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ORIGINAL ARTICLE

Quantifying positional and temporal movement patterns in professional rugby union using global positioning system

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Abstract
This study assessed the positional and temporal movement patterns of professional rugby union players during competition using global positioning system (GPS) units. GPS data were collected from 33 professional rugby players from 13 matches throughout the 2012–2013 season sampling at 10 Hz. Players wore GPS units from which information on distances, velocities, accelerations, exertion index, player load, contacts, sprinting and repeated high-intensity efforts (RHIE) were derived. Data files from players who played over 60 min (n = 112) were separated into five positional groups (tight and loose forwards; half, inside and outside backs) for match analysis. A further comparison of temporal changes in movement patterns was also performed using data files from those who played full games (n = 71). Significant positional differences were found for movement characteristics during performance (P < 0.05). Results demonstrate that inside and outside backs have greatest high-speed running demands; however, RHIE and contact demands are greatest in loose forwards during match play. Temporal analysis of all players displayed significant differences in player load, cruising and striding between halves, with measures of low- and high-intensity movement and acceleration/deceleration significantly declining throughout each half. Our data demonstrate significant positional differences for a number of key movement variables which provide a greater understanding of positional requirements of performance. This in turn may be used to develop progressive position-specific drills that elicit specific adaptations and provide objective measures of preparedness. Knowledge of performance changes may be used when developing drills and should be considered when monitoring and evaluating performance.

Keywords: *GPS, conditioning, microtechnology, rehabilitation, rugby union*

Introduction

A greater understanding of player movement patterns in rugby union, together with the anthropometric and physiological characteristics of players, may give an indication of the positional requirements of performance. This in turn may facilitate the planning and implementation of training programmes that elicit physiological adaptations specific to individual playing demands. Furthermore, knowledge of movement characteristics may enable coaches to monitor individual and team performance during match play (Quarrie, Hopkins, Anthony, & Gill, 2013).

To date, the majority of studies have investigated the game demands in rugby union through time motion analysis (TMA) systems (Austin, Gabbett, & Jenkins, 2011a, 2011b; Roberts, Trewartha, Higgitt, El-Abd, & Stokes, 2008). For example, recent research examining Super 14 rugby found front row forwards, back row forwards, inside backs and outside backs to cover ~4662, 5262, 6095 and 4774 m, respectively, with sprinting contributing to ~10%, 10%, 15% and 13% of the total distance, respectively (Austin et al., 2011a).

Although the total accumulated time players engage in high-intensity exercise during a match

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can be relatively brief and the distance sprinted by players short, it has been proposed that the ability of players to perform repeated high-intensity efforts (RHIE) may be critical to the outcome of the game (Austin et al., 2011a; Roberts et al., 2008). Using TMA, prior research has aimed to quantify the characteristics of rugby union, with specific attention to RHIE (Austin et al., 2011a). From understanding the movement, and more specifically the RHIE characteristics of performance, drills may then be developed to provide a position-specific training stimulus. However, as highlighted by Cunniffe, Proctor, Baker, and Davies (2009), labour-intensive motion analysis methods are largely dependent on trained users. Due to the complex movement patterns and varied nature of game play considerable subjectivity may exist when interpreting data, making comparison between coders and studies potentially problematic. More recently, the emergence of portable global positioning system (GPS) tracking units in sport have provided an alternative means of analysis (McLellan, Lovell, & Gass, 2011). To utilise the data collected from GPS it is important sport scientists and coaches have an understanding of expected movement patterns. However, currently only three studies have examined TMA of elite rugby union using GPS units (Cahill, Lamb, Worsfold, Headey, & Murray, 2013; Coughlan, Green, Pook, Toolan, & O'Connor, 2011; Cunniffe et al., 2009) with two of these studies using only a very small sample of players (*n* = 2; Coughlan et al., 2011; Cunniffe et al., 2009). Furthermore, the reliability and construct validity of 1 and 5 Hz devices used in these studies suggest they may lack the sensitivity to accurately quantify changes in movement patterns in team sport (Coutts & Duffield, 2010; Jennings, Cormack, Coutts, Boyd, & Aughey, 2010).

Recent advancements in GPS technology have made 10 Hz units commercially available which appear to be more accurate for quantifying movement patterns in team sports (Castellano, Casamichana, Calleja-Gonzalez, Roman, & Ostojic, 2011; Varley, Fairweather, & Aughey, 2012). For example, Varley et al. (2012) reported that a 10 Hz GPS unit was two to three times more accurate for instantaneous velocity during tasks completed at a range of velocities compared to criterion measure, six times more reliable for measuring maximum instantaneous velocity and had a coefficient of variation less than or similar to the calculated smallest worthwhile change during all phases of acceleration/deceleration. Therefore, to enhance knowledge of the movement patterns of elite rugby union players using GPS, further research is required sampling at 10 Hz.

Previous research has also assessed how movement patterns and physical demands change throughout match play in team sports using GPS (Austin & Kelly, 2012). Understanding how movement variables change may give an indication of the most demanding periods of play and may help understand the effects of fatigue and/or pacing throughout a game (Austin & Kelly, 2012). This may further facilitate preparation of position-specific drills and may aid player evaluation during and following match play. The aim of this study was to examine the movement patterns of elite rugby union using GPS sampling at a frequency of 10 Hz, with particular attention to the sprint and RHIE characteristics of performance and temporal changes in movement.

