Abstract

Purpose: In team sports, fatigue is manifested by a self-regulated decrease in movement distance and intensity. There is currently limited information on the effect of fatigue on movement patterns in rugby union match play, particularly for players in different position groups (backs vs. forwards). This study investigated the effect of different match periods on movement patterns of professional rugby union players. ***Methods***: Global positioning system (GPS) data were collected from 46 professional match participations to determine temporal effects on movement patterns. ***Results:*** Total relative distance ($m.min^{-1}$) was decreased in the 2^{nd} half for both forwards (-13, ±8%; ES = *very likely* large) and backs (-9, ±7%; ES = *very likely* large). A larger reduction in high-intensity running distance in the 2^{nd} half was observed for forwards (-27, ±16%; ES = *very likely* medium) than for backs (-10, ±15%, ES = *unclear*). Similar patterns were observed for sprint (>6 $m.s^{-1}$) frequency (forwards -29, ±79%; ES = *likely* small vs. backs -13, ±18%; ES = *possibly* small) and acceleration (>2.75 $m.s^{-2}$) frequency (forwards -27, ±24%; ES = *likely* medium vs. backs -5, ±46%, ES = *unclear*). Analysis of 1^{st} and 2^{nd} half quartiles revealed differing pacing strategies for forwards and backs. Forwards display a “slow-positive” pacing strategy, while the pacing strategy of backs is “flat”. ***Conclusions:*** Forwards suffered progressively greater performance decrements over the course of the match, while backs were able to maintain performance intensity. These findings reflect differing physical demands, notably contact and running loads, of players in different positions.

Key words: Pacing, team sport, intensity, temporal, GPS

Introduction

In team sports, fatigue can be broadly identified by reductions in self-regulated movement distance and/or intensity during a match[1]. Accordingly, acute fatigue in team sports has been evidenced by a decline in total and high-intensity (>3.6 $m.s^{-1}$) running distance across progressive game segments in soccer[2], rugby league[3], Australian rules football[4], rugby sevens[5] and rugby union[6-8] .

Contemporary models of team sport pacing suggest that players regulate their efforts based on macro-, meso- and micro pacing strategies[9]. The macro-pacing strategy is determined prior to the start of the match based on intrinsic (hydration, fuel availability, motivation) and extrinsic (ambient temperature, opposition) factors. This macro-pacing 'schema' is then modified between halves (meso-pacing) and continuously (micro-pacing) in response to in-match factors such as exertion, opposition and score line[9]. The net result of this type of strategy is that players regulate exercise intensity throughout matches to ensure sufficient physiological reserves to complete that match, and to be able to up-regulate activity levels during intense periods of play.

To date, only 3 studies have reported changes in temporal patterns of movement within rugby union matches. Analysis from successive 10 minutes periods of matches indicate that rugby union players typically adopt a 'slow-positive' pacing strategy in terms of total distance covered, starting games at higher running intensities with a gradual decline (~10%) throughout each half[7,8]. Roberts et al.[7] reported that high intensity running distance remained consistent throughout match segments. In contrast, Jones et al.[8] showed large reductions (~50%) in high intensity running in periods 30-40 minutes and 50-60 minutes during match play. Lacome et al.[6] found no change in exercise to rest ratios from 1st to 2nd half in international rugby players, concluding that there was not an obvious decrease in performance due to fatigue[6], indicating a 'flat' pacing strategy.

An important consideration in determining pacing and fatigue in rugby union is the presence of physical contact. Physical contact has been shown to reduce total running performance in rugby league players participating in small-sided games[10-12]. These results suggest that players will adjust their pacing 'schema' in response to the contact demands present. Rugby union forwards are exposed to more contact activities than backs during match play[7,13,14], and as such may be more likely to display signs of fatigue during match play. This may be the reason why forwards are substituted more often than backs during rugby union matches[1]. No study has previously assessed whether the fatigue pattern of rugby union players is affected by position.

The aim of this research project is to report the influence of match period and playing position (forward or back) on the movement patterns of professional rugby union players. This information will be useful for rugby union coaches attempting to protect fatigued players from injury, as well as optimize the impact of substitutes during matches.

Methods

Subjects

This research was performed in partnership with a South African professional rugby union team. Nineteen players (age 26 ± 2 years; body mass 101.5 ± 12.2 kg, stature 1.86 ± 0.07 m) volunteered to take part in the study and provided data from 24 matches in the 2013 rugby season. From these matches, a total of 105 individual match participations were documented. The study was approved by the University of Johannesburg Ethical Review Committee and followed the code of ethics of the World Medical Association (Declaration of Helsinki). Written informed consent was obtained from all players.

Design

A prospective, observational, longitudinal design was used to assess the impact of fatigue on movement characteristics of professional rugby players.

Methodology

All matches took place between March and October 2013 during the local rugby season and were part of first-class professional competitions. Movement patterns were assessed with SPI Pro GPS devices (GPSports, Canberra, Australia) (mass = 76 g; size = 87 x 48 x 20 mm), that sample positioning data at a frequency of 5Hz and contain a tri-axial accelerometer that samples at 100 Hz. The devices were worn during match play, supported between the shoulder blades by an elasticated harness worn underneath the playing jersey. The validity and reliability of these units has been shown to be acceptable for the assessment of movement variables in team sports [15-17].

