©Journal of Sports Science and Medicine (2018) **17**, 633-639
http://www.jssm.org

Research article

Heart Rate-Index Estimates Oxygen Uptake, Energy Expenditure and Aerobic Fitness in Rugby Players

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Abstract
The purpose of the study was to verify the suitability of heart rate-index (HR_{index}) in predicting submaximal oxygen consumption ($\dot{V}O_2$), energy expenditure (EE) and maximal oxygen consumption ($\dot{V}O_{2max}$) during treadmill running in rugby players. Fifteen professional rugby players (99.8 ± 12.7 kg, 1.85 ± 0.09 m) performed a running incremental test while $\dot{V}O_2$ (breath-by-breath) and heart rate (HR) were measured. HR_{index} was calculated (actual HR/resting HR) to predict submaximal and maximal $\dot{V}O_2$ ({[(HR_{index} x 6)-5.0] x (3.5 body weight)}) and EE. Measured and predicted $\dot{V}O_2$ and EE were compared by two-way RM-ANOVA (method, speed), correlation and Bland-Altman analysis. Measured and predicted $\dot{V}O_{2max}$ were compared by paired t-test, correlation and Bland-Altman analysis. Submaximal $\dot{V}O_2$ and EE significantly increased (baseline $\dot{V}O_2$: 8.1 ± 1.6 $ml \cdot kg^{-1} \cdot min^{-1}$ $\dot{V}O_{2max}$: 46.8 ± 4.3 $ml \cdot kg^{-1} \cdot min^{-1}$, baseline EE: 0.03 ± 0.01 $kcal \cdot kg^{-1} \cdot min^{-1}$, peak EE: 0.23 ± 0.03 $kcal \cdot kg^{-1} \cdot min^{-1}$) as a function of speed ($p < 0.001$ and $p < 0.001$ for $\dot{V}O_2$ and EE respectively) yet measured and predicted values at equal treadmill speeds were not significantly different ($p = 0.17$; $p = 0.16$) and highly correlated ($r = 0.95$; $r = 0.94$). The Bland-Altman analysis confirmed a non-significant bias between measured and estimated $\dot{V}O_2$ (measured: 40.3 ± 10.7, estimated: 40.7 ± 10.1 $ml \cdot kg^{-1} \cdot min^{-1}$, bias = 1.35 $ml \cdot kg^{-1} \cdot min^{-1}$, z = 1.12, precision = 3.39 $ml \cdot kg^{-1} \cdot min^{-1}$) and EE (measured: 20.0 ± 0.05 $kcal \cdot kg^{-1} \cdot min^{-1}$, estimated: 20.0 ± 0.05 $kcal \cdot kg^{-1} \cdot min^{-1}$, bias = 0.00 $kcal \cdot kg^{-1} \cdot min^{-1}$, z = 0.04, precision = 0.02 $kcal \cdot kg^{-1} \cdot min^{-1}$). Estimated and predicted $\dot{V}O_{2max}$ were not statistically different ($p = 0.91$), highly correlated ($r = 0.96$), and showed a non-significant bias (bias = 0.17, z = 0.22, precision = 1.29 $ml \cdot kg^{-1} \cdot min^{-1}$). HR_{index} is a valid field method to track $\dot{V}O_2$, EE and $\dot{V}O_{2max}$ during running in rugby players.

Key words: Rugby union; cardiorespiratory fitness; sports medicine; game demands.

Introduction

Rugby Union requires players to maintain high performance levels and imposes substantial physical workloads for prolonged periods of time across the playing season (Quarrie et al., 2017). To accomplish optimum results, it is necessary to develop a range of player capacities (e.g. low to high intensity running, strength training.) and skills (e.g. passing, kicking, wrestling) in a combination that may vary according to playing position, competitive level and match situation (Austin et al., 2011). In this context, a knowledge of the demands of the game (i.e. internal and external workload and energy expenditure (EE)) it is necessary to customize training practices and nutritional strategies, for optimal body composition and performance, for specific positional roles and competitive levels (Fontana et al., 2015; 2016).

The internal and external workload of rugby has been studied using different methodological approaches like the session-rating of perceived exertion (RPE), heart rate (HR) monitors and global positioning systems (GPS) (Cunniffe et al., 2009; Halson, 2014; Quarrie et al., 2017). On the contrary, few studies have focused on EE in rugby players: overall daily EE in rugby players was estimated using SenseWear armbands (Bradley, et al. 2015a; 2015b) or calculating the EE of accelerated running by using GPS in Rugby League players (Kempton et al., 2015). However, possibly due to the practical and technical limitations of the above methods in field conditions (Morehen et al., 2016), the EE of actual playing/training in Rugby Union is still unreported.