Methods

To examine the movement patterns of elite rugby union match play, 33 professional rugby players [25, standard deviation (SD) = 4 yrs, 104.0, *SD* = 10.6 kg] provided 141 GPS data files from six European Cup and seven Celtic League matches between November and February during the 2012–2013 season, with each player providing on average 4, *SD* = 2 data files each. Prior to providing informed consent, participants were given information outlining the rationale, potential applications and procedures associated with the study. Ethical approval was given by the Swansea University Ethics Committee.

GPS units (MinimaxX v.4.0, Catapult Innovations, Melbourne, Australia) were fitted into the back of a custom made vest so that the unit was positioned in the centre area of the upper back and slightly superior to the shoulder blades, with no restriction to the range of movement of the upper limbs and torso. To facilitate familiarisation to wearing the units, players were required to wear the vests and GPS units during outdoor training sessions throughout the season.

Data files were only included for the analysis of movement if a minimum of 60 min match play was performed (McLellan et al., 2011). Analysis was therefore conducted from 53 forward and 59 back data files. To analyse positional demands players were separated into positional groups; tight forwards (27 data files; prop, hooker, second rows), loose forwards (26 data files; open-side flanker, blind-side flanker, number 8), half backs (14 data files; scrum-half, outside-half), inside backs (17 data files; inside centre, outside centre) and outside backs (28 data files; wingers, full-back). Movement data were downloaded and analysed using Catapult Sprint software (Catapult Innovations, Melbourne, Australia) for analysis of distances covered. Distances at different velocity zones were analysed according to the classification system described by McLellan et al. (2011). Walking (0–1.6 $m{\cdot}s^{-1}$), jogging (1.6–2.7 $m{\cdot}s^{-1}$), cruising (2.7–3.8 $m{\cdot}s^{-1}$) and striding

(3.8–5.0 m·s^{-1}) were categorised as low-speed movement, while high-intensity running (5.0–5.5 m·s^{-1}) and sprinting (>5.6 m·s^{-1}) were regarded as high-speed movements (Gabbett, Jenkins, & Abernethy, 2012). Within the units a tri-axial piezoelectric linear accelerometer system, which samples at a frequency of 100 Hz allows for the detections of short high-intensity bursts in rugby union that do not allow the attainment of high speed. With use of these accelerometers, repeated high-intensity exercise (RHIE) patterns were analysed according to Gabbett et al. (2012) who defined a RHIE bout (Austin et al., 2011a; Spencer et al., 2004) so that it may be defined as three or more high acceleration (>2.79 m·s^{-2}), high speed (5 m·s^{-1}) or contact efforts with less than 21 s recovery between efforts. Contact efforts were detected using a MinimaxX (Catapult Innovations, Melbourne Australia) custom setting previously demonstrated to be valid in quantifying the contact load of collision sport athletes (Gabbett, Jenkins, & Abernethy, 2010). Additionally, two custom parameters derived from accelerometry to express the instantaneous and accumulative demands of exercise; exertion index (EI; Wisbey, Montgomery, Pyne, & Rattray, 2010) and player load are reported (Young, Hepner, & Robbins, 2012).

In addition, a temporal analysis of movement patterns was investigated using data files from players who completed the full game (n = 71). Matches were separated into 10 min periods with time played >40 min in each half excluded. For the analysis of temporal movement, distances covered at low (1–2 m·s^{-2}), moderate (2–3 m·s^{-2}) and high (>3 m·s^{-2}) accelerations and decelerations were categorised according to previous temporal research by Akenhead, Hayes, Thompson, and French (2013).

As game time varied between positional groups, a comparison of positional movement demands was made relative to game time (e.g. metres per minute; referred to as meterage, m·min^{-1}). Positional differences were examined using a one-way analysis of variance (ANOVA) with Bonferroni corrected post hoc analysis. Time-course changes in movement patterns were examined using repeated measures ANOVA, with Bonferroni corrected pairwise comparisons. Data were analysed using SPSS v20 for Windows (SPSS Inc., Chicago, IL), with the level of significance set at P < 0.05, and represented as mean, SD.

Results

There were significant differences between positional groups for game-time (P < 0.001; Table I), EI (P < 0.001), player load (P < 0.01) and total number of contacts (P < 0.001). Post hoc analysis showed half backs, inside backs and outside backs had significantly greater EI values (43.2, SD = 11.3, 45.9, SD = 7.8 and 44.1, SD = 10.0, respectively) than tight forwards (32.8, SD = 8.3; P < 0.05), but not loose forwards (37.5, SD = 9.9; P > 0.05).

Player load values for loose forwards and half backs (625, SD = 104 and 617, SD = 81, respectively) were significantly greater than tight forwards (528, SD = 97; P < 0.05), however, inside and outside backs were not significantly different from other positions (582, SD = 63 and 590, SD = 77, respectively; P > 0.05). A greater number of total contacts were detected for tight forwards compared to outside backs (30, SD = 15 vs. 16, SD = 8, P < 0.05). Furthermore, there were a significantly greater number of contacts for loose forwards (38, SD = 16) than half backs (19, SD = 9), inside backs (21, SD = 11) and outside backs (P < 0.05).

