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Research article

Running and Metabolic Demands of Elite Rugby Union Assessed Using Traditional, Metabolic Power, and Heart Rate Monitoring Methods

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Abstract

The aims of this study were (1) to analyze elite rugby union game demands using 3 different approaches: traditional, metabolic and heart rate-based methods (2) to explore the relationship between these methods and (3) to explore positional differences between the backs and forwards players. Time motion analysis and game demands of fourteen professional players (24.1 ± 3.4 y), over 5 European challenge cup games, were analyzed. Thresholds of 14.4 km·h^{-1}, 20 W.kg^{-1} and 85% of maximal heart rate (HR_{max}) were set for high-intensity efforts across the three methods. The mean % of HR_{max} was 80.6 ± 4.3 % while 42.2 ± 16.5% of game time was spent above 85% of HR_{max} with no significant differences between the forwards and the backs. Our findings also show that the backs cover greater distances at high-speed than forwards (% difference: +35.2 ± 6.6%; p<0.01) while the forwards cover more distance than the backs (+26.8 ± 5.7%; p<0.05) in moderate-speed zone (10-14.4 km·h^{-1}). However, no significant difference in high-metabolic power distance was found between the backs and forwards. Indeed, the high-metabolic power distances were greater than high-speed running distances of 24.8 ± 17.1% for the backs, and 53.4 ± 16.0% for the forwards with a significant difference (+29.6 ± 6.0% for the forwards; p<0.001) between the two groups. Nevertheless, nearly perfect correlations were found between the total distance assessed using the traditional approach and the metabolic power approach (r = 0.98). Furthermore, there is a strong association (r = 0.93) between the high-speed running distance (assessed using the traditional approach) and the high-metabolic power distance. The HR monitoring methods demonstrate clearly the high physiological demands of professional rugby games. The traditional and the metabolic-power approaches shows a close correlation concerning their relative values, nevertheless the difference in absolute values especially for the high-intensity thresholds demonstrates that the metabolic power approach may represent an interesting alternative to the traditional approaches used in evaluating the high-intensity running efforts required in rugby union games.

Key words: Rugby union, GPS, heart rate monitoring, metabolic power.

Introduction

Rugby union is a dynamic and complex contact-sport in which power, speed, agility and endurance are required (Smart et al., 2013). Several studies to date have analyzed game demands in elite rugby union players (Austin et al., 2011; Cahill et al., 2013; Cuniffe et al., 2009; Lacome et al., 2014; Lindsay et al., 2015; Quarrie et al., 2013; Roberts et al., 2008). These studies have demonstrated that rugby union is characterized by frequent bouts of very-high intensity efforts: sprinting, tackling and wrestling to name just some. The motion analyses carried out in these studies also revealed that elite rugby union players covered 4500-7500 m including 300-800 m above high-speed running (HSR) (> 14.4 km·h^{-1}) threshold with significant differences depending on playing positions. These studies also showed that the backs covered greater distance in HSR, and sprinting (> 25 km·h^{-1}) zones, while the forwards performed more bouts of static exertion (scrummaging and rucking phases) and wrestling phases (Austin et al., 2011; Cahill et al., 2013; Roberts et al., 2008; Lacome et al., 2014). However, Gabbett (2015) and Reardon et al. (2015) demonstrated the limitations (underestimation and difficult interpretation) of using an absolute threshold value to analyze high-intensity running efforts. Furthermore, the sequence of wrestling and rucking phases generated in small side spaces require less continuous running activity but numerous accelerations and changes of velocity. Thus, it may be that the traditional approach is not representing true game demands, particularly the high-intensity running demands.

It has been stated that the analysis of the accelerations and the decelerations may represent an interesting assessment method to monitor running demands (Dalen et al., 2016). Linked to this, Lacome et al. (2014) examined accelerations in their analysis of demands during international rugby union games. Their findings revealed that the backs had a greater mean duration and maximal acceleration while the mean acceleration values were higher in the forwards. Furthermore, accelerations, decelerations, changes of direction and sprint running represent the predominant running activity in team sport games. Despite this, they too often get neglected (Dalen et al., 2016). Yet, these types of running actions contribute significantly to the increases in metabolic energy expenditure generated during a game (di Prampero et al., 2005; Osgnach et al., 2010). Indeed, several studies (Dalen et al., 2016; Lacome et al., 2014; Owen et al., 2015) were focused on the accelerations/decelerations during team sports games, because they showed that considering only the movement speed would induce an underestimation of high-intensity running efforts. Therefore, using accelera-

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tions/decelerations should allow for a better estimate of positional demands in team sports such as rugby union.