The validity of measures from the accelerometer in the SPI-Pro unit has not been established. Waldron et al.[18] showed the reliability of accelerometer measures to be acceptable (CV = 4.7-5.2%). Research has shown correlations between high intensity impacts (>8G) and markers of muscle damage[16], as well as neuromuscular markers of post-match fatigue[19] in rugby league. These results show that accelerometer data may be an indicator of the overall mechanical load that players are exposed to.

Players were familiarized with the use of the GPS units at practice sessions before using them in matches. Units were switched on prior to the commencement of the warm up, typically 45 minutes before kickoff, to ensure adequate time to establish satellite signal.

Following matches, data were downloaded and analyzed on a personal computer using Team AMS software (Version 10, GPSports™, Canberra, Australia). Data were "cleaned" by removing data recorded during warm up, half time and periods when players were not on the field. Data were then exported to excel (Microsoft, Redmond, USA) and SPSS (Version 22.0, IBM.com) for statistical analysis.

Total playing time, total distance (m) covered and maximum speed ($m.s^{-1}$) were recorded from the GPS files. Movement patterns were quantified based on distance covered in discrete speed zones (low intensity running – 0-4 $m.s^{-1}$ and high intensity running - > 4$m.s^{-1}$) based on the delineations of Quarrie et al.[20] Data were normalized to distance per minute played ($m.min^{-1}$) to account for differences in total playing time as a result of substitutions and in match stoppages. Total sprint (>6 $m.s^{-1}$) and acceleration (>2.75 $m.s^{-2}$) counts were calculated, and reported as frequencies (1 every N minutes). Accelerometer data were recorded as the total number of impacts >5G and total high intensity impacts >8G, and normalized to playing time.

Only data files collected from "whole game players" were included in this study. Players were designated whole game players if they completed the entire 1st half and at least 35 minutes in the 2^{nd} half. 46 GPS data files (forwards = 19, backs = 27) made up the final data set. The raw data files were separated into 1^{st} half or 2^{nd} half files, and further separated according position group (forward or back)[7,13]. Temporal analysis of movement patterns was investigated by further dividing each 1^{st} half and 2^{nd} half file into quartiles.

Statistical Analysis

Assessment of changes in movement characteristics of backs and forwards across match halves was performed using a paired samples t-test. Temporal changes in movement patterns were examined for each position group using a separate mixed design factorial analysis of variance (ANOVA), to compare position (back, forward) by match period (1^{st} half quartile 1-4 and 2^{nd} half quartile 1–4). Assumptions of sphericity were assessed using the Mauchly test of sphericity, with any violations adjusted by use of the Greenhouse-Geisser correction. No significant interaction (position x quartile) effects were found. Where significant effects of position were observed, independent samples t-tests with Bonferroni corrections were used to determine difference in position per quartile. Where significant effect of quartile was present, the magnitude of difference was determined by comparing quartiles through a series of paired sample t-tests with Bonferroni corrections. The level of significance was set at $P < 0.05$, for these assessments.

Given the practical nature of this study, differences were also analysed using magnitude-based inference network to determine the likelihoods that the true value of the effects represent substantial change[21]. Magnitude of effects were therefore, expressed as effect sizes with 95% confidence limits. Effect sizes of 0.2, 0.5, 0.8 and 1.2 were considered small, medium, large and very large respectively[22]. The smallest practically meaningful effect was considered to be 0.2. Effects were deemed unclear if their confidence intervals overlapped both the thresholds for substantiveness, meaning that the effect could be substantially positive and negative. Qualitative descriptors are used to describe the likelihood that the true magnitude of the effect is substantial according to the following schema: <0.5%, most unlikely; 0.5-5%, very unlikely; 5-25%, unlikely; 25-75%, possibly; 75-95%, likely; 95-99.5%, very likely; >99.5%, most likely. Confidence limits and magnitude-based inferences were calculated from p-values using a custom designed spreadsheet downloaded from the internet (www.sportsci.org). Group mean data are reported as mean ± SD and difference between groups or time points are reported as % change, ±95%CL.

Results

Changes in movement variables from 1^{st} to 2^{nd} half

Table 1 presents the differences in the movement variables for backs and forwards between the 1^{st} and 2^{nd} halves. The relative distance covered in the 2^{nd} half was decreased for both forwards (-13, ±8%; ES = *very likely* large) and backs (-9, ±7%; ES = *very likely* large) indicating an overall reduction in match intensity of ~10%. Backs and forwards differed in their movement profile across halves both in terms of low intensity and high intensity running. Both position groups displayed large reductions in low intensity running distance between halves (forwards -10, ±8%; ES = *very likely* large; backs -7, ±9%; ES = *very likely* large). Forwards showed a medium sized reduction in high intensity running from 1st to 2nd half (-27, ±16%; ES = *very likely* medium), while it was *unclear* whether match half has any effect on high intensity running distance for backs (-10, ±15%, ES = *unclear*).

