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The physical demands of English elite level rugby union

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Abstract

The aim of this study was to assess the physical demands of English elite level rugby union match-play. Player movements were captured by five distributed video cameras and then reconstructed on a two-dimensional plane representing the pitch. Movements based on speeds were categorised as standing, walking, jogging, medium (Low Intensity Activity: LIA) and high-intensity running, sprinting and static exertion (scrummaging, rucking, mauling and tackling) (High Intensity Activity: HIA). Position groups were defined as forwards (tight and loose) and backs (inside and outside). Backs travelled more total distance than forwards (6127 ± 724 m *vs* 5581 ± 692; $P < 0.05$) and greater distances walking (2351 ± 287 *vs* 1928 ± 2342 m, $P < 0.001$) and high-intensity running (448 ± 149 *vs* 298 ± 107 m, $P < 0.05$). Forwards performed more HIA than backs (9:09 ± 1:39 *vs* 3:04 ± 1:01 min:s, $P < 0.001$) attributable to more time in static exertion (7:56 ± 1:56 *vs* 1:18 ± 0:30 min:s, $P < 0.001$) although backs spent more time high-intensity running (0:52 ± 0:19 *vs* 1:19 ± 0:26 min:s. $P = 0.004$). Players travelled a greater distance in the first 10-min period compared to 50-60 and 70-80min but there was no difference in the amount of HIA performed during consecutive 10-min periods during match-play. These results show the differing physical demands between forwards and backs with no evident deterioration in HIA performed during match-play.

Introduction

In order to optimise the training regimes of players, the physical demands of rugby union need to be properly understood. In this sport however, the frequent bouts of physical contact make physiological data especially difficult to collect given the intrusive nature of blood sampling and the problems associated with players carrying instrumentation. Therefore, one of the most effective methods with which to quantify to activity in rugby union is through the use of time-motion analysis. This technique can be used by the researcher to quantify the type, duration and frequency of discrete movements making up the intermittent activity patterns in team sports. In addition to using time-motion data to improve training specificity, there is also a need to accurately quantify match demands for the purposes of designing more specific exercise protocols that allow the investigation of issues specific to rugby union.

Traditionally, time-motion analysis data has been presented in terms of mode, frequency and duration of activity. These activities are most often classified as standing, walking, jogging, cruising, sprinting and static intense activity (McLean, 1992; Deutsch, Maw, Jenkins, & Reaburn , 1998; Duthie, Pyne, & Hooper, 2005). Using these classifications, the investigator must decide which activity the player is performing and the duration of the activity based on observation of each player's running characteristics. Recent studies from elite southern hemisphere rugby have used this technique to provide insight into the relative work performed in different physical activities, but did not measure distances travelled or speeds attained by the players (Duthie *et al*., 2005; Deutsch, Kearney, & Rehrer, 2007). Quantification of the distances travelled by players over half a match has been performed in under-19 age-group rugby (Deutsch *et al*., 1998).

However, players at this age are unlikely to have the same physical capabilities of those performing at elite senior level, thus potentially impacting on the amount of work performed during match-play. Furthermore, distances were calculated as the product of time spent performing the activity and an assigned speed determined outside of match-play, rather than the actual speed achieved. Alternative time-motion techniques have been presented for soccer (Ohashi, Miyagi, Nagahama, Ogushi, & Ohashi, 1988; Castagna & D'Ottavio, 2001; Mallo, Navarro, Garcia-Aranda, Gilis, & Helsen, 2007) and handball (Pers, Bon, Kovacic, Sibila, & Dezman, 2002) which utilise automatic and semi-automatic player tracking techniques to provide speed and distance over the course of a match. More recently an objective time-motion analysis method for team sports was found to be both accurate and reliable for estimating speeds and distances travelled during rugby union (Roberts, Trewartha, & Stokes, 2006).

Only one study has reported detailed player movement data in the professional era in English rugby union (Eaton & George, 2006). This study provided detailed analyses of average work performed via a multi-camera, player coding technique but data on the accuracy and reliability of the analysis technique was not available. Therefore the principal aim of this study is to provide an assessment of the physical demands of English elite level rugby union using an accurate and reliable objective time-motion analysis technique in order to provide data for enhancing training practices and for the development of research tools specific to rugby union. Fatigue experienced during match-play may be manifested in terms of the amount of high-intensity activity performed by the players during progressive time-periods of the match. For example, in soccer, fatigue has been shown to occur both temporarily during, and towards the end of a match (Mohr, Krustrup, & Bangsbo, 2003). To date, the patterns of fatigue during match-play have received little attention in studies assessing the physical demands of rugby union. Therefore, a further aim is to investigate any changes in activity patterns during the course of the match in order to evaluate whether there is any deterioration in HIA performed.

Methods

Participants

All players observed in this study were taking part in English Premiership level rugby and playing for the same club. In order to make inter-positional observations the players were divided into forwards and backs. Within these groups players were then subdivided using the following classifications: props and seconds rows (tight forwards, n = 8), hooker and back row (loose forwards, n = 6), outside halves and centres (inside backs, n = 7) and wingers and full back (outside backs, n = 8). Scrum halves were excluded from the analysis due to the limited sample and unique physical demands of that position (Duthie *et al*., 2005; Deutsch *et al*., 2007). Consent to record the matches was granted by the rugby club and ethics approval was obtained. All analysed matches were played at the same venue and took place in season 2002-03 or season 2003-04. All matches took place at the same venue between the months of November and February. No rain fell during match-play and the state of the playing surface was determined by the experimenters during the camera calibration prior to the start of the match to be firm. For the matches recorded, the win/loss record for the home team containing the players used for analysis were as follows: lost 20-22, won 24-18, won 52-8, lost 12-58, won 36-3.

