Profiling Professional Rugby Union Activity After Peak Match Periods

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Abstract

The aim of this investigation was to quantify professional rugby union player activity profiles after the most intense (peak) passages of matches. Movement data were collected from 30 elite and 30 sub-elite professional rugby union athletes across respective competitive seasons. Accelerometer-derived PlayerLoad™ and Global Navigation Satellite System-derived measures of mean speed and metabolic power were analysed using a rolling average method to identify the most intense 5-600 second passages (i.e. worst case scenarios) within matches. Player activity profiles immediately post their peak 5-600 second match intensity were identified using five epoch duration-matched intervals. Mean speed, metabolic power and PlayerLoad™ declined sharply (~ 29 to 86%) post the most intense 5-600 seconds of matches. Post the most intense periods of rugby matches, exercise intensity declined below the average match-half intensity 81% of the time and seldom returned to or exceeded it, likely due to a host of individual physical and physiological characteristics, transient and/or accumulative fatigue, contextual factors and pacing strategies. Typically, player exercise intensities after the most intense passages of matches were similar between match-halves, positional groups and levels of rugby competition. Accurate identification of the peak exercise intensities of matches and movement thereafter using novel methodologies has improved the limited understanding of professional rugby union player activity profiles post the worst case scenarios of matches. Findings of the present study may inform match representative training prescription, monitoring and tactical match decisions (e.g. substitutions and positional changes).

Keywords

Global Positioning Systems, accelerometers, football, rugby, activity profile, performance analysis

Introduction

Collison-based team sports such as rugby union are characterised by low-intensity activity interspersed with frequent bouts of high-intensity activity.[1] If rugby union training is prescribed relative to the average activity profile of a match, players will likely be underprepared for the most intense periods of match-play.[2] Despite the majority of team sport competition being spent at submaximal intensity, high-intensity activities are often aligned with key events that determine match outcome.[3,4] For example, in rugby league 56.1% of 2083 repeated high-intensity efforts (1169) occurred within 5 minutes of either scoring or defending a try during 21 semi-professional matches across 11 teams.[4] Similarly, 83% of 360 goals scored in professional soccer were preceded by at least one powerful physical action of the scoring or the assisting player, with straight line sprinting the most frequent action prior to goal scoring.[3] These results signify the importance of physically conditioning team sport athletes for high-intensity passages within matches.

Activity profile analyses have evolved substantially over the past 30 years, due largely to technological and methodological advances. Analyses have evolved from reporting whole match movement values[5], to segmenting movement completed into discrete match periods (e.g. halves, quarters, rotations),[6,7] to movement relative to time on field,[8,9] to movement within pre-defined periods of matches[10] and more recently, to movement within rolling average time periods.[2,11,12] The segmentation of player movements into discrete periods allows practitioners to detect fluctuations in player movement (i.e. peaks and troughs), that is not possible with whole match values. A better understanding of within-match fluctuations in player movement may enable practitioners to prescribe training that is more representative of the rigors of competition.

Several wearable tracking technologies and analysis techniques have been used to identify peak periods of athletic movement and quantify reductions in activity thereafter. Numerous studies have reported a decline in player distance covered and high-intensity activity ($\geq$ 18 km.h^{-1}) within and between match-halves during team sports, possibly due to fatigue,[10,13] pacing strategies,[14] or a host of contextual factors.[15] For instance, professional rugby union athletes performed the highest relative distance (m.min^{-1}) in the first 10 minutes of each match-half, declining thereafter.[10] Similarly, distance travelled during the first 5 minutes of each rugby league match-half was significantly higher than the 5 minute periods later in the halves ($p < 0.001$).[16] Large reductions in total distance covered comparing the peak 5-minute period to the period immediately subsequent were also observed ($p < 0.001$).[16] However, the most intense periods of player movement during a match do not fall completely within pre-defined periods of time, and therefore likely underestimate peak periods and overestimate subsequent periods of activity.[11,12,17]

During international rugby competition, both high-speed running ($\geq$ 5.0m·s^{-1} or $\geq$ 18 km.h^{-1}) and relative distance (m.min^{-1}) were consistently underestimated by pre-defined compared to rolling period analyses of 60-300 seconds.[11] Pre-defined epoch analyses on average underestimated relative distances covered by ~11% and high-speed running by up to ~ 20% compared to rolling epoch analyses, with the greatest underestimations occurring using the 60 second epoch.[11] Therefore, researchers and practitioners should use rolling or moving average time period analyses when trying to accurately identify and quantify the worst case scenarios of rugby matches and movement thereafter.[11,12]

No study to date has used a large range of rolling epoch durations (i.e. 5 seconds to 10 minutes) to examine athlete activity profiles post the peak periods of matches, using Global Navigation Satellite System (GNSS) and accelerometry. Player movement after the most intense passages of matches is likely dependent on the duration of the peak period analysed, competition level and playing position, yet research examining these factors is scarce. Activity profile data the worst case scenarios of matches may inform match-specific high-intensity interval training (HIIT) prescription, programming for both high-intensity periods and for "active recovery" periods between efforts using game-based methodologies such as small-sided games. Further, accurate identification of the peak intensity of matches using rolling epoch analysis and quantifying subsequent intensity declines thereafter may be useful to inform match-day substitution or rotation decisions and player positional changes.

The aim of this study was to quantify rugby union athlete activity profiles post the most intense periods of matches, across two professional competition levels (elite and sub-elite), two broad positional groups (forwards and backs), two match-halves (first and second) and across eight durations (5 to 600 seconds).

Methods

A descriptive observational time motion analysis was performed using wearable GNSS with integrated accelerometer technology during professional rugby union competitions. Many methods pertaining to the participants, equipment and data collection, measures of peak movement and data filtering and processing have been established, published and described in detail.[18,19] Consequently, the methodology is described in brief, with more detail provided on the novel statistical analyses used to investigate rugby player activity profiles post the peak periods of professional matches.