The metabolic power approach, initially proposed by di Prampero et al. (2005) and substantiated by Osgnach et al. (2010) may represent an interesting complement to the traditional approach in order to evaluate running demands during team sport. Indeed, this approach takes into consideration the accelerations/decelerations and the speed at which they are performed. Furthermore, Kempton et al. (2015) highlighted that this approach contributed to a better understanding of rugby league game demands. However, the metabolic power approach is not without limitations. Buchheit et al. (2015) questioned the validity and the reliability of the metabolic power approach applied to soccer training drills. They showed that the metabolic power approach demonstrated poor reliability above 20 $W \cdot kg^{-1}$. They also highlighted that the metabolic power approach underestimated (≈ 20%) the energy expenditure recorded through O_2 consumption.

HR based methods also permit physiological demands during team sport games to be assessed (Esposito et al., 2004). Regarding rugby union, some studies (Deutsch et al., 1998; Sparks and Coetzee 2013) performed with young rugby union players highlighted important metabolic system demands (e.g. 50% of time is spent above 85% HR_{max}). Moreover, Virr et al. (2014) highlighted significant difference in HR responses between the forwards and the backs during senior women's rugby union games: the forwards displayed higher mean HR and spent more time above 80% of HR_{max} compared to the backs. Nevertheless, HR monitoring remains rarely used in studies analyzing physiological game demands in rugby union, particularly in professional players (Cunniffe et al. 2009). Therefore, using HR-based methods should allow coaches and players alike to better understand and estimate the metabolic demands during professional rugby union games

Assessing and understanding more precisely the running and metabolic demands of elite rugby union is fundamental for trainers, coaches and players alike to optimize the training process. It also allows for trainers to align the training demands with competition requirements and thus improve the specificity of training in these players~~.~~ (Bradley et al., 2015; Vaz et al., 2015). Therefore, the aims of our study were (1) to analyze elite rugby union game demands using 3 different approaches: traditional, metabolic and heart rate-based methods (2) to explore the relationship between these methods and (3) to explore positional differences between the backs and forwards players.

Methods

Participants

Fourteen (7 forwards and 7 backs) professional rugby union players (24.1 ± 3.4 years; 101.4 ± 12.2 kg and 1.89 ± 0.07 m) playing in the first division in France (Top 14) volunteered to participate in this study. The positions represented for the forwards were: prop, 2nd row, wing flanker and number 8. The positions represented for the backs were: fly-half, center, winger and full-back. The different positions were represented to limit the influence of the specific demands of each position within the groups. Each position has been represented at least once or several times. All subjects gave informed consent to participate in the experiments in accordance with the Declaration of Helsinki. The study protocol was conducted in accordance with the ethical standards and the guidelines of the Ethical Committee of the University of Rennes which approved this study protocol.

Procedure

The physical activity and the HR were measured during 5 European *Challenge cup* (season 2014-2015) among the same team. The players' match activity was recorded by GPS technology (SPI-HPU, 15 Hz extrapolated from 5 Hz signal, GPSport, Canberra, Australia). The individual's running speed, accelerations and decelerations were assessed from GPS signal. HR was measured using HR monitors (Polar T34, Polar Electro, Kempele, Finland). The GPS units recorded and synchronized speed, accelerations/deceleration data from the GPS signal and HR data. Before each match, the GPS units and the HR monitors were positioned in purpose built vests to minimize unwanted movements during contact phases. At the end of the game, the data were downloaded using Team AMS software (GPSport system, Canberra, Australia). Individual HR_{max} was established during the YoYo intermittent recovery test level 2 (YYIRT2) (Bangsbo et al., 2008) conducted 1 month before the first game. Each match (80 min) was analyzed across each 10 min segments (8 x 10 min segments per game) to allow for a range of statistical analyses comparing the two external approaches with the HR-based method.

Variables used in different approaches

Speed, metabolic and HR zones are presented in Table 1. In agreement with Coutts and Duffield (2010) and Kempton et al., (2015), the threshold for HSR distance and high metabolic power (HMP) distance were set to 14.4 $km \cdot h^{-1}$ and 20 $W \cdot kg^{-1}$ respectively. The thresholds for accelerations and decelerations were set at ± 2.5 $m \cdot s^{-2}$ (Cunniffe

Table 1. Intensity zones for the traditional, metabolic power approaches and HR-based method.

Zones		Traditional approach ($km \cdot h^{-1}$)		Metabolic power approach ($W \cdot Kg^{-1}$)		HR based method ($\%HR_{max}$)
1		0-6		0-10		< 71
2		6-10.2		10-20		71-78
3		10.2-14.4		20-35.5		78-85
4	HSR Zone	14.4-19.8	HMP Zone	35.5-55	HHRE Zone	85-92
5	HSR Zone	19.8-24.9	HMP Zone	> 55	HHRE Zone	> 92
6	HSR Zone	> 24.9	HMP Zone		HHRE Zone	

MP: metabolic power; $\%HR_{max}$: percentage of maximal heart rate; HSR: high speed running; HMP: high metabolic power; HHRE: high heart rate exertion.

