Title: Physiological profile and energy expenditure of high level badminton players

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Introduction

Knowledge about cardiorespiratory and metabolic demands, as well as activity profile during competitions provides usually the basis for adequate performance assessment and evidence-based design of training programs. Despite the well-known popularity of badminton, information on physiological players' profile and energy expenditure during this activity are still very limited. The few papers present in the literature focused on heart rate (HR) (Cabello Manrique & Gonzalez-Badillo, 2003; Cabello Manrique, Padial, & A., 2004; Ghosh, Mazumdar, & Goswami, 1990; Kim, 2002) and blood lactate concentration during the match (Cabello Manrique & Gonzalez-Badillo, 2003; Cabello Manrique et al., 2004). Only two investigations included also pulmonary oxygen uptake ($\dot{V}_{O_2}$) measurement (Faccini & Dai Monte, 1996; Faude et al., 2007). Taking together, these investigations suggest that badminton can be defined as an intermittent sport activity characterized by short duration-high intensity efforts, followed by short recovery periods with very high physiological demand.

HR monitoring is a widespread indirect method to evaluate the metabolic demands during matches or specific training sessions. Indeed, based on the linearity of the relationship between HR and $\dot{V}_{O_2}$, the individual HR–$\dot{V}_{O_2}$ regression line obtained in the laboratory can be used to determine the exercise intensity and the physiological demands for the specific HR measured on the field. With the same approach, training workloads can be also defined and controlled.

However, due to its intermittent nature badminton monitoring by HR could introduce possible estimation error sources and alter the linearity of the HR-$\dot{V}_{O_2}$ relationship on the field. Consequently, this indirect $\dot{V}_{O_2}$ estimation strategy through HR monitoring can be applied only when the relationship determined in the laboratory will be verified and compared to that found on the field during specific tasks at different exercise intensities.

Beyond these traditional physiological measures, the availability of microelectronics devices and multisensor systems (WMS), that combine accelerations signals to HR, provides an alternative, noninvasive method of automatic monitoring activity and allow researchers to estimate how much energy individuals are expending during specific tasks (Wixted, 2007). To the best of our knowledge, measures of energy expenditure during badminton activity using MS are not yet available.

Noticeably, only one study on physiological demands of badminton (Faude et al., 2007) has been published after the introduction of the rally point scoring system (RPSS) in 2006. The current format with 3 games up to 21 points ("3x21") introduced by the Badminton World Federation (BWF) in 2006 changed some aspects of temporal structure and activity profile (Chen & Chen, 2008) that may influence the physiological demands of badminton. Due to the BWF intention to test a new scoring system (http://www.bwfbadminton.org/news_item.aspx?id=85879) of 5 games up to 11 points ("5x11"), a feedback from cardiorespiratory and metabolic engagement during "5x11" may provide important information for badminton practitioners and trainers.

Indeed, it is reasonable to assume that under the "5x11" scoring system, overall match duration and exercise and resting periods may all be affected, thus determining a change in the physiological demands during competitions.

For all these reasons, the aims of this study are: (i) to compare the HR–$\dot{V}_{O_2}$relationship determined on the field during badminton-specific tasks to that found in the laboratory during a standard treadmill test (STUDY 1); (ii) to compare the energy expenditure and match analysis of badminton competition under the conventional "3x21" with the new "5x11" RPSS (STUDY 2); (iii) to validate the use of multisensors systems to assess physiological demands of badminton activities compared to portable metabolimeters and HR monitoring devices (STUDY 3).

Materials and Methods

Participants

After receiving a full explanation of the aim of the study and of the experimental procedures fourteen badminton high level athletes competing at national and international competitions signed the informed consent form to volunteer to the study. The anthropometric characteristics of the group are summarized in Table 1. Before each experimental session all the participants were asked to abstain from ergogenic beverages in the 24 hours preceding the tests. They were also instructed to report to the testing session without any form of physical exercise of heavy intensity in the last 48 hours. The study was approved by the local University Ethical Committee and performed according to the principles of the 1975 Declaration of Helsinki.

This study was funded by the World Badminton Federation.

Experimental design

Participants were tested in a laboratory at constant temperature (20 ± 1 °C) and relative humidity (50 ± 5 %) for the assessments of maximal aerobic power ($\dot{V}_{O2_{max}}$). Moreover, on three separate days the energy expenditure during a match with two different scoring systems as well as during 5-min games at three different intensities (LOW, MODERATE and HIGH) was evaluated on field.