Methodology

Movement data were collected from 30 elite and 30 sub-elite professional rugby union athletes across respective seasons. All players gave informed consent to participate, and the study was approved by the Victoria University Human Research Ethics Committee in the spirit of the Helsinki Declaration. The 30 elite players (18 forwards and 12 backs) played in the 2015 Super 15 Rugby competition, an international rugby union competition played between 5 Australian, 5 New Zealand and 5 South African teams. The Super 15 competitive season comprised of 18 rounds with 2 bye rounds per team, making 16 total matches (8 home, 8 away). The Super 15 team finished 10th on the ladder of 15 teams and finished the season with 7 wins and 9 losses. The 30 sub-elite players (16 forwards and 14 backs) played in the 2014 National Rugby Championship, an Australian competition played between 9 teams from 5 states and territories, with the season comprising of 8 matches (4 home, 4 away) prior to a finals series for the top 4 finishing teams. This team finished 1st on the ladder of 9 teams and finished the regular season with 8 wins and 0 losses. The National Rugby Championship is the highest standard of rugby union played in Australia below Super 15 and international representative rugby.

Player movement data were collected via commercially available OptimEye™ S5 GPS and GLONASS-enabled receivers with an embedded tri-axial piezoelectric accelerometer (firmware version 7.22, Catapult Sports, Melbourne, Australia).[20] Accelerometer-derived PlayerLoad™ and GNSS-derived measures of mean speed ($m.min^{-1}$) and metabolic power ($W.kg^{-1}$) were analysed using a rolling average method[17,21] to identify the maximum mean (peak) values for 5, 10, 20, 30, 60, 120, 300 and 600 second durations. The three measures of maximum mean or peak movement investigated were: Playerload™ (au, accelerometer-derived), mean speed ($m.min^{-1}$, GPS-derived) and metabolic power ($W.kg^{-1}$, GPS-derived) as they provide estimates of global external load and are frequently reported in research and used in practice. Acceleration, total distance, high-speed running distance and estimated metabolic power were ranked as the most important variables in the eyes of elite football practitioners[22], lending further support for the chosen measures. Playerload™ has been reported to have a moderate to high test-retest reliability and exhibited convergent validity with measures of exercise intensity on an individual basis. However, authors cautioned making between athlete comparisons in loading when using recordings from between the scapulae (commonly done in team sports) to identify lower-limb movement patterns.[23]

Despite poor validity for measuring intermittent exercise, metabolic power has been suggested to be of use as a global indicator of external load, encompassing accelerated, decelerated and speed-based running.[24] Justifying this view, metabolic power displayed good accuracy when compared to a criterion method (radar) utilising both 5 Hz [coefficient of variation (CV) = 4.5%] and 10 Hz (CV = 2.4%) GPS devices.[25] Moreover, distances covered above high (> 20 $W.kg^{-1}$) and very high (> 35 $W.kg^{-1}$) metabolic power thresholds exhibited comparable or reduced variability when compared to high-speed running distances (CV = 4.5-12% vs. 4.7-23%).[25] During the peak intensity periods of rugby league matches, metabolic power was greater for hookers, half-backs and fullbacks compared to middle forwards and outside backs.[24] Further, the way in which players accumulated metabolic power (i.e. via acceleratory or speed-based movements) differed between playing positions, providing coaches with valuable information that may aid training monitoring and prescription. Although metabolic power should not be used in isolation as a measure of external load as the combination of acceleratory and speed-based running into one metric masks the underlying mechanism of the load.[26]

Player activity profiles immediately post their maximum mean (peak) 5 to 600 s were identified using five epoch duration-matched intervals. Using the 60 s (1-minute) epoch as an example, the peak 1-minute intensity during matches was identified for each measure (i.e. PlayerLoad™, mean speed and metabolic power) using a rolling average and then subsequent activity was measured across five duration-matched 1-minute epochs (i.e. 0 to 1, 1 to 2, 2 to 3, 3 to 4 and 4 to 5 minutes). Five duration-matched intervals were chosen to enable fair comparison between the intensity during the peak and subsequent periods, with five intervals chosen to reveal the time-course of intensity fluctuations post the most intense passages of play. The total number of match-half estimates analysed across five duration-matched intervals post the peak 5- to 600-s periods of elite and sub-elite rugby can be seen in Table 1.

Statistical Analyses

Each of the three measures of maximum mean movement were analysed with the general linear mixed modelling procedure (Proc Mixed) in SAS. The measures were log-transformed prior to analysis to reduce non-uniformity of error.[27] The fixed effects in the model were player position (backs, forwards) interacted with match-half (1st, 2nd), interacted with time on the field to adjust for this variable. The random effects in the model were player identity and match identity.

Peak 5- to 600-second values for the three movement measures alongside values for each of the five duration-matched subsequent intervals were calculated as means ± SD (Figures 1 to 6). The effect of peak intensity attained during any given duration on subsequent movement during the five duration-matched intervals post peak was assessed via percent decline from peak (Table 2). The match-half mean intensity for each measure is presented (dashed line, Figures 1 to 6) to provide an easy visual gauge of the influence of peak intensity periods on player activity profiles post.