Table 2. **Mean values (± SD) for running demands from traditional approach: absolute and relative distances, peak speed, number of sprints, accelerations and decelerations depending on playing position.**

	Periods	Forwards (n=22)	Backs (n=24)	p-value	ES (Cohen's d)
	Total distance	2792.6 ± 402.9 (58.2 ± 8.4)	3042.4 ± 426.3 (64.5 ± 9.3) *	.109 (.045)	Small - .6 ± .6 (- .7 ± .5)
Distance covered in each speed zones (m)	**0-6 km·h^{-1}**	1130.5 ± 306.9 (23.7 ± 6.5)	1474.0 ± 336.2 ** (30.2 ± 9.3) **	.005 (.005)	Moderate 1.1 ± .6 (0.8 ± .6)
	6-10.2 km·h^{-1}	649.4 ± 192.8 (13.6 ± 6.5)	554.5 ± 211.3 (11.7 ± 7.2)	.085 (.082)	Moderate .7 ± .6 (.7 ± .6)
	10.2-14.4 km·h^{-1}	623.3 ± 152.1 (13.0 ± 3.9)	491.4 ± 154.3 * (10.2 ± 4.3) *	.014 (.014)	Moderate 1 ± .6 (1.1 ± .6)
	14.4-18.9 km·h^{-1}	305.5 ± 97.3 (6.4 ± 3.0)	296.1 ± 102.1 (6.3 ± 3.2)	.697 (.148)	Unclear .1 ± .5 (.1 ± .5)
	18.9-24.9 km·h^{-1}	86.2 ± 52.9 (4.0 ± 2.0)	189.4 ± 54.3 *** (1.8 ± .2) ***	< .001 (< .001)	Large -1.5 ± .4 (-1.5 ± .6)
	>24.9 km·h^{-1}	8.5 ± 34.8 (.1 ± .7)	45.1 ± 35.6 ** (6.3 ± .8) **	.003 (.003)	Moderate - 1.0 ± .4 (-1.0 ± .5)
	HSRD (>14.4 km·h^{-1})	397.2 ± 117.9 (8.3 ± 2.6)	537.1 ± 127.2 ** (11.3 ± 2.7) **	.002 (.002)	Moderate -1.0 ± .4 (-1.0 ± .4)
Peak speed (km·h^{-1})		24.3 ± 3.7	28.6 ± 4.0 **	.003	Large (- 1.3 ± .5)
Number of sprints (n) (n·min^{-10})		.43 ± 1.60 (.09 ± .03)	2.2 ± 1.6 ** (.47 ± 0.03) **	.003 (.002)	Moderate -1.0 ± .5 (-1.1 ± .5)
Number of acc. (>2.5 m·s^{-2})		19.1 ± 8.9 (.4 ± .2)	19.1 ± 9.8 (0.4 ± 0.2)	.963 (.924)	Unclear .1 ± 1.5 (.1 ± 1.5)
Number of dec. (<- 2.5m·s^{-2})		14.2 ± 6.2 (.3 ± .1)	16.2 ± 6.5 (.3 ± .1)	.326 (.281)	Unclear - .4 ± .6 (- .3 ± .5)

In the table, the top values represent absolute values for one full half period (independently of 1st or 2nd half), and the values in brackets correspond to relative time values. TD: total distance; DC: distance covered; HSRD: high speed running distance; Acc: accelerations; Dec: decelerations; ES: effect size (Cohen's d) presented with 90% confidence interval. * Significant difference between forwards and backs, * p<0.05; ** p<0.01; *** p<0.001.

et al., 2009). The internal load was evaluated using training impulse method (TRIMP), calculated from the Stagno et al.'s (2007) method and the time spent above 85% of HR_{max} was taken as the threshold for high HR exertion (HHRE).

The equations of energy-cost from di Prampero et al. (2005) and subsequently used by Osgnasch et al. (2010) provide the metabolic power variables such as metabolic load (absolute and relative), metabolic power average (MPA) and the distance covered in the different metabolic power zones. Percentage difference between (1) the equivalent distance (ED) (2) total distance (TD); and the percentage difference between the (3) HMP and (4) HSR distances were also used to compare and contrast the traditional and metabolic power approaches.

