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Article Title: Acceleration-Based Running Intensities of Professional Rugby League Match-Play

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ABSTRACT

Rugby league involves frequent periods of high-intensity running including acceleration and deceleration efforts, often occurring at low speeds. **Purpose:** To quantify the energetic cost of running and acceleration efforts during rugby league competition to aid in prescription and monitoring of training. **Methods:** Global Positioning System (GPS) data were collected from 37 professional rugby league players across two seasons. Peak values for relative distance, average acceleration/deceleration and metabolic power (P_{met}) were calculated for ten different moving average durations (1-10 min), for each position. A mixed-effects model was used to assess the effect of position for each duration, and individual comparisons were made using a magnitude-based inference network. **Results:** There were *almost certainly* large differences in relative distance and P_{met} between the 10-min window and all moving averages <5 min in duration (ES = 1.21-1.88). Fullbacks, halves and hookers covered greater relative distances than outside backs, edge forwards and middle forwards for moving averages lasting between 2-10 min. Acceleration/deceleration demands were greatest in hookers and halves compared to fullbacks, middle forwards and outside backs. P_{met} was greatest in hookers, halves and fullbacks compared to middle forwards and outside backs. **Conclusions:** Competition running intensities varied by both position and moving average duration. Hookers exhibited the greatest P_{met} of all positions, due to high involvement in both attack and defence. Fullbacks also reached high P_{met}, possibly due to a greater absolute volume of running. This study provides coaches with match data that can be used for the prescription and monitoring of specific training drills.

Keywords: Match analysis, metabolic power, GPS, acceleration, football.

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INTRODUCTION

The importance of Global Positioning Systems (GPS) for quantifying rugby league competition has been thoroughly documented[1,2]. Recently, the most intense periods of match-play have been described, using a moving average method[3]. Briefly, this method applied a moving average to match position-time data to determine the peak relative distance achieved during competition amongst professional rugby league players, for a range of moving average durations. It was observed that as the length of the moving average was reduced, the maximal relative running intensity increased significantly. Such data demonstrated running intensities as high as 156 ± 12 $m \cdot min^{-1}$ for a 1-min window. These values present substantially greater physical demands than previously reported by the relative distances for rugby league match-play, which typically range between 80-100 $m \cdot min^{-1}$ [4]. Whilst such data regarding the running intensities of rugby league are useful, it could be suggested that they are limited in their ability to account for the varying match demands of different positions. Gabbett et al.[5] reported that collisions (i.e. hit-ups and tackles) are more frequent in hit-up forwards than any other position. Subsequently, the ability of forwards to cover large relative distances may become impaired, due to the constant presence of opposition players[6]. These positions are regularly required to accelerate, decelerate and change direction, for which the physical demands are typically not accounted for by traditional velocity-based methods[7].

Previously, di Prampero et al.[7] presented a theoretical model that quantified the energetic cost of accelerations and decelerations. This model considers the energetic cost of accelerated running on flat terrain to be equivalent to the known physiological cost of uphill running at a constant pace[8]. Using the acceleration of a player at any time point, an instantaneous energy cost can be estimated. This cost can be summated to provide an estimation of overall energy expenditure throughout the activity, or multiplied by velocity, as an indication of metabolic power (P_{met}; $W \cdot kg^{-1}$)[8]. Recently, this model has been applied to team sports such

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as soccer[9], Australian football (AFL)[10], rugby sevens[11] and rugby league[12]. For example, amongst professional soccer players, Osgnach et al.[9] estimated the distance players would have covered at a constant pace, using the total energy expenditure throughout the match (equivalent distance, ED). It was found that players ED exceeded actual distance by around 20%. Using a similar analysis amongst AFL players, Coutts et al.[10] reported a difference of just 10-11%, indicating a greater percentage of constant running amongst these athletes. However, when considering rugby league players, Kempton et al.[12] reported higher differences of 27-29%, suggesting a greater proportion of accelerated running contributed to energy expenditure compared to soccer and AFL players.

