, Nice, France) was used to characterise match activity profiles in the team. The workings, accuracy and reliability of this system in measuring player movements in elite soccer competition have been described in more detail elsewhere (Di Salvo et al. 2007; Carling et al., 2008; Randers et al., 2010).

In this study, repeated-sprint bouts and individual sprinting actions are referred to as ‘high-intensity’ rather than ‘sprinting’ movement. The speed threshold commonly used for the analysis of ‘sprint’ actions in professional soccer match-play refers to 0.5s runs performed at velocities above 25.0km/h (Bradley et al., 2009; Di Salvo, Gregson, Atkinson, Tordoff, & Drust, 2009; Gregson, Drust, Atkinson, & Di Salvo, 2010).

However, while soccer players perform numerous intense running actions during competition, there is a large inter-individual variation in the velocities at which they begin to sprint. Therefore, some runs might not achieve the necessary velocity classification threshold for sprinting leading to underestimations in performance (Abt & Lovell, 2009). In addition, players frequently do not achieve their maximum running velocity in match-play (Rampinini et al., 2007). Thus, to analyse intense running efforts in the present players, high-intensity actions were defined as runs performed at velocities >19.8 km/h over a minimum duration of 1-s. A similar definition was previously used to analyse competitive physical performance in the present professional soccer team (Carling, 2010). The mean distance and duration of high-intensity actions were analysed as was the % of the total distance run that was covered by players in high-intensity activity.

The mean recovery time for consecutive high-intensity actions over the course of games was calculated from the time (in seconds) that elapsed between all performed runs (Bradley et al., 2009). High-intensity actions were classified according to the recovery duration between consecutive efforts (Bucheit et al., 2010): ≤30s, 31-60s and ≥61s. Consecutive efforts with very short recovery durations of ≤20s were also analysed separately. Information on the peak number of high-intensity actions performed over 1-, 3- and 5-min periods (e.g., 1-2mins, 6-9mins and 10-15mins) was recorded.

The characteristics of physical activity during recovery periods interspersing consecutive high-intensity actions were analysed by calculating the proportion (%) of the overall time between actions spent in standing (0-0.6 km/h), walking (0.7-7.1 km/h), jogging (7.2-14.3 km/h) and running (14.4-19.7 km/h).

The extreme physical demands of match-play in team-sports can be examined using information from analysis of ‘repeated high-intensity bouts’ (Spencer, Bishop, Dawson, & Goodman, 2005). The definition of a repeated high-intensity bout was similar to that previously employed in analyses of play in international soccer (Gabbett, 2010) and field-hockey (Spencer et al., 2004) competition: a minimum of three consecutive high-intensity actions with a mean recovery duration of equal or less than 20s between efforts. The number of individual high-intensity actions and recovery time between these efforts in each repeated high-intensity bout was measured. Also recorded were the mean and peak speed and duration and distance of individual high-intensity actions making up each bout.

Repeated sprint ability test

A laboratory test of repeated sprint ability was performed on a Woodway Force non-motorized treadmill (Force 3.0, Waukesha, WI, USA). The non-motorized treadmill was set up with 1 horizontal load attached to the vertical strut and 4 individual vertical load cells under the running surface. The subject was attached to a horizontal rod by means of a hip-belt. The rod's posterior end was fixed to the rear of the treadmill. The rod was serially connected to a force transducer permitting measurement of horizontal force. Vertically mounted force transducers recorded the vertical force applied to the treadmill bed. Power output was calculated from vertical force and horizontal force data. Both horizontal and vertical load cells were calibrated before and after each test using a range of known mass. Treadmill belt speed, distance and horizontal forces were collected at a sampling rate of 10 Hz via the XPV7 PCB interface (Fitness Technology, Adelaide, Australia) and analysed using the Force 3.0 Software (Innervations Software, Joondalup, Australia).

Reliability trials of running performance in amateur soccer players during this repeated-sprint test performed using the same experimental set up have been performed

(Nedelec, Berthoin & Dupont, 2011). Results for intraclass correlation coefficient (ICC), typical error of measurement (TEM) and coefficients of variation (CV) for peak power output were 0.91, 91W, and 4.1%, respectively. The ICC, TEM and CV for mean power output were 0.99, 27 W and 1.4%, respectively. The ICC, TEM and CV for percentage decrement score were 0.65, 3.3% and 32.1%, respectively.