Statistical analyses

All analyses were carried out with R Statistical Software (R. 3.3.1, R Foundation for Statistical Computing). An independent t-test was used to determine the differences between the 2 groups (forwards vs backs) for the YYIRT2 and HR_{max}. For game demand analysis, the data were used for the analysis only if the player completed a complete half period in the game. 46 such periods (forwards: 22; backs: 24) were completed in total across the 5 games (n=26 for the 1st half and n=20 for the 2nd half) in 14 different players. A linear mixed effects model was used to describe each quantitative characteristic of performance Y, where the outcome variable "Y" is predicted by fixed effect for "groups" (forwards Vs backs) and "games" (games) as well as a random intercept for each "player". This model can be expressed using the following formula:

$$Y_{ij} = \beta_0 + \beta_1 \times groups_i + \beta_2 \times games_{ij} + b_i + \varepsilon_{ij}$$

Where i = is one player and j corresponds to the repeated measures (i.e. games). Beta are the fixed effect coefficients and b is the random effect coefficient for each player which is assumed to be normally distributed. The packages nlme and lsmeans were necessary to implement such a model. The mean ± standard deviation (SD) for each group were derived from the linear mixed effects model (lsmeans). If one variable was not normally distributed (e.g. sprint count), a log-transformation was performed before analyses. The level of significance was set at p≤0.05. Effect sizes (ES) were evaluated from the Cohen's d. ES values were along with 90% confidence interval. ES of ≤ 0.2, 0.21-0.60, 0.61-1.20, 1.21-2.0, ≥2.0 were respectively considered as trivial, small, moderate, large and very large (Batterham and Hopkins, 2006). However, if the 90% CI over-lapped positive and negative values, the magnitude was deemed unclear. The ES were calculated from the means and the variances (allowing the calculation of the SD) from the linear mixed effects models. When significant difference was observed, the percentage of difference between the 2 values were presented with 95% confidence interval.

The relationships between the game demand parameters, depending on the different 10 min segments, have been studied using Pearson correlation coefficient. The correlations were performed separately for the forwards and backs (n=91 for the forwards, n=106 for the backs). The correlation coefficients were presented with 95% confidence interval (%95CI). The magnitude of the effects was qualitatively assessed in accordance with Hopkins et al. (2009) as follows: trivial r>0.1, small 0.1-0.3, moderate 0.3-0.5, large 0.5-0.7, very large 0.7-0.9, nearly perfect 0.9-0.99, and perfect r=1.

Results

YYIRT2 and HR_{max}

The backs covered a significant greater distance in YYIRT2 than forwards: 1251.4 ± 145.5 m vs. 948.6 ± 198.3 m; (p<0.05; +31.9 ± 6.2%; d = 1.8 ± 0.6; ES: large). No significant difference was revealed for HR_{max} with similar levels attained among the back (195.5 ± 3.3 bpm) and forward players (193 ± 4 bpm).

Game demands description

Traditional approach: The mean TD covered during a typical match half was 2896.8 ± 340.8 m (60.9 ± 6.5 $m.min^{-1}$) including 468.9 ± 142.8 m (9.9 ± 3.0 $m.min^{-1}$) covered with a speed faster than 14.4 $km.h^{-1}$. The minimal and maximal values for TD covered during the same game were: 4722 m and 7758 m, respectively. Table 2 presents the results of the forwards and backs using traditional approaches. It shows that the forwards covered greater distance in the 10.2-14.4 $km.h^{-1}$ speed zone than the backs (p<0.05; +26.8 ± 0.7%; d = 1.0 ± 0.6; ES: moderate). The backs covered greater distance in HSR zones (p<0.01; +35.2 ± 6.6%; d = 1.0 ± 0.4; ES: moderate) especially due to significantly greater distances covered above 18.9 $km.h^{-1}$ (p<0.01; +119.7 ± 6.2%; d = 1.50 ± 0.4; ES: large). No significant difference (p>0.05) was found between the backs and forwards with respect to the number of accelerations and decelerations

Metabolic power approach: The mean ED covered during one half period of the game was 3175.1 ± 383.8 m (66.7 ± 7.4 $m{\cdot}min^{-1}$) including 659.1 ± 142.1 m (13.2 ± 2.9 $m{\cdot}min^{-1}$) covered in high-metabolic power zones (>20 $W{\cdot}kg^{-1}$). Table 3 presents all the metabolic power approach results according to the different playing positions/groups. The forwards covered greater distance in 10- 20 $W{\cdot}Kg^{-1}$ (p<0.05; +24.9 ± 5.4%; d = 0.9 ± 0.6;

Table 3. Mean values (± SD) for running demands from metabolic power approach: metabolic load, absolute and relative distance in the different metabolic power zones depending on the groups.