As previously stated, the running demands of certain positions in rugby league are limited due to the presence of opposition players and as a result may increase the reliance on acceleration abilities. Fullbacks have been shown to exhibit a greater running intensity than any other position, due to the open-style running requirements of this position[3]. In contrast, Kempton et al.[12] compared distance covered over a high-power (HP) threshold of 20 $W \cdot kg^{-1}$ with distance covered over a traditional high-speed (HS) threshold of 14.4 $km \cdot hr^{-1}$. The difference between these two values was strongly influenced by position, with hit-up forwards covering 76% more distance at HP compared to HS, whilst the difference for outside backs (wingers and centres) was just 37%. These data outline a significant oversight by previous match-play analysis techniques, where high-intensity activities performed at low velocities were unaccounted for. However, the HP and HS data reported by these authors are representative of absolute match values, and have limited application in the prescription and monitoring of training. Therefore, the aim of this study was to describe the acceleration-based duration-specific running demands of rugby league match-play, for the development of precise training methodologies. The overloading of these demands through an appropriately periodized program may result in increases in relevant physical capacities, and in turn, match performance.

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METHODS

Design

GPS data were collected during the 2013 and 2014 National Rugby League (NRL) competitive seasons, to establish the duration- and position-specific acceleration-based running demands of rugby league. Prior to the commencement of the study, all subjects were informed of the aims and requirements of the research, and informed consent was obtained. The Institutional Human Ethics Committee approved all experimental procedures.

Subjects

Thirty-seven professional rugby league players (age; 27.0 ± 5.1 yr, mass; 98.5 ± 8.8 kg and stature; 1.84 ± 0.05 m) from the same club volunteered for this study. Data was collected throughout during 43 matches of the 2013 (12 wins, 10 losses, 1 draw, final position 7th) and 2014 NRL seasons (9 wins, 11 losses, final position 12th). It must be noted that some minor rule changes were introduced at the beginning of the 2014 season, aimed to increase the amount of time the ball was active in play (e.g. total game-time once stoppages are removed). However, data obtained from a commercial statistics provided (Prozone, Sydney, Australia) revealed that ball-in-play time, for matches involving the team in question, between season was similar between the 2013 and 2014 season (mean ± SD; 52.7 ± 5.0 min and 53.0 ± 3.9 min, respectively), and therefore this was deemed to have little effect.

A typical training week consisted of 2-3 field sessions, 1-2 resistance sessions and 1-2 recovery-based sessions. Each match was 80 min in duration that was separated into two 40-min halves. Players were classified by playing position as follows (n = number of observations): fullbacks (n = 39), outside backs (n = 153), halves (half-back and five-eighth; n = 81), middle forwards (props and locks; n = 200), edge forwards (second rowers; n = 81) and hookers (n = 58). The mean (± SD) number of observations per player was 17 ± 13.

Methodology

The match running demands of players were recorded using a portable GPS unit at a sampling rate of 15 Hz (SPI HPU, GPSports, Canberra, Australia). These units were worn in a customized padded pouch in the player’s jersey and positioned in the centre of the upper back area, slightly superior to the scapulae. The number of satellites and HDOP during match play were 8.3 ± 1.4 and 1.1 ± 0.1, respectively. Whilst the validity and reliability of GPS for measures of total distance have been established[13,14], the inter-unit reliability of GPS for assessing accelerations during team sport movements has been questioned[15]. To account for this issue, each player wore the same unit for the entire study. Lastly, whilst the validity of the calculations of di Prampero et al.[7] for estimating the energetic requirements of team sports movements has varied between studies[16-18], mean P_{met} has recently been presented as a stable marker of locomotor load, where acceleration- and velocity based running are accounted for (coefficient of variation, CV% = 4.5%)[13]. As a result, this measure was selected as the most appropriate measure for quantifying the chaotic nature of rugby league match-play.

Upon completion of each match, GPS data were extracted using the appropriate proprietary software (Team AMS, Canberra, Australia). A total of 612 individual match files were obtained. Each file was trimmed to include only match time (excluding extra-time periods) and within-match stoppages (i.e. decision referred to video referee), and the average total match duration was 86 ± 13, 84 ± 12, 52 ± 14, 81 ± 15, 47 ± 15 and 87 ± 9 min for fullbacks, halves, hookers, edge forwards, middle forwards and outside backs, respectively. If a player’s match time was less than 10 min, the file was removed from analysis. Velocity-time curves were linearly interpolated to 15 Hz, and a fourth-order Butterworth filter applied with a 1-Hz cut-off frequency. Following this, each file was further analysed using customised MATLAB® software (Version 8.4.0.150421, MathWorks Inc, MA, USA). This method allowed the computation of a number of output variables for each player, including relative distance ($m \cdot min^{-1}$), absolute acceleration/deceleration ($m \cdot s^{-2}$) and metabolic power (P_{met}; $W \cdot kg^{-1}$)[9]. For this study, relative distance was representative of the traditional model, where accelerated running is ignored. For the acceleration/deceleration measure, all values (accelerations and decelerations) were made to be positive, and this variable provided an indication of the total acceleration requirements of the athlete, irrespective of velocity. Finally, P_{met} was calculated by integrating the instantaneous velocity and acceleration, using the energetic calculations detailed previously[7,9].