Indirect calorimetry, based on the direct measure of oxygen uptake ($\dot{V}O_2$), is the most common method to determine EE in exercise laboratories (Jequier et al, 1987). In addition, based on the well-known linear relationship between heart rate (HR) and $\dot{V}O_2$, alternative indirect approaches for the $\dot{V}O_2$ estimate and the subsequent estimate of EE have been developed (Åstrand et al., 2003). These approaches allow accurate and precise estimates of EE in a variety of activities (Achten and Jeukendrup, 2003) and have been successfully applied in studies of elite Rugby Union (Da Lozzo and Pogliaghi, 2013); however, their practical applicability is reduced by the need of a preliminary incremental test in the laboratory (to establish the individual HR/$\dot{V}O_2$ relationship), that increases the overall financial cost and reduces the time-efficiency of the approach.

In 2011 Wicks and colleagues developed a simple HR index (HR_{index}) method to estimate $\dot{V}O_2$ in healthy non-athletes and clinical populations without the need for a laboratory test to determine the individual HR/$\dot{V}O_2$ relationship. The method was based on the observation that a valid linear relationship exists between HR_{index} (calculated as actual HR/resting HR) and $\dot{V}O_2$ expressed in multiples of the resting metabolic rate ($\dot{V}O_{2METs}$) (Wicks et al., 2011). Within the well-known limitations related to the use of HR measurement for $\dot{V}O_2$ estimation (Achten and Jeukendrup, 2003), the HR_{index} method may provide a new, low cost and easy to use alternative to existing methods to estimate $\dot{V}O_2$ and EE during Rugby activities. In fact, HR monitors are relatively "cheap" equipment, already used by elite clubs and may also represent a convenient investment for lower level clubs offer-

Received: 21 June 2018 / Accepted: 25 September 2018 / Published (online): 20 November 2018

ing important information on the absolute and relative intensity of exercise to a wide range of coaches and athletes. Furthermore, HR_{index} has been investigated in its applicability in predicting aerobic fitness ($\dot{V}O_{2max}$) (Esco et al., 2012; Haller et al., 2013), a possibility that could be useful to determine and monitor players' fitness levels without requiring expensive metabolic-carts.

However, this appealing field method is based on a linear $HR_{index}/\dot{V}O_2$ relationship that has only been validated in a non-athletic population. Consequently, the application of HR_{index} to individuals with a high fitness level requires preliminary validity verification.

Within this background, the current study tested the following hypotheses: *i)* a valid linear relationship between $HR_{index}/\dot{V}O_{2METs}$ can be confirmed in rugby players; *ii)* $\dot{V}O_2$ and EE of incremental treadmill running can be accurately and precisely estimated based on HR_{index} in rugby players; *iii)* players' $\dot{V}O_{2max}$ can be estimated using HR_{index}.

Methods

Subjects

Fifteen professional rugby players (24 ± 3 years, 8 forwards: 106 ± 10 kg, 1.89 ± 0.09 m, 18 ± 8 % fat mass; 7 backs: 93 ± 11 kg, 1.81 ± 0.08 m, 14 ± 6 % fat mass) playing in the Italian Rugby Union First Division, were recruited and included in the study after they gave their written, informed consent. The study was approved by the Departmental Ethics Committee and all experiments were done in accordance with the principles laid down in the Declaration of Helsinki. All participants were non-smokers, free of any musculoskeletal, respiratory, cardiovascular and metabolic conditions that may influence the physiological responses during exercise testing. All the incremental tests were conducted in the exercise physiology laboratory of the sports sciences section of the University of Verona on an electromagnetically controlled treadmill (Runrace, Technogym, Italy).

Resting heart rate and anthropometry

Participants were instructed to avoid any physical exercise in the 48 hours before the testing session. In the morning, after medical clearance and after a 10-min rest in a seated position, HR was measured for a period of 3 min, using a heart rate monitor (Polar Electro Oy, Finland, acquisition frequency: 5 seconds). Resting HR was identified as the lowest HR of the three minutes of monitoring (Haller et al., 2013). Then, body mass (digital scale, Seca 877, Seca, Leicester, UK), height (vertical stadiometer, Seca, Leicester, UK) and percentage of body fat (based on the sum of the 6-skinfold thickness (Fontana et al., 2015)) were determined.