All participants were free from illness and injury and testing took place during the mid-season winter break. After one familiarisation trial, 12 out of the 20 players performed 6 consecutive 6s sprints with each sprint separated by a 20s passive recovery period. This mode of exercise, number and duration of sprint repetitions and recovery duration and type are similar to those frequently employed in studies on field sports (Spencer et al., 2005). To ensure pacing did not occur participants completed a maximal single sprint test prior to the repeated-sprint test and were subsequently expected to achieve a time for their first sprint within 95% of that of their single maximal sprint performance (Castagna et al., 2008).

Mean running velocity was calculated over 6s for each individual sprint effort. These individual mean values for velocity were subsequently averaged to obtain a mean value for all 6 sprints (mean velocity). Out of 6 the individual mean velocity values obtained for the consecutive sprints, the fastest mean velocity value was identified (highest mean velocity). The peak running velocity attained over the 6 sprints was recorded (peak velocity). A performance decrement score (% performance decrement) to evaluate declines in the mean velocity of consecutive sprints was calculated using the methodology described by Dupont, McCall, Prieur, Millet, & Berthoin (2010).

Statistical Analyses

Statistical analyses were conducted using SPSS for Windows Version 14.0 (SPSS Inc., Chicago, IL, USA). Results are reported as means and standard deviations (mean±SD) unless otherwise stated. A one-way analysis of variance (ANOVA) was used to test for differences in means in match performance measures across positional roles. A two-way ANOVA was used to explore differences across positional roles in the mean time spent in different categories of running speed during the recovery periods between high-intensity actions. To isolate any differences in the frequency of recovery periods (classed according to the time duration) interspersing consecutive high-intensity actions across positional roles, a two-way ANOVA was also used. Where appropriate, follow-up univariate analyses using Bonferroni-corrected pair wise comparisons were employed.

The known-group effect difference technique was used to assign participants into two groups ('highest' or 'lowest' ranked performers) based on individual performance levels observed in the repeated-sprint test (Rampinini et al., 2007). These included mean velocity over the 6 sprints, fastest mean velocity, peak velocity and % performance decrement. Measures of match performance (% of the overall distance run covered in high-intensity running, frequency of and recovery time between high-intensity actions, % of these actions interspersed by short recovery times (≤20s and ≤30s), and the frequency of repeated high-intensity bouts and the mean and peak speed of individual actions within these bouts) in a minimum of 5 matches played in entirety during the same season were subsequently compared between the highest and lowest ranked groups using unpaired t-tests. Pearson's product-moment correlations were also employed to examine relationships between repeated-sprint ability test scores and measures of match performance. The correlation coefficients (r) were interpreted in accordance with the following scale of magnitude (Hopkins, Marshall, Batterham, &

Hanin, 2009): ≤ 0.1, trivial; >0.1-0.3, small; >0.3-0.5, moderate; >0.5-0.7, large; >0.7-0.9, very large; and >0.9-1.0, almost perfect. Finally, effect sizes (ES) for statistical differences were determined. Effect size was assessed using the following criteria: ≤0.2 trivial, >0.2–0.6 small, >0.6–1.2 moderate, >1.2-2.0 large, and >2.0 very large (Batterham & Hopkins, 2006). The level of statistical significance was set at $p \leq 0.05$.

Results

Match performance

In relation to the total distance covered, the percentage of distance run in high-intensity activities varied across positional roles ($p<0.001$). Highest values were observed in fullbacks and lowest in central-defenders respectively (FB=8.6±1.2% vs. CD=5.1±1.4% vs. CM=6.2±1.3% vs. WM=8.3±2.2% vs. CF=7.3±1.6%, ES range= moderate: 0.8 to very large: 2.7). The mean recovery duration between high-intensity actions also varied across positional roles ($p<0.001$, ES range = large: 1.5 to very large: 2.2) with longest and shortest durations observed in central-defenders and fullbacks respectively (Table 1). For all positions, the most commonly observed recovery duration between consecutive high-intensity actions was ≥61s (67.0±9.6% of the total number of actions) with the highest frequency in central-defenders (76.5±8.4% of the total). A statistical interaction was observed between recovery duration and positional role ($p<0.001$). Respectively, the lowest and highest frequencies of consecutive high-intensity actions separated by recovery durations ≤30s and 31-60s were observed in central-defenders and fullbacks. The lowest and highest frequency of very short recovery durations (≤20s) between high-intensity actions was observed in central-defenders and central midfielders respectively. Effect sizes for these statistical differences across positional roles ranged from moderate to large (0.6-1.8).