The customized MATLAB® software was then used for the computation of a moving average over each output variable, using ten different durations (1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 min), and the maximum value for each duration was recorded. For example, for a 1-min rolling average, the software identified the 900 consecutive data points (i.e. 15 samples per second for 60 seconds) where the subject exhibited the highest values. For a 2-min rolling average, 1800 samples were used, etc. As a result, for each match, maximum values for each of the three output variables (relative distance, acceleration/deceleration, P_{met}) were calculated for each of the 10 moving average durations. Data was then collated by playing position, and averaged across all observations for that positional group, for between-position comparisons.

Statistical Analyses

Data distribution was assessed for normality using the Shapiro-Wilk test. If a dataset violated the assumption of normality, the data was log-transformed to reduce the non-uniformity of error. A multilevel linear mixed-effects model was constructed to determine differences in the individual responses in running intensity between positions (n = 6) for each moving average duration (n = 10). Individuals were included as a random effect in the model, to correct for pseudoreplication. When significant main effects were observed, data were entered into a customized spreadsheet (Microsoft Excel; Microsoft, Redmond, USA), where pairwise comparisons between groups were made using a magnitude-based inference

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network[19]. This method assessed the probability that differences were greater than the smallest worthwhile difference (SWD), calculated as 0.20 × the between-subject standard deviation (SD). Further, to examine the effect of moving average duration on running intensities, a magnitude-based approach was used to compare moving averages 1-9 to the 10-min moving average, for each outcome variable. Quantitative chances of real differences in variables were assessed qualitatively as: <1%, *almost certainly not*; 1-5%, *very unlikely*; 5-25%, *unlikely*; 25-75%, possibly; 75-97.5%, *likely*; 97.5-99% *very likely*; >99%, *almost certainly*[19]. A difference was considered substantial when the likelihood that the true value was greater than the SWD exceeded 75%. Descriptive statistics are presented as mean ± SD, while all other data are reported as mean and 90% confidence limits (CL), unless otherwise stated. Where necessary, statistical analyses were performed using R statistical software (R 3.1.0, R foundation for Statistical Computing)[20] using the *lme4* package, and significance was set at $p < 0.05$.

RESULTS

The mixed-model analysis revealed significant main effects duration for each outcome variable. Figure 1 illustrates the increasing running demands of competition as a function of moving average duration. Comparisons with the 10-min moving average revealed *almost certainly* large increases in relative distance covered and P_{met} for moving averages 1 to 4 min in duration, and *almost certainly* large increases in acceleration/deceleration for moving averages 1 to 2 min in duration (Table 1). All windows shorter than 8-min were *almost certainly* greater for both acceleration/deceleration and P_{met} respectively. For relative distance covered, all windows except for the 9-min window were *almost certainly* higher when compared to the 10-min moving average.

A significant effect of position was observed for all moving average durations for both relative distance and $P_{met.}$ For acceleration/deceleration, the model revealed significant effects for moving averages of 2 to 10 min in duration, but no differences between position for the 1-

min window. Maximum relative distances for each moving average duration are displayed in Table 2. There were *likely* small to moderate increases in relative distance covered for hookers and halves compared to edge forwards, outside backs and middle forwards across all moving averages. Fullbacks exhibited *almost certainly* large increases in relative distance compared to outside backs for moving averages of 5 to 10 min in duration.

Table 3 illustrates positional differences in acceleration/deceleration demands across moving averages 2 to 10 min in duration. Edge forwards exhibited at least *likely* small increase in acceleration/deceleration demands compared to fullbacks, outside backs and middle forwards for moving averages between 2 and 4 min in duration. For moving averages greater than this, the difference was *likely* to be moderate. Halves and hookers presented at least *likely* moderate increases compared to outside backs and middle forwards for all moving averages at least 2 min in duration.

Fullbacks and hookers maintained a greater P_{met} compared to edge forwards, outside backs and middle forwards across all moving average durations, and the magnitude of these differences were at least *likely* to be moderate (Table 4). Halves were also able to attain a greater P_{met} than outside backs and middle forwards for moving averages 2 to 10 min in duration, but exhibited poorer values compared to fullbacks for the 1 min window.