Forwards also differed from backs in the rate of decline in sprint and acceleration frequency. Forwards performed less sprints (-29, ±79%; ES = *likely* small) and less accelerations (-27, ±24%; ES = *likely* medium) in the 2nd half compared to the 1st. In contrast, there were no notable changes in sprint (-13, ±18%; ES = *possibly* small) or acceleration frequency (-5, ±46%, ES = *unclear*) for backs. Both backs and forwards displayed small reductions in the total number of impacts sustained between halves (forwards -9, ±17%; ES = *possibly* small; backs -10, ±10%, ES = *likely* small), but there was no meaningful change in either position group for high intensity impacts (forwards -9, ±50%; ES = *unclear*; backs -2, ±9%; ES = *most likely trivial*).

Temporal changes in movement patterns
A number of significant effects of position (back, forward) and match period (1st half Q1-4, 2nd half Q1-4) were found across movement variables, and these are illustrated in Table 2 and 3, and in Figure 1. Significant effects of position were present for relative distance, maximum speed, low- and high-intensity distance, sprint and acceleration frequency and total and high-intensity impacts. Of note, was that there was a decrease in maximum speed of forwards from 1st half Q1 to 2nd half Q1 (-10, ±6%). During the same time period, backs maintained their maximum speed (4, ±12%). This resulted in the magnitude of difference between forwards and backs for maximum speed increasing from a medium sized difference early in the 1st half to a large or very large difference for most of the 2nd half. Similar effects were present for sprint and acceleration frequency, where the magnitude of difference between forwards and backs was small to medium during the early periods of the match, but progressed onward to become large to very large differences.

There was little difference in the relative distance covered by backs and forwards until the final match period (2nd half Q4), where forwards covered significantly more distance (forwards 69 ± 13 vs. backs 56 ± 10 m.min^{-1}, ES = *most likely* large). Forwards covered more low-intensity distance than backs during the 2nd half Q2 and Q4 (*very likely* large to *most likely* very large differences) (figure 1b). There was a significant difference in high-intensity running distance between backs and forwards in the first period of the 2nd half (forwards 8 ± 4 vs. backs 13 ± 4 m.min^{-1}, ES = *most likely* very large). It was notable that both forwards and backs experienced declines in high-intensity running distance of ~ 35% percent over the course of the match, but these declines followed different patterns. Forwards high-intensity running distance declined 23, ±36% (ES = *likely* small) from Q1 to Q4 during the 1st half, while backs maintained their high-intensity running distance (-2, ±140%; ES = *unclear*) during the same period. Thereafter, forwards maintained their high-intensity running distance from 1st half Q4 to 2nd half Q4 (-7, ±47%; ES = *unclear*). Backs maintained similar high-intensity running distances from 1st half Q1 to 2nd half Q3 before a dramatic drop off in the last quartile of the 2nd half (-35, ±31%; ES = *likely* large).

A significant effect of position was present for both total and high-intensity impacts, with significant differences between forwards and backs in various quartiles. The largest difference observed was in 1st half Q3 (high-intensity impacts forwards 0.6 ± 0.3 vs. backs 1.1 ± 0.4 >8G.min^{-1}, ES = *most likely* very large. Overall, backs typically exceeded forward measures for both accelerometer measures (small to very large differences), but no clear time course was apparent for these differences.

No significant effect of match period was observed in any movement category for forwards. Backs demonstrated a reduction in activity levels in the final quartile of the 2nd half, resulting in significant differences from other match periods for total, relative, low- and high-intensity distance.

Discussion

The purpose of this study was to report the effects of match related fatigue on the physical performance of professional rugby union players in different position groups (backs vs. forwards). The main finding was that there was an ~10% decrease in distance covered per minute from 1st to 2nd half for both backs and forwards. This change was attributable to a -10, ±8% (ES = *very likely* large) decrease in low intensity running distance and a -27, ±16% (ES = *very likely* medium) decrease in high intensity distance across halves for forwards. For backline players, a similar size decrease was present for low intensity running (-7, ±9%; ES = *very likely* large) across halves, but it was *unclear* whether a real change in high intensity running was observed (-10, ±15%, ES = *unclear*). Sprint (-29, ±79%; ES = *likely* small) and acceleration frequency (-27, ±24%; ES = *likely* medium) were significantly reduced across halves for forwards, but remained consistent for backs (sprint frequency -13, ±18%; ES = *possibly* small; acceleration frequency -5, ±46%, ES = *unclear*). These findings indicate that the rate of decay in physical outputs of performance likely differs between forwards and backs in professional rugby union. Understanding the reasons for these performance changes of the course of a match could be key to implementing improved training programs and strategies within this sport.

This is the first study to include position groups as a factor in the analysis of movement patterns across a match with regard to fatigue. Roberts et al.[7] reported no difference in total distance or high intensity running distance between match halves for all players. Jones et al.[8] also reported no difference in total, high or low speed distance per half, although there were reductions in cruising (2.7 to 3.8 m.s^{-1}) and striding (3.8 to 5.0 m.s^{-1}) distance for all players. The large differences the physical requirements of players in different positions has been regularly documented[13,14], and it is possible that important information was missed in these studies due to the heterogeneity of the player groups. The findings of this study show that there were reductions in total running distance between halves for both backs and forwards, and a significant reduction in high-intensity running in the 2nd half for forwards. These differences are likely due to the differing roles and responsibilities of players in different positions. Forwards are regularly involved in contests for possession which results in a greater amount of physical contact with other players, while backs are generally involved in tactical movements to score or advance field position and as a result are able to move more freely around the pitch with less contact involvements[14].