Camera locations

Five video cameras (4 Sony DCR-TRV900E, Japan; 1 Panasonic AG DP2000B, Japan) were positioned around a rugby pitch at predetermined locations (Figure 1) ensuring that the total area of the playing surface could be viewed. Each camera view was fixed. The height of the cameras above the playing surface was between 5-8 m and camera locations were 3-5 m from the nearest sideline. A global 2D cartesian co-ordinate system was constructed with the origin located in one corner of the playing area (Figure 1).

INSERT FIGURE 1 HERE

Camera calibration and recording procedure

Prior to each match, a calibration of each camera view was performed by recording sequences of four calibration poles (height = 1.0 m) positioned on the playing surface in known locations. With the camera views fixed, the full duration of the matches were then recorded

Data analysis

For each camera, the top points of each of the four calibration poles were digitised four times each using Peak Motus software (version 8.0, Peak Performance Technologies, Inc., Colorado) to permit 2D camera calibration using the affine scaling technique. This created a 2-dimensional plane at 1.0 m above the playing surface. Match videos were time-coded (V9 time code generator, IMP Electronics, Cambridgeshire) to allow camera views to be synchronised.

To reconstruct player movements, a single point (participant's hip centre to represent whole body motion) was digitised at a rate of 1 Hz for the second and third quarters (20-60 min) of the match. If the player left the view of one camera, time and position were noted so that digitisation could be continued at the corresponding time point in the appropriate camera view. Real-space co-ordinates from each camera were merged and displacements (1-second intervals) were derived. These displacements were smoothed using the Hanning local neighbourhood averaging method and categorised into the following discrete activity classifications similar to those described by Castagna and D'Ottavio (2001): standing/non purposeful movements (0-0.5 $m \cdot s^{-1}$), walking (0.5-1.7 $m \cdot s^{-1}$), jogging (1.7-3.6 $m \cdot s^{-1}$), medium-intensity running (3.6-5.0 $m \cdot s^{-1}$), high-intensity running (5.0-6.7 $m \cdot s^{-1}$) and maximal speed running (>6.7 $m \cdot s^{-1}$).

Tests for reliability and accuracy of the current time-motion technique were carried out on a separate occasion. A participant performed a series of prescribed runs of measured distance outside of match-play, during which speed was also determined using timing gates. When comparing distances travelled, inter- and intra-operator reliability measures were (coefficient of variation, CV) 0.9 and 0.5%, while corresponding reliability values for speeds obtained were 6.0 and 3.4%. The accuracy of the method was determined by comparing the measured routes and speeds with estimated distances and speeds, returning CV values of 2.1 and 8.3 % respectively (Roberts *et al.*, 2006).

A further classification of 'static exertion' was used to categorise scrums, rucks, mauls, line-out lifts and tackles. Participation in a scrum was judged to be from the front row engagement to break up or when the player was seen to be detached following the release of the ball. Periods of rucking and mauling were timed from when the player entered into contact to their detachment from the ruck or maul. Bouts of static exertion were recorded manually by the operator referring to the time-code display on the video footage during the digitising process. Final calculations included the time spent in static exertion at appropriate time-points during the match, overwriting other movement classifications at these times.

For each player the following data were derived for 40 min of match-play (20-60 min) and then summarised according to positional group: total distance travelled, total distance travelled in each activity mode, total and % time spent in each activity mode, frequency of activities in each activity mode, and mean and maximum duration of activity modes.

In order to quantify the time spent by players in low and high-intensity exercise, the activity categories were grouped as Low Intensity Activity (LIA) (standing, walking, jogging and medium-intensity running) and High Intensity Activity (HIA) (high-intensity running, sprinting and static exertion). In the event of sequential bouts of HIA, the duration of all sequential bouts were considered to represent one period of HIA and were therefore summed to provide a time for a single HIA bout. Sequential bouts of LIA were treated in the same manner. The distances and frequency of activities were normalised to 80 min in order to estimate the values for the full match duration.

Additional analysis was performed on footage for the full match duration on five forwards and five backs in order to identify more detailed changes in activity patterns during match-play. Calculations were made for every 10-min period for: total distance travelled, distance travelled in high intensity running, sprinting and high intensity running and sprinting combined (running work), total time spent in static exertion, total time spent in HIA, mean duration of HIA activities, maximum duration of HIA activities and distance travelled by forwards in the 20-s period following a scrum.

In order to compare the ability to extrapolate 40 min of data to 80 min, a comparison was made between this period doubled and the full 80 min analysis for the players used in the whole match analysis. Analysis was made by using a measure of the typical error of the estimate (TEE) (Hopkins, 2000) for total and 'running work' distances and time spent in work activities.