The magnitudes of effects (differences or changes in means; standard deviations derived from random effects) were evaluated by standardisation, which was performed by dividing each effect by the between-player standard deviation in a typical match. This standard deviation was derived for ease of calculation from four separate analysis (for each position and half) by adding the variances for the random effects for player identity and the residual, converting the resulting variances to standard deviations and deriving the harmonic mean, which provided an appropriate mean standard deviation for all pairwise comparisons of positions and halves.[28] The smallest worthwhile difference or change in means is 0.2 standard deviations; thresholds for moderate, large and very large differences are 0.6, 1.2 and 2.0, respectively.[27] Thresholds for evaluating standard deviations (derived by taking square roots of random-effect variances) were half these values.[29] Uncertainty in effects was expressed as 90% compatibility intervals[30] and as probabilities that the true effect was substantially positive and negative. These probabilities were used to make a qualitative probabilistic non-clinical magnitude-based inference about the true (huge-sample) effect,[27] effectively Bayesian assessment with a non-informative prior.[31] If the probabilities of the effect being substantially positive and negative were both > 5%, the effect was reported as unclear. The scale for interpreting the probabilities was as follows: 25-75%, possible; 75-95%, likely; 95-99.5%, very likely; > 99.5%, most likely. Decisively substantial differences were considered as those that met the following criteria: standardised effect (ES) ≥ 0.2 and ≥ 95% very likely (i.e. the compatibility interval falls entirely in substantial values).[27,31]

Results

Activity profile declines post peak periods of matches

Movement intensity measured by mean speed, metabolic power and PlayerLoad™ declined sharply (~ 29 to 86%) post the most intense 5 to 600 seconds of matches (Table 2 and Figures 1-6). Shorter duration, higher-intensity peak periods caused larger declines in intensity during subsequent periods (Table 2 and Figures 1-6). For example, intensity declined by ~ 78 to 86% post the peak 5 to 30 seconds of elite and sub-elite rugby competitions. In contrast, intensity declined by ~ 30% post the peak 600 seconds across both levels of rugby (Table 2). Using Figure 1, panel A as an example, the 5 second peak mean speed for backs in the first half was 423 $m.min^{-1}$ (7.1 $m.s^{-1}$ or 25 $km.h^{-1}$), with intensity declining 79% to an average of 88 $m.min^{-1}$ (1.5 $m.s^{-1}$ or 5.3 $km.h^{-1}$) in the following 25 seconds (five duration-matched intervals post). On the other end of the duration spectrum, the 600 second peak mean speed for backs in the first half was 82 $m.min^{-1}$ with intensity declining 29% to 58 $m.min^{-1}$ during the five intervals post.

In general, there was a greater intensity decline post the peak periods of elite matches as measured by PlayerLoad™ (69%) and metabolic power (69%) when compared to mean speed (66%) when averaged across 5 to 600 second epochs, both positions and match-halves (mean difference ~ 3%, Table 2). Similarly, in sub-elite rugby greater intensity declines (~ 5%) were measured by PlayerLoad™ (66%) and metabolic power (66%) when compared to mean speed (61%). The largest intensity decline disparity between the three measures was post the peak 20 s of sub-elite matches (mean speed declined 63% vs. metabolic power and PlayerLoad™ declining 84 and 85% respectively, Table 2). Post the most intense periods of rugby matches, exercise intensity as measured by mean speed, metabolic power and PlayerLoad™ declined below the average match-half intensity (dashed lines, Figures 1 to 6) 81% of the time (742 of 911 interval 1 to 5 occasions).

Match-half activity profile differences post peak periods of matches

Of the elite match-half activity comparisons during intervals 1 to 5 post the peak periods of matches, only 9 (1.6%) were very likely substantial (i.e. ES $\geq$ 0.2 and $\geq$ 95% likely).[32] All very likely substantial match-half effects were of small to moderate magnitude (ES range: 0.5 to 1.1, 95-99.9% likely). All substantial match-half differences illustrated reduced player exercise intensity after the most intense passages of play in the second match-half compared to the first.

Of the sub-elite match-half activity comparisons during intervals 1 to 5 post peak intensities, 33 or 15% were very likely substantial. Each measure of mean speed, metabolic power and PlayerLoad™ contributed 15, 10 and 8 very likely substantial differences respectively, with no evident epoch duration trends. Whilst the majority (65%) of match-half differences were either trivial or unclear, 77/79 interval 1 to 5 comparisons revealed a likely ($\geq$75% likely) intensity declines during the second compared to first match-halves. Of the very likely substantial sub-elite match-half differences, 24/33 or 73% revealed forwards had decreased second match-half intensity post the peak 5 to 600 seconds of matches when compared to backs (ES range: 0.5 to 1.9, 95-100% likely).

Positional activity profile differences post peak periods of matches

The intensity decline post the peak 5 to 600 seconds of rugby were mostly similar between positional groups across both levels of competition. Of the 229 elite and 226 sub-elite interval 1 to 5 post peak comparisons, only 17 or 7.4% and 14 or 6.2% respectively displayed substantial (i.e. ES $\geq$ 0.2 and $\geq$ 95% likely) differences between positions. Where very likely substantial differences were evident between forwards and backs (elite: 17/229, sub-elite: 14/226), the majority (elite: 9, sub-elite: 9) were detected by PlayerLoad™. Where substantial active recovery profile differences existed between positions, mean speed and metabolic power were greater for backs than forwards for 8/8 elite and 5/5 sub-elite intervals (ES: 0.5 to 1.6, $\geq$ 95% likely). In contrast, PlayerLoad™ was greater for forwards vs. backs for 9/9 elite and 9/9 sub-elite intervals (ES: 0.5 to 1.8, $\geq$ 95% likely).

Discussion

The aim of this investigation was to quantify the activity profile of professional rugby union athletes post the most intense periods (i.e. worst case scenario) of matches. This study was the first to sequentially track movement intensity declines post the most intense periods of team sport matches using GNSS and accelerometry. Mean speed, metabolic power and PlayerLoad™ declined sharply (~ 29 to 86%) post the most intense 5 to 600 seconds of professional rugby matches, with the magnitude of decline principally dependent on the peak intensity attained during any given period. Typically, the intensity decline post the peak 5 to 600 seconds of professional rugby matches were similar between match-halves, positional groups and levels of competition. However, where substantial (i.e. ES ≥ 0.2 and ≥ 95% likely) differences arose, exercise intensity post peak periods of matches declined to a greater extent in second match-halves, backs produced greater mean speed and metabolic power, whereas forwards produced more PlayerLoad™.