The highest number of high-intensity actions recorded in any one 1-min (n=5) and 5-min (n=11) period was observed in a fullback and in a 3-min period (n=7) jointly in a fullback and a central-midfielder.

Table 1 about here.

The analysis of activity patterns interspersing consecutive high intensity actions showed that players across all positional roles spent the major part of recovery in walking and jogging activities (Table 2). However, a statistical interaction was observed between positional role and recovery time spent in the four locomotor activities ($p<0.001$). Substantial differences were observed in recovery activity profiles in central-defenders and centre-forwards compared to other positional roles. Players in the latter role notably, spent more time in walking compared to all other roles (statistical differences from $p<0.01$ to $p<0.001$) but less time in the 'running' threshold than fullbacks, central- and wide midfielders (statistical differences from $p<0.01$ to $p<0.001$). More time spent in 'running' was reported in central-midfielders compared to all other positional roles (all statistical differences: $p<0.001$). Effect sizes for these statistical differences ranged from small to very large (0.4-2.9).

Table 2 about here.

Across all players, an average of 1.1±1.1 exercise bouts that met the criteria for repeated high-intensity activity were performed per player per match with a statistical difference observed between positional roles ($p<0.001$, ES range = moderate: 1.0 to large: 1.3) (Table 3). On average, fullbacks performed approximately 4 times as many repeated high-intensity bouts per match than central-defenders. The mean number of individual high-intensity actions per bout was similar across positional roles (p=0.486) whereas the mean duration (p=0.006) and length of actions (p=0.002) varied with highest values observed in fullbacks. Recovery duration also varied across positional roles (p=0.044) with the shortest recovery time interspersing actions in bouts observed in central-defenders. Small to moderate (0.5-0.7) effect sizes for these statistical differences were observed.

Table 3 about here.

The maximum number of repeated high-intensity bouts observed in any one match equalled 6 (in a wide-midfielder) and the peak number of individual high-intensity actions reported within any one single bout of repeated high-intensity activity was 7 (in a centre-forward). Figure 1 presents a graphical representation containing quantitative and qualitative information on this intense bout of activity. The overall duration of this bout was 111.0s equating to one high-intensity action every 15.9s. Maximum and minimum recovery times between individual high-intensity actions within this bout were 9.5s and 40.0s. Respectively, the mean duration and length of these high-intensity actions were: 3.1±0.8s (range: 2.1-4.7s) and 18.4±4.8m (range: 12.1m-27.4m). The mean speed of actions was 25.0±1.9km/h-1 with a peak speed of 28.2km/h observed in the final effort of the bout. Of the recovery activity between efforts, 69.1% was spent in walking, 22.3% in jogging and 10.8% in running activities respectively.

Figure 1 about here.

No significant decrements in the mean and maximum velocity of individual high-intensity actions performed during repeated high-intensity bouts were observed irrespective of the number of consecutive efforts (3, 4, 5 or 6) performed in each bout (Table 4).

Table 4 about here.

Laboratory repeated-sprint ability test

In all players, analysis of performance across the 6 consecutive 6s sprints showed a mean velocity of 15.8±1.1km/h, a highest mean velocity of 17.3±1.4km/h and a peak velocity of 20.3±1.3km/h. The performance decrement across sprints was 8.9±2.6% respectively. Players assigned to the group ranked highest in the four scores in the treadmill test generally did not display better performance ($p>0.05$) in any of the match activity parameters (Table 5). In contrast, a greater frequency of high-intensity actions with recovery times ≤20s ($p=0.007$, ES = very large: 2.0) and ≤30s ($p=0.028$, ES = large: 1.5) was observed in players assigned to the group reporting the lowest % performance decrement. Finally, no significant correlation coefficients were observed between any of the scores obtained the repeated sprint ability test and measures of match-play performance ($p>0.05$). The highest correlations (positive and negative) were observed between the mean velocity of treadmill sprints and recovery time between high-intensity actions ($r=0.419$, considered moderate), and the % decrement score and frequency of high-intensity actions interspersed by recovery times ≤20s ($r=-0.507$, considered large).