Statistical analysis

Data for total distances, % time, total time, number of activities and mean and maximum duration for each activity are presented as the mean ± standard deviation (*s*). Analysis of variance (ANOVA) was used to determine differences in the mean data for total distances, % time and total time for each activity between forwards and backs. Furthermore, ANOVA was employed to establish any differences between positional groupings of tight forwards, loose forwards, inside backs and outside backs. In the event of a difference in the positional groups, a post-hoc test (Tukey) was used to reveal between which groups this difference lay. Residuals from the ANOVA were checked for normality. A Chi-square test was used to determine differences in number of activities between positional groups. For the detailed 10-min comparison, a repeated measures ANOVA was used. Statistical significance was accepted at the $P < 0.05$ level..

Results

Total distance

Backs covered more distance than forwards throughout the course of the match (Table 1). Much of this difference is attributable to the backs walking a significantly greater distance ($P < 0.001$) and partly to covering greater distances running at high-intensity ($P = 0.005$). The greatest distance covered by any positional group during sprinting was 280 ± 185m by the outside backs (Table 1) This group covered more than twice as much distance in this activity than inside backs, although this difference was not statistically significant ($P = 0.382$).

Time spent in each activity

The forwards spent a greater percentage of time in HIA activities than the backs (11.5 ± 1.8 *vs* 3.8 ± 1.3%, respectively; $P < 0.001$). Although the backs spent more time performing high intensity running than the forwards (1.6 ± 0.5 *vs* 1.1 ± 0.4%, respectively; $P = 0.004$), the difference in HIA was mainly attributable to the forwards spending a greater proportion of time in static exertion than backs (9.9 ± 2.4 *vs* 1.6 ± 0.6%, respectively; $P < 0.001$). As a proportion of the total time spent in HIA activities, the backs spent 58% and 42% of time in running activities and static exertion respectively while the corresponding values for the forwards were 13% and 87%. Backs spent more time walking than forwards (46.0 ± 4.6 *vs* 35.0 ± 4.3%, respectively; $P < 0.001$), while outside backs walked for a greater proportion of the match than inside backs (48.9 ± 3.9 *vs* 42.5 ± 2.5%, respectively, $P = 0.01$). No differences were found between tight and loose forwards for the amount of time spent in any activity. The positional differences found above were the same when expressed as actual time spent in each activity (min:s) (Table 2).

Frequency and mean duration of activities

The forwards performed more discrete bouts of HIA than backs (131 ± 36 *vs* 82 ± 30; $P < 0.001$) with a longer mean duration for each bout (4.1 ± 0.8 *vs* 2.3 ± 0.3 s; $P < 0.001$). The mean duration for each bout of LIA was longer for backs (29.9 ± 14.1 s) than for forwards (22.6 ± 4.2 s), although this was not statistically significant ($P = 0.075$). The forwards performed more bouts of static exertion than backs (89 ± 21 *vs* 24 ± 10; $P < 0.001$) and for a longer mean duration (5.2 ± 0.8 *vs* 3.6 ± 0.8 s; $P < 0.001$). These differences were a result of the forwards taking part in 21 ± 12 scrums (mean duration 7.3 ± 1.1 s) as well as performing more rucks (35 ± 8 *vs* 11 ± 6, $P < 0.001$), mauls (25 ± 8 *vs* 4 ± 4, $P < 0.001$) and tackles (14 ± 4 *vs* 10 ± 4, $P = 0.042$) than backs. The tight forwards (12 ± 3), loose forwards (16 ± 4) and inside backs (13 ± 3) all performed more tackles than the outside backs (8 ± 2; all $P < 0.001$). The forwards also performed mauls for a longer mean duration than backs (6.7 ± 1.4 *vs* 2.5 ± 1.9 s; $P < 0.001$) and attended rucks for a longer mean duration than backs, although this was not statistically significant (4.2 ± 0.6 *vs* 3.7 ± 0.7 s, $P = 0.064$). Inside backs attended more rucks than outside backs (13 ± 5 *vs* 10 ± 6 s, $P < 0.001$).

More bouts of high-intensity running were performed by backs than forwards (59 ± 28 *vs* 41 ± 16; $P < 0.001$). The mean duration of high-intensity running was very short for all positional groups and the small difference between backs and forwards was not statistically significant (1.5 ± 0.2 *vs* 1.3 ± 0.3 s, $P = 0.061$). Backs performed more sprints than forwards (23 ± 19 *vs* 16 ± 15; $P < 0.001$) with no difference in the mean duration (1.2 ± 0.3 *vs* 1.2 ± 0.3 s; $P = 0.891$) (Table 3). Furthermore, outside backs (31 ± 21) performed more sprints than tight forwards (14 ± 14), loose forwards (19 ± 18) and inside backs (15 ± 7; all $P < 0.001$).

The maximum duration for a discrete HIA period for forwards was greater than that for backs (21.0 ± 7.4 *vs* 7.6 ± 2.3 s; $P < 0.001$). Backs had a longer maximum LIA period than forwards (209.9 ± 94.9 *vs* 118.1 ± 29.5 s; $P = 0.002$). The maximum LIA period was longer for outside backs than tight and loose forwards (244.8 ± 115.7 *vs* 112.6 ± 12.4 s; $P = 0.004$, and 125.3 ± 44.1 s; $P = 0.016$, respectively) with no difference between inside and outside backs.