Experimental procedures and measurements

When the subjects reported to the laboratory for the individual $\dot{V}_{O2_{max}}$assessment, anthropometric and plicometric data were collected. Then each participant performed an intermittent incremental square-wave test on a treadmill ergometer (RAM s.r.l., mod.770s, Padua, Italy) with 1% incline for the maximal aerobic power assessment. Each load lasted 5 minutes to permit the assessment of the aerobic capacity during a steady-state condition. At the end of each load the athletes were asked to describe the general, muscular and respiratory rate of perceived effort on a Borg scale (6-20). After 1, 3 and 5 minutes from the end of each square-wave, the lactate concentration ($[La^-]_b$) was measured by an enzymatic-amperometric sensor (LAC^{PRO}, Bio Sensor Technology GmbH, Berlin, Germany). $\dot{V}_{O_2}$, expiratory ventilation ($\dot{V}_E$), and other gas exchange parameters were measured on a breath-by-breath basis by a portable metabolimeter (K4b^2, Cosmed S.r.l., Rome, Italy) that was calibrated before each test with a known mixture of gas (15% O_2, 5% CO_2). Beyond respiratory variables, heart rate (HR) was continuously monitored by a heart rate monitor (S810, Polar Electro Oy ©, Kempele, Finland).

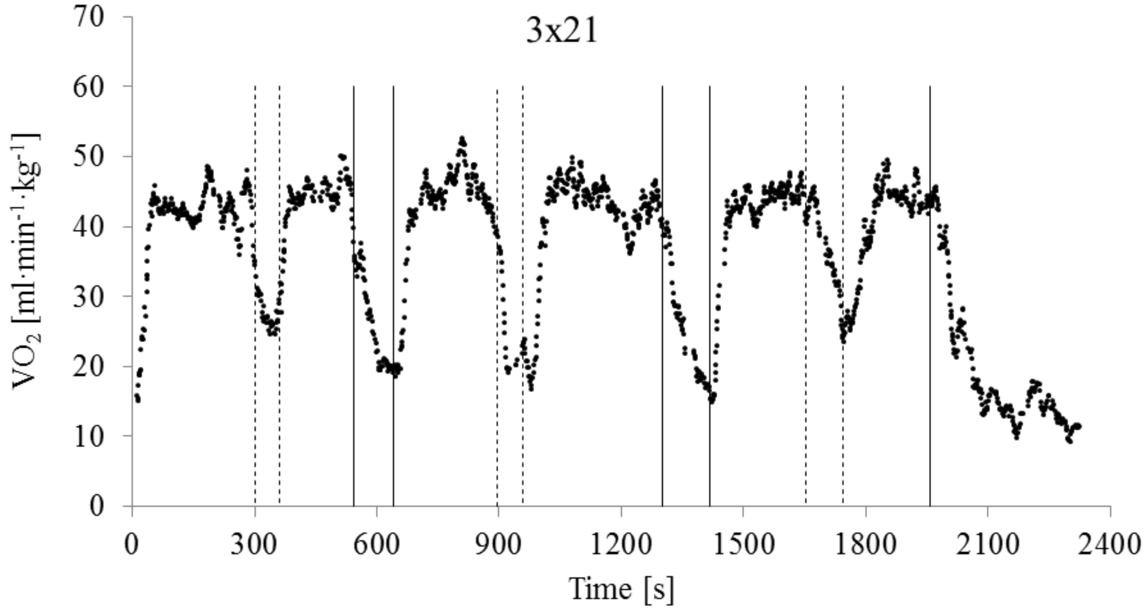
After having completed the session in the laboratory, the athletes were evaluated on the field on three separate days for the assessment of the energy expenditure under different game conditions.

The metabolic expenditure of a match with two different scoring rules was assessed by an indirect calorimetric approach (IC) in a subgroup of eleven subjects (males/females: 7/4; age: 19.5 ± 3.4 yrs; body mass: 64.0 ± 6.8 kg; body mass index (BMI): 21.1 ± 0.8 kg/m^2). One participant was excluded because of an ankle accident. In this phase $\dot{V}_{O_2}$ and other several cardiorespiratory variables were collected, during playing a match composed by 3 games up to 21 points ("3x21"). After at least 24 hours the athletes were asked to play against the same opponent but in this case the match was constituted by 5 games of 11 points ("5x11"). The metabolic results of the two types of matches were compared.

An example of oxygen uptake during two matches with different scoring rules of a representative athlete is shown in Figure 1.