	Periods	Forwards (n = 22)	Backs (n = 24)	p-value	ES (Cohen's d)
	ML absolute (kj)	1507.8 ± 277.7	1488.5 ± 303.7	.578	Unclear .1 ± .3
	ML relative ($kj.kg^{-1}$)	14.1 ± 2.4	15.7 ± 2.6	.080	Moderate - .9 ± .8
	MPA ($W{\cdot}kg^{-1}$)	5.0 ± 0.7	5.5 ± .7 *	.032	Moderate - 1.0 ± .7
Distance covered in each metabolic power zones (m)	**Equivalent distance**	3040.7 ± 451.1 (63.4 ± 9.6)	3353.5 ± 98.2 (71.0 ± 10.5) *	.078 (.036)	Moderate - .8 ± .7 (- 1.0 ± .7)
	0-10 $W{\cdot}kg^{-1}$	1497.8 ± 313.8 (31.3 ± 6.6)	1820.6 ± 341.3* (38.5 ± 7.3) **	.012 (.008)	Large - 1.3 ± .7 (-1.4 ± .7)
	10-20 $W{\cdot}kg^{-1}$	710.1 ± 204.8 (14.9 ± 4.1)	568.3 ± 223.5 * (12.0 ± 4.5) *	.033 (.038)	Moderate - .9 ± .6 (- .9 ± .7)
	20-35 $W{\cdot}kg^{-1}$	416.5 ± 134.1 (8.72 ±2.8)	400.2 ± 145.6 (8.43 ± 3.0)	.698 (.7970)	Unclear .2 ± .7 (.1 ± .9)
	35-55 $W{\cdot}kg^{-1}$	123.0 ± 51.1 (2.58 ± 1.1)	194.6 ± 52.9 ** (4.09 ± 1.1) **	.001 (.001)	Large - 1.3 ± .5 (- 1.3 ± .5)
	>55 $W{\cdot}kg^{-1}$	30.6 ± 40.2 (.6 ± 0.9)	85.0 ± 44.4 *** (1.8 ± .9) ***	.001 (.001)	Large - 1.6 ± .6 (- 1.6 ± .6)
	HMPD (>20 $W{\cdot}kg^{-1}$)	571.7 ± 184.7 (12.0 ± 3.8)	672.9 ± 198.2 (14.2 ± 4.1)	.105 (.078)	Moderate - .7 ± .7 (- .8 ± .7)

In the table, the top values represent absolute values for one full half period (independently of 1^{st} or 2^{nd} half), and the values in brackets correspond to relative time values. ML: metabolic load; MPA: metabolic power average; ED: equivalent distance; DT: distance travelled; HMPD: high metabolic power distance; ES: effect size (Cohen's d) presented with 90% confidence interval. * Significant difference between forwards and backs, * p<0.05; ** p<0.01; *** p<0.001.

ES: moderate), while no significant difference was found between the backs and forwards in HMP zones despite the fact that the backs covered greater distances than forwards in the 35-55 $W \cdot kg^{-1}$ zone ($p<0.01$; +58.3 ± 7.0%; d = 1.3 ± 0.5; ES: large).

HR-based method: The mean % of HR_{max} was 80.6 ± 4.3% during a typical match half. The time spent, above 85 % of HR_{max} during an average half of a game was 20.0 ± 7.8 min (42.2 ± 16.5%). Table 4 shows that the forwards spent more time at 85-92% of their HR_{max} than the backs ($p<0.01$; +67.6 ± 6.3%; d = 1.2 ± 0.6; ES: large). However, no significant difference was found between the 2 groups for the time spent above 85% of HR_{max}.

Comparisons and relationships between the approaches: The percentage difference between traditional and metabolic power variables showed that ED was greater than TD by 10.1 ± 3.4% in the backs and 9.0 ± 3.3% in the forwards with no significant difference between groups. The HMP distances were greater than HSR distances ($p<0.01$, +40.6 ± 7.0%; d = 1.3 ± 0.5; ES: large). This percentage of change between the HMP and HSR was significantly different depending on the positional groups: 24.8 ± 17.1% for the backs and 53.4 ± 16.0% for the forwards ($p<0.001$; +29.6 ± 6.0% for the forwards; d = 1.7 ± 0.4; ES: large).

Several correlations were also conducted to ascertain the strength of association between these methods. There is a highly significant correlation between the traditional and metabolic power approaches (ED and TD covered r = 0.98 (0.97-0.99); $p<0.001$). Moreover, there was a highly significant relationship between HSR and HMP distances (r = 0.93; (0.90-0.95); $p<0.001$). Concerning the relationships between the running demands and the HR-based method parameters: TD covered, ED and metabolic load show the highest correlation with the TRIMPS (r = 0.58 (0.42-0.70), 0.57 (0.41-0.68) and 0.59 (0.44-0.71) respectively, $p<0.001$ for the backs; and r = 0.47 (0.29-0.62), 0.49 (0.32-0.63) and 0.46 (0.28-0.61) respectively, $p<0.001$ for the forwards).