DISCUSSION

The present study investigated the acceleration-based running requirements of professional rugby league competition, concurrently with traditional velocity-based methods, using a novel rolling average method[3]. Whilst the duration-specific running demands of rugby league have been investigated previously[3], the present study was able to describe the elevated accelerated/decelerated running demands of halves and hookers, and the greater P_{met} values achieved by halves, hookers and fullbacks when compared to other positional groups. In addition, the peak acceleration-based running intensities achieved during match-play increased

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substantially as the length of the moving average applied decreased. The interactions of peak running intensity and moving average durations observed in this study provide additional benefit for coaches and practitioners when attempting to replicate position-specific competition movement demands using specific training methodologies.

Recently, Furlan et al.[11] utilized a 2-min moving average, to determine the peak periods of Rugby Sevens performance. The authors observed that relative distance underestimated the intensity of the identified peak period when compared to the $P_{met,}$ calculated using the methods of Gray[21], which suggests the incorporation of acceleration-based methods are necessary when quantifying team sport movement demands. The findings of this study are in support of this notion, where the inclusion of acceleration-based indices assist in differentiating the varying positional requirements of rugby league. In the present study, accelerations/decelerations were calculated as the rate of change in velocity, regardless of the direction of change. This may be considered a limitation, as the energetic cost of acceleration has been suggested to be far greater than that of deceleration[9]. However, this variable was intended to represent the overall acceleration and deceleration load imposed on the athlete, rather than an estimate of energy consumption. Recent research has demonstrated that GPS possess poor inter-unit reliability for both acceleration counts >3 $m \cdot s^{-2}$ and >4 $m \cdot s^{-2}$ (CV% = 31% and 43%, respectively), and deceleration counts <-3 $m \cdot s^{-2}$ and <-4 $m \cdot s^{-2}$ (CV% = 42% and 56%, respectively)[15]. However, in the present study, each player was assigned the same unit for each match, and this coupled with the 'smoothing' effect of the moving average method, may have provided a more stable measure for differentiating demands between positions and durations.

This study observed higher average acceleration/deceleration amongst halves and hookers, compared to outside backs and middle forwards, for moving averages 2 to 10 min in duration. These findings are similar to whole match acceleration and decelerations counts (acceleration and deceleration efforts exceeding >2.78 $m \cdot s^{-2}$ and <-2.78 $m \cdot s^{-2}$, respectively)

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observed by Kempton et al.[12], where adjustables (halves, hookers and fullbacks) were substantially different from all other positions. Taken together, these differences would suggest that for positions where acceleration/deceleration requirements are high, athletes may benefit from training methodologies that mimic these demands. For improvements in performance to occur, these qualities should be progressively overloaded through an appropriately periodized program. This could be facilitated through the incorporation of strength and power training, due to the well-established links with acceleration[22] and change-of-direction[23] performance. Specifically, to improve field sport acceleration, training should be targeted towards improving the rate of force production[22], through explosive power movements such as plyometrics or resisted sprint training[24].

The present study is the first to analyse the duration-specific metabolic demands of rugby league competition. In theory, the metabolic power method integrates the energetic demands of accelerated running with traditional velocity-based methods[7]. In the present study, the peak metabolic demands of match-play were substantially higher in hookers compared to outside backs, edge forwards and middle forwards across all moving average durations. Previously, the hooker position has been grouped with fullbacks and halves due to somewhat similar competition requirements, in that they are responsible for providing structure and organisation in both attack and defence. However, modern defensive strategies require the hooker to be located in the centre of the field, exposing them to a similar number of absolute collisions compared to hit-up forwards (40 ± 13 vs. 44 ± 13 per game)[25], in addition to them attending most rucks in attack to distribute the ball to other players. As a result of this, it is common for teams to utilize a second hooker on the interchange bench, in order to maintain the intensity around the ruck throughout a match. This was evident in the present study, where although the average match time was similar between hookers (52 ± 14 min) and middle forwards (47 ± 15 min), hookers exhibited a considerably higher P_{met} response compared to other positions. However, it must be noted that the findings of the present study are reflective of the interchange strategy of the team in question, and this may differ between clubs. Future research may benefit from examining the factors which may limit players from maintaining running intensities throughout a match, which may inform individual interchange and conditioning strategies.