Table 5 about here.

Discussion

This study is the first to investigate in detail the characteristics of repeated high-intensity movement activity patterns in professional soccer match-play and the demands specific to positional role. The major findings were that mean recovery time between high-intensity actions varied substantially in relation to positional role with the longest and shortest values observed in central-defenders and fullbacks respectively. While the majority of consecutive high-intensity actions were interspersed by recovery durations >61s, those performed following a very short recovery time (≤20s) were more frequently observed in central-midfielders. The majority of recovery time interspersing high-intensity actions in players across all positional roles was active in nature with the major part of this activity spent in walking. However, central-midfielders spent significantly more recovery time moving at higher intensities compared to other positional roles. The frequency of repeated high-intensity bouts (a minimum of three consecutive high-intensity actions with a recovery period ≤20 seconds between actions) varied across positional roles and was highest in fullbacks. While no significant relationships were generally observed between performance measures obtained in a treadmill repeated-sprint ability test and those in match-play, players with the lowest performance decrement performed a higher frequency of high-intensity actions interspersed by short recovery times (≤20s and ≤30s).

Information regarding the mean recovery durations between high-intensity actions is valuable for estimating the average work-to-rest ratios during soccer match-play (O'Donoghue et al., 2005). In this study, a mean recovery duration of 139s across all players was observed with shortest and longest values observed in fullbacks (116s) and in central defenders (194s) respectively. Unfortunately, this level of information does not provide insights into repeated intense movement patterns commonly known as repeated-sprint activity (Spencer et al., 2005). The majority of consecutive high-intensity actions (67.0%) observed in the present players was performed after a recovery period ≥61s. Research in international youth soccer match-play has also reported recovery times between high-intensity actions generally greater than 60s in duration (Bucheit et al., 2010). Although approximately one fifth of consecutive high-intensity actions performed were interspersed by short recovery durations (≤30 seconds), the present results nevertheless suggest that these players had sufficient time to completely recover ‘physiologically’ from the majority of high-intensity actions. 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 performed in succession (Balsom, Seger, Sjodin, & Ekblom, 1992). In addition, the present players performed an average of 1.1 RHI bouts per match with these comprising only 3 consecutive high-intensity actions. This result is substantially lower than the 4.8 repeated sprint bouts per match observed in international female soccer (Gabbet & Mulvey, 2008). This discrepancy may be explained by differences in respective methods employed to collect movement data as manual coding techniques are known to lead to overestimations in high-intensity running performance (Carling et al., 2008). It may also be due to the strict inclusion criteria employed here to define high-intensity movements (runs performed at velocities >19.8 km/h and minimum 1-s duration). In comparison, Bradley et al. (2010) defined high-intensity work as any movement performed at velocities >19.8 km/h but for a minimum of 0.5s in English Premier League players. Use of this latter definition might have led to identification of more repeated high-intensity bouts in the present group of players. These discrepancies in definitions across studies suggest a need for consensus to ensure standardisation in the classification of movement thresholds (according to speed and duration) for time motion analyses of professional soccer play.

The low frequency of repeated high-intensity bouts observed in the present team nevertheless suggests that this specific fitness component might not play as crucial a role in elite match performance as commonly believed. Alternatively, the prescription of supplementary specific conditioning programs to improve performance in the present group of elite soccer players could be warranted. However, a low occurrence of repeated high-intensity running sequences was also reported in international youth soccer competition (Bucheit et al., 2010). Additional analyses not reported in the results showed that an international wide-midfielder playing in the present team did not record a single RHI bout in 35% (7 out of 20) of matches analysed. These results therefore tend to lend support to other research findings in that the need to frequently reproduce highly intense efforts is perhaps not central to success. Indeed, high-ranked teams in the English Premier League (Top 10) were shown to perform less high-intensity running than low-ranked peers (Di Salvo et al., 2009). Over the four study seasons, qualification for European competition was successfully achieved on 3 occasions by the present team who also won its National Championship in the final season.