Discussion

The aims of our study were (1) to analyze elite rugby union game demands using 3 different approaches (traditional, metabolic and heart rate-based methods) so as to quantify the running and metabolic demands during professional rugby union matches (2) to explore the relationship between these different methods and (3) to explore positional differences between the backs and forwards players. Our findings showed the back players covered greater HSR (>14.4 $km.h^{-1}$) distance than the forwards (+35.2 ± 6.6%; ES: moderate) while the forwards covered greater distances than the backs in the moderate (10-14.4 $km.h^{-1}$) speed zone (+26.8 ± 0.7%; ES: moderate). However, this traditional approach seems to underestimate high-intensity running efforts, particularly in the forwards who presented more than a 50% difference between HSR and HMP distances. The mean % of HR_{max} (regardless of playing position) was 80.6 ± 0.6%, with 42.2 ± 2.4% of the time was spent above 85% of HR_{max}. There were no significant differences between the forwards and the backs in this respect. The forwards do spend significantly more time however, in the 85-92% HR_{max} zone compared to the backs (+67.6 ± 6.3%; ES: large).

Game demands assessed using traditional, metabolic and HR-based methods

Several studies have analyzed high-level rugby union game demands (Austin et al., 2006; Cahill et al., 2013; Lacome et al., 2014; Quarrie et al, 2012; Roberts et al., 2008). Collectively, these studies found that the mean distance covered during games was 4200 m – 6500 m with significant differences between backs and forwards

Table 4. **Mean values (± SD) for HR-based method: time spent and percentage of time spent in each intensity zone by groups.**

	Periods	Forwards (n = 22)	Backs (n = 24)	p-value	ES (Cohen's d)
	Average % of HR_{max}	80.4 ± 7.2	81.6 ± 8.0	.452	Unclear (- .3 ± .6)
Time spent (min) (Percentage of time spent, %)	**< 71% HR_{max}**	6.5 ± 8.4 (13.7 ± 17.7)	7.7 ± 8.9 (16.0 ± 18.9)	.697 (.704)	Unclear - .2 ± .9 (-.2 ± .8)
	71-78% HR_{max}	9.1 ± 3.8 (12.8 ± 7.7)	6.1 ± 3.8 * (19.0 ± 8.3)	.018 (.016)	Moderate 1.0 ± .6 (1.0 ± .6)
	78-85% HR_{max}	12.8 ± 4.6 (26.8 ± 9.5)	12.1 ± 4.9 (25.3 ± 10.0)	.468 (.540)	Unclear .2 ± .4 (.2 ± .6)
	85-92% HR_{max}	18.1 ± 6.7 (37.9 ± 13.7)	10.8 ± 7.3 ** (22.8 ± 14.8) **	.004 (.004)	Large 1.2 ± .6 (1.2 ± .6)
	>92% HR_{max}	4.0 ± 7.5 (8.5 ± 14.8)	8.1 ± 8.2 (17.2 ± 17.5)	.094 (.091)	Moderate - .8 ± .7 (- .8 ± .7)
	HHRE (>85% HR_{max})	22.2 ± 11.4 (46.4 ± 24.0)	19.0 ± 12.4 (40.2 ± 26.1)	.388 (.432)	Unclear .4 ± .8 (.4 ± .8)

In the table, the top values represent absolute values for the time spent (min) during one full half period (independently of 1st or 2nd half), and the values in brackets correspond to the percentage of time spent in each HR intensity zones. $\%HR_{max}$: percentage of maximal heart rate; HHRE: high heart rate exertion; ES: effect size (Cohen's d) presented with 90% confidence interval. * Significant difference between forwards and backs, * $p<0.05$; ** $p<0.01$.

especially for the distance covered in the highest speed zones (Austin et al., 2011; Cahill et al., 2013; Quarrie et al., 2012; Roberts et al., 2008). The present study presents similar findings. Indeed, the back players covered greater distance ($p<0.05$) in HSR and walking zones (0-6 $km \cdot h^{-1}$) than the forwards, and statistically significant differences ($p<0.05$) were also found with respect to the distance covered above 18.9 $km \cdot h^{-1}$. The backs performed more sprints but there were no significant differences found between the two positional groups with respect to accelerations and decelerations. The forwards, for their part, covered greater distances ($p<0.05$) in moderate speed zones (10.2-14.4 $km \cdot h^{-1}$). Running activity in the game can be influenced by different contextual factors including the level of the opponent, the ball-in-play time, the specific playing positions as well as playing conditions (ground and weather) (Gabbett, 2015; Hullin et al., 2015). Indeed, the games analyzed took place during the autumn and winter seasons. During this period, playing conditions promote a “forwards game style”, with more rucking-based / wrestling activity in small confined spaces. This may explain the lack of significant differences in our findings between the 2 groups in terms of absolute TD covered. Moreover, the fitness level can also influence player’s game activity (Smart et al., 2014) and running activity (Swaby et al., 2016). However, even if no significant difference was observed between the forwards and the backs for the absolute value of TD covered, the p-value was close to 0.10. Indeed, the significant difference for the relative value ($m.min^{-1}$) should make it possible to indicate a small significant difference between forwards and the backs about the total distance covered, even if the limited number of data failed to demonstrated significant difference for the absolute values.