Table 1. Participants' characteristics. *:P<0.05 *vs* dominant side

	All	Males	Females	
Participants [n]	14	9	5	
Age [yrs]	18.8 ± 3.6	19.6 ± 3.8	17.4 ± 2.9	
Body Mass [kg]	63.6 ± 7.4	67.5 ± 5.5	56.5 ± 4.4	
Height [cm]	173.4 ± 9.8	178.4 ± 8.2	164.4 ± 4.7	
$\dot{V}_{O2max}$ [ml $\cdot min^{-1} \cdot kg^{-1}$]	52.3 ± 6.9	55.2 ± 6.3	45.8 ± 1.1	
All	*Dominant side*	*Non dominant side*		*P*
Dominant Upper arm CSA [cm^2]	42.3 ± 7.6	39.4 ± 5.2*		< 0.05
Dominant Forearm CSA [cm^2]	41.9 ± 7.3	38.5 ± 4.4*		< 0.05
Dominant Thigh CSA [cm^2]	167.6 ± 23.2	162.0 ± 20.3*		< 0.05
Males				
Dominant Upper arm CSA [cm^2]	47.5 ± 5.1	42.4 ± 5.2*		< 0.05
Dominant Forearm CSA [cm^2]	47.5 ± 3.1	41.1 ± 3.4*		< 0.05
Dominant Thigh CSA [cm^2]	185.5 ± 10.6	176.9 ± 8.4*		< 0.05
Females				
Dominant Upper arm CSA [cm^2]	35.8 ± 4.1	35.6 ± 1.5		n.s.
Dominant Forearm CSA [cm^2]	34.8 ± 3.4	35.2 ± 2.9		n.s.
Dominant Thigh CSA [cm^2]	145.2 ± 9.4	143.4 ± 13.3		n.s.



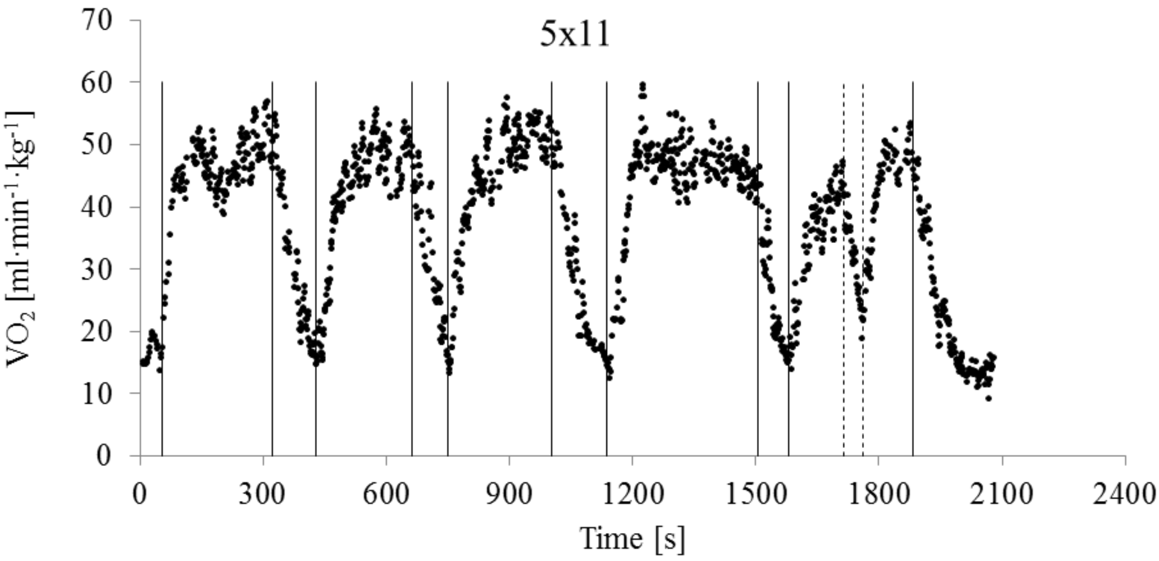


Figure 1. Example of the oxygen uptake during two different matches: “3x21” (upper panel) and “5x11” (lower panel). Continuous line indicates the beginning and the end of each game and the dotted lines refer to the beginning and the end of the interval within the game.

Overall match duration, games duration, rally time, rest time, effective playing time (EPT), shots per rally, work density, and shot frequency were also recorded to determine the temporal structure of the games. In addition, frequency of rally and rest time distribution were calculated.