Comparisons of absolute and relative distances covered are shown in Tables I and II, respectively. There were significant differences between positional groups for total absolute difference covered and absolute distances covered walking, striding, high-intensity running, low-speed running and high-speed running (P < 0.05; Table I). Furthermore, there were significant differences in relative total distance and relative distances covered between positional groups for walking, cruising, striding, high-intensity running, sprinting, low-speed running and high-speed running (P < 0.05; Table II).

Significant positional group differences were found for the number of sprints performed and the mean and maximum sprint distances covered (P < 0.05). Inside and outside backs performed a significantly greater number of sprints (20, SD = 7 and 20, SD = 6) compared to loose forwards (10, SD = 6) and half backs (12, SD = 5; P < 0.05), while tight forwards completed the least number of sprints compared to all other positional groups (4, SD = 3; P < 0.05). Half backs (19.1, SD = 5.7 m), inside backs (17.8, SD = 2.7 m) and outside backs (18.5, SD = 3.1 m) covered greater mean distances sprinting compared to tight forwards (13.1, SD = 5.4 m; P < 0.05) but not compared to loose forwards (15.5, SD = 3.9 m; P > 0.05). Furthermore, the maximum distance covered in a sprint effort was greater for inside and outside backs (49.2, SD = 16.1 m and 42.3, SD = 10.5 m) compared to loose and tight forwards (19.5, SD = 10.1 m and 29.4, SD = 11.7 m; P < 0.05), while loose forwards and half backs (40.2, SD = 13.9 m) covered greater distances than tight forwards (19.5, SD = 10.1 m; P < 0.05).

A summary of RHIE characteristics are displayed in Table III. There were significant positional group differences for the number of RHIE bouts, the maximum number of efforts per bout, the mean and maximum effort recovery time within a RHIE

Table I. Mean (±SD) total time played and distance covered (m) within each speed zone

	n	Time (min)	Total	Walking	Jogging	Cruising	Striding	HI running	Sprinting	Low-speed	High-speed
Tight forwards	27	78 ± 12	4757 ± 885	2085 ± 435	1071 ± 228	1014 ± 283	441 ± 184	81 ± 43	65 ± 46	4610 ± 856	147 ± 80
Prop	4	70 ± 8	3698 ± 574	1756 ± 309	917 ± 102	706 ± 352	218 ± 147	51 ± 34	51 ± 51	3596 ± 507	102 ± 80
Hooker	7	73 ± 7	4746 ± 651	1832 ± 278	1151 ± 197	1094 ± 198	523 ± 187	88 ± 40	58 ± 26	4600 ± 625	147 ± 57
Second row	16	83 ± 13	5027 ± 864	2278 ± 424	1074 ± 251	1056 ± 261	460 ± 153	86 ± 45	72 ± 52	4869 ± 846	158 ± 89
Loose forwards	26	87 ± 12	5244 ± 866	2225 ± 340	1092 ± 221	997 ± 262	620 ± 219[a]	140 ± 63[a]	166 ± 116[a]	4935 ± 755	306 ± 171[a]
Blind-side flanker	7	79 ± 14	4868 ± 854	2024 ± 493	969 ± 221	1017 ± 236	611 ± 231	134 ± 28	113 ± 34	4621 ± 847	247 ± 29
Open-side flanker	9	93 ± 5	5741 ± 627	2249 ± 167	1194 ± 139	1090 ± 212	748 ± 200	185 ± 72	268 ± 129	5281 ± 509	453 ± 194
Number 8	10	88 ± 13	5059 ± 924	2344 ± 295	1087 ± 252	899 ± 306	512 ± 182	104 ± 48	112 ± 78	4843 ± 818	216 ± 117
Half backs	14	83 ± 12	5693 ± 823[a]	2436 ± 372	1123 ± 265	1041 ± 243	711 ± 236[a]	155 ± 71[a]	226 ± 112[a]	5311 ± 705	381 ± 172[a]
Scrum half	5	70 ± 6	4987 ± 725	2225 ± 371	909 ± 238	852 ± 192	674 ± 281	144 ± 98	177 ± 107	4661 ± 557	322 ± 20
Outside half	9	90 ± 6	6086 ± 595	2254 ± 336	1241 ± 203	1146 ± 206	731 ± 222	160 ± 56	253 ± 111	5673 ± 491	413 ± 155
Inside backs	17	91 ± 11[a]	5907 ± 709[a]	2545 ± 391[ab]	1067 ± 187	1008 ± 143	700 ± 126[a]	209 ± 56[ab]	378 ± 149[abc]	5321 ± 610	586 ± 182[abc]
Inside centre	10	88 ± 13	5661 ± 825	2357 ± 320	1090 ± 218	979 ± 167	689 ± 134	204 ± 64	344 ± 102	5114 ± 733	548 ± 135
Outside centre	7	95 ± 5	6258 ± 276	2815 ± 332	1034 ± 142	1050 ± 98	717 ± 123	216 ± 47	425 ± 196	5616 ± 110	642 ± 234
Outside backs	28	92 ± 10[a]	6272 ± 1065[ab]	2999 ± 590[abcd]	1201 ± 310	908 ± 205	593 ± 132[a]	174 ± 52[a]	392 ± 135[abc]	5701 ± 1007[ab]	566 ± 171[abc]
Winger	18	91 ± 10	6181 ± 1121	2980 ± 633	1140 ± 303	862 ± 186	604 ± 134	178 ± 53	409 ± 151	5586 ± 1066	587 ± 190
Full back	10	92 ± 11	6436 ± 991	3032 ± 536	1314 ± 306	991 ± 222	572 ± 133	166 ± 53	361 ± 99	5909 ± 907	527 ± 131