Elite and sub-elite rugby players reduced their intensity by up to 86% post peak periods, with intensity below the average ~ 40 minute match-half mean speed, metabolic power and PlayerLoad™ 81% of the time (Figures 1 to 6). Similarly, during elite rugby sevens competition, running intensity was reduced to a very large extent (46-64%) following the most intense 2-minute period of the match (relative distance ES: 2.9, metabolic power ES: 4.1, both $p < 0.001$) identified using rolling average epoch analyses.[17] Moreover, during professional rugby league matches, the most physically intense 5 minutes were significantly greater than both the subsequent (ES range: 1.7-3.5) and mean (ES range: 2.0-4.3) 5-minute periods for total distance, high-speed distance, high-power distance and metabolic power (p <0.001).[33] Temporal intensity reductions have been used as evidence of match-related fatigue during football matches.[13,16] Whilst multiple central and peripheral physiological mechanisms (e.g. reduced motor drive, glycogen depletion and accumulation of metabolites) can cause reductions in movement intensity by impeding excitation-contraction coupling,[34] a myriad of contextual factors underpin the exercise intensity of team sport athletes at any given point in time. Too often time-motion analysis research uses a reductionist approach, examining team sport movement in isolation, thereby failing to acknowledge that the nature of team sport movement is very complex, chaotic and relates to a host of contextual factors. To attribute declines in exercise intensity post the peak periods of matches solely to fatigue or pacing strategies would be erroneous. Hence, player exercise intensity during team sport matches may be attributed to a culmination of physical/physiological characteristics, contextual factors, fatigue and pacing.

Contextual factors have been broadly classified into: situational factors, match-related factors and individual player characteristics.[15] Situational factors relate to things such as opposition strength[35] and between match recovery time.[36] Match-related factors include but are not limited to: collision demands (frequency & intensity),[37] possession status,[38] match scoreline,[39] playing formation,[40] field position and phase of play[41] and team success.[42] An individual's exercise intensity during match-play is also underpinned by their physical characteristics (e.g. maximum speed, reactive strength index, lean mass index etc.)[43]

Declines in physical output have been ascribed to player's adopting pacing strategies in an attempt to distribute their energy resources (e.g. plasma free fatty acids, plasma and muscle triglycerides, plasma glucose, muscle glycogen and phosphocreatine stores etc.) throughout a match.[14] Whilst numerous investigations have examined pacing during team sport competition, it is very difficult to establish its existence as fluctuations in exercise intensity may also be due to match-related transient and/or accumulative fatigue and other contextual factors.[6,33] The sharp intensity declines following the peak periods of professional rugby matches in the present study may be partially due to player's pacing their efforts (regulating their energy expenditure) to minimize physiological disturbances (e.g. heat stress, inorganic phosphate, proton, lactate and magnesium accumulation and inhibition of calcium release etc.)[34] as they attempt to recover from intense exercise bouts,[44] and/or could be due to a host of contextual factors. For example, high-intensity activities are often aligned with key events (e.g. goal/try scoring) that determine match outcome.[3,4] Given scoring has been associated with higher-intensity movement, and post scoring there are time delays in play for conversion kicks, officiating decisions and to time to reset the field of play, these contextual factors will naturally reduce movement intensity of all players to a large extent. To best ascertain the cause of reduced player movement, future research should overlay visual match-analysis with player tracking solutions to synchronise peak and post peak player movement with several contextual factors (e.g. ball in/out of play/possession). Synchronisation of physical, technical and tactical data during the most intense periods of matches and periods thereafter will further enhance our understanding of player fatigue and pacing strategies.

Accurate identification of the peak intensity of matches using rolling epoch analysis and quantifying subsequent intensity declines may be useful to inform match-day substitution or rotation decisions and player positional changes. For instance, live player movement data may be collected via GNSS receivers and relayed to a receiver antenna connected to a computer, with proprietary software allowing for real-time player movement tracking. If historical data have been collected on the previous peak intensities of matches for a cohort of interest, it would be possible in real-time to identify similarly intense periods (via pre-defined alerts set within the software) and quantify inevitable declines in exercise intensity thereafter. Such data may be relayed from the person watching and interpreting the live data stream (e.g. sport scientist) to a coach, ideally providing them with context around the values such as the current match average exercise intensity and/or normative historical values for the team, position or player of interest. Preferably, such activity profile data would be used in conjunction with performance analyst technical key performance indicators to help inform the coach's expert opinions on tactical decisions, such as player substitutions, rotations or positional changes.

Intensity declines after the most intense periods of elite and sub-elite rugby matches are similar between positional groups (backs and forwards). In contrast, professional AFL midfielders consistently displayed greater total distance, low speed activity, moderate speed running and high speed running distance than key position players during and post the peak 3-minutes of matches.[45] Unfortunately, there is a dearth of literature investigating positional movement differences after the most intense periods of football competition, with studies tending to group playing positions.[17,33,44] Given rugby forwards are typically heavier, taller and have a greater percentage of body fat, backs have greater relative aerobic and anaerobic power, forwards spend greater time engaged in physical contact with opposition, and forwards complete greater total work with lower work: rest ratios than backs,[1] one might expect movement differences between positions post the peak intensity period of competition. It is likely that several situational and match-related contextual factors are contributing to the lack of positional activity profile differences post the peak periods of matches, with individual player fatigue not the only culprit. For example, given higher intensity activities are often aligned with goal/try scoring,[3,4] and post scoring reviews often occur before one player takes a conversion kick, both positions movement are likely equally reduced during these "rest" periods.