The findings presented here suggest that fatigue is likely to manifest differently for players in different positions. Despite dividing the player group into two broad groups (backs and forwards), these groups remain largely heterogeneous. A limitation of this study was that the data sample collected was not large enough to allow examination of the fatigue profiles of individual playing positions. Future research should aim to further differentiate players into smaller or even individual position groups.

In order to gain a greater understanding of how players may pace themselves through a professional rugby union match, each half of data was divided into quartiles to provide 8 discrete time periods (1st half Q1-4 and 2nd half Q1-4) for examination. It should be noted that while the changes in movement patterns observed in this study have been generally attributed to player fatigue, there are multiple explanations. Current pacing theory[9], suggests that players will alter their pacing strategy in response to factors such as the standard of opposition, the match situation or score line. Ambient conditions such as the presence of rain or heat and humidity would also affect pacing. This model of pacing is supported by research in professional rugby league indicating that diverse factors such as playing home or away, playing following a short recovery cycle, whether a team won or lost and the standard of the opposition all affected exercise intensity[23]. It has also been demonstrated that the introduction of substitutes to a match will affect pacing [2]. Therefore, while it is possible to produce a generalized pacing model for rugby union from the data presented here, it is vital to interpret this in the context of the multitude of intrinsic and extrinsic factors that may affect pacing.

When player pacing was examined across quartiles, it was apparent that forwards exhibit a "slow-positive"[1] pacing strategy with regard to total relative and high-intensity running distance. This indicates that forwards start out the match at a high level of running intensity and gradually decline throughout the match. In contrast, the backs exhibited a "flat" pacing strategy, maintaining total relative and high-intensity running distance throughout the match until a large drop-off in the final quartile (2nd half Q4). It is unclear whether the large decrement in movement variables for backs in the final quartile was due to fatigue or pacing. It is possible that the outcome of (win/lose) of the match was already apparent in the final quartile and as a result players may have reduced intensity, or team tactics may have changed. The differing pacing strategies or fatigue profiles of backs and forwards is also apparent in maximum speed, sprint and acceleration frequency variables. Although backs are known to outperform forwards in these movement categories[24], the magnitude of differences in these movement categories are small to medium in the early periods of the game (1st half Q1-2), but become large to very large during the middle periods (1st half Q3 to 2nd half Q3).

Since contact involvement is such an important factor in determining fatigue, it was hoped that the accelerometer data provided by the GPS units would provide an insight into the contact loads that players experience. Analysis of accelerometer data indicates that backs experience more total and high intensity G-forces than forwards. Therefore, referring to these G-forces as impacts is likely incorrect as it is known that forwards experience more physical contacts than backs[7,13,14] during match play. Since backs sprint and accelerate more frequently than forwards, it is likely that the accelerometer data reported here is reflective of acceleration/deceleration forces of running as well as actual physical collisions.

Research in rugby league has shown no relationship between contact events (tackles and hit-ups) and accelerometer measures[19], but did show that accelerometer measurements were correlated with decreases in peak rate of force development and peak power up to 24 h post match. These findings indicate that even though accelerometer measures do not match up with the number of contact events that players are exposed to during rugby union match play, they may be an important indicator of physical load.

A further limitation in the use of GPS and accelerometers to quantify physical load in rugby union players is the exposure of players to "non-running" exertions such as scrums, mauls and rucks[14]. During these phases of play, players essentially wrestle for possession of the ball and are involved in largely isometric muscle contractions, which have significant energy costs, but will not be reflected as high intensity movements by either GPS or accelerometers.

Previous research suggests that when players are exposed to multiple contact efforts, total and high intensity movement rates cannot be maintained[12]. Research has demonstrated that forwards are exposed to a larger number of contact involvements than backs during rugby union match play[7,13,14]. In addition, forwards are exposed to a greater volume of "non-running" exertions than backs during match play[14]. Our findings suggest that, forwards experience greater fatigue than backs during match play based on reductions in high intensity running, maximal speed, sprint and acceleration frequency. This is likely due to the larger volume of contact and "non-running" exertions that forwards are exposed to.

For backs the rate of overall and high intensity movement was reduced between halves, but this was the result of a large reduction in the final quarter of the 2nd half. Total and high intensity running distance was essentially maintained for backs through out the first 7 match periods (1st half Q1 to 2nd half Q7). This is in contrast to most team sports where there is a significant reduction in high intensity running distance in the 2nd half[5,25,26]. The relative distance per match for backs in this study (67 ± 6 m.min^{-1}), is lower than that of other team sports (~110 m.min^{-1})[5,25,26], and is perhaps not high enough to elicit a fatigue related reduction in high intensity running distance in the absence of large contact demands.

The degree of contact involvement of backs and forwards could not be established in this study because the accelerometer measures used were not reflective of contact events. The accelerometer data presented does not explain the difference in fatigue profile between backs and forwards according to the proposed model.

This study provides an interesting departure point for future analysis of pacing in rugby union matches, but some aspects should be improved upon. Of concern is that there are differences in the physical profiles of players within the back and forward positional groups. Insufficient data was available in this study to assess individual positions, but future research should aim to establish the whole match and transient fatigue profiles of players in individual positions. Secondly, this research was conducted on players representing a single team and may only reveal the results of their particular conditioning program or playing style. Further research should make comparisons across teams at different playing standards to determine how pacing strategies may differ. Finally, the application of improved methods of measuring contact and non-running exertions will greatly assist in the interpretation of fatigue data for rugby union players.