Incremental test

On the same day, participants performed a step-wise incremental test consisting of 1-minute baseline measurements, 3 minutes of warm-up at 8.0 km/h, followed by step-wise increments of 0.5 km/h every minute until volitional exhaustion. The treadmill was set at 1% gradient to replicate outdoor over-ground running (Jones and Doust, 1996). The above ramp incremental protocol was chosen to obtain a time to exhaustion around 8-12 minutes (American College of Sports Medicine, 2017) using a method extensively described elsewhere (Pogliaghi et al., 2014). In brief, based on previous data by our group and others (Duthie et al., 2003; Pogliaghi and De Roia, 2007) we anticipated $\dot{V}O_{2max}$ values ranging between 46 and 52 $ml \cdot kg^{-1} \cdot min^{-1}$; considering the following energy cost of running (American College of Sports Medicine, 2017):

$\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$) = 3.5 + [0.2 x speed ($m \cdot min^{-1}$)] + [0.9 x speed ($m \cdot min^{-1}$) x grade (%)]
(grade is in decimal form: 1%= 0.01)

we estimated a maximum running speed of 200-230 m/min (12-14 km/h). Starting from 8 km/h (i.e. the lowest speed at which all subjects would run) and using 0.5 km/h increments, subjects will be exhausted between 8-12 min.

Breath-by-breath pulmonary gas exchange and ventilation were continuously measured using a metabolic cart (Quark b^2, Cosmed, Italy) as previously described (De Roia et al., 2012). Oxygen uptake ($\dot{V}O_2$), HR, and EE were calculated for each 1-minute step as average of last 10 second of each step. Maximal $\dot{V}O_2$ ($\dot{V}O_{2max}$) and maximal HR (HR_{max}) were determined as the highest values reached upon exhaustion.

Estimation of $\dot{V}O_2$ using HR_{index} method

After verification of Wick's relationship between METs and HR_{index} (see below in "statistical analysis"), individual HR_{index} was calculated as actual HR/resting HR and the Wick equation was applied to estimate a 5-s average $\dot{V}O_2$ for each step during the incremental test and to estimate $\dot{V}O_{2max}$ (Wicks et al., 2011):

$\dot{V}O_2$($L \cdot min^{-1}$) = {[(HR_{index} x 6)-5.0] x (3.5 body weight (kg))}

Finally, energy expenditure (EE-HR_{index}), relative to time ($kcal \cdot min^{-1}$) was calculated for every step of the incremental exercise based on an energy equivalent for $\dot{V}O_2$ equal to 5.0 $kcal \cdot L^{-1}$ (di Prampero, 1986).

Statistical analysis

Data are presented as means ± standard deviation throughout. After preliminary assumptions were verified, the linear relationship between HR_{index} and METs, was modelled and Pearson's product moment correlation coefficient was calculated. The original Wicks equation and equation derived from this sample of rugby players were compared through the difference between R^2 (Field, 2013). Furthermore, differences among mean values of directly measured and estimated $\dot{V}O_2$ and between measured and estimated EE were compared by two-way Repeated Measures ANOVA (method of estimate and speed), followed by Holm-Sidak correction. In addition, directly measured and the predicted values of $\dot{V}O_{2max}$ were compared using a paired t-test.

The correlation between measured and estimated submaximal $\dot{V}O_2$, $\dot{V}O_{2max}$, and between measured and estimated EE were also modelled and Pearson's product moment correlation coefficient was calculated. Lastly, a Bland-Altman analysis followed by one-sample z test was used to determine accuracy, and precision of the measured and estimated $\dot{V}O_2$, EE, and $\dot{V}O_{2max}$ values. All statistical analyses were performed using SigmaPlot 11.0 (Systat Software Inc) and $\alpha = 0.05$; statistical significance was accepted when $p < \alpha$. 95% Confidence Intervals (CI) were also reported (Cumming, 2014).

Results

The mean resting value of HR was 61 ± 5 b/min. All the subjects completed the incremental test with no adverse events (time to exhaustion= 12.0 ± 2.83 minutes, maximal speed = 14 ± 1.4 km/h, $\dot{V}O_{2max}$ = 47.1 ± 4.3 ml·kg^{-1}·min^{-1}). HR, $\dot{V}O_2$, and EE values increased as a function of speed during the incremental test. Submaximal and maximal data are presented in Table 1.