In contrast to the hooker position, halves and fullbacks are commonly required to complete the entire match. The similarly elevated P_{met} values observed for halves would indicate these positions reach similar peak running intensities to hookers, and although they are not regularly interchanged, they are not exposed to the same collision loads of interchanged players[25], allowing them to recover from high-intensity periods of match-play more adequately. However, an interesting finding of the present study was the elevated P_{met} response observed in the fullback position. In defence, for the majority of gameplay fullbacks are positioned behind the defensive line and are not required to move forward and retreat over 10 m, nor are they required to be involved in regular physical collisions, as is necessary for most other positions. As a result, the acceleration/deceleration demands of this position are substantially lower than that of halves and hookers (Table 3). However, the lower acceleration/deceleration demands did not translate to a lower P_{met} of this position, with fullbacks exhibiting similar P_{met} values to halves and hookers. These findings illustrate the strength of the metabolic power method for integrating the varying match-play requirements of each position, however the findings of the present study question the grouping of halves, hookers and fullbacks when describing competition running requirements. This positional grouping method may affect the prescription of specific training based on competition demands, as the way an athlete achieves high-intensity running must be addressed – whether that be the open-style running for fullbacks, or the acceleration-based running of halves and hookers.

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If athletes are to be adequately prepared for the most intense periods of competition, training prescription should account for the acceleration-based running requirements common to rugby league. The novel methodology of the present study may attenuate this implication, in comparison to that of previous research, where the metabolic power method was used to describe the mean P_{met} sustained in range of team sports, such as rugby sevens (~10 $W \cdot kg^{-1}$)[11], soccer (~8 $W \cdot kg^{-1}$)[9], rugby league (~9 $W \cdot kg^{-1}$)[12] and AFL (~10 $W \cdot kg^{-1}$)[10]. However, these values represent whole-match averages, and fail to account for the peaks in running intensity imposed on players throughout a match. Furlan et al. [11] observed that peak P_{met} for a 2-min moving average was significantly greater than the average of the entire period. In the present study, large increases in P_{met} were observed between the 10-min moving average and all moving averages <5 min in duration (ES 1.21-1.83). This phenomena may be due to athletes adopting pacing strategies, where energy is distributed across the period to allow for completion of the entire match[26], or possibly the stochastic nature of team sports such as rugby league. Regardless of the mechanism behind these differences, it would be beneficial to condition athletes for these peaks in intensity observed throughout a match. However, it is important to note that these findings are reflective of the tactical strategies of one team only, and future research may benefit from investigating these running demands across a number of clubs concurrently.

Despite the theoretical advantages associated with the integration of velocity and acceleration when quantifying team sport movement demands, the metabolic power method[7] is not without limitation. For example, this method assumes the biomechanics, frequency of movement of the limbs, and environmental conditions to be similar between uphill running on a treadmill at constant speed and accelerated running on flat terrain[7,9]. Recently, the validity of this method in team sports has been questioned, due to the inability to account for the metabolic cost of sport-specific activities such as dribbling and turning[16], or in rugby league, tackling and

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wrestling[12]. In addition, this method is unable to account for differences in body size or running economy[16], which may potential influence the metabolic cost of running. However, whilst the "metabolic" nature of this measure can be questioned, this variable still reflects a relatively stable measure which collaborates accelerated and decelerated running with traditional velocity-based techniques[13]. Future research may benefit from validating this energetic model in rugby-league specific conditions, potentially accounting for positional differences in body size and running economy.

PRACTICAL APPLICATIONS

The results of the present study show that the peak running requirements of rugby league competition differ according to position, and increase as the duration of the moving average decreases. Using the framework provided by the current study, coaches may differentiate the training prescribed to each positional group. More specifically, if the aim of training is to replicate and overload competition demands, specific small-sided games (SSG) could be used. For example, fullbacks may benefit from open-style games such as offside touch, played on large field dimensions, as these games have been shown to generate high velocity-based running intensities[27]. In contrast, the acceleration-based demands could be achieved through small, tight games, with a greater importance placed on support plays[28]. Lastly, the findings of the current study suggest that the P_{met} measure may be useful as a global measure of external training load, due to the interaction of both acceleration and velocity-based running.

CONCLUSIONS

The present study has provided a holistic overview of the peak metabolic demands of rugby league competition. The main findings demonstrated that although the metabolic power calculations incorporate both acceleration- and velocity-based movements, the method in which athletes achieve metabolic power differs by position. The findings of this study allow

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coaches to prescribe and monitor specific training drills according to duration- and position-specific competition requirements, and appropriately overload athletes to achieve increases in match performance. The findings of the present study also question the use of a combined "adjustables" positional group when describing competition movement demands.