Practical Applications

The presence of fatigue during match play is both a risk factor for injury, and results in reduced accuracy of technical skill execution[3]. The ability to avoid, or reduce the effect of fatigue would therefore confer a performance advantage. The results of this study suggest that the onset of fatigue occurs relatively early on in rugby union matches for forwards, but that the physical performance of backs is unaffected by fatigue for the majority of the game. This suggests that participation as a forward in rugby union is physically challenging and that a high level of specific physical preparation is required to cope with the demands of the game. While backs in this study did not demonstrate significant reductions in physical outputs, their skill involvements were not measured, and it is possible that the effects of fatigue would be revealed there. Improved understanding of the physical demands and fatigue profile that players experience will lead to improved conditioning programs. Knowledge of the fatigue profile of rugby union players will also influence the timing of tactical substitutions, with coaches aiming to replace tiring players before their reduced physical capacity affects team performance.

Conclusion

This research provides evidence that rugby union forwards experience decreases physical performance during the 2^{nd} half of matches. It is proposed that these changes in movement patterns occur due to fatigue resulting from running and contact involvements during match play. Backs displayed reductions in low intensity running distance, but were able to maintain most physical performance measures for the majority of the match. This difference in the fatigue profile of backs and forwards may reflect that backs experience a lesser degree of fatigue during match play due to lower running loads and contact involvements.

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References

1. Waldron M, and Highton J. Fatigue and pacing in high-intensity intermittent team sport: an update. *Sports Med.* 2014;44(12):1645-58. doi:10.1007/s40279-014-0230-6.
2. Bradley PS, and Noakes TD. Match running performance fluctuations in elite soccer: indicative of fatigue, pacing or situational influences? *J Sports Sci.* 2013;31(15):1627-38. doi:10.1080/02640414.2013.796062.
3. Kempton T, Sirotic AC, Cameron M, and Coutts AJ. Match-related fatigue reduces physical and technical performance during elite rugby league match-play: a case study. *J Sports Sci.* 2013;31(16):1770-80. doi:10.1080/02640414.2013.803583.
4. Wisbey B, Montgomery PG, Pyne DB, and Rattray B. Quantifying movement demands of AFL football using GPS tracking. *J Sci Med Sport.* 2010;13(5):531-6. doi:10.1016/j.jsams.2009.09.002.
5. Higham DG, Pyne DB, Anson JM, and Eddy A. Movement patterns in rugby sevens: Effects of tournament level, fatigue and substitute players. *J Sci Med Sport.* 2011;15(3):277-82 doi:10.1016/j.jsams.2011.11.256.
6. Lacome M, Piscione J, Hager JP, and Bourdin M. A new approach to quantifying physical demand in rugby union. *J Sports Sci.* 2013;32(3):290-300. doi:10.1080/02640414.2013.823225.
7. Roberts SP, Trewartha G, Higgitt RJ, El-Abd J, and Stokes KA. The physical demands of elite English rugby union. *J Sports Sci.* 2008;26(8):825-33. doi:10.1080/02640410801942122.
8. Jones MR, West DJ, Crewther BT, Cook CJ, and Kilduff LP. Quantifying positional and temporal movement patterns in professional rugby union using global positioning system. *Eur J Sport Sci.* 2015;15(6):1-9. doi:10.1080/17461391.2015.1010106.
9. Edwards AM, and Noakes TD. Dehydration: cause of fatigue or sign of pacing in elite soccer? *Sports Med.* 2009;39(1):1-13.
10. Johnston RD, Gabbett TJ, Walker S, Walker B, and Jenkins DG. Are three contact efforts really reflective of a repeated high-intensity effort bout? *J Strength Cond Res.* 2014;29(3):816-21 doi:10.1519/JSC.0000000000000679.
11. Johnston RD, Gabbett TJ, Seibold AJ, and Jenkins DG. Influence of physical contact on pacing strategies during game-based activities. *Int J Sports Physiol Perform.* 2014;9(5):811-6. doi:10.1123/ijspp.2013-0424.
12. Johnston RD, Gabbett TJ, and Jenkins DG. Influence of Number of Contact Efforts on Running Performance During Game-Based Activities. *Int J Sports Physiol Perform.* 2014;10(6):740-5. doi:10.1123/ijspp.2014-0110.
13. Duthie G, Pyne D, and Hooper S. Time motion analysis of 2001 and 2002 super 12 rugby. *J Sports Sci.* 2005;23(5):523-30. doi:10.1080/02640410410001730188.
14. Deutsch MU, Kearney GA, and Rehrer NJ. Time - motion analysis of professional rugby union players during match-play. *J Sports Sci.* 2007;25(4):461-72. doi:10.1080/02640410600631298.
15. Petersen C, Pyne D, Portus M, and Dawson B. Validity and reliability of GPS units to monitor cricket-specific movement patterns. *Int J Sports Physiol Perform.* 2009;4(3):381-93.
16. McLellan CP, Lovell DI, and Gass GC. Performance analysis of elite Rugby League match play using global positioning systems. *J Strength Cond Res.* 2011;25(6):1703-10. doi:10.1519/JSC.0b013e3181ddf678.