A strong positive and linear relationship was found between HR_{index} and METs (METs = 5.89 x HR_{index} – 4.88, R^2= 0.92, Figure 1), almost identical to that reported by Wicks in sedentary individuals (METs = (HR_{index} x 6) – 5, R^2= 0.95). The application of our equation did not significantly improve the prediction R^2 compared to the original equation reported by Wicks (ΔR^2 = -0.00069, $p < 0.001$). Therefore, the original Wicks equation was used for the estimation of $\dot{V}O_2$ and EE.

Repeated measures ANOVA showed a significant main effect of speed on the submaximal values of $\dot{V}O_2$ and EE ($p < 0.001$ and $p < 0.001$ for $\dot{V}O_2$ and EE respectively). On the contrary, there was no significant effect of method (measured *vs*. predicted) ($p = 0.17$; $p = 0.16$) on submaximal $\dot{V}O_2$ and EE values (Figure 2 panels A and B). Furthermore, measured and estimated values of $\dot{V}O_2$ (ml·kg^{-1}·min^{-1}) and measured and estimated values of EE were highly correlated ($\dot{V}O_2$: Figure 2 panel C, r = 0.96, p = 0.00, 95% CI [0.95, 0.97]; EE: Figure 2 panel D, r = 0.94, p = 0.00 95% CI [0.92, 0.95]). In addition, the Bland-Altman analysis confirmed a non-significant bias and a relatively small imprecision between measured and estimated $\dot{V}O_2$ (Figure 2 panel E, bias = 0.60 ml·kg^{-1}·min^{-1}, z = 0.52, precision = 2.89 ml·kg^{-1}·min^{-1}) and between measured and estimated EE (Figure 2 panel F, bias = 0.00 kcal·kg^{-1}·min^{-1}, z = 0.04, precision = 0.02 kcal·kg^{-1}·min^{-1}). Finally, estimated $\dot{V}O_{2max}$ was not significantly different from the measured value (47.1 ± 4.3 *vs*. 46.8 ± 4.3 ml·kg^{-1}·min^{-1}, p = 0.91, 95% CI [44.0, 47.9]). Furthermore, measured and estimated values were highly correlated (r = 0.96) and with a non-significant bias (bias = 0.17, z = 0.22) and good precision (precision = 1.29 ml·kg^{-1}·min^{-1}).

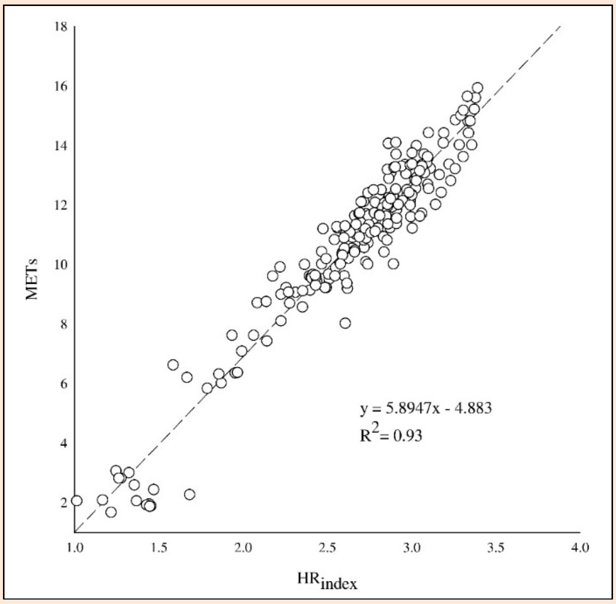

Figure 1. Exercise-response relationship between METs and HR_{index} in rugby players is displayed. The group regression line (dashed black) is displayed along with the regression equation parameters.

Table 1. Values of Heart rate (HR), directly measured oxygen consumption and energy expenditure ($\dot{V}O_2$; EE).