Despite the overall low frequency of repeated high-intensity bouts, performance demands differed significantly across positional roles with fullbacks performing the most bouts. In addition, the occurrence of consecutive high-intensity actions with recovery durations ≤20s between efforts was more common in central midfielders. When rest periods between high-intensity actions are below 30s in duration, subsequent sprint performance can deteriorate due to decreases in adenosine triphosphate concentration and intramuscular pH slowing phosphocreatine resynthesis (Spencer et al., 2005). Therefore, players in these positional roles potentially experienced transient fatigue during certain phases of match-play. However, analysis of the maximum and mean running velocity of the individual efforts performed in repeated high-intensity bouts showed in general that players were able to maintain performance even when 6 high-intensity actions were performed successively with ≤20s rest between runs. Analysis of data on mean and maximum velocity of consecutive high-intensity actions demonstrated no significant changes between the first and final effort across repeated high-intensity bouts. In addition, analysis of the most intense repeated high-intensity bout performed by a centre-forward showed that the mean and maximal speed of the final high-intensity actions (7^{th} action) was higher than corresponding measures for the previous 6 individual efforts. However, the possible occurrence of fatigue patterns in repeated high-intensity performance as matches progressed (e.g., towards the end of games) was not examined here and might warrant inclusion in a future study.

Overall, these results suggest that the present players were able to reproduce performance when called upon to perform sporadic but extreme sequences of high-intensity running in match-play. A reasonable explanation for this lack of a decline in velocity across multiple high-intensity efforts may be due to the relatively short length of runs (~16m) thereby allowing adequate replenishing of the phosphocreatine system between efforts (Abt, Siegler, Akubat, & Castagna, 2011; Bishop et al., 2001). Indeed, resynthesis of phosphocreatine stores appears to be related to the distance of efforts as stores are more adequately replenished following repeated 15-m sprints than repeated 40-m sprints (Balsom et al., 1992).

The mode of recovery (passive or active) and to a lesser extent, the intensity of active recovery, can potentially affect subsequent high-intensity performance (Spencer et al., 2005). Oxygen uptake and phosphocreatine resynthesis during repeated high-intensity exercise are notably restricted by active recovery (Dupont, Moalla, Guinhouya, Ahmaidi, & Berthoin, 2004). The analysis of running activities interspersing high-intensity actions showed that the majority of recovery was active in nature (98%) and that majority of this time was spent in lower intensity movement (<14.3km/h). In comparison, 93% of recovery time between sprints in international female soccer competition (Gabbett & Mulvey, 2008) was active in nature. Importantly, statistical differences in recovery intensity were reported here in respect to positional role. Central-midfielders performed substantially more movement at higher intensities (speeds of 14.3-19.8km/h) between consecutive high-intensity actions compared to other positional roles, a finding that is in accordance with a report on amateur soccer (Orenduff et al. 2010). Therefore, practitioners might aim to specifically develop the capacity of central-midfielders to recover actively at higher levels of intensity.

In the repeated-sprint ability treadmill test, players who reported the lowest % performance decrement reported a greater frequency of high-intensity actions interspersed with recovery times ≤20s and ≤30s in duration. This result suggests that those with a greater resistance to fatigue in a treadmill test of repeated-sprint ability are able to perform a greater frequency of high-intensity actions with short rest intervals in competition. In contrast, no association was observed between test scores and the % of the overall distance run that was covered in high-intensity exercise or the frequency of high-intensity actions and recovery time between efforts. Related research in professional soccer showed that players who performed better in a repeated-sprint ability field test of similar intensity performed more high-intensity running in competition although the performance decrement across sprints was unrelated to this aspect of match performance (Rampinini et al., 2007). However, the authors did not investigate the relationship between running performance in a repeated-sprint ability test and the frequency and characteristics of repeated high-intensity bouts as done here.

Therefore, the general lack of an association here between the frequency of, and mean and peak velocity of repeated high-intensity bouts in match-play and treadmill measures of repeated-sprint ability is of note. On the whole, these results might suggest a lack of empirical support for the construct validity of the present and similar tests of repeated-sprint ability as predictors of high-intensity match performance in professional soccer. However, additional research is required to determine the reliability of the present test and its applicability for use in professional soccer and future studies using both laboratory and field tests of repeated-sprint ability to evaluate performance in a larger and wider sample of professional teams are warranted to verify the present findings.