17. Coutts AJ, and Duffield R. Validity and reliability of GPS devices for measuring movement demands of team sports. *J Sci Med Sport.* 2010;13(1):133-5. doi:10.1016/j.jsams.2008.09.015.
18. Waldron M, Worsfold P, Twist C, and Lamb K. Concurrent validity and test-retest reliability of a global positioning system (GPS) and timing gates to assess sprint performance variables. *J Sports Sci.* 2011;29(15):1613-9. doi:10.1080/02640414.2011.608703.
19. McLellan CP, and Lovell DI. Neuromuscular responses to impact and collision during elite rugby league match play. *J Strength Cond Res.* 2012;26(5):1431-40. doi:10.1519/JSC.0b013e318231a627.
20. Quarrie KL, Hopkins WG, Anthony MJ, and Gill ND. Positional demands of international rugby union: Evaluation of player actions and movements. *J Sci Med Sport.* 2012;16(4):353-9. doi:10.1016/j.jsams.2012.08.005.
21. Hopkins WG. Probabilities of clinical or practical significance. *Sportscience.* 2002;6(201):16.
22. Hopkins WG, Marshall SW, Batterham AM, and Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc.* 2009;41(1):3-13. doi:10.1249/MSS.0b013e31818cb278.
23. Kempton T, and Coutts AJ. Factors affecting exercise intensity in professional rugby league match-play. *J Sci Med Sport.* 2015. [Epub ahead of print] doi:10.1016/j.jsams.2015.06.008.
24. Cahill N, Lamb K, Worsfold P, Headey R, and Murray S. The movement characteristics of English Premiership rugby union players. *J Sports Sci.* 2013;31(3):229-37. doi:10.1080/02640414.2012.727456.
25. Sirotic AC, Coutts AJ, Knowles H, and Catterick C. A comparison of match demands between elite and semi-elite rugby league competition. *J Sports Sci.* 2009;27(3):203-11. doi:10.1080/02640410802520802.
26. Mohr M, Krustrup P, and Bangsbo J. Match performance of high-standard soccer players with special reference to development of fatigue. *J Sports Sci.* 2003;21(7):519-28. doi:10.1080/0264041031000071182.

Figure Captions

Figure 1 – Relative total (a.), low-intensity (b.) and high intensity (c.) distance covered by backs and forwards in each quartile of 2 halves of rugby union matches. # indicates significant difference between positions for a match period and * indicates significant difference for backs from 2nd half Q4

Table 1 – Movement variables of whole game players from different position groups (backs/forwards) during the 1st half and 2nd half in professional rugby union matches.

	Forwards (N=19)				Backs (N=27)			
	1st Half	2nd Half	ES	Qualitative inference	1st Half	2nd Half	ES	Qualitative inference
Time Playing (mins)	47 ± 7	50 ± 8	small	*unclear*	46 ± 3	50 ± 7	medium	*likely*
Total Distance (m)	3485 ± 696	3163 ± 391	medium	*likely*	3160 ± 275	3129 ± 394	trivial	*unclear*
Relative Distance ($m.min^{-1}$)*	74 ± 11*	65 ± 8	large	*very likely*	70 ± 8*	63 ± 5	large	*very likely*
Maximum Speed ($m.s^{-1}$)	7.3 ± 0.9	7.3 ± 1.3	trivial	*unclear*	8.6 ± 1.2	8.6 ± 1.0	trivial	*most likely trivial*
Low intensity distance <$4m.s^{-1}$ ($m.min^{-1}$)	62 ± 8*	56 ± 8	large	*very likely*	56 ± 4*	52 ± 4	large	*very likely*
High intensity distance >$4m.s^{-1}$ ($m.min^{-1}$)	12 ± 6*	9 ± 4	medium	*very likely*	13 ± 4*	11 ± 3	small	*unclear*
Sprint frequency (>$6m.s^{-1}$)	1 every 14 ± 14 min*	1 every 20 ± 25 min	small	*likely*	1 every 7 ± 5 min	1 every 8 ± 17 min	small	*possibly*
Acceleration frequency (>$2.75m.s^{-2}$)	1 every 9 ± 17 min*	1 every 13 ± 7 min	medium	*likely*	1 every 5 ± 10 min	1 every 5 ± 9 min	trivial	*unclear*
Total impacts (>$5G.min^{-1}$)	8.7 ± 2.4	7.9 ± 3.2	small	*possibly*	10.0 ± 3.5	9.0 ± 3.0	small	*likely*
High intensity impacts (>$8G.min^{-1}$)	0.8 ± 0.3	0.7 ± 0.3	small	*unclear*	1.1 ± 0.3	1.1 ± 0.4	trivial	*most likely trivial*

*Note: Data presented as mean ± SD. * indicates significant difference from 2nd half within position group (P < 0.05). ES indicates effect size of difference from 1st to 2nd half. Qualitative inference is a statement regarding the likelihood that the true value represents a substantial change. Sprint and acceleration frequency indicate how regularly players exceeded the speed and acceleration thresholds indicated.*

Table 2 – Temporal changes in locomotive movement patterns throughout match play quartiles for profession rugby union forwards and backs completing a whole game.