	Speed (km/h)	#	HR (b/min)	$\dot{V}O_2$ (ml·kg^{-1}·min^{-1})	EE (kcal·kg^{-1}·min^{-1})
	0.0	15	81±12	8.1±1.6	0.03±0.01
	8.0	15	123±21	26.9±4.8	0.12±0.03
	8.5	15	144±14	32.0±3.2	0.15±0.02
	9.0	15	150±13	34.4±2.5	0.17±0.02
	9.5	15	157±14	36.2±2.3	0.18±0.02
	10.0	15	161±12	37.5±2.6	0.18±0.02
	10.5	15	165±12	39.3±1.9	0.19±0.02
	11.0	15	171±12	41.1±2.1	0.20±0.02
	11.5	15	172±11	41.5±2.7	0.20±0.02
	12.0	15	175±10	43.0±2.5	0.21±0.02
	12.5	12	177±9	44.9±2.9	0.22±0.03
	13.0	11	180±9	44.9±3.0	0.22±0.03
	13.5	10	180±11	46.3±2.9	0.23±0.03
	14.0	10	183±11	46.9±2.8	0.24±0.03
	14.5	8	186±11	47.4±3.8	0.24±0.03
	15.0	5	184±13	48.3±5.7	0.25±0.05
	15.5	4	182±9	51.4±4.0	0.25±0.05
	16.0	1	192	53.3	0.23
Max	14±1.4	15	186±9	47.1±4.3	0.23±0.03

Data are presented for each speed of the incremental test (Speed) along with the number of players that completed the step (#). Speed "0" refers to the minute of baseline in a standing position (resting HR for HR_{index} calculation was recorded at a different time).

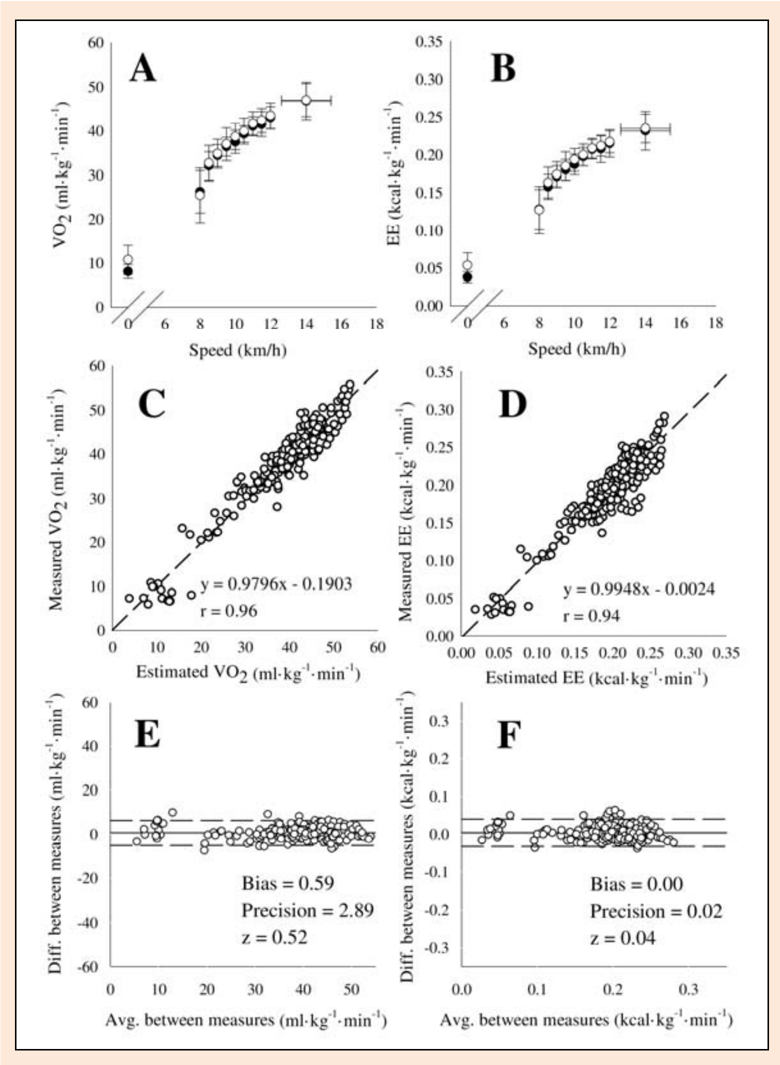

Figure 2. Panel A and B: mean directly measured and estimated VO_2 (A) and EE (B) are displayed as functions speed. Panel C and D: individual estimated VO_2 (C) and EE (D) values are plotted as functions of directly measured values. Panel E and F: Individual differences between the measured and estimated VO_2 (E) and EE (F) values are plotted as functions of the mean of the two measures. Bias (i.e., mean difference between measures; solid line) and precision (i.e., limits of agreement; dashed line) are displayed along with numerical values and the results of the one-tail z test on the bias.