On a third day, in a subgroup of eight athletes (males/females: 4/4; age: 16.8 ± 2.0 yrs; body mass: 63.3 ± 8.4 kg; BMI: 21.3 ± 1.4 kg·m^{-2}, mean ± standard deviation), the metabolic expenditure of three different playing was estimated by WMS (Actiwave Cardio©, CamNtech Ltd., Cambridge, United Kingdom) and compared to the minute energy expenditure (EE/min) derived by IC, being considered as the reference value. Moreover, in addition to the cardiorespiratory parameters previously cited, the HR-$\dot{V}_{O_2}$relationship was also assessed and compared with the one obtained in laboratory during a standard treadmill test. Each game lasted 5 minutes and the intensity was randomly chosen among LOW, MODERATE and HIGH level of effort. In all the field sessions, from 1 minute after the end of the practice, every two minutes $[La^-]_b$ was measured till a decrease in the value was observed. The peak value was used to compute the metabolic equivalent of $[La^-]_b$ for further analysis. In all the field test at the end of each set the general, muscular and respiratory effort perceived was determined on a 6-20 RPE scale.

Data analysis

Cardiopulmonary data measured by the metabolimeter on a breath-by-breath basis were computed off line. After having removed spurious data a moving average on 4 samples was applied. The $\dot{V}_{O2_{max}}$ was established from the plateau attained by the relationship between oxygen uptake and the increasing workload. The minute energy expenditure was calculated as the sum of the aerobic energy equivalent, the lactic energy equivalent and the anaerobic alactic energy sources. The former was calculated considering the oxygen equivalent; regarding the lactic contribution the energy equivalent for blood lactate accumulation of 3.3 $ml \cdot kg^{-1} \cdot mM^{-1}$ was used. Then the latter was computed by the hydraulic model of muscle energetic assuming a time constant of phosphocreatine decrease equal to 23 s.

The energy expenditure estimated by WMS was based on a branched model (Brage et al., 2007) that took into account several factors among which sleeping heart rate, body mass index, age and the gender of the subjects. A multisensor device able to combine acceleration signals and HR was adopted to improve the estimation accuracy indeed, during the computation the accelerometer signals were considered in conjunction with heart rate to avoid the errors that usually occur in estimating EE by acceleration alone.

The metabolic expenditure obtained by gas analysis (enriched with the lactate metabolic equivalent) (IC) and by WMS were computed off-line as the mean of the last minute where the data remained in a steady state condition.

Statistical analysis

Data were analyzed by a statistical software package (SigmaPlot v.12.5, SysStat Software Inc, San Jose, CA, USA). The normal distribution of the sample was checked by a Shapiro-Wilk Test.

STUDY 1: A Student t-test was executed to test the null hypothesis of a difference between the HR-$\dot{V}_{O2}$relationships obtained in laboratory and on field. Moreover, a one-way ANOVA for repeated measures was applied to test the null hypothesis of a difference among the cardiorespiratory and metabolic variables assessed during the sets played at the three intensities (LOW, MODERATE and HIGH).

STUDY 2: A student t-test was evaluated the presence of a difference between temporal structure and rallies characteristics between the two RPSS. A two-way ANOVA for repeated measures was executed to test the null hypothesis of a difference between the EE measured during the two matches with different scoring rules, considering the different rule as factor and sets as levels. A Holm-Sidak post hoc test was used when necessary.

STUDY 3: A two-way ANOVA for repeated measures was also executed to detect the presence of differences between the EE estimated by MS and the one given by IC in each intensity level, with the type of device as factors and the different intensity of set as levels. A Holm-Sidak post hoc test was used when necessary. A one-way ANOVA for repeated measure tested the null hypothesis of a difference among the general, muscular and respiratory RPE values at the three different intensities. A linear regression analysis was adopted to check the agreement between the EE estimated by MS and by IC. Afterwards, a Bland and Altman statistics was performed to further evaluate the association between the two methods. A Student *t* test on the linear regression line, between the mean EE and the difference in the EE of the two devices (the estimated by the MS and the reference one given by IC) to estimate the possible occurrence of a proportional statistical bias in the difference between methods at increasing EE was executed.

If not otherwise stated data are expressed as mean ± stadrad deviation (SD). Moreover, in all the statistical analysis the level of statistical significance was set at P<0.05.

Results

STUDY 1

Comparison of HR-$\dot{V}_{O_2}$ relationship between standard treadmill test and badminton specific tasks.

In figure 2 $\dot{V}_{O_2}$ and HR data of a representative subject during the three intensities are reported.