The metabolic power approach showed results similar to the traditional approach. Indeed, the analyses of intensity zones reveal the same significant differences between the forwards and the backs regardless of the approach used (Tables 2 and 3), namely the backs covered greater distances than the forwards within the lowest (<10 $W \cdot kg^{-1}$) (+21.6 ± 4.9%; ES: moderate) and highest (>35 w. kg^{-1}) (+58.3 ± 7.0%; ES: large) metabolic zones. The greater distances in the lowest speed (<6 $km \cdot h^{-1}$) and metabolic (<10 $W \cdot kg^{-1}$) zones suggests that these two intensity zones correspond to walking. As, the greatest intensity zones (above 18.9 $km \cdot h^{-1}$ and 35 $W \cdot kg^{-1}$, respectively) seem to inform the same running efforts. Indeed, a constant motion of 19 $km \cdot h^{-1}$ was considered from energy cost equations of the metabolic power approach (di Prampero et al., 2005), as an effort performed within a 20-35$W \cdot kg^{-1}$ zone. However, if performed with an acceleration of at least 1 $m \cdot s^{-2}$, this running effort will be considered as an effort performed above 35 $W \cdot kg^{-1}$. Moreover, the forwards, like in the traditional approach, covered greater distances in moderate intensity metabolic zones (10-20 $W \cdot kg^{-1}$) compared to the backs. The similarities between the two approaches suggest that they provide similar results. Furthermore, the correlations between the two external methods highlighted the close relationships between them. However, comparing the results for the distance covered above the thresholds of high-intensity running efforts, there were notable differences between the two approaches. Indeed, the traditional approach demonstrated significant differences in HSR distance, whereas the metabolic power approach no showed significant difference in HMP distances between the forwards and the backs. Despite a nearly perfect relationship ($r = 0.93$) between the two distances, a difference about of 35% exists between them, with a greater variation in the forwards (53% *Vs* 25%). These greater differences may be explained by the fact that the forwards covered significantly ($p<0.05$) greater distances in moderate speed zones which is just under the traditional approach threshold of high-intensity running. Based on the equations of energy-cost from di Prampero et al. (2005) the running efforts performed with light or moderate accelerations may be as demanding as constant running efforts performed above the traditional HSR threshold. Therefore, the metabolic approach, considering the speed and the energy cost demands of the accelerations for the analysis the high-intensity running efforts, can constitute a complement/alternative to the traditional approach, especially in the forwards.

Concerning the HR-based method, our findings show that the mean percentage of HR_{max} during elite rugby union games is 80% HR_{max}. Sparks and Coetzee (2013) also found a comparable value of 82% HR_{max} during college rugby union games reflecting the contribution of the aerobic pathway. Furthermore, 20 min (≈ 42% of total game duration) were spent above 85% of HR_{max} including 6 min (≈ 13% of total game duration) spent above 92% of HR_{max} during each half. However, the results are lower than the values presented by Coetzee and Sparks (2013) and Deutsch et al. (1998) who highlighted that on average, more than 50% of game time is spent at a high-intensity (> 85% HR_{max}) in junior and university level rugby union games. The time lost on invalid scrums in professional rugby games increase recovery time thus decreasing the HR responses, particularly amongst the back players. Furthermore, the greater fitness level in professional players promotes faster recovery between efforts (Smart et al., 2013). Moreover, our findings do not highlight significant differences in HHRE (> 85% of HR_{max}) between the back and the forward players. Several factors like the nature of the opposition, of the game and environmental factors (weather, field, stress) associated with a limited number of data failed to demonstrate significant difference between the forwards and backs for the time spent in high-intensity. However, the forwards spent more time in the 85-92% HR_{max} zone than the backs (+67.6 ± 6.3%; ES: large). Deutsch et al. (1998) and Lacome et al. (2014) demonstrated that forwards present a work:rest ratio lower than backs, mainly due to the greater frequency of participation in rucking/scrummaging, static efforts and wrestle phases which contributes to an increased time in this zone in forward players specifically (Deutsch et al., 1998; Lindsay et al., 2015). Indeed, the rucking, wrestling and contact phases induce increases in HR and require a greater anaerobic energy contribution (Deutsch et al., 1998; Mullen et al., 2015). The contact phases also influence running performance. Mullen et al. (2015) and Johnston et al. (2015) both demonstrated a decrease in high intensity running performance during game simulation protocols integrating multiple contacts compared to bouts of efforts with no or single contact.