Whole match analysis

When the first and second half were compared, no differences were found for total distance covered (3020 ± 302 *vs* 2987 ± 359 m; $P = 0.539$), distance covered in high-intensity running and sprinting combined ('running work') (223 ± 132 *vs* 208 ± 94 m; $P = 0.770$) and time spent in HIA (3:11 ± 2:06 *vs* 2:57 ± 1:57 min:s; $P = 0.339$). Analysis of the distances travelled over successive 10-min periods of match-play revealed a greater distance travelled in the first 10 min compared with the periods of 50-60 and 70-80 min (838 ± 72 *vs* 704 ± 51 m, $P = 0.008$ and 734 ± 91 m, $P = 0.027$) (Figure 2). No differences were found between 10-min time periods for distances travelled in high intensity running, sprinting or 'running work' (Figure 3). Furthermore, there were no differences between the total (Figure 4), average or maximum time spent in HIA activities or in static exertion over the 10-min periods. When the number of high-intensity running bouts performed within 20 s after each scrum were totalled for the forwards, out of twenty-five scrums (5 players x 5 scrums) more bouts of high intensity running were performed after the first five (12 bouts) compared to the last five scrums (3 bouts) during match-play. There were no bouts of sprinting recorded within 20 s after a scrum for any 10-min period.

When the 20-60 min data for total distance was doubled (5825 ± 798 m) and compared to the total distance for the full match analysis (6006 ± 643 m), there was a TEE of 170.33 m and 2.7% when presented as a co-efficient of variation (CV). The corresponding values for total distances travelled in 'running work' and total time spent in work activities were 72.3 m (15.3%) and 40.3 s (12.7%), respectively.

Discussion

The purpose of the current study was to use an objective time-motion analysis method in order to provide quantitative data on the physical demands of elite level rugby union. It has been shown that forwards perform HIA activities for longer periods than backs due to a greater involvement in activities defined as static exertion and that the latter spend a greater proportion of HIA time performing running activities. There is also evidence to suggest that inside backs spend more time performing static exertion activities than outside backs. Although it appears that players may travel further during the first 10-min period of match-play, the HIA activity patterns suggest that there is no reduction in the amount of HIA performed as the match progresses, as defined in the current study.

The present study identified a greater total distance travelled by the backs than the forwards, which is in agreement with one of the only other studies to report distances travelled in rugby union (Deutsch *et al*., 1998). The total distances covered are greater in the current study for forwards (5581 *vs* 4240 m) and backs (6217 *vs* 5640 m), but these differences are small when it is considered that the current study reports data for 80 min compared to 70 min of match-play for under-19 age group rugby (Deutsch *et al*., 1998). Furthermore, compared to senior level, age-group rugby may adopt a different playing style and participants may be less physically developed, potentially impacting on distances travelled. The difference in total distance travelled by backs and forwards in the current study was largely due to the greater distance covered while walking. Backs also covered a greater distance in high intensity running than forwards, and whilst this might contribute less to the total distance covered than walking, it is perhaps more important in match-play since episodes of high-intensity running and sprinting are more likely to influence aspects of match-play that determine the outcome of a match.

There were no statistically significant differences between the inside and outside backs for performance parameters but there were some non-significant differences in activity patterns which are worthy of note. Outside backs sprinted 280 ± 185 m compared to 124 ± 78 m by inside backs, while the latter spent 1:33 ± 0:22 min in static exertion compared to 1:05 ± 0:30 by the outside backs. These results may suggest different roles during match-play for the two backs positional groups, resulting in differing demands whereby the inside backs appear to perform more HIA comparable to that of forwards. This is not entirely surprising given the proximity of the inside backs to the forwards in the standard team formation of what can be a highly structured game.

The differences in distances covered in each activity were reflected in the percentage time and total time spent in each activity. For percentage and total time, results comparable to those in the current study were presented for centres and props (Docherty, Wenger, & Neary, 1988) and more recently for Super 12 rugby (Duthie *et al*., 2005; Deutsch *et al*., 2007). The time spent in periods of HIA and LIA for forwards (HIA, 14%; LIA 86%) and backs (HIA, 6%; LIA 94%) in Super 12 rugby (Duthie *et al*., 2005) were similar to those found for forwards (HIA, 12%; LIA 88%) and backs (HIA, 4%; LIA 96%) in the present study, although there were some differences in the individual activity categories which might be due to activity selection criteria or player differences, or may be a reflection of different patterns of play in the northern and southern hemispheres. In any case, the findings of the current study support previous work describing the intermittent nature of elite rugby union match-play whereby short bouts of high intensity activity are interspersed with relatively long periods of rest or low intensity activity.