Accelerometer-derived PlayerLoad™ detected the majority of substantial positional differences post peak periods, indicating improved sensitivity compared to GNSS-derived measures in doing so. In congruence, accelerometers outperformed GNSS in quantifying positional and match-half differences in player peak intensities during professional rugby union competition.[46] In the present study, where substantial positional movement intensity differences occurred post peak periods, PlayerLoad™ was greater for forwards vs. backs (ES: 0.3-1.5), whilst GNSS-derived mean speed and metabolic power was greater for backs vs. forwards (ES: 0.3-1.7). Findings suggest that GNSS-derived measures of mean speed and metabolic power were sensitive to detecting fluctuations in player movement for backs, whilst PlayerLoad™ was more sensitive to detecting movement fluctuations of forwards and detecting positional pack differences. These finding make intuitive sense given forwards are typically involved in a greater frequency of collisions, tackles, rucks, lineouts etc., which contribute to vertical acceleration not measured by GNSS technology. Given accelerometer-derived PlayerLoad™ displayed improved sensitivity in quantifying positional differences both during[18,46] and post peak periods of rugby matches in the present study, we recommend the use of accelerometers alongside GNSS technology to holistically quantify rugby union activity profiles. However, practitioners and researchers should be aware of current technological limitations in quantifying player movement. For example, many scrummaging movements that rugby union forwards frequently complete (e.g. scrums, rucks, mauls) often entail prolonged static exertions which may not be detected by accelerometers[1] and should be quantified more completely using a raft of technologies in future research.

Metabolic power and PlayerLoad™ consistently measured larger intensity declines post peak periods of matches when compared to mean speed. Consistent with our findings, relative distance (i.e. mean speed) underestimated the intensity of peak periods of rugby sevens matches when compared to metabolic power.[44] Theoretically these findings make intuitive sense, as the metabolic power model[47] considers both speed and acceleration, whereas relative distance/mean speed only quantifies the velocity of movement. Further, movements that incur little horizontal displacement (e.g. collisions, tackles and many sport-specific movements) are likely underestimated by GNSS.[48] Accelerometers that quantify tri-axial accelerations at much higher sampling frequencies than GNSS evidently quantify a greater proportion of player rapid acceleratory movements that incur little horizontal displacement. By being able to quantify more of what rugby players physically do (external load), accelerometer-derived PlayerLoad™ and GNSS-derived metabolic power displayed improved sensitivity in quantifying exercise intensity fluctuations compared to a speed-based metric. Present findings are in support of others[24,44] in recommending the use of acceleration-based indices alongside speed-based metrics to measure the external load of rugby players.

Practical Applications

- Activity profile data post peak periods of matches may inform match-specific high-intensity interval training (HIIT) prescription, programming for both high-intensity periods and for “active recovery” periods between efforts using game-based methodologies such as small-sided games.

- The right tool needs to be used for the job. Accelerometers were better able to detect positional movement differences between forwards and backs post peak periods. GNSS-derived measures of mean speed and metabolic power were more sensitive to detecting fluctuations in player movement for backs, whilst PlayerLoad^{TM} was more sensitive to detecting movement fluctuations of forwards.
- Both speed- and acceleration-based measures should be used to quantify the external load of rugby players.
- Real-time declines in player movement post intense periods of matches may inform coach tactical decisions such as player positional changes, player substitutions or rotations.

Conclusions

This study is the first to sequentially track the time-course of the intensity decline post the most intense periods of rugby union matches using GNSS and accelerometry. Mean speed, metabolic power and PlayerLoad^{TM} declined sharply (~ 29-86%) post the most intense 5-600 seconds of professional rugby competition, with the magnitude of decline principally dependent on the peak intensity attained during any given period. Post the most intense periods of rugby competition, exercise intensity declined below the average match-half intensity 81% of the time and seldom returned to or exceeded it, likely due to a host of individual physical and physiological characteristics, transient and/or accumulative fatigue, contextual factors and pacing strategies. Typically, exercise intensity declines post the peak intensities of matches were similar between match-halves, positional groups and levels of rugby union competition.

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The authors report no conflict of interest.

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Table 1: Total number of match-half estimates analysed across five duration-matched intervals (Int 1-5) post the peak periods of elite (Super 15) and sub-elite (NRC) rugby.

Elite mean speed estimates

Epoch Duration (s)	Int 1	Int 2	Int 3	Int 4	Int 5
5	416	415	415	413	394
10	416	417	407	393	382
20	418	404	403	396	398
30	411	404	397	388	390
60	403	386	371	367	368
120	377	357	345	327	303
300	358	271	244	208	166
600	274	200	94	1	0

Sub-elite mean speed estimates

Epoch Duration (s)	Int 1	Int 2	Int 3	Int 4	Int 5
5	268	266	264	264	265
10	263	260	262	262	260
20	262	265	261	258	258
30	264	260	259	257	252
60	255	246	248	240	230
120	254	240	225	205	182
300	221	172	131	97	70
600	130	58	29	0	0

Elite PlayerLoad™ estimates

Epoch Duration (s)	Int 1	Int 2	Int 3	Int 4	Int 5
5	420	419	420	416	414
10	418	415	409	406	407
20	415	407	406	401	400
30	410	405	406	405	400
60	404	389	381	379	366
120	378	350	335	320	302
300	346	276	247	215	175
600	285	203	99	4	0

Sub-elite PlayerLoad™ estimates

Epoch Duration (s)	Int 1	Int 2	Int 3	Int 4	Int 5
5	269	264	264	265	265
10	261	258	260	257	257
20	258	254	254	253	250
30	261	256	253	248	246
60	256	242	235	224	219
120	250	236	224	208	182
300	212	178	140	108	78
600	143	76	42	0	0

Elite metabolic power estimates

Epoch Duration (s)	Int 1	Int 2	Int 3	Int 4	Int 5
5	405	413	409	405	400
10	416	412	409	398	376
20	409	395	396	388	382
30	399	395	388	384	376
60	402	376	366	349	346
120	372	335	322	318	285
300	319	235	205	175	150
600	218	130	74	2	0