[a]Significant difference compared to tight forwards; [b]significant difference compared to loose forwards; [c]significant difference compared to half backs; [d]significant difference compared to inside backs.
HI, high-intensity; m, metres; SD, standard deviation.
$P < 0.05$.

Table II. Mean (±SD) meterage ($m \cdot min^{-1}$) within each speed zone

	n	Total	Walking	Jogging	Cruising	Striding	HI running	Sprinting	Low-speed	High-speed
Tight forwards	27	60.7 ± 6.0	26.5 ± 2.8	13.7 ± 2.1	12.9 ± 3.2[e]	5.6 ± 2.3	1.1 ± 0.6	0.8 ± 0.6	58.8 ± 5.3	1.9 ± 1.0
Prop	4	52.7 ± 4.1	25.1 ± 3.7	13.2 ± 1.9	9.9 ± 4.2	3.0 ± 1.8	0.7 ± 0.5	0.7 ± 0.7	51.3 ± 3.1	1.4 ± 1.0
Hooker	7	65.0 ± 2.9	25.2 ± 3.4	15.7 ± 1.5	15.0 ± 2.1	7.1 ± 2.4	1.2 ± 0.5	0.8 ± 0.4	63.0 ± 3.0	2.0 ± 0.7
Second row	16	60.8 ± 5.4	27.5 ± 2.1	12.9 ± 1.9	12.8 ± 2.8	5.6 ± 1.9	1.1 ± 0.6	0.9 ± 0.7	58.8 ± 4.5	2.0 ± 1.2
Loose forwards	26	60.8 ± 8.4	25.6 ± 2.3	12.6 ± 2.4	11.6 ± 3.3	7.2 ± 2.7	1.6 ± 0.6	1.9 ± 1.2[a]	57.0 ± 7.4	3.5 ± 1.7[a]
Blind-side flanker	7	61.8 ± 8.6	25.3 ± 2.0	12.3 ± 2.7	13.1 ± 3.7	7.9 ± 3.6	1.7 ± 0.4	1.4 ± 0.5	58.7 ± 8.6	3.2 ± 0.5
Open-side flanker	9	63.2 ± 8.2	24.3 ± 2.0	12.9 ± 1.7	11.9 ± 2.8	8.1 ± 2.3	2.0 ± 0.7	2.9 ± 1.3	57.3 ± 7.1	4.9 ± 2.0
Number 8	10	57.9 ± 8.2	26.9 ± 2.1	12.5 ± 2.8	10.3 ± 3.1	5.8 ± 1.8	1.2 ± 0.5	1.3 ± 0.8	55.5 ± 7.2	2.4 ± 1.2
Half backs	14	69.1 ± 7.5	29.6 ± 3.5[b]	13.6 ± 2.8	12.6 ± 2.7[e]	8.7 ± 3.2[ae]	1.9 ± 0.9[a]	2.7 ± 1.3[a]	64.5 ± 6.1[b]	4.6 ± 2.0[a]
Scrum half	5	71.7 ± 7.1	32.0 ± 4.5	13.0 ± 2.8	12.3 ± 2.8	9.7 ± 3.9	2.0 ± 1.3	2.5 ± 1.4	67.1 ± 4.9	4.6 ± 2.7
Outside half	9	67.7 ± 7.7	28.2 ± 1.9	13.9 ± 2.9	12.8 ± 2.8	8.2 ± 2.8	1.8 ± 0.7	2.8 ± 1.3	63.1 ± 6.5	4.6 ± 1.8
Inside backs	17	65.6 ± 5.1	28.0 ± 2.2	11.8 ± 2.1	11.1 ± 1.3	7.7 ± 1.2[a]	2.3 ± 0.6[ab]	4.2 ± 1.7[abc]	58.6 ± 3.3	6.5 ± 2.0[abc]
Inside centre	10	65.4 ± 4.8	26.9 ± 1.3	12.4 ± 2.0	11.2 ± 1.3	7.8 ± 0.8	2.3 ± 0.6	3.9 ± 1.1	58.3 ± 3.5	6.2 ± 1.2
Outside centre	7	65.9 ± 5.8	29.5 ± 2.2	10.9 ± 2.0	11.1 ± 1.5	7.6 ± 1.7	2.3 ± 0.6	4.5 ± 2.3	59.1 ± 3.2	6.8 ± 2.8
Outside backs	28	68.8 ± 10.0	32.6 ± 4.7[abd]	13.2 ± 3.2	10.0 ± 2.2[ac]	6.5 ± 1.5	1.9 ± 0.6[a]	4.3 ± 1.6[abc]	62.2 ± 9.1	6.3 ± 2.0[abc]
Winger	18	67.6 ± 10.3	32.5 ± 5.2	12.5 ± 3.1	9.5 ± 1.9	6.7 ± 1.5	2.0 ± 0.6	4.6 ± 1.9	61.1 ± 9.4	6.5 ± 2.3
Full back	10	71.0 ± 9.7	32.8 ± 4.0	14.3 ± 3.3	10.9 ± 2.5	6.3 ± 1.6	1.8 ± 0.5	3.9 ± 1.0	64.3 ± 8.6	5.7 ± 1.4