	Pos.	1st Half				2nd Half			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Total Distance (m)	Fwd	874 ± 163	875 ± 200	866 ± 285	832 ± 221	736 ± 183	801 ± 175	771 ± 160	786 ± 133
	Back	795 ± 121*	761 ± 107	783 ± 103	784 ± 123	819 ± 143*	805 ± 144*	806 ± 164	693 ± 126
		(*likely* medium)	(*very likely* medium)	(*likely* small)	(*unclear*)	(*likely* medium)	(*unclear*)	(*unclear*)	(*likely* medium)
Relative Distance (m.min^{-1})	Fwd	74 ± 14	73 ± 11	71 ± 17	69 ± 15	64 ± 13	69 ± 11	67 ± 11	69 ± 13$^{\#}$
	Back	69 ± 10*	67 ± 11*	68 ± 10*	68 ± 10*	66 ± 9*	65 ± 7*	66 ± 12*	56 ± 10
		(*possibly* small)	(*likely* small)	(*unclear*)	(*unclear*)	(*unclear*)	(*possibly* small)	(*unclear*)	(*most likely* large)
Maximum Speed (m.s^{-1})	Fwd	6.8 ± 0.7	6.9 ± 1.1	6.2 ± 0.8$^{\#}$	6.3 ± 1.4	6.1 ± 0.7$^{\#}$	6.3 ± 1.0$^{\#}$	6.5 ± 1.4$^{\#}$	6.2 ± 1.3$^{\#}$
	Back	7.5 ± 1.6	7.7 ± 1.3	7.5 ± 1.4	7.4 ± 1.3	7.8 ± 1.1	7.3 ± 1.4	7.8 ± 1.1	7.2 ± 1.4
		(*likely* medium)	(*likely* medium)	(*most likely* large)	(*very likely* large)	(*most likely,* very large)	(*very likely* large)	(*most likely,* large)	(*very likely,* medium)
Low intensity distance <4m.s^{-1} (m.min^{-1})	Fwd	60 ± 11	61 ± 9	61 ± 14	60 ± 11	56 ± 11	60 ± 8$^{\#}$	57 ± 10	59 ± 10$^{\#}$
	Back	57 ± 7*	54 ± 8	55 ± 7*	56 ± 7*	54 ± 7	54 ± 6	53 ± 9	48 ± 7
		(*possibly* small)	(*very likely* large)	(*likely* medium)	(*likely* small)	(*unclear*)	(*very likely* large)	(*likely* small)	(*most likely,* very large)
High intensity distance >4m.s^{-1} (m.min^{-1})	Fwd	13 ± 7	12 ± 6	10 ± 8	10 ± 7	8 ± 4$^{\#}$	9 ± 6	10 ± 5	9 ± 7
	Back	12 ± 6	13 ± 6*	14 ± 6	12 ± 5*	13 ± 4	11 ± 5*	13 ± 5	9 ± 5
		(*unclear*)	(*unclear*)	(*likely* medium)	(*possibly* small)	(*most likely* very large)	(*possibly* small)	(*likely,* medium)	(*unclear*)

Note: Data presented as mean ± SD (*qualitative inference* and effect size). *Qualitative inference is a statement regarding the likelihood that the true value represents a substantial change* Effect size indicates the magnitude of that change. Both statements refer to differences between forwards and backs during the same time period. Pos. indicates position group forward (Fwd) or back. Q1-4 indicate quartiles for each half, mean duration of each quartile was 12 ± 2 min for backs and forwards. Sprint and acceleration frequency indicate how regularly players exceeded the speed and acceleration thresholds indicated. $^{\#}$ indicates significant difference from back position group during the same time period, * indicates significant difference from 2nd half Q4.

Table 3 – Temporal changes in sprint, acceleration and impact frequency throughout match play quartiles for profession rugby union forwards and backs completing a whole game.

	Pos.	1st Half				2nd Half			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Sprint frequency (>6m.s^{-1})	Fwd	1 every 14 ± 11 min	1 every 13 ± 11 min	1 every 15 ± 8 min	1 every 21 ± 17 min#	1 every 33 ± 16 min#	1 every 29 ± 24 min#	1 every 20 ± 15 min#	1 every 16 ± 11 min
	Back	1 every 7 ± 7 min (*possibly* medium)	1 every 5 ± 6 min (*likely* medium)	1 every 6 ± 9 min (*likely* large)	1 every 7 ± 8 min (*likely* large)	1 every 6 ± 9 min (*very likely,* very large)	1 every 9 ± 11 min (*likely* large)	1 every 7 ± 10 min (*likely* large)	1 every 8 ± 8 min (*possibly* medium)
Acceleration frequency (>2.75m.s^{-2})	Fwd	1 every 7 ± 8 min	1 every 9 ± 10 min	1 every 15 ± 14 min#	1 every 13 ± 16 min#	1 every 13 ± 16 min#	1 every 14 ± 12 min#	1 every 14 ± 9 min#	1 every 12 ± 11 min
	Back	1 every 6 ± 8 min (*unlikely* small)	1 every 5 ± 6 min (*likely* medium)	1 every 5 ± 7 min (*very likely* large)	1 every 5 ± 7 min (*very likely* large)	1 every 4 ± 7 min (*very likely* very large)	1 every 6 ± 8 min (*likely* large)	1 every 5 ± 7 min (*likely* large)	1 every 7 ± 6 min (*possibly* medium)
Total impacts (>5G.min^{-1})	Fwd	9.3 ± 4.5	9.2 ± 2.4	8.2 ± 3.7	7.4 ± 2.1#	8.2 ± 3.7	9.4 ± 4.8	8.2 ± 3.1	8.7 ± 4.0
	Back	10.4 ± 5.3 (*unclear*)	10.0 ± 3.9 (*unclear*)	10.4 ± 4.1 (*likely* medium)	9.6 ± 4.8 (*likely* medium)	9.7 ± 3.7 (*possibly* small)	9.4 ± 3.3 (*unclear*)	10.0 ± 3.6 (*likely* medium)	7.1 ± 4.0 (*possibly* small)
High intensity impacts (>8G.min^{-1})	Fwd	0.8 ± 0.6	0.9 ± 0.4	0.6 ± 0.3#	0.8 ± 0.5	0.8 ± 0.5	0.8 ± 0.4	0.7 ± 0.4	0.8 ± 0.4
	Back	1.0 ± 0.5 (*possibly* small)	1.1 ± 0.4 (*likely* medium)	1.1 ± 0.4 (*most likely* very large)	1.1 ± 0.7 (*likely* small)	1.1 ± 0.5 (*likely* medium)	1.2 ± 0.6 (*very likely* medium)	1.1 ± 0.5 (*likely* large)	0.9 ± 0.7 (*unclear*)