Sub-elite metabolic power estimates

Epoch Duration (s)	Int 1	Int 2	Int 3	Int 4	Int 5
5	262	265	266	263	261
10	264	261	263	263	261
20	260	261	255	251	250
30	266	259	254	251	248
60	258	241	240	228	219
120	245	227	215	192	170
300	206	151	115	92	66
600	106	46	25	0	0

Table 1: Mean speed, metabolic power and PlayerLoad™ percent (%) decline from peak intensity period (5-600s) for elite and sub-elite rugby competition, by playing position. Each measure of exercise intensity (mean speed, metabolic power, PlayerLoad™) was averaged across peak period (5- to 600-s) duration-matched intervals 1-5 post and across both match-halves (first and second halves).

	Epoch duration (s)							
	5	**10**	**20**	**30**	**60**	**120**	**300**	**600**
Mean speed								
Elite backs	79	82	82	81	71	59	42	29
Elite forwards	78	81	82	80	70	58	42	30
Sub-elite backs	80	82	63	76	66	53	39	24
Sub-elite forwards	77	82	78	75	65	53	37	26
Metabolic power								
Elite backs	85	88	86	84	76	62	43	28
Elite forwards	84	84	84	82	73	62	42	32
Sub-elite backs	86	88	85	82	73	59	41	34
Sub-elite forwards	84	84	80	74	64	52	36	25
PlayerLoad™								
Elite backs	86	86	86	85	78	65	47	31
Elite forwards	86	85	85	80	71	61	41	29
Sub-elite backs	88	88	84	81	69	57	41	42
Sub-elite forwards	83	83	76	74	64	53	38	25
Mean of all measures and positions								
Elite rugby	83	84	84	82	74	61	46	31
Sub-elite rugby	83	85	79	78	68	55	39	29
Elite minus sub-elite	0	-1	5	4	6	6	7	2

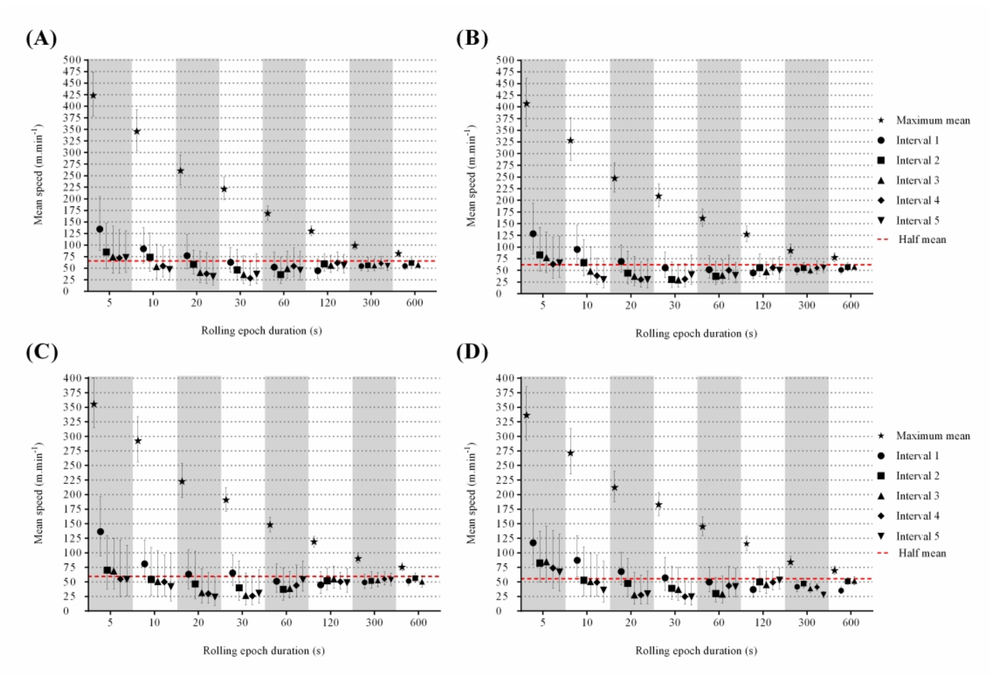

Figure 1: Super 15 Rugby duration specific (5-600 s) maximum mean speed (m.min-1) and mean speed post (duration-matched intervals 1-5). Panels by playing position and match-half. (A); backs 1st match-half, (B); backs 2nd match-half, (C); forwards 1st match-half, (D); forwards 2nd match-half. Data presented are means ± standard deviation.

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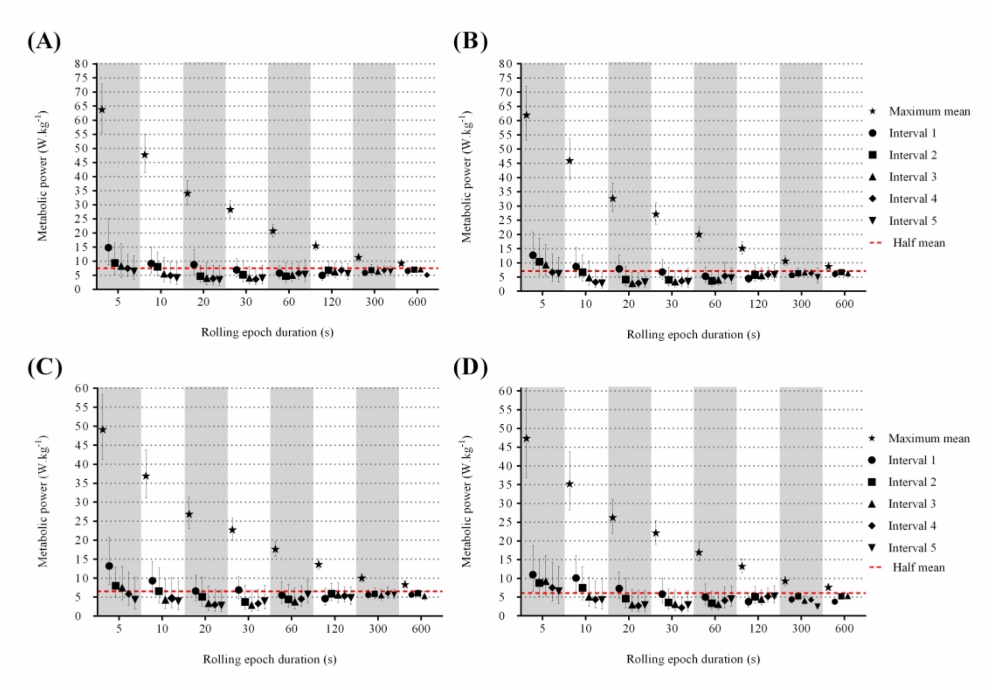