[a]Significant difference compared to tight forwards; [b]significant difference compared to loose forwards; [c]significant difference compared to half backs; [d]significant difference compared to inside backs; [e]significant difference compared to outside backs.
HI, high-intensity; $m \cdot min^{-1}$, metres per minute; SD, standard deviation.
$P < 0.05$.

Table III. Mean (±SD) description of repeated high-intensity exercise (RHIE) bout characteristics from competition

	Tight forwards (n = 27)	Loose forwards (n = 26)	Half back (n = 14)	Inside back (n = 17)	Outside back (n = 28)
RHIE bouts	11 ± 8	13 ± 7[ab]	5 ± 4	7 ± 7	6 ± 6
Efforts per bout					
Mean	4 ± 1	4 ± 1	3 ± 0	3 ± 0	4 ± 0
Max	7 ± 4	7 ± 3[c]	5 ± 2	4 ± 2	5 ± 2
Effort recovery time (s)					
Mean	8.1 ± 2.0[bc]	7.3 ± 1.2[bc]	6.5 ± 2.3[b]	4.9 ± 1.6	4.7 ± 1.9
Max	19.3 ± 1.9[bc]	18.8 ± 2.7[b]	17.3 ± 4.8	15.3 ± 5.3	15.4 ± 5.7
RHIE bout recovery time (s)					
Min	153 ± 201	90 ± 122	375 ± 513	343 ± 533	304 ± 460
Mean	398 ± 219	457 ± 376	612 ± 286	751 ± 463[d]	551 ± 405
Max	886 ± 492	1039 ± 579	1068 ± 591	1237 ± 556	968 ± 614

[a]Significant difference compared to half backs; [b]significant difference compared to outside backs; [c]Significant difference compared to inside backs; [d]Significant difference compared to tight forwards.
SD, standard deviation; s, seconds.
$P < 0.05$.

bout and the mean recovery time between RHIE bouts ($P < 0.05$; Table III).

Despite there being no difference in meterage between the two halves, Table IV demonstrates significant time effect differences in player load, cruising (m·min^{-1}) and striding (m·min^{-1}) from the first to the second half. Table IV also displays temporal changes in movement patterns in 10 min periods, with significant time effect changes in player load, RHIE bout number, contacts, total meterage and meterage at several velocities ($P < 0.05$, Table IV).

Discussion

The aim of the present study was to examine the movement patterns of professional rugby union players, whereby such data may help coaches and practitioners understand the physiological demands underpinning rugby union performance (Austin et al., 2011a). Sampling at a frequency of 10 Hz, the present study is the first assessment of the movement patterns in rugby union using units valid and reliable for detecting high acceleration/deceleration and high-speed movements associated with rugby union (Castellano et al., 2011; Varley et al., 2012). The study is also the first to report EI, player load, and provide a detailed analysis of sprint and repeated high-intensity characteristics using GPS technology. Furthermore, we demonstrate temporal changes in movement characteristics throughout match play in rugby union.

Total distances reported in the present study are smaller than those previously reported (Cahill et al., 2013; Coughlan et al., 2011; Cunniffe et al., 2009) using GPS to assess movement patterns. However, values for all players, forwards and backs are similar to values obtained by TMA reported by previous research (Austin et al., 2011b; Quarrie et al., 2013; Roberts et al., 2008). With advancements in methodology it could be assumed that the greatest discrepancies in results would be via TMA methods. However, methodological issues may explain differences with previous GPS research. For example, research by Coughlan et al. (2011) and Cunniffe et al. (2009) only assessed the movement patterns of one forward and one back. However, this does not explain differences to the research by Cahill et al. (2013) who conducted a comprehensive analysis of English Premiership rugby which assessed 276 GPS data files. Furthermore, 1 and 5 Hz units have been proposed to underestimate distance covered following a tortuous route (Duffield, Reid, Baker, & Spratford, 2010; Petersen, Pyne, Portus, & Dawson, 2009), therefore variances in the total distances covered in the present study compared to previous research may not directly relate to measurement error. Other possible explanations for differences in movement characteristics may be due to differing playing standards, the team assessed, opponents' tactics, varied game characteristics and the period of the season from which games were assessed.