Tests of repeated-sprint ability in field sports are generally designed to replicate a highly stressful period of play during a match and measure the ability to resist fatigue and maintain high performance levels (Oliver et al., 2007). Current tests are generally short in duration (<3 min) and involve repetition of 6-7 sprints over a distance of 30m with an active recovery period between sprints lasting 25s (Reilly, 2005, Carling, Reilly & Williams, 2009). Results from this study tend to support this consensus as the maximum number of high-intensity actions observed across 3- and 5-min time periods equalled 7 and 11 equating to one action per 26 seconds and 27 seconds respectively. In contrast, a mean recovery time of 13.6s was observed between consecutive high-intensity actions recorded in repeated high-intensity bouts and analysis of the most extreme demands of match-play showed that players performed up to 5 high-intensity actions within a 1-min period (1 bout every 12.0s) and 7 efforts within a period of 111s (1 run every 15.9s). In addition to recovery periods between these high-intensity actions being generally active in nature, the duration of these intervals is towards the lower end of the scale for those typically used in tests to assess repeated-sprint ability in soccer players (Spencer et al., 2005).

These findings therefore suggest that fitness personnel might employ repeated-sprint ability tests with a maximum active recovery period of 15s between consecutive efforts. A repeated-sprint test specific to the most intense period of soccer play identified in this study and potentially sufficient to elicit an overload stimulus might require 7 high-intensity actions (running speed >19.8km/h maintained over a length of ~20m) with 15s active recovery intervals between efforts and inclusion in the latter of running activities at both low and moderate intensities. In addition, large oscillations within these extreme bouts of exercise in the length and duration of individual high-intensity actions and in the recovery duration between efforts were reported in this study. As observed in the most intense bout of activity performed by a forward player (Figure 1), the characteristics of high-intensity actions are probably linked to the tactical requirements of the game situations. The length of efforts and the recovery period interspersing these determine the physiological responses to high-intensity exercise (Svensun & Drust, 2005). Therefore, future tests of repeated-sprint ability might be designed to take into account such variations to provide a more ecologically valid assessment of players' ability to perform repeated high-intensity exercise.

In summary, this study has provided an insight into repeated high-intensity activity profiles and the extreme demands of match-play in professional soccer. A methodological limitation of this investigation was the relatively low number of players included for analysis and that these came from only one club. Therefore, the patterns observed might be a reflection of only this particular team and/or the League in which it competes. Nevertheless, these results have implications for the design and validity of tests of repeated-sprint ability in terms of the frequency, distance and duration of high-intensity actions and the nature of recovery between efforts. In contrast, doubts can be raised on current evidence on the validity of the present and potentially other laboratory repeated-sprint ability tests to predict competitive physical performance. These results may also cast doubt on the relative importance of repeated high-intensity activity and therefore the need for conditioning programs in an attempt to improve the general and/or position specific ability of professional soccer players to perform repeated high-intensity work. While such fitness training interventions can induce substantial improvements in football-specific endurance (Ferrari Bravo et al., 2008), the relative importance of repeated-sprint ability to team performance in professional soccer and notably the outcome of matches remains unexplored.

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Table 1: Frequency of recovery periods based on the time elapsed between consecutive high-intensity actions in relation to positional role.

Recovery duration (s)	All Players (n=353)	Fullback (FB) (n=80)	Central-defender (CD) (n=73)	Central-midfielder (CM) (n=70)	Wide-midfielder (WM) (n=80)	Centre-forward (CF) (n=50)	Bonferroni Post hoc analysis
Mean recovery time (s)	139.0±42.6	115.8±18.6	194.6±48.4	134.7±28.5	120.5±24.1	129.3±27.6	CD>FB[a],CM[a],WM[a],CF[a];CM>FB[b]
% ≤20s	14.3±6.0	16.1±5.6	10.8±5.3	16.4±5.6	15.3±5.7	12.4±6.3	FB>CD[a],CF[b];CM>CD[a],CF[b];WM>CD[a]
% ≤30s	18.9±7.0	21.6±6.3	14.0±6.5	21.0±6.4	20.2±6.1	16.9±6.6	FB>CD[a],CF[b];CM>CD[a],CF[c];WM>CD[a]
% 31-60s	14.1±6.0	16.6±5.6	9.5±5.2	14.2±5.5	15.2±5.0	15.1±6.0	FB>CD[a];CF>CD[a];CM>CD[a];WM>CD[a]
% ≥61s	67.0±9.6	61.8±7.6	76.5±8.4	64.8±8.1	64.6±8.0	68.0±8.2	CD>FB[a],CM[a],WM[a],CF[a];CF>FB[a]

Post hoc analysis: a=p<0.001, b=p<0.01, c=p<0.05

Table 2: Characteristics of running activities during recovery periods interspersing consecutive high-intensity actions in relation to positional role.