Methodological differences might have influenced the findings of these studies; for example, in the current study, mean sprint duration was 1.2 for both forwards and backs with other studies reporting values of 2.5 and 3.1 s (Duthie *et al*., 2006) and 2.0 and 3.2 s (Deutsch *et al*., 2007). These differences can be explained by the fact that the current analysis method will only categorise a player as 'sprinting' if a certain threshold speed is reached, whilst the others determined the activity category by subjectively judging the running gait of the player. It is possible that when using the latter method, the player may be judged to be performing at maximal intensity whilst accelerating and therefore not moving at a defined sprint speed such as that used in the present study. The data capture rate of 1Hz in the current study may account for a shorter estimated sprint time compared to previous studies due to the fact that speeds greater than 6.7 $m \cdot s^{-1}$ are not detectable if attained for a duration of less than 1 second. Interestingly, the only other study to categorise sprints using defined speeds during rugby union reported mean sprint durations of 1.0 and 1.9 s for forwards and backs, respectively (Eaton & George, 2006). Furthermore, movements in this study were captured at a rate of 10Hz and as in the current study, were still shorter than those using a subjective analysis method. Some explanation for differing sprint durations may also be attributed to differences in the playing conditions during data collection. Both Duthie *et al*. (2005) and Deutsch *et al*.

(2007) collected data during Super 12 matches. Due to Southern hemisphere climate, there is more likely to be a firmer playing surface than during the winter of the English Premiership season for the data collection of the current study and that of Eaton and George (2006). Depending on the purpose of the analysis, each of the approaches utilised by the aforementioned studies can be useful; for example, in developing training programmes, the total duration of a sprint including phases of acceleration (as reported by Duthie *et al*., 2006 and Deutsch *et al*., 2007) are extremely useful. The method used in the current study allows objective measurement of speed, but is also highly sensitive to changes in player movement speed, since the technique employed assigns a displacement every second. As a result, the number of changes in movement speeds reported is greater and the mean activity durations are less than in previous studies (Deutsch *et al*., 1998; Duthie *et al*., 2005; Deutsch *et al*., 2006). The findings of the current study, therefore, more closely reflect the frequency of changes in activity and therefore the physical demand imposed on players since they are constantly required to overcome inertia. Repeated acceleration and deceleration impose greater physiological demand (Reilly & Bowen, 1984) and results in greater muscle damage (Thompson, Nicholas, & Williams, 1999) than continuous running.

The greater amount of time spent walking and high-intensity running by the backs contrasts with the greater amount of time spent performing static exertion by the forwards. This activity category represents the greatest difference between the forwards and backs, confirming the contrasting roles of the two positional groups. Not only did the forwards carry out more bouts of static exertion (89 ± 21 *vs* 24 ± 10) but performed them for a longer mean duration (5.2 ± 0.6 *vs* 3.6 ± 0.9 s). Duthie *et al*. (2005) reported that forwards performed bouts of static exertion for a mean duration of 7.3 s with a duration of 3.8 s for backs. As similar methods to determine static exertion were used in this study, the small difference in the mean duration of static exertion for forwards could be attributed to the contrasting styles of play by northern and southern hemisphere teams. This possible difference in activity patterns is further demonstrated by the fact that in the current study the mean frequency of scrums per match was 21, compared to 29 in another study of English Premiership (Eaton & George, 2006) and 38 in elite southern hemisphere rugby (Deutsch *et al*., 2007). It should be acknowledged that in the current and other rugby union time-motion studies, it has not been possible to quantify the intensity of activity when players perform bouts of static exertion, and it is assumed that all players are performing high-intensity activity during all periods of static exertion. While the intensity is technically challenging to quantify, the importance of these phases of play in determining the outcome of matches, warrants further work to investigate more closely the demands of these activities.

The greater distance travelled in the first 10 min of the match compared to the periods of 50-60 and 70-80 min was not associated with any differences in distances travelled in high-intensity running and sprinting, meaning that the greater total distances travelled in the first 10 min will have been at lower intensities. Furthermore, neither total nor mean duration of HIA activities differed in consecutive 10 min periods. This is in agreement with another study of rugby union which reported no differences between the first and second half of match-play for average duration and time spent in similar movement categories (Duthie *et al*., 2005). In contrast, a reduction in high intensity running and sprinting towards the end of elite association football match-play has been demonstrated (Mohr *et al*., 2003). It was beyond the scope of the current study to quantify the intensity of static exertion and it is therefore possible that in rugby union, fatigue is manifested as a reduction in the intensity of static exertion bouts rather than the quantity of static exertion or high-intensity running. Furthermore, the current study did not quantify backwards running, which although infrequent, would incur a greater energy expenditure than running forwards. It should be noted that rugby, particularly at elite level, is a highly structured game in which player movements during play are determined to a large degree by tactical decision making on the pitch by key players and a pre-determined game plan. Therefore, even though the player may travel a required distance, the quality of static exertion may deteriorate at certain time points or towards the end of the match. In soccer, it has been demonstrated that during the 5-min period following the most intense 5-min activity period of the match, the player performs less HIA than for an average 5-min period (Mohr *et al*., 2003). It is possible that this notion of 'temporary fatigue' whereby there is a reduction in HIA performed immediately following an intense bout and a subsequent recovery later on during match-play (Krustrup *et al*., 2004) is also relevant for rugby. More sensitive measures may be required to further elucidate factors of fatigue in match-play which may only occur during short phases of play at irregular intervals, but the findings of the present study provide no evidence of deterioration in HIA over the period of a rugby match in terms of movement patterns or time spent in HIA activities.

In terms of practical applications, the data derived from time-motion analysis is essential in helping to inform fitness assessment and research models. In order to assess parameters of match specific performance, it would be most applicable to simulate periods of match-play with the highest exercise intensity, appropriately weighted for static exertion and running. It is during these periods that fatigue is likely to occur, possibly affecting the ability of the player to perform physical and cognitive skills.