Our findings support previous research which show that movement demands and thus the physiological demands of performance vary between positional groups (Cahill et al., 2013; Quarrie et al., 2013; Roberts et al., 2008). For example, this study found outside backs covered a greater distance (~6272 vs. ~5244 m), at a greater meterage (~68.8 vs. ~60.8 m·min^{-1}), performed a greater number of sprints (~20 vs. ~10) and reached a greater maximum velocity (~7.8 vs. 6.9 m·s^{-1}) than loose forwards ($P < 0.05$). In addition to quantifitying movement patterns, this study is the first to characterise EI and player load accumulated during performance. EI values further demonstrate that forwards have lesser

Table IV. Temporal changes (mean ± SD) in movement patterns throughout match play (n = 71)

	0–10 min	10–20 min	20–30 min	30–40 min	40–50 min	50–60 min	60–70 min	70–80 min	First half	Second half
Player load·min^{-1}	7.8 ± 1.1	7.0 ± 1.2[ad]	6.7 ± 1.4[ad]	6.2 ± 1.5[ad]	7.6 ± 1.2	6.3 ± 1.1[abd]	5.8 ± 1.7[abcd]	6.0 ± 1.5[abcd]	6.9 ± 0.8	6.5 ± 0.9*
Meterage ($m \cdot min^{-1}$)	75.3 ± 13.6	68.4 ± 12.5[a]	65.8 ± 11.1[ad]	62.0 ± 14.0[ad]	74.3 ± 12.9	62.5 ± 10.2[ad]	58.2 ± 16.3[abcd]	61.8 ± 18.1[abcd]	67.6 ± 8.0	64.7 ± 10.2
EI·min^{-1}	0.58 ± 0.19	0.49 ± 0.16[ad]	0.46 ± 0.14[ad]	0.41 ± 0.16[ad]	0.56 ± 0.16	0.42 ± 0.12[ad]	0.39 ± 0.16[abcd]	0.41 ± 0.17[abd]	0.49 ± 0.12	0.45 ± 0.11
Walking ($m \cdot min^{-1}$)	29.3 ± 7.1	30.1 ± 5.0	30.0 ± 5.5	30.6 ± 6.4	30.2 ± 6.6	29.2 ± 5.6	28.6 ± 6.7	30.6 ± 9.3	29.8 ± 4.3	29.8 ± 5.4
Jogging ($m \cdot min^{-1}$)	14.5 ± 4.6	13.7 ± 4.0	12.1 ± 3.7[ad]	12.3 ± 5.0[d]	14.8 ± 3.9	12.3 ± 3.3[d]	11.6 ± 5.7[ad]	11.8 ± 5.4[d]	12.9 ± 2.6	12.8 ± 3.5
Cruising ($m \cdot min^{-1}$)	15.1 ± 4.5	12.0 ± 4.4[a]	11.1 ± 4.0[ad]	9.7 ± 3.7[ad]	13.8 ± 5.0	10.6 ± 3.9[ad]	9.1 ± 5.1[abd]	9.0 ± 4.3[abd]	11.8 ± 2.7	10.6 ± 2.8*
Striding ($m \cdot min^{-1}$)	9.1 ± 3.9	7.3 ± 3.0[a]	7.4 ± 3.4[a]	5.7 ± 3.5[ad]	8.8 ± 3.8	6.4 ± 3.4[ad]	5.0 ± 3.0[abcd]	5.7 ± 3.6[ad]	7.4 ± 2.0	6.5 ± 2.2*
HI running ($m \cdot min^{-1}$)	2.2 ± 1.6	1.9 ± 1.6	2.1 ± 1.6	1.4 ± 1.3[ad]	2.1 ± 1.5	1.7 ± 1.3	1.3 ± 1.0[ad]	1.6 ± 1.4	1.9 ± 0.8	1.7 ± 0.8
Sprinting ($m \cdot min^{-1}$)	4.8 ± 4.0	3.3 ± 3.0	3.1 ± 2.8[a]	2.1 ± 2.4[ad]	4.6 ± 4.4	2.2 ± 2.7[ad]	2.6 ± 3.0[ad]	3.0 ± 3.1	3.4 ± 2.1	3.0 ± 2.1
High-speed ($m \cdot min^{-1}$)	7.0 ± 4.9	5.2 ± 4.1	5.2 ± 3.8	3.4 ± 3.1[ad]	6.8 ± 5.1	3.9 ± 3.6[ad]	3.9 ± 3.5[ad]	4.6 ± 4.0	5.3 ± 2.7	4.7 ± 2.8
Low-speed ($m \cdot min^{-1}$)	68.0 ± 12.7	63.1 ± 10.2	60.6 ± 9.2[ad]	58.5 ± 12.1[ad]	67.6 ± 10.4	58.5 ± 8.9[ad]	54.2 ± 14.9[abcd]	57.1 ± 16.7[ad]	62.0 ± 6.6	59.7 ± 9.1
High dec > –3 $m \cdot s^{-2}$ (m)	7.2 ± 3.6	5.6 ± 3.1[ad]	5.9 ± 3.7	4.4 ± 3.3[ad]	7.4 ± 4.0	4.3 ± 3.1[acd]	4.2 ± 3.0[acd]	4.0 ± 3.4[acd]	28.3 ± 10.6	25.9 ± 12.1
Mod dec –3 to –2 $m \cdot s^{-2}$ (m)	11.2 ± 5.0	9.5 ± 4.0[ad]	8.7 ± 3.7[ad]	7.7 ± 4.0[ad]	11.7 ± 4.2	8.0 ± 3.6[ad]	7.0 ± 4.2[abd]	7.1 ± 4.2[abd]	44.2 ± 11.7	42.3 ± 13.2
Low dec –2 to –1 $m \cdot s^{-2}$ (m)	34.2 ± 10.7	29.2 ± 9.5[d]	27.8 ± 9.1[ad]	24.4 ± 10.0[ad]	34.6 ± 8.9	24.9 ± 8.3[ad]	23.0 ± 10.6[abd]	23.1 ± 9.8[abcd]	133.8 ± 23.2	128.6 ± 25.4
Low acc 1 to 2 $m \cdot s^{-2}$ (m)	43.5 ± 12.9	36.6 ± 10.4[ad]	37.2 ± 11.0[ad]	31.5 ± 11.3[ad]	44.4 ± 10.8	32.5 ± 10.4[ad]	29.9 ± 12.6[abcd]	30.8 ± 12.4[acd]	172.6 ± 29.0	165.8 ± 32.5
Mod acc 2 to 3 $m \cdot s^{-2}$ (m)	16.2 ± 5.7	13.5 ± 4.8[ad]	13.4 ± 5.1[ad]	11.4 ± 5.2[ad]	17.2 ± 6.2	11.8 ± 4.3[ad]	10.7 ± 5.3[abcd]	11.5 ± 6.0[ad]	64.0 ± 14.6	62.9 ± 18.4
High acc >3 $m \cdot s^{-2}$ (m)	11.7 ± 5.3	9.9 ± 4.8	10.3 ± 5.9	9.1 ± 5.5	11.2 ± 4.9	8.5 ± 3.7[ad]	8.6 ± 5.1[ad]	9.1 ± 6.9	47.3 ± 15.2	46.5 ± 24.6
RHIE bouts	1.2 ± 1.2	1.2 ± 1.4	1.7 ± 2.2	1.3 ± 2.1	1.7 ± 1.6	1.0 ± 1.2[d]	0.9 ± 1.2[d]	0.9 ± 1.0[d]	4.6 ± 4.1	5.3 ± 4.6
Contacts	2.9 ± 2.5	3.1 ± 3.0	4.1 ± 4.6	3.7 ± 5.0	4.0 ± 3.8	2.5 ± 2.2[d]	2.3 ± 2.1[d]	2.5 ± 2.4[d]	12.3 ± 9.5	12.6 ± 9.8