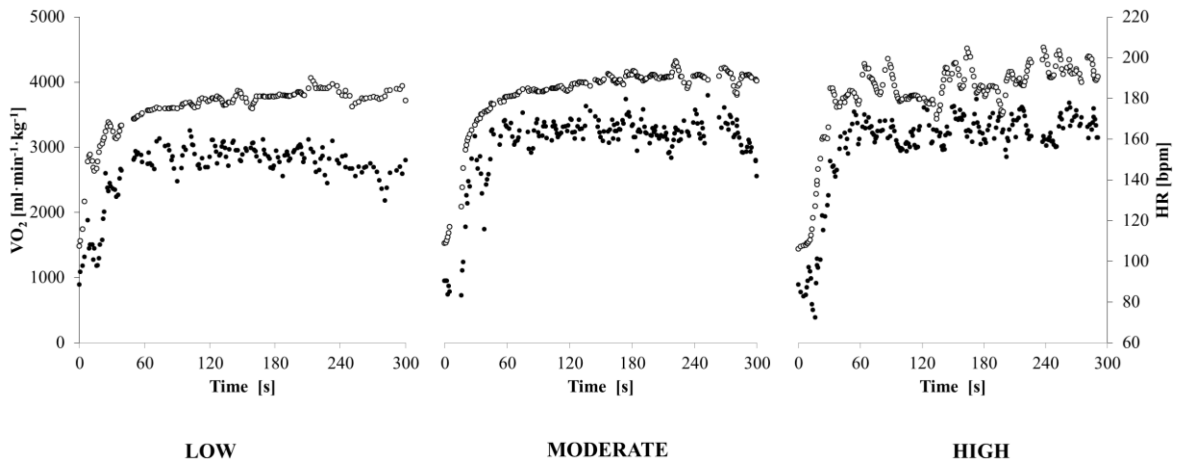


Figure 2. $\dot{V}_{O_2}$ and HR patterns measured in a representative subject during the different intensities game. Black circles and white circles refer to $\dot{V}_{O_2}$ and HR, respectively.

In Figure 3 and 4 mean values of metabolic and respiratory parameters at the three different game intensities are depicted. Data are expressed as the percentage of the maximum value obtained in laboratory during the standard treadmill test. By the one-way ANOVA for repeated measures only oxygen uptake of HIGH resulted to be significantly higher than LOW while CO_2 production increased both in MODERATE and HIGH compared to LOW intensity practices. $[La^-]_b$ measured during HIGH was significantly higher than LOW and MODERATE intensity level, and the value of MODERATE significantly increased compared to LOW, as well (Figure 3). $\dot{V}_E$, respiratory tidal volume (VT), respiratory frequency (RF) and HR were significantly higher at MODERATE and HIGH compared to LOW intensity (Figure 4). No differences were found in all these parameters, except to $[La^-]_b$, between MODERATE and HIGH level of effort.

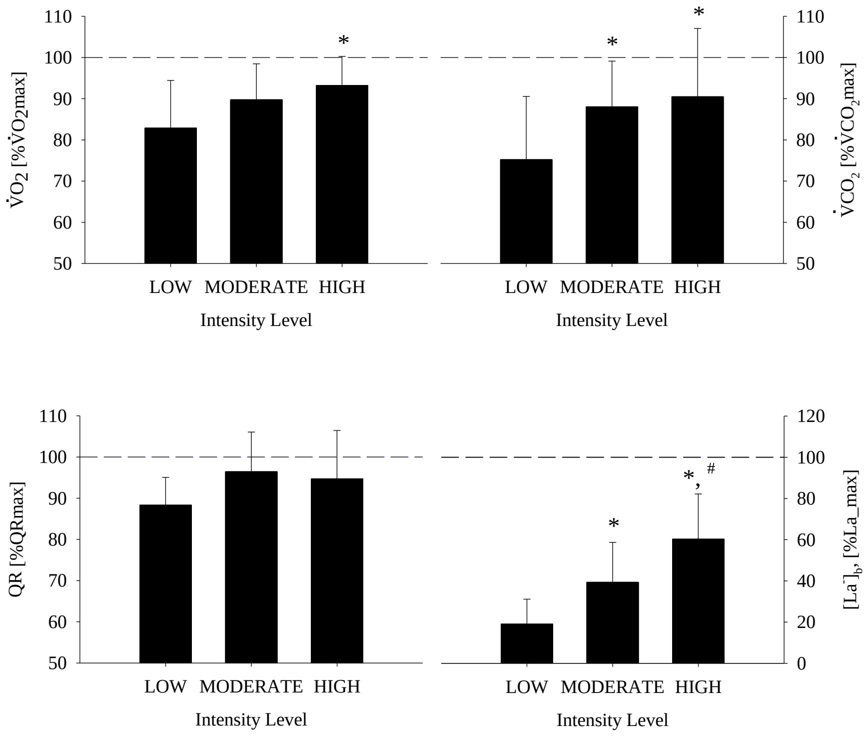


Figure 3. Metabolic parameters measured during the three different playing intensities. Panel A, B, C and D depict respectively oxygen uptake $\dot{V}_{O_2}$, carbon dioxide production $\dot{V}_{CO_2}$, QR and $[La^-]_b$ as the percentage of the maximal values obtained during incremental treadmill test. *P<0.05 vs. LOW; #P<0.05 vs MODERATE.