Discussion

With the aim to validate, in an athletic population, the use of a "field" method developed by Wicks et al. (2011) in sedentary individuals, we tested the hypothesis that VO_2, EE, and VO_{2max} can be accurately predicted using HR_{index} in rugby players during incremental treadmill running. The study confirmed a valid linear relationship between HR_{index}/VO_{2METs} in well-trained professional rugby players, that was not different from that previously validated in non-athletic adults (Wicks et al., 2011). In agreement with our hypothesis, the predicted VO_2, EE, and VO_{2max} were not significantly different from the direct measures, and highly correlated with them. The validity of the HR_{index}-based approach in this population offers the opportunity to estimate submaximal VO_2 and EE from simple HR measures, sparing the requirement of a preliminary test to determine the individual HR-VO_2 relationship. Furthermore, HR_{index} could offer new and inexpensive alternatives to the existing indirect methods (e.g. 20-m shuttle run test) for the assessment and periodic monitoring of athletes' aerobic fitness (VO_{2max}).

The measurement of internal load and EE is particularly important in rugby, where the individualization of training and recovery strategies could be challenging as a consequence of player numbers, size and heterogeneity, the variability of movement tasks and the high training loads of the game (Fontana et al., 2015; Quarrie et al., 2013). However, the existing methods to estimate EE present limitations: the gold standard method, i.e. the doubly labelled water technique (Schoeller et al., 1986), has been used in elite Rugby League (Morehen et al., 2016) to measure EE, providing a good estimation of the EE during a certain "time window". Still, this method is impractical to track short-term variations of EE and, when used to monitor daily or weekly EE, it is prone to error due to the confounding effect of non-rugby activities and to the possible inaccuracy in recording food consumption (Gropper and Smith, 2013). In addition, the high financial costs, the need for specific equipment and trained staff make this method inaccessible to all but the top-level elite clubs.

Match analysis and global positioning systems devices have also been used to estimate EE (Cummins et al., 2017; Kempton et al., 2015). However, these techniques may lead to possible EE underestimations due to the inability to account for static efforts (e.g. scrums, mauls) as well as short-distance running that represent the primary movement characteristics of players in the forward role during a rugby match (Buchheit et al., 2015; Dubois et al., 2017; Quarrie et al., 2013). Dubois et al. (2017) recently compared the metabolic demands of professional Rugby Union using these two methods (i.e. match analysis and GPS) and HR monitors, finding that both match analysis and GPS were unable to detect 40% of the HR-detected exertion (Dubois et al. 2017). SenseWear Armbands were also used to assess EE in Rugby Union during off-season and on-season periods (Bradley, et al. 2015a; 2015b), but their use is limited since they cannot be worn during matches, physical contact or during bad weather conditions. Finally, as for the double labelled water technique, both GPS and Armbands may be affordable/manageable by top level clubs only.

The HR_{index} approach allows sports scientists to estimate EE, overcoming most of the limitations of the above methods; furthermore, it eliminates the requirement of the preliminary identification of the individual HR/$\dot{V}O_2$ relationship, inherent to previously applied HR-based methods (Da Lozzo and Pogliaghi, 2013).

In the present investigation we found that the approach originally developed by Wicks et al. (2011), in non-athletic populations, retains its validity when applied to well-trained rugby players. The fact that the anthropometric (body mass, height and % body fat) and functional characteristics ($\dot{V}O_{2max}$) of the rugby players tested in our study were comparable to those of their international counterparts (Duthie et al., 2003a; Fontana et al., 2015). suggests the generalizability of our findings to First Division players; however, further investigation in these populations is warranted.

The use of HR to estimate and monitor EE during intermittent exercise is sometimes questioned due to: *i)* inability of HR to account for the anaerobic component of exercise, potentially causing an underestimation of energy expenditure of highly intense, intermittent activities; *ii)* a relatively slow response to changes of exercise intensity (*i.e.* a relatively slow "on-phase", mirrored by a slow "off-phase" when intensity decreases, similar to the time-course of $\dot{V}O_2$) (Miyamoto and Niizeki, 1992); *iii)* a disproportionately high response of HR at very low exercise intensities (Achten and Jeukendrup, 2003). In addition, coaches and researchers should be aware of the effect of environmental factors and within subject variation on the HR/$\dot{V}O_2$ relationship during activity: hydration status, fatigue and increases in core temperature (Achten and Jeukendrup, 2003) may lead to non-metabolic increases of HR that could bias $\dot{V}O_2$ and EE estimation during very long training/game sessions and in the summer period.