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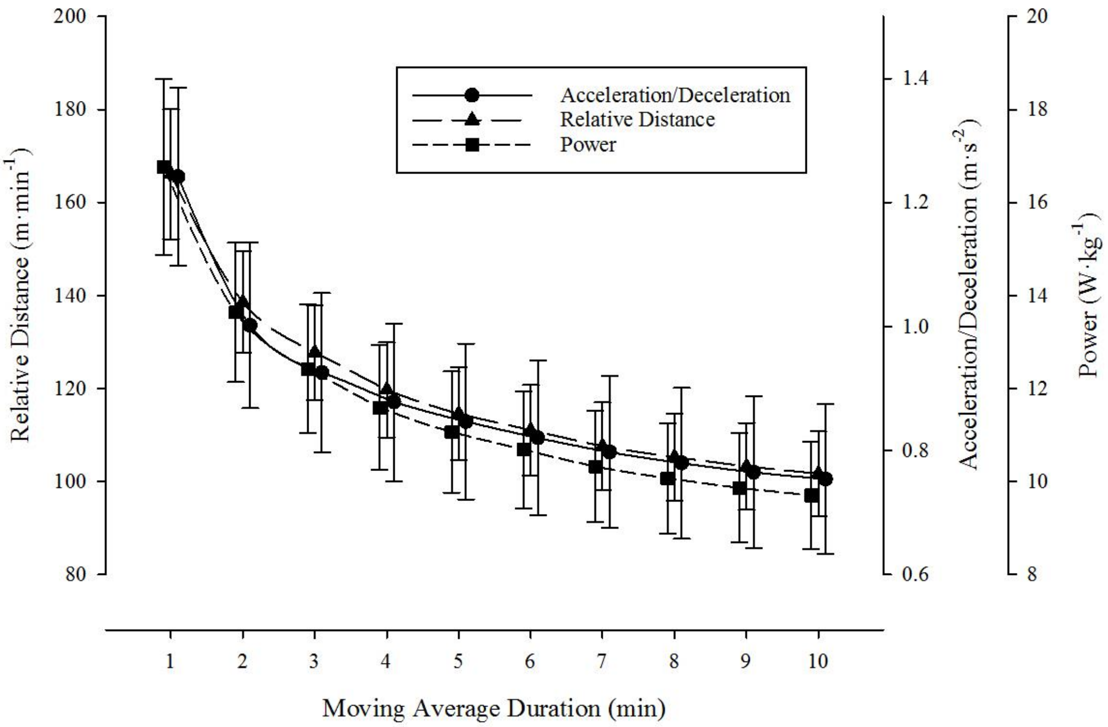

Figure 1. Maximum running intensities of rugby league match-play by rolling average duration. Data are presented as mean ± SD for each outcome variable.

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Table 1: Magnitude of increase in running intensities compared to 10-min moving average. Differences are presented as mean ± 90% confidence limits (90% CL).

Moving Average Length (min)	Relative Distance ($m{\cdot}min^{-1}$)		Acceleration/Deceleration ($m{\cdot}s^{-2}$)		Metabolic Power ($W{\cdot}kg^{-1}$)	
	Mean ± 90% CL	**Effect size, likelihood of effect**	**Mean ± 90% CL**	**Effect size, likelihood of effect**	**Mean ± 90% CL**	**Effect size, likelihood of effect**
1	64 ± 5	1.88, Almost certainly large ↑	0.49 ± 0.04	1.76, Almost certainly large ↑	7.1 ± 0.5	1.83, Almost certainly large ↑
2	37 ± 3	1.76, Almost certainly large ↑	0.25 ± 0.02	1.39, Almost certainly large ↑	3.9 ± 0.3	1.65, Almost certainly large ↑
3	26 ± 2	1.61, Almost certainly large ↑	0.17 ± 0.01	1.13, Almost certainly moderate ↑	2.7 ± 0.2	1.46, Almost certainly large ↑
4	18 ± 1	1.36, Almost certainly large ↑	0.12 ± 0.01	0.90, Almost certainly moderate ↑	1.9 ± 0.1	1.21, Almost certainly large ↑
5	13 ± 1	1.12, Almost certainly moderate ↑	0.09 ± 0.01	0.70, Almost certainly moderate ↑	1.4 ± 0.1	0.97, Almost certainly moderate ↑
6	9 ± 1	0.89, Almost certainly moderate ↑	0.07 ± 0.01	0.52, Almost certainly small ↑	1.0 ± 0.1	0.75, Almost certainly moderate ↑
7	6 ± 1	0.61, Almost certainly moderate ↑	0.04 ± 0.01	0.35, Almost certainly small ↑	0.6 ± 0.1	0.51, Almost certainly small ↑
8	4 ± 1	0.38, Almost certainly small ↑	0.03 ± 0.01	0.21, Possibly small ↑	0.4 ± 0.1	0.31, Very likely small ↑
9	2 ± 1	0.17, Possibly trivial ↑	0.01 ± 0.01	0.09, Very unlikely trivial ↑	0.2 ± 0.1	0.14, Unlikely trivial ↑

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Table 2: Peak relative distances ($m \cdot min^{-1}$) of professional rugby league players by position for each moving average duration (± SD).