However, an objective assessment of skill performance during match-play is difficult to achieve and therefore investigation into rugby-specific skills would be most appropriately carried out in controlled conditions.

This is the first study to show total distances run and changes in HIA performed over the course of match-play by senior elite rugby union players in the professional era, with findings that broadly confirm those of previous studies in rugby union. The greater distance travelled by backs is mainly attributable to walking while the forwards spend more time performing static exertion activities. This study also demonstrates the highly intermittent nature of rugby union and the importance of a player's ability to accelerate and decelerate. While there was a greater total distance travelled during the first compared to the last 10 min of match-play, this does not appear to be associated with a reduced ability to perform high intensity activity as defined in the current study.

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Table 1. Total distance (m) travelled in each activity category (mean ± *s*).

	Forwards			Backs		
	Tight forwards	Loose Forwards	All Forwards	Inside Backs	Outside Backs	All Backs
Stand	355 ± 52	352 ± 53	354 ± 50	317 ± 22	272 ± 82[b]	293 ± 63[a]
Walk	1840 ± 224	2045 ± 208	1928 ± 234	2161 ± 155[b]	2517 ± 277[bcd]	2351±287[a]
Jog	1985 ± 466	2075 ± 326	2024 ± 400	2094 ± 224	1936 ± 418	2010 ± 340
Med run	807 ± 225	819 ± 218	812 ± 214	917 ± 164	725 ± 223[d]	815 ± 215
High run	275 ± 114	327 ± 98	298 ± 107	439 ± 107	456 ± 185	448 ± 149[a]
Sprint	144 ± 189	192 ± 203	164 ± 189	124 ± 78	280 ± 185	207 ± 185
Total	5408 ± 702	5812 ± 666	5581 ± 692	6055 ± 455	6190 ± 929	6127 ± 724[a]

[a] significantly different to forwards, $P < 0.05$; [b] significantly different to tight forwards, $P < 0.05$; [c] significantly different to loose forwards, $P < 0.05$; [d] significantly different to inside backs, $P < 0.05$

Table 2. Total time (min:s) spent in each movement speed range (mean ± *s*)

	Forwards			Backs		
	Tight forwards	Loose Forwards	Forwards Mean	Inside Backs	Outside Backs	Backs Mean
Stand	27:42± 6:10	23:34 ± 4:34	25:55 ± 5:45	25:14 ± 3:27	21:37 ± 6:34	23:18 ± 5:30
Walk	26:37 ± 3:10	29:58 ± 3:06	28:03 ± 3:29	34:01 ± 2:01[b]	39:11 ± 3:05[bcd]	36:47 ± 3:41[a]
Jog	13:19 ± 2:52	14:01 ± 2:03	13:37 ± 2:29	13:57 ± 1:30	13:17 ± 3:07	13:36 ± 2:27
Med run	3:14 ± 0:56	3:17 ± 0:52	3:15 ± 0:52	3:39 ± 0:39	2:53 ± 0:54	3:15 ± 0:52
LIA	70:52 ± 1:55	70:50 ± 1:25	70:51 ± 1:39	76:52 ± 0:36[bc]	76:58 ± 1:20[bc]	76:56 ± 1:01[a]
High run	0:49 ± 0:20	0:58 ± 0:17	0:52 ± 0:19	1:18 ± 0:19	1:21 ± 0:33	1:19 ± 0:26[a]
Sprint	0:17 ± 0:21	0:26 ± 0:17	0:20 ± 0:23	0:17 ± 0:10	0:36 ± 0:28	0:27 ± 0:23
SE	8:03 ± 1:22	7:47 ± 1:39	7:56 ± 1:56	1:33 ± 0:22[bc]	1:05 ± 0:30[bc]	1:18 ± 0:30[a]
HIA	9:08 ± 1:55	9:10 ± 1:25	9:09 ± 1:39	3:08 ± 0:36[bc]	3:02 ± 1:20[bc]	3:04 ± 1:01[a]

[a] significantly different to forwards, $P<0.05$; [b] significantly different to tight forwards, $P<0.05$; [c] significantly different to loose forwards, $P<0.05$; [d] significantly different to inside backs, $P<0.05$. LIA (Low Intensity Activity); HIA (High Intensity Activity).

Table 3. Frequency and mean duration (seconds) of activity bouts in work categories (mean ± *s*).

		Forwards			Backs		
		Tight forwards	Loose Forwards	All Forwards	Inside Backs	Outside Backs	All Backs
Hi-run	No.	36 ± 16	48 ± 16	41 ± 16	58 ± 16	61 ± 37b	59 ± 28[a]
	Av dur	1.4 ± 0.2	1.3 ± 0.3	1.3 ± 0.2	1.6 ± 0.3	1.5 ± 0.2	1.5 ± 0.2
Sprint	No.	14 ± 14	19 ± 18	16 ± 15	15 ± 7	31 ± 21 [bcd]	23 ± 19[a]
	Av dur	1.2 ± 0.3	1.3 ± 0.3	1.2 ± 0.3	1.1 ± 0.2	1.3 ± 0.3	1.2 ± 0.3
Static Exer	No.	91 ± 19	87 ± 25	89 ± 21	29 ± 7[bc]	18 ± 10[bc]	24 ± 10[a]
	Av dur	5.3 ± 0.9	5.0 ± 0.6	5.2 ± 0.8	3.2 ± 0.6[bc]	3.9 ± 0.9[bc]	3.6 ± 0.8[a]

[a] significantly different to forwards, $P < 0.05$; [b] significantly different to tight forwards, $P < 0.05$; [c] significantly different to loose forwards, $P < 0.05$;
[d] significantly different to inside backs. No. (number of activities), Av dur (average duration of activities).