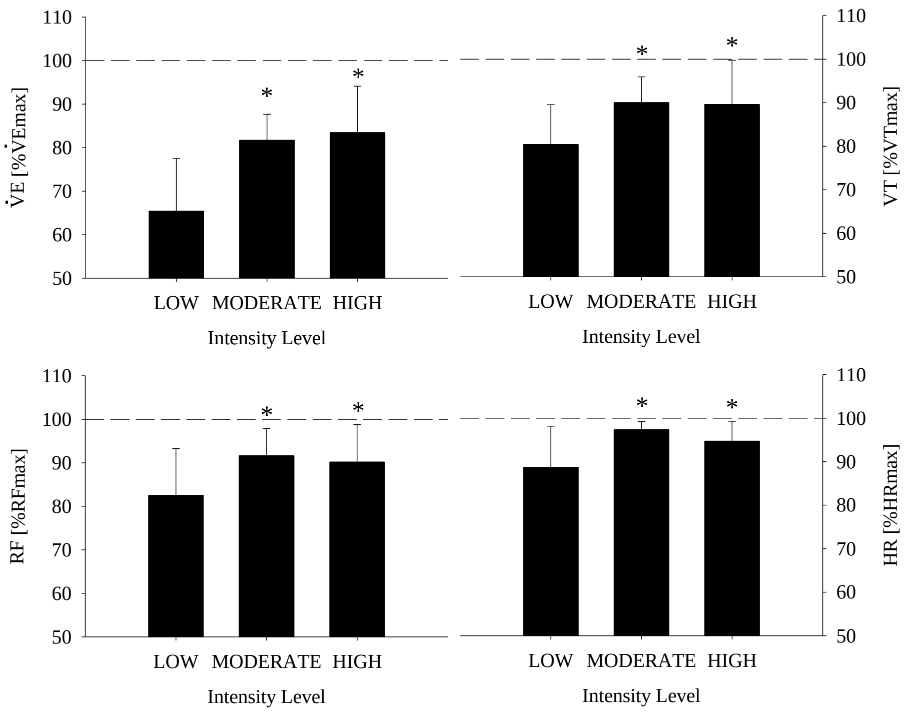


Figure 4. Cardio-ventilatory parameters measured during the three different playing intensities. Panel A, B, C and D depict respectively minute ventilation ($\dot{V}_E$), tidal volume (VT), respiratory

frequency (RF) and heart rate (HR) as the percentage of the maximal values obtained during incremental treadmill test. *P<0.05 vs. LOW; #P<0.05 vs MODERATE.

The HR-$\dot{V}_{O_2}$ relationship determined in the laboratory was computed on the average of the last 15 seconds at each step. The two average regression lines obtained in laboratory and on field are shown in figure 5. The Pearson product moment correlation coefficient obtained during incremental test and during the sets at different intensities were 0.657 and 0.391, respectively. The mean value of the linear regression line slope significantly decreased in the field tests (1.51 ± 0.41, 1.01 ± 1.59 bpm·mlO_2^{-1}·min·kg for laboratory and field settings, respectively; P<0.05, Figure 5). On the other hand the mean intercept obtained during match simulations were significantly higher (about +25%; P<0.05).