Moving Average (min)	Fullback	Halves	Hooker	Edge Forwards	Outside Backs	Middle Forwards	Effect Size > 0.60
1	179 ± 15[bcdef]	168 ± 12[ef]	172 ± 14[def]	165 ± 11	164 ± 14	163 ± 14	FB > HA, EF, OB & MF
2	148 ± 13[bdef]	142 ± 9[def]	146 ± 11[bdef]	137 ± 9	137 ± 10	135 ± 10	FB & HK > EF & OB; FB, HA & HK > MF
3	134 ± 11[bdef]	131 ± 8[def]	136 ± 11[bdef]	127 ± 9	125 ± 9	125 ± 10	FB & HK > EF & MF; FB, HA & HK > OB
4	127 ± 10[def]	124 ± 10[def]	127 ± 11[def]	119 ± 9	117 ± 9	117 ± 10	FB & HK > EF, FB; HA & HK > OB & MF
5	122 ± 9[def]	120 ± 9[def]	122 ± 11[def]	114 ± 8	112 ± 8	111 ± 10	FB, HA & HK > EF, OB & MF
6	119 ± 9[def]	116 ± 8[def]	118 ± 11[def]	111 ± 8[ef]	107 ± 8	108 ± 9	FB, HA & HK > EF, OB & MF
7	116 ± 10[def]	113 ± 8[def]	114 ± 11[def]	108 ± 8[ef]	104 ± 8	104 ± 9	FB, HA & HK > EF, OB & MF
8	114 ± 9[bdef]	110 ± 8[def]	111 ± 11[def]	106 ± 8[ef]	102 ± 7	102 ± 9	FB > EF; FB, HA & HK > OB & MF
9	111 ± 8[bdef]	108 ± 8[def]	110 ± 11[def]	104 ± 8[ef]	100 ± 7	100 ± 9	FB > EF; FB, HA & HK > OB & MF
10	109 ± 8[def]	107 ± 8[def]	108 ± 11[def]	102 ± 7[ef]	99 ± 7	98 ± 11	FB & HK > EF; FB, HA & HK > OB & MF

FB = Fullback, HA = Halves; HK = Hooker, EF = Edge Forwards; OB = Outside Backs; MF = Middle Forwards, [a] = greater than FB; [b] = greater than HA; [c] = greater than HK; [d] = greater than EF; [e] = greater than OB; [f] = greater than MF. All observed differences are >75% likelihood of being greater than the SWD (calculated as 0.2 x between-subject SD).

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Table 3: Peak average acceleration/deceleration ($m \cdot s^{-2}$) of professional rugby league players by position for each moving average duration (± SD).

Moving Average (min)	Fullback	Halves	Hooker	Edge Forwards	Outside Backs	Middle Forwards	Effect Size > 0.60
1	1.22 ± 0.16	1.26 ± 0.14	1.28 ± 0.13	1.27 ± 0.1	1.23 ± 0.16	1.23 ± 0.14	N/A
2	0.98 ± 0.14	1.05 ± 0.13[aef]	1.06 ± 0.14[aef]	1.04 ± 0.11[aef]	0.96 ± 0.12	0.99 ± 0.13	HA & HK > OB
3	0.89 ± 0.12	0.98 ± 0.12[aef]	0.99 ± 0.14[aef]	0.95 ± 0.11[aef]	0.88 ± 0.12	0.91 ± 0.13	HA & HK > FB & OB
4	0.85 ± 0.12	0.93 ± 0.13[aef]	0.94 ± 0.14[aef]	0.90 ± 0.11[aef]	0.84 ± 0.12	0.86 ± 0.12	HA & HK > FB & OB
5	0.83 ± 0.12	0.90 ± 0.13[aef]	0.91 ± 0.14[aef]	0.88 ± 0.11[aef]	0.8 ± 0.11	0.83 ± 0.12	HK > FB; HA, HK & EF > OB
6	0.80 ± 0.11	0.87 ± 0.13[aef]	0.88 ± 0.13[aef]	0.85 ± 0.1[aef]	0.78 ± 0.11	0.80 ± 0.13	HA, HK & EF > OB
7	0.79 ± 0.11	0.85 ± 0.12[aef]	0.85 ± 0.13[aef]	0.83 ± 0.1[aef]	0.76 ± 0.11	0.78 ± 0.13	HA, HK & EF > OB
8	0.77 ± 0.11	0.83 ± 0.12[aef]	0.83 ± 0.13[aef]	0.81 ± 0.1[aef]	0.74 ± 0.11	0.76 ± 0.12	HA, HK & EF > OB
9	0.75 ± 0.11	0.82 ± 0.12[aef]	0.82 ± 0.13[aef]	0.8 ± 0.1[aef]	0.73 ± 0.11	0.74 ± 0.13	HA, HK & EF > OB
10	0.75 ± 0.11	0.81 ± 0.12[aef]	0.81 ± 0.13[aef]	0.78 ± 0.1[aef]	0.72 ± 0.11	0.73 ± 0.13	HA, HK & EF > OB