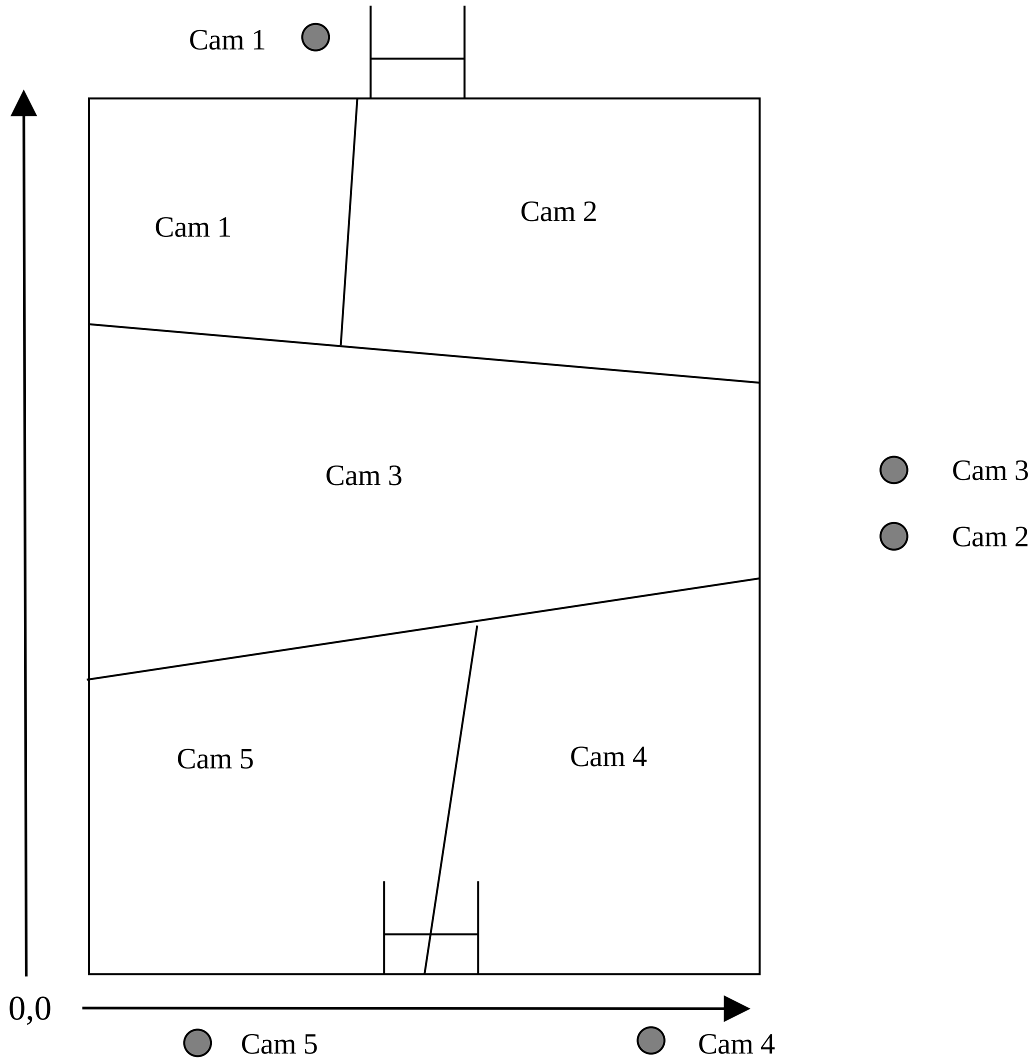

Figure 1. Camera locations around playing area perimeter.