Within these limitations, HR has been shown to be a valuable method to the track physiological responses in field conditions during different activities ranging from soccer (Alexandre et al., 2012) to a military loaded run (Colosio and Pogliaghi, 2018); furthermore, no differences were found between HR response during field or laboratory tests performed by either professional or amateur soccer players (Chamari et al., 2005; Hoff et al., 2002). These findings support the overall validity of HR monitoring to estimate $\dot{V}O_2$ and EE during outdoor activities/team sports under ecological conditions.

The third objective of this investigation was to compare directly measured values of $\dot{V}O_{2max}$ with the values predicted using HR_{index}. Similar to previous studies (Esco et al., 2012; Haller et al., 2013; Wicks and Oldridge, 2016), the average predicted $\dot{V}O_{2max}$ (47.1 ± 4.3 $ml \cdot kg^{-1} \cdot min^{-1}$) was not significantly different from the measured $\dot{V}O_{2max}$ (46.8 ± 4.3 $ml \cdot kg^{-1} \cdot min^{-1}$, $p = 0.91$) and they were highly correlated ($r = 0.96$). This finding supports the general applicability of HR_{index} to investigate the mean fitness level of a group of subjects (or team). Furthermore, and in contrast with the existing literature, (Esco et al., 2012; Haller et al., 2013), our study demonstrated a good agreement between the predicted and measured values of $\dot{V}O_{2max}$ (mean bias between values = 0.17 $ml \cdot kg^{-1} \cdot min^{-1}$, $z = 0.22$, precision = 1.29 $ml \cdot kg^{-1} \cdot min^{-1}$). While these results seem promising, repeatability of the method remains to be determined.

It should be noticed that the ramp incremental protocol used in this investigation was chosen to respond to two main requirements: *i)* the validation of the $HR_{index}/\dot{V}O_2$ relationship across a wide range of intensities (from low to maximal effort) without including some of the confounding factors that could be present in the most common field tests (*e.g.* changes of direction, terrain characteristics) *ii)* to obtain a time to exhaustion around 8-12 minutes and by doing so, an accurate $\dot{V}O_{2max}$ (American College of Sports Medicine, 2017). Regarding the second point, our time to exhaustion was slightly higher than expected (12.0 ± 2.83 minutes). However, it has been shown that, $\dot{V}O_{2max}$ is unaffected by speed increments in trained subjects (Kang et al. 2001; Sperlich et al. 2015). The above data support the validity of the measured values for $\dot{V}O_{2max}$ of the present study.

Finally, considering the laboratory environment of this investigation and the limitations of HR measurements, further studies should investigate HR_{index} applicability outside the laboratory environment, during training/game and field testing sessions.

Conclusion

We validated the use of the HR_{index}, originally developed by Wicks et al. (2011) on a non-athletic population, to estimate $\dot{V}O_2$, EE and $\dot{V}O_{2max}$ of treadmill running in professional rugby players. The main advantages of HR_{index} in comparison to existing methods are: *i)* low costs and minimal staff training requirements *ii)* time efficiency *iii)* the possibility to obtain time-resolved EE estimates with daily frequency *iv)* the applicability during matches/training. Finally, HR_{index} appears to provide accurate estimates of $\dot{V}O_{2max}$ in this population of professional rugby players. Within the limitation of HR-based methods, and even if further studies are needed to validate EE estimates deriving from HR_{index} in ecological conditions, this low cost and easy-to-use field method could give insight into the demands of the game in different positional roles and competitive levels, informing the customization of training practices and nutritional strategies.

Acknowledgements

The authors express their gratitude to the participants who made this data collection possible. The reported experiments comply with the current laws of the country; in which they were performed. The authors have no conflicts of interests to declare.

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Key points

- HR-index/METs relationship is valid in highly trained individuals.
- HR-index estimates oxygen uptake and energy expenditure in rugby players during running.
- HR-index could also allow indirect estimations of athletes' maximal oxygen uptake at an individual or group level.
- The main advantages of this method are: *i)* low costs and minimal staff training requirements *ii)* time efficiency *iii)* the possibility to obtain time-resolved EE estimates with daily frequency *iv)* applicability during matches/training.
- Within the limitation of HR methods, HR-index could give insight into the energetic demands of rugby.

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