[a]Significant difference from 0 to 10 min; [b]significant difference from 10 to 20 min; [c]significant difference from 20 to 30 min; [d]significant difference from 40 to 50 min.
Acc, accelerations; dec, decelerations; EI, exertion index; HI, high-intensity; m, metres; $m \cdot min^{-1}$, metres per minute; $\cdot min^{-1}$, per minute; Mod, moderate; RHIE, repeated high-intensity exercise; SD, standard deviation.
*Significant difference from first half. $P < 0.05$.

running demands compared to backs; however, they have greater contact and repeated high-intensity demands. Loose forwards performed a significantly greater number of contacts (~38) compared to half, inside and outside backs (~19, ~21, ~16), while tight forwards performed a significantly greater number than outside backs (~16). Furthermore on average loose forwards performed the greatest amount of RHIE bouts (~13) which was significantly greater than half backs (~5) and outside backs (~6). Previous TMA studies have included measures of static exertion (tackling, rucking, scrummaging, etc.) as high-intensity activity and shown that despite performing less high-intensity running, forwards spent the greatest time in high-intensity activity due to their greater demands in static exertion (Austin et al., 2011b; Roberts et al., 2008). For example, Roberts et al. (2008) found forwards performed a significantly greater number of static exertion activities (~89 vs. ~24) and spent greater time performing high-intensity activities (running and static exertion) than backs (~9:09 vs. ~3:04 min). Coupled with locomotive demands, this may explain why although non-significant, loose forwards had greater player load values than half, inside and outside backs. Loose forwards did, however, have significantly greater player load values than tight forwards. Despite performing a similar number of total contacts to loose forwards, an important role of tight forwards is to scrummage where prolonged static exertion may not be detected by accelerometers. For example, tight forwards exert and are subjected to greater forces during scrummaging (Quarrie & Wilson, 2000) which may result in "temporary fatigue"; whereby there is a reduction in high-intensity activity performed immediately following an intense bout, with a subsequent recovery later in performance (Mohr, Krustrup, & Bangsbo, 2003). This may be characterised by reduced locomotive patterns compared to loose forwards following a scrum. Thus, despite advances in inertial sensor technology which may help to characterise the movement patterns of rugby players, in particular loose forwards, further research is required to quantify the physiological demand of performance.

The present study has also assessed temporal changes in movement patterns from data files of players who completed full games. Similar to the findings of Austin and Kelly (2012) the present study found transient fatigue throughout each half in multiple measures of low- and high-intensity movement and low to high acceleration and deceleration movements. Furthermore, although the number of RHIE bouts and contacts did not significantly change during any 10-min period during the first half, both measures were significantly reduced at 50–60, 60–70 and 70–80 min compared to 40–50 min. The study also shows that player load, cruising and striding values were significantly reduced from the first to second half.