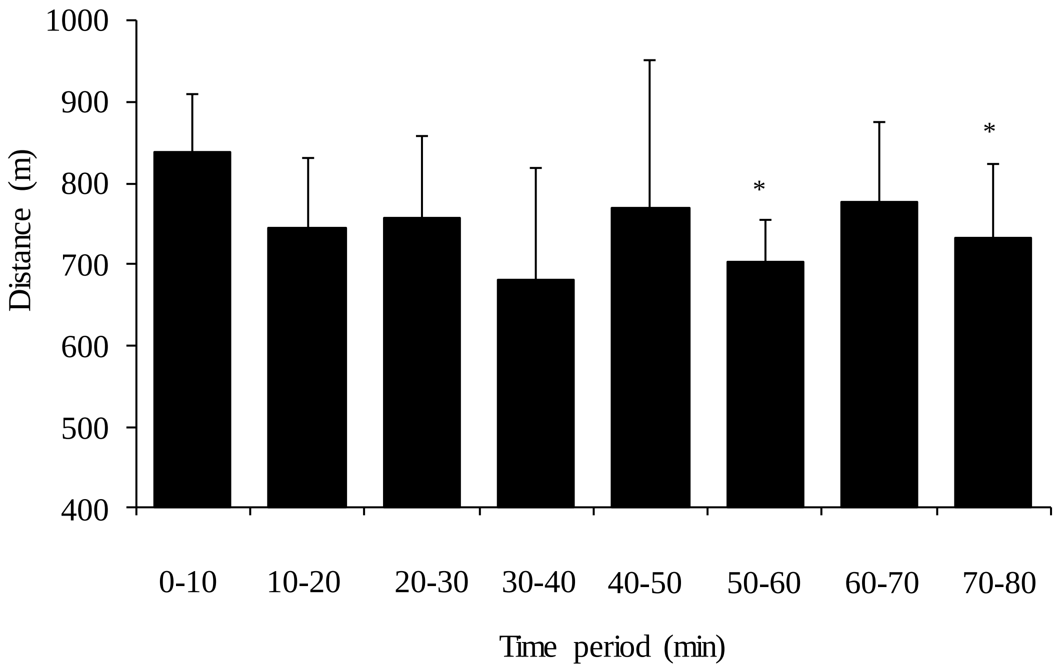

Figure 2. Total distance (m) travelled over each 10min period during match play (n = 10). *Significantly different to 0-10min, $P < 0.05$.

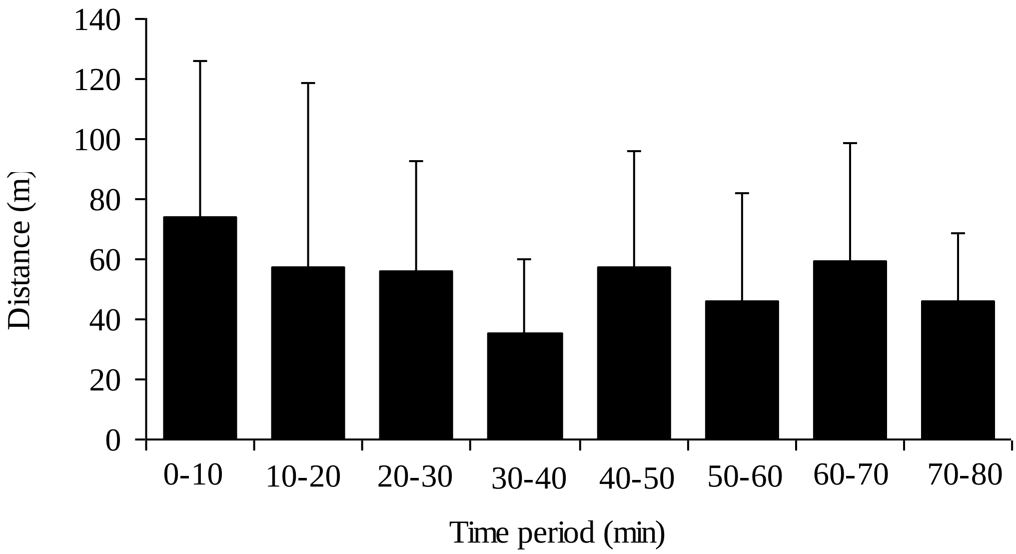

Figure 3. Distance travelled for ‘running work’ over each 10-min period of match-play (n = 10).

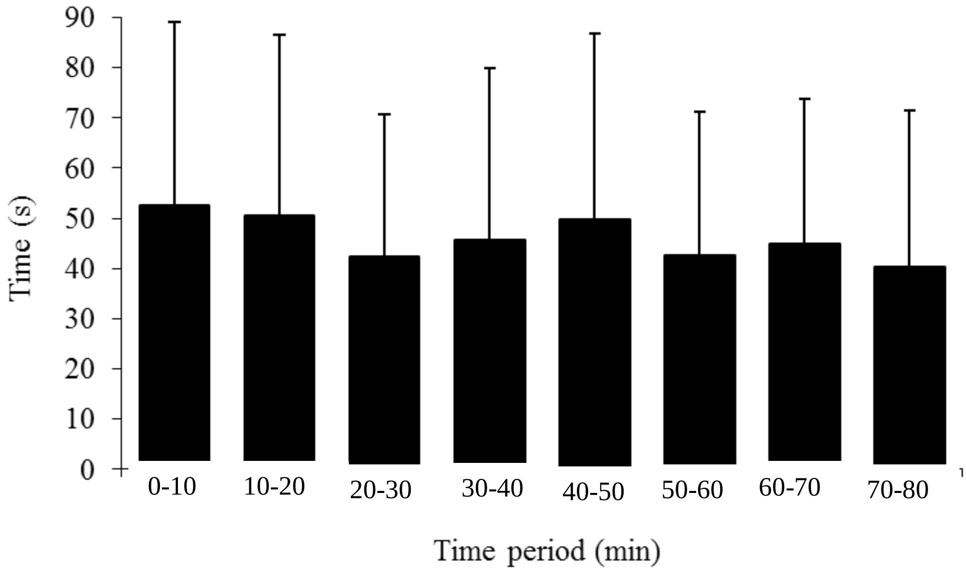

Figure 4. Time spent performing work activities during each 10-min period of match-play (n = 10).