Figure 2: Super 15 Rugby duration specific (5-600 s) maximum metabolic power (W.kg-1) and metabolic power post (duration-matched intervals 1-5). Panels by playing position and match-half. (A); backs 1st match-half, (B); backs 2nd match-half, (C); forwards 1st match-half, (D); forwards 2nd match-half. Data presented are means ± standard deviation

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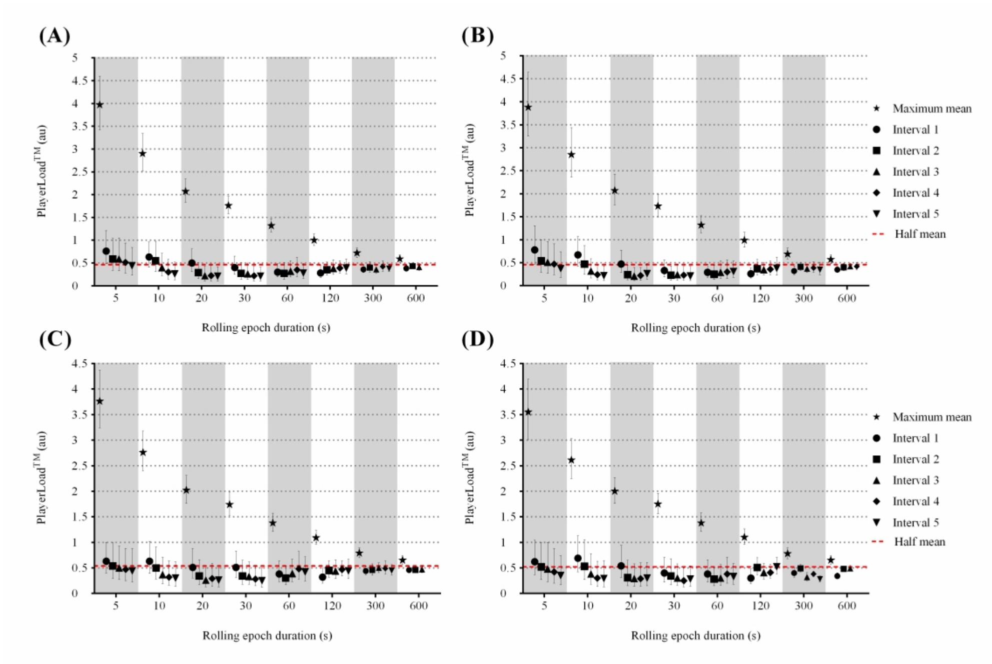

Figure 3: Super 15 Rugby duration specific (5-600 s) maximum mean PlayerLoadTM (au) and PlayerLoadTM post (duration-matched intervals 1-5). Panels by playing position and match-half. (A); backs 1st match-half, (B); backs 2nd match-half, (C); forwards 1st match-half, (D); forwards 2nd match-half. Data presented are means ± standard deviation

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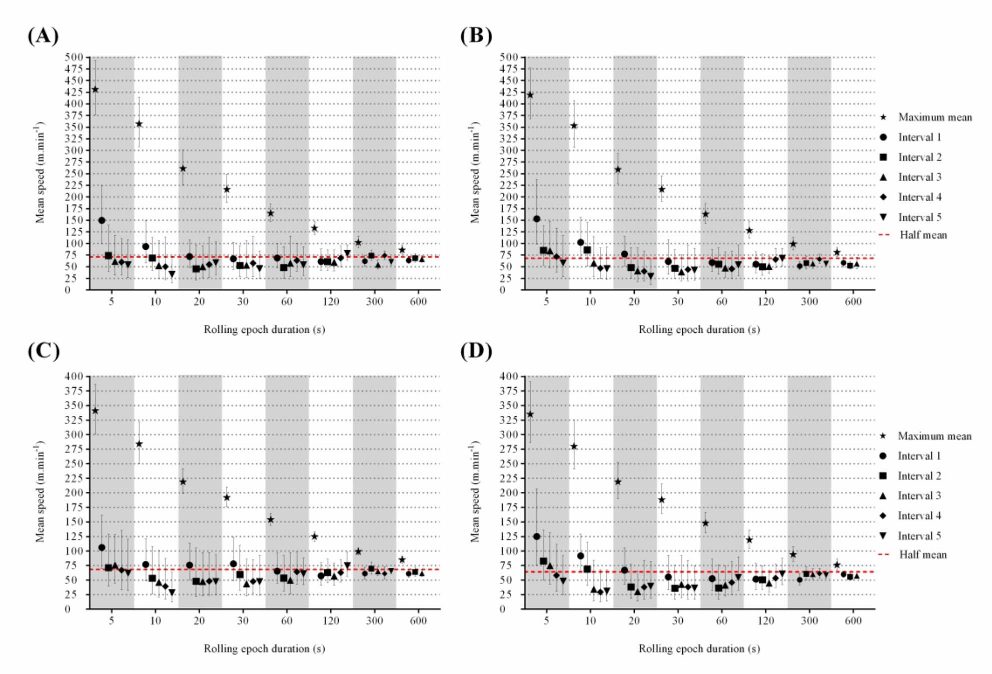