Relationships between the traditional, metabolic power and HR-based methods

Near perfect correlations between the TD and ED (r = 0.98) and between the HSR and HMP distances (r = 0.93) were found in this study supporting the work of Castagna et al. (2016) who demonstrated similar associations. Our findings and those from Castagna et al. (2016) suggest that the two approaches are strongly associated, both have merit and seem to provide similar results. They can be used independently to assess the external load during outdoor team sports' games therefore. However, the percentages difference found between the two approaches in terms of the high-intensity running efforts (+ 53% vs 25%, in forwards and backs respectively) demonstrated a noteworthy difference in the two approaches in terms of the quantification of absolute distance covered, especially in forwards players ($p<0.05$). Indeed, the forwards covered a greater proportion of their running efforts in moderate speed zones (6 - 14.4 $km \cdot h^{-1}$). Furthermore, they took part in more constant motion going from ruck to ruck, and they move in smaller spaces, which do not permit them to reach high speeds but requires several accelerations (Deutsch et al., 1998; Lacome et al., 2014). Therefore, the metabolic power, considering the energy cost of accelerations, may represent an interesting complement or alternative to the traditional approach to assess high-intensity running efforts.

The TD, ED and the metabolic load presented the highest level of correlation with the TRIMP. However, all these parameters cannot account for more than 40% of the HR exertion, demonstrating the limits of the GPS/accelerometer technology to analyze the rugby union physical demands. The levels of correlation seem to be greater in the backs players. This can be explained by the greater participation of the forwards in static efforts, wrestling and rucking/scrummaging phases (Lacome et al., 2014; Roberts et al., 2008). These actions cannot be monitored from microtechnology but generate a great metabolic demand. Nevertheless, a recent study (Highton et al., 2016) demonstrated that there was a significant relationship (r = 0.63) between the external load assessed from GPS and internal load evaluated from spirometry (O_2 consumption) during a protocol simulating rugby efforts. However, the energy expenditure was, in all cases, underestimated (≈ -45%) by the GPS assessment compared to the evaluation of internal load, especially when the activity included collision.

Limitations

Whilst this study examined 14 players over the course of 5 European *Challenge Cup* games, studying more players over more games is certainly warranted to get a better understanding of the nature of the associations and differences across the measurement approaches here. Such results would be more informative in terms of exploring differences between forwards and backs in terms of TD, ED and metabolic load variables. Furthermore, several studies (Clarke et al., 2014; Lacome et al., 2014; Reardon et al., 2015) have used individual thresholds based on individual physiological components (maximum aerobic speed (MAS), speed at the second ventilatory threshold and/or maximal speed) to quantify running activity. In this study, "generic" zones and threshold based on previous studies were used to compare the different approaches (Coutts and Duffield 2010; Kempton et al., 2015). Questions remain however, about the relevance of using intensity zones and generic thresholds for the elite RU players. Moreover, equivalence between the traditional (>14.4 $km \cdot h^{-1}$) and metabolic (>20 $W \cdot kg^{-1}$) thresholds can be questioned. Indeed 20 $W.kg^{-1}$ approximately corresponding to a value of about 57 $ml \cdot kg^{-1} \cdot min^{-1}$ (Osgnach et al., 2009) may represent a value slightly higher than that of an elite RU player: around 50 to 55 $ml \cdot kg^{-1} \cdot min^{-1}$ (Duthie, Pyne and Hooper, 2003). Furthermore, 14.4 $km \cdot h^{-1}$ may be lower than MAS in elite rugby union players (around 15.5 $km \cdot h^{-1}$ in international rugby union French players) (Lacome et al., 2014). Therefore, the individualization of speed and metabolic power thresholds from maximal tests would allow for a better estimation of the high-intensity running efforts required in rugby union

Conclusion

This study considers the running and the metabolic demands of professional rugby union games. The backs covered a greater distance in high-speed running than the forwards. Nevertheless, no significant difference was found between these 2 groups concerning the distance covered at high-metabolic power. Furthermore, the metabolic power approach, which considers the accelerations and the running speed to evaluated the running demands, increases of more than 40%, the distance covered at high-intensity compared to the traditional approach. Even if the 2 methods remain extremely correlated (r = 0.93, for the high-intensity efforts), the differences in absolute values between these 2 approaches (+ 53% and 25%, in forwards and backs respectively) seem to demonstrate that the metabolic power approach represents a method that may represent a more informative alternative to the traditional approach used to analyze game performance/running activity. Our findings show that it can be useful to assess the high-intensity running efforts, particularly in forward players who performed more running efforts below the traditional approach HSR threshold. Nevertheless, the metabolic power method is not without some limitations. For example, the assessment based on the GPS signal alone demonstrates poor reliability above 20 $W \cdot kg^{-1}$ (Buchheit et al., 2015). Finally, the HR monitoring remains rarely used within professional rugby union. Therefore, HR-based methods also provide interesting information about the metabolic demands during professional rugby union games which can help coaching staff in the design of training drills, conditioned games and ultimately optimize training programs. However, further studies with larger samples across more games are necessary to better understand HR responses during elite competitive rugby union games.

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Key points

- Elite/professional rugby union players
- Heart rate monitoring during official games
- Metabolic power approach

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