Despite high-speed meterage exhibiting the greatest percentage reduction from 0 to 10 min between 30 and 40 min, the greatest reductions in movement in the second half compared to the first 10 min were found in low-speed movements such as cruising and striding supporting previous research in rugby union by Roberts et al. (2008). Previous TMA research by Roberts et al. (2008) found no difference between halves for total distance covered (~3020 vs. 2987 m), distance covered in high-intensity running and sprinting (~223 vs. 208 m) and time spent in high-intensity activity (~3:11 vs. 2:57 min). However, further analysis of the distances travelled over successive 10 min periods of match play revealed that greater total distance was covered in the first 10 min compared with the periods of 50–60 and 70–80 min (Roberts et al., 2008). However, Roberts et al. (2008) found no differences between 10 min time periods for distances travelled in high-intensity running, sprinting or "running work", and there were no differences between the total, average or maximum time spent in high-intensity activities or in static exertion over the 10 min periods, suggesting that changes in distance covered may have been characterised by a reduction in low-intensity activities, which may be characterised by an inability to maintain defensive position or run supporting lines in attack (Roberts et al., 2008).

The present study also demonstrates an increase in high intensity, sprinting and high-speed meterage during the final 10 min of the match to values not statistically different to any other 10-min period. Mooney, Cormack, O'Brien, and Coutts (2013) suggest that reductions in low speed compared to high-speed movements may be evidence of "pacing" whereby players sacrifice distances covered at low speeds to compensate for the demands of high-speed movement. Coaches and sport scientists should therefore be aware of transient fatigue in rugby union, with further research required to investigate differences between positions (Austin & Kelly, 2012) and temporary fatigue characteristics (Mohr et al., 2003). Following recent research (Cormack, Mooney, Morgan, & McGuigan, 2013; Mooney et al., 2013), the effect of preparedness and fatigue on work rate and transient fatigue should also be investigated in rugby union. Moreover, the effect of substitutes on team movement patterns requires investigation.

The data presented from the present study, together with anthropometric and physiological characteristics of players, may enhance knowledge of the positional requirements of performance. This in turn may help monitor preparedness and performance (Austin et al., 2011a), inform the planning of position-specific programmes that elicit physiological adaptations (Austin et al., 2011a) and facilitate rehabilitation (Coughlan et al., 2011). Austin et al. (2011a) explain that by using maximum periods of activity coupled with minimum periods of recovery; the most demanding passages of play may be replicated providing coaches with a sense of their players' preparedness to meet the requirements of competition. For example, using the present data, a protocol for an inside back which would represent the mean average RHIE characteristics of match play would require players to perform four high-intensity efforts interspersed by 4.9 s with 12:31 min between bouts. However, it is proposed that coaches should use minimum, mean, maximum and SD values reported in the study as a reference to modulate RHIE protocols which may allow progressions in intensity during training and rehabilitation. Varying the high-intensity activity periods may allow coaches to work on and integrate various high-intensity activities patterns. Therefore, activity periods may be shorter or may consist of multiple activities. To assist in the identification of activity patterns during RHIE bouts, synchronisation of GPS software with motion analysis software coaches may allow coaches to identify the characteristics of RHIE bouts which may allow great specificity and progression of protocols.

Consideration should also be given to the duration of "recovery" between RHIE bouts. Using average and SD values, recovery times may be adjusted to increase intensity of effort. Furthermore, temporal analyses from the study highlight the most intense periods of performance and the expected reductions in several measures of movement for all players. Knowledge of "worst-case" meterage values may be used to modulate and manage intensity of effort, and may be a valuable monitoring tool when quantifying preparedness which would be an important process in assessing the progress of an injured player (Coughlan et al., 2011). Temporal analysis from the study also highlights the potential importance GPS monitoring may have during match play by allowing sport scientists to observe individual or team movement patterns and potentially advise on tactical decisions (e.g. substitutions). Additionally, knowledge of variations in movement patterns may aid the application of match-day strategies to enhance performance (e.g. half-time re-warm up; Mohr, Krustrup, Nybo, Nielsen, & Bangsbo, 2004).

Practical applications

The findings of the present study may be used to facilitate the planning and implementation of training programmes that elicit appropriate and specific physiological adaptations. Knowledge of team, position and individual temporal movement patterns may also aid the preparation of conditioning and rehabilitation drills. Monitoring of temporal patterns, in particular low-speed movements and player load may allow coaches and sport scientist to assess preparedness for performance and fatigue during match play. Knowledge of transient fatigue may also have important implications for tactical decisions made during match play and the use of match-day strategies to enhance performance.

This study has characterised the movement patterns of professional rugby players, demonstrating variances in positional demands which may be used to help understand the physiological demands of individuals. This in turn may be used to devise positional specific drills to enhance physiological preparation for performance and may be used for the monitoring and management of individuals. We also show evidence of transient fatigue in rugby union which may also have important implications for physiological preparation, assessment and monitoring of performance.

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