Figure 4: National Rugby Championship duration specific (5-600 s) maximum mean speed (m.min-1) and mean speed post (duration matched intervals of 1-5). Panels by playing position and match-half. (A); backs 1st match-half, (B); backs 2nd match-half, (C); forwards 1st match-half, (D); forwards 2nd match-half. Data presented are means ± standard deviation

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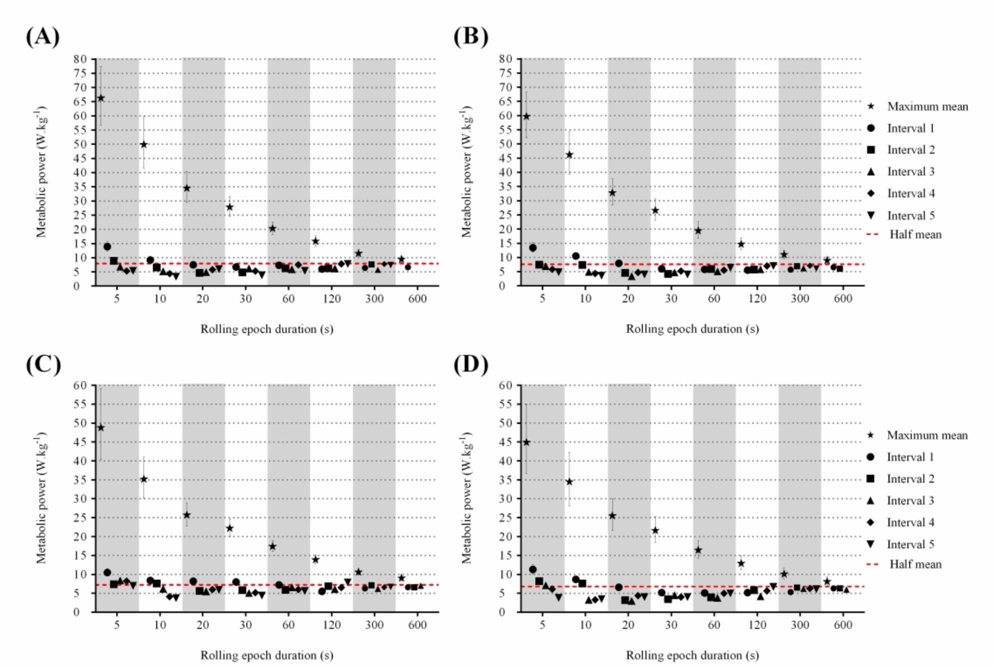

Figure 5: National Rugby Championship duration specific (5-600 s) maximum metabolic power (W.kg-1) and metabolic power post (duration-matched intervals 1-5). Panels by playing position and match-half. (A); backs 1st match-half, (B); backs 2nd match-half, (C); forwards 1st match-half, (D); forwards 2nd match-half. Data presented are means ± standard deviation.

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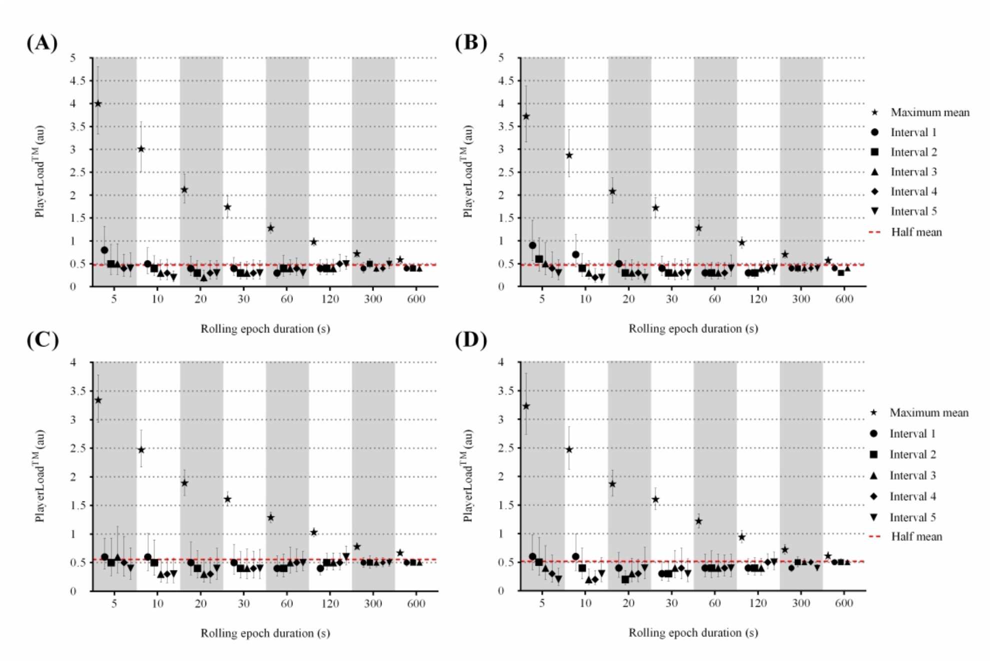

Figure 6: National Rugby Championship duration specific (5-600 s) PlayerLoadTM (au) and PlayerLoadTM post (duration-matched intervals 1-5). Panels by playing position and match-half. (A); backs 1st match-half, (B); backs 2nd match-half, (C); forwards 1st match-half, (D); forwards 2nd match-half. Data presented are means ± standard deviation.

165x110mm (600 x 600 DPI)