Running activity	All Players (n=353)	Fullback (FB) (n=80)	Central-defender (CD) (n=73)	Central-midfielder (CM) (n=70)	Wide-midfielder (WM) (n=80)	Centre-forward (CF) (n=50)	Bonferroni Post hoc analysis
% Standing	1.7±0.9	1.6±0.8	2.0±0.9	1.6±1.0	1.7±1.0	1.6±0.9	
% Walking	61.3±4.3	61.3±3.6	62.7±2.7	56.9±3.0	62.2±4.9	64.3±2.4	CD>FB[b],CM[a];CF>FB[a],CD[b],CM[a],WM[a]
% Jogging	30.3±3.4	30.2±3.2	30±2.4	32.7±2.3	29.4±4.4	28.9±2.3	FB>CF[c];CM>FB[a],CD[a],CM[a],CF[a]
% Running	6.7±1.7	6.9±1.1	5.3±0.9	8.9±1.5	6.7±1.2	5.2±0.8	FB>CD[b],CF[b];CM>FB[a],CD[a],WM[a],CF[a];WM>CD[b],CF[b]

% = percentage of recovery time spent in each running activity
Post hoc analysis: a=p<0.001, b=p<0.01, c=p<0.05

Table 3: Frequency of repeated high-intensity bouts and characteristics of high-intensity actions within these bouts in relation to positional role.

Repeated high-intensity bouts	All Players (n=353)	Fullback (FB) (n=80)	Central-defender (CD) (n=73)	Central-midfielder (CM) (n=70)	Wide-midfielder (WM) (n=80)	Centre-forward (CF) (n=50)	Bonferroni Post hoc analysis
N° of bouts	1.1±1.1	1.6±0.8	0.4±1.1	1.3±0.6	1.4±1.1	0.6±0.8	FB>CD[a],CF[a];CM>CD[a],CF[b];WM>CD[a],CF[a]
N° HIA per bout	3.3±0.5	3.4±0.6	3.3±0.5	3.2±0.4	3.2±0.4	3.3±0.6	
HIA duration (s)	2.7±0.7	2.9±0.7	2.5±0.8	2.5±0.7	2.6±0.6	2.8±0.7	FB>CD[c]
HIA distance (m)	16.5±4.9	18.2±4.6	15.0±5.6	14.9±5.0	16.2±3.9	17.4±4.4	FB>CD[b],CM[b]
HIA recovery time (s)	13.6±4.4	14.4±5.2	11.4±3.7	13.7±4.7	13.6±4.4	13.9±4.4	FB>CD[c]

HIA: high-intensity actions
Post hoc analysis: a=p<0.001, b=p<0.01, c=p<0.05

Table 4: Comparison of mean and maximal running velocity of consecutive high-intensity actions in repeated high-intensity bouts characterised according to the number of consecutive actions observed within bouts.

	Repeated high-intensity bouts					
Number of consecutive HIA	HIA 1	HIA 2	HIA 3	HIA 4	HIA 5	HIA 6
Maximum velocity (km/h)						
3 consecutive actions	24.9	24.7	24.9			
4 consecutive actions	24.7	24.8	24.4	24.5		
5 consecutive actions	25.0	24.9	24.8	25.8	24.4	
6 consecutive actions	24.9	25.1	24.5	25.0	27.3	25.1
Mean velocity (km/h)						
3 consecutive actions	22.1	22.0	22.1			
4 consecutive actions	21.9	21.9	22.0	21.9		
5 consecutive actions	22.0	22.3	21.9	22.0	21.5	
6 consecutive actions	21.8	21.4	21.4	22.2	22.9	22.2