FB = Fullback, HA = Halves; HK = Hooker, EF = Edge Forwards; OB = Outside Backs; MF = Middle Forwards, [a] = greater than FB; [b] = greater than HA; [c] = greater than HK; [d] = greater than EF; [e] = greater than OB; [f] = greater than MF. All observed differences are >75% likelihood of being greater than the SWD (calculated as 0.2 x between-subject SD).

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Table 4: Peak average metabolic power ($W \cdot kg^{-1}$) of professional rugby league players by position for each moving average duration (± SD).

Moving Average (min)	Fullback	Halves	Hooker	Edge Forwards	Outside Backs	Middle Forwards	Effect Size > 0.60
1	18.1 ± 1.9^{bcdef}	17.0 ± 1.9^{f}	17.4 ± 1.8^{def}	16.7 ± 1.5	16.6 ± 1.9	16.4 ± 1.9	FB > EF, OB & MF
2	14.6 ± 1.5^{bdef}	14.1 ± 1.6^{ef}	14.4 ± 1.6^{def}	13.6 ± 1.2	13.4 ± 1.4	13.3 ± 1.4	FB > EF; FB & HK > OB & MF
3	13.0 ± 1.2^{def}	12.8 ± 1.3^{ef}	13.3 ± 1.6^{def}	12.5 ± 1.2	12.1 ± 1.3	12.1 ± 1.3	FB & HK > OB & MF
4	12.2 ± 1.2^{def}	12.1 ± 1.4^{def}	12.4 ± 1.5^{def}	11.6 ± 1.2	11.3 ± 1.2	11.3 ± 1.3	FB, HA & HK > OB & MF
5	11.7 ± 1^{def}	11.6 ± 1.3^{def}	11.8 ± 1.5^{def}	11.1 ± 1.1^{ef}	10.7 ± 1.1	10.7 ± 1.3	FB, HA & HK > OB & MF
6	11.4 ± 1^{def}	11.2 ± 1.3^{def}	11.4 ± 1.4^{def}	10.8 ± 1.0^{ef}	10.3 ± 1.0	10.4 ± 1.2	FB, HA & HK > OB & MF
7	11.0 ± 1^{def}	10.9 ± 1.2^{def}	11.0 ± 1.4^{def}	10.5 ± 1.0^{ef}	9.9 ± 1.0	10.0 ± 1.2	FB, HA & HK > OB & MF
8	10.7 ± 1^{def}	10.6 ± 1.2^{ef}	10.8 ± 1.3^{def}	10.2 ± 1.0^{ef}	9.7 ± 1.0	9.8 ± 1.2	FB, HA & HK > OB & MF
9	10.5 ± 1^{def}	10.4 ± 1.2^{ef}	10.6 ± 1.4^{def}	10.0 ± 1.0^{ef}	9.5 ± 1.0	9.6 ± 1.1	FB, HA & HK > OB & MF
10	10.3 ± 1^{def}	10.2 ± 1.2^{def}	10.4 ± 1.4^{def}	9.8 ± 0.9^{ef}	9.3 ± 0.9	9.4 ± 1.1	FB, HA & HK > OB & MF

FB = Fullback, HA = Halves; HK = Hooker, EF = Edge Forwards; OB = Outside Backs; MF = Middle Forwards, [a] = greater than FB; [b] = greater than HA; [c] = greater than HK; [d] = greater than EF; [e] = greater than OB; [f] = greater than MF. All observed differences are >75% likelihood of being greater than the SWD (calculated as 0.2 x between-subject SD).