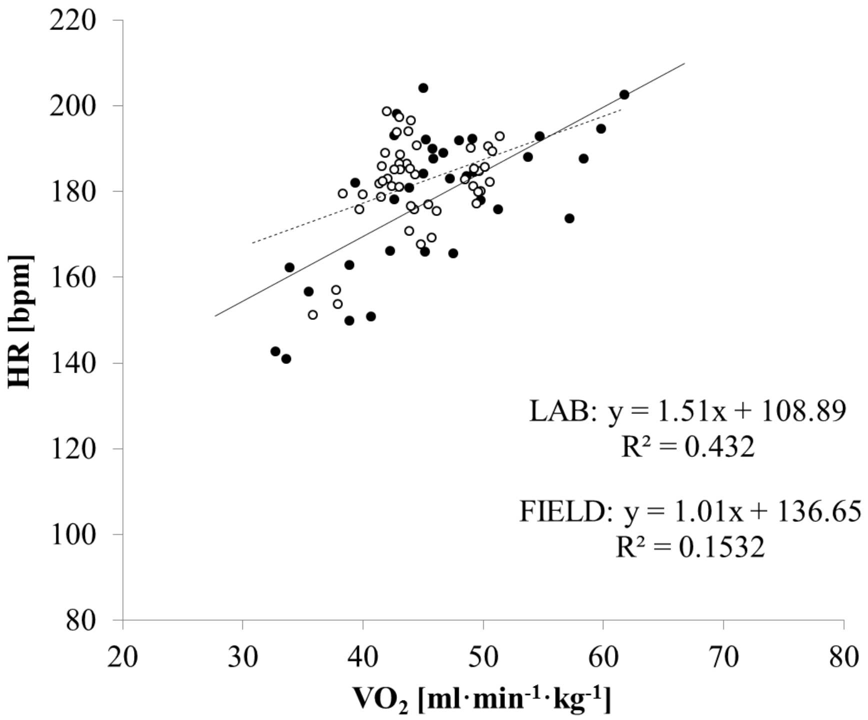


Figure 5. HR-$\dot{V}_{O_2}$ relationship. Black circles refer to data acquired during laboratory incremental test and white circles represent data measured on field during rallies simulations at different intensities.

STUDY 2

Temporal structure and energy expenditure of badminton competition under conventional "3x21" with the new "5x11" RPSS.

As expected the duration of each game was shorter during "5x11" compared to "3x21" (P<0.05) with a mean game time of 282 ± 32 s and 582 ± 35 s for "5x11" and 3x21", respectively. However, the total time necessary to complete a match was similar (1910 ± 193 s and 1987 ± 338 s for "5x11" and 3x21", respectively; P: n.s.). A mean of 105 ± 8 and 90 ± 6 rallies were played and 601±23 and 558±86 shots executed during the "3x21" and the "5x11", respectively. Mean rally time was 6.0 ± 4.0 s and 6.3 ± 4.2 s, and mean rest time was 9.6 ± 3.6 s and 9.4 ± 3.3 s for "3x21" and "5x11", respectively. 84.5% ("3x21") and 83.2% ("5x11") of all rallies lasted between 1 and 10 s, with a rally time between 4 and 8 s occurring most frequently (Figure 6). In contrast, rest time was mostly situated for both conditions between 8 and 14 s (80.4% and 82.0% for "3x21" and "5x11", respectively) (Figure 7). Shots per rally were 5.7±0.9 and 6.2±1.0, with a shot frequency of 0.9±0.2 shot·s^{-1} and 1.0±0.2 shot·s^{-1} under the "3x21" and the "5x11" format, respectively. Lastly, EPT was 32±3% and

30±3%, with a work density of 0.72 and 0.70 for "3x21" and the "5x11", respectively. Number of rallies played and EPT were the only variables significantly different between the two scoring systems ($P<0.05$). Data from temporal structure of the matches are reported in table 2.

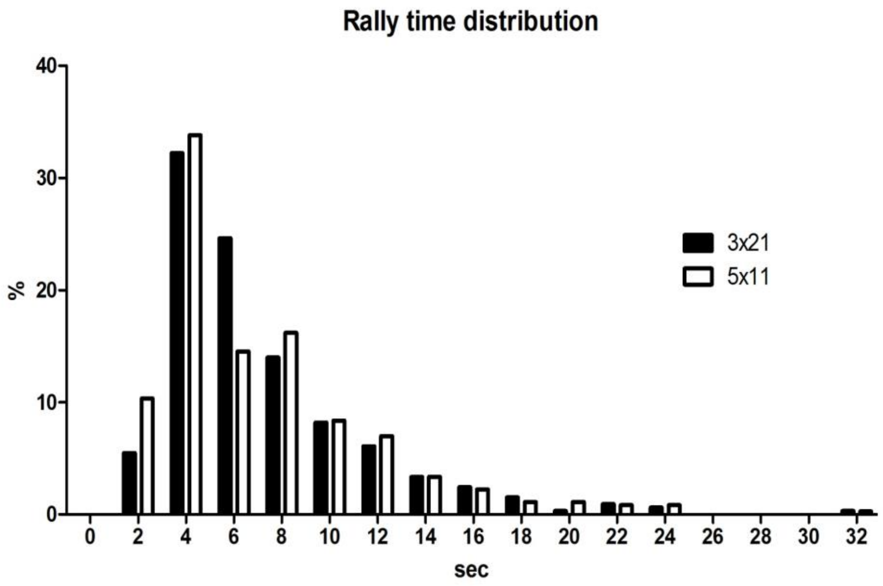


Figure 6. Histogram depicting the distribution of the rally time along the game duration. Black bars and white bars refer to "3x21" and "5x11" scoring rule, respectively.