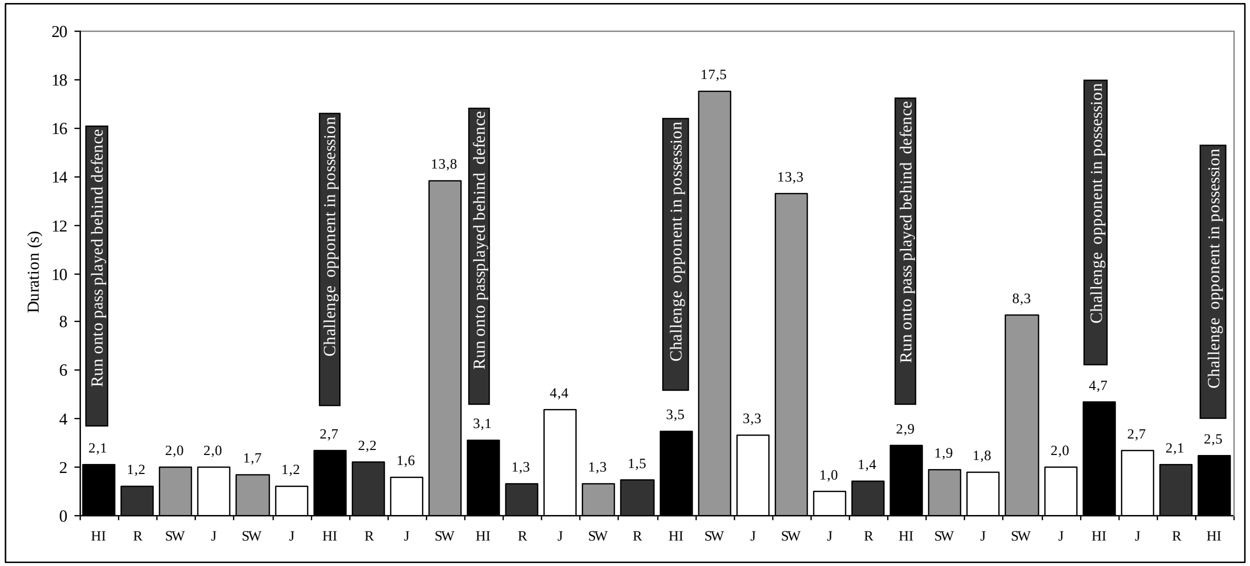
HIA: high-intensity actions

Table 5: Competitive high-intensity running activity profiles in two groups of professional soccer players (highest and lowest ranked performers) ranked according to performance measures of repeated sprint ability determined during a non-motorised treadmill test.

RSA treadmill test performance	Mean velocity (km/h)		Highest mean velocity (km/h)		Peak velocity (km/h)		Performance decrement (%)	
Match performance	Lowest ranked	Highest ranked	Lowest ranked	Highest ranked	Lowest ranked	Highest ranked	Lowest ranked	Highest ranked
High-intensity actions								
% Total distance covered	7.1±1.5	6.4±1.2	7.1±1.5	6.4±1.2	6.8±1.5	6.7±1.4	6.5±1.5	7.0±1.3
Mean number	40.0±5.2	40.2±6.6	40.0±5.2	40.2±6.6	40.7±5.4	39.6±6.3	39.0±6.4	41.2±5.1
Mean recovery time (s)	141.6±20.5	147.0±29.3	141.6±20.5	147.0±29.3	141.1±20.8	147.4±29.0	148.7±28.3	139.7±20.5
% Recovery time ≤20	15.3±4.2	13.6±5.3	15.3±4.2	13.6±5.3	15.6±4.2	13.3±5.1	11.2±3.7	17.7±3.0*
% Recovery time ≤30	18.6±4.9	17.9±6.1	18.6±4.9	17.9±6.1	19.0±4.8	17.5±6.1	15.1±4.7	21.5±3.8#
Repeated high-intensity bouts								
Mean number	1.1±0.9	1.1±0.9	1.1±0.9	1.1±0.9	0.9±0.9	1.4±0.9	1.0±1.0	1.3±0.7
Mean velocity	21.9±0.1	21.9±0.2	21.9±0.1	21.9±0.2	21.9±0.1	21.9±0.2	22.0±0.1	21.9±0.1
Maximum velocity	27.2±2.2	27.2±2.1	27.2±2.2	27.2±2.1	27.4±2.3	27.0±1.9	27.9±0.5	26.8±2.5

RSA: repeated sprint ability
* $p<0.01$: difference between lowest and highest ranked group
# $p<0.05$: difference between lowest and highest ranked group

Figure 1: Descriptive characteristics of the most intense of repeated high-intensity activity bout represented by the peak number of high-intensity actions performed by a centre-forward.



Movement classification: HI=High-intensity, R=Running, J=Jogging and SW=Standing/Walking