Note: Data presented as mean ± SD (*qualitative inference* and effect size). *Qualitative inference is a statement regarding the likelihood that the true value represents a substantial change* Effect size indicates the magnitude of that change. Both statements refer to differences between forwards and backs during the same time period. Pos. indicates position group forward (Fwd) or back. Q1-4 indicate quartiles for each half, mean duration of each quartile was 12 ± 2 min for backs and forwards. Sprint and acceleration frequency indicate how regularly players exceeded the speed and acceleration thresholds indicated. # indicates significant difference from back position group during the same time period, * indicates significant difference from 2nd half Q4.

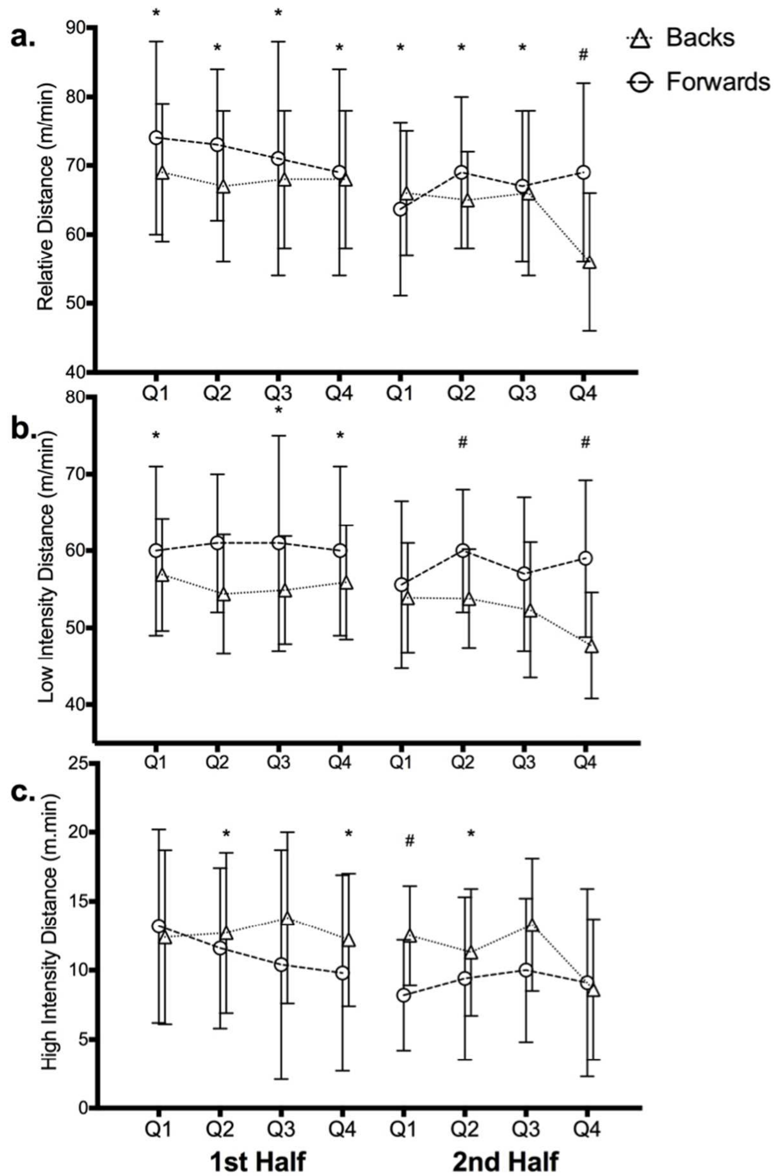

Figure 1 – Relative total (a.), low-intensity (b.) and high intensity (c.) distance covered by backs and forwards in each quartile of 2 halves of rugby union matches. # indicates significant difference between positions for a match period and * indicates significant difference for backs from 2nd half Q4
141x216mm (150 x 150 DPI)