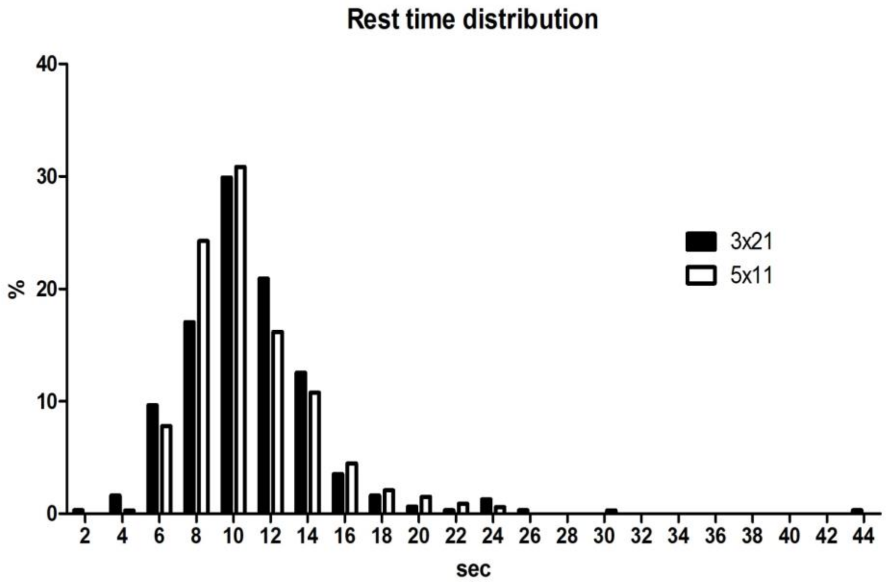


Figure 7. Histogram graph representing the distribution of rest time along the game duration. Black bars and white bars refer to "3x21" and "5x11" scoring rule, respectively.

Table 2. Comparative results of traditional "3x21" to "5x11" badminton match characteristics. Values reported by Phomsoupha and Laffaye, (Phomsoupha & Laffaye, 2015) are also listed. *P<0.05 vs "5x11"

	Phomsoupha and Laffaye (2015) (mean range)	Data from this study "5x11" (mean ±SD)	Data from this study "3x21" (mean ±SD)
Match duration (s)	1020 – 2378	1910 ± 193	1987 ± 388
Rally time (s)	4.1 – 10.4	6.3 ± 4.2	6.0 ± 4.0
Rest time (s)	9.71 – 26.7	10.3 ± 3.4	9.6 ± 3.6
EPT (%)	27.7 – 38.5	30 ± 4	34 ± 3*
Work density	0.36 – 0.57	0.70 ± 0.47	0.75 ± 0.47
Shots per rally (n.)	3.5 – 11.1	6.8 ± 0.4	6.2 ± 0.5
Shot frequency (shot·s^{-1})	0.8 – 1.1	1.0 ± 0.2	0.9 ± 0.2

The $\dot{V}_{O2}$, $\dot{V}_E$ and HR, expressed as percentage of the maximum value obtained during treadmill test, measured during "3x21" were similar to the data measured during "5x11" (72 ± 8% and 73 ± 8%; 62 ± 23% and 61 ± 21%; 86 ± 5% and 85 ± 6%, respectively; P: n.s. for all the parameters comparison). The minute EE measured during each game of "3x21" was significantly lower than the second and third game of "5x11" (about -11%, P < 0.05, Figure 8 panel A) but the mean value of minute EE required to complete the whole game was similar between the two scoring systems (50.1 ± 7.6 kJ/min and 50.7 ± 7.1 kJ/min, for "3x21" and "5x11" respectively; P = n.s.). The metabolic expenditure of a single game was significantly lower in the "5x11" scoring rule (about -50%, P < 0.05) however, at the end of the match the total EE was similar to "3x21" (1782 ± 553 kJ and 1627 ± 267 kJ, for "3x21" and "5x11" respectively; P: n.s.; figure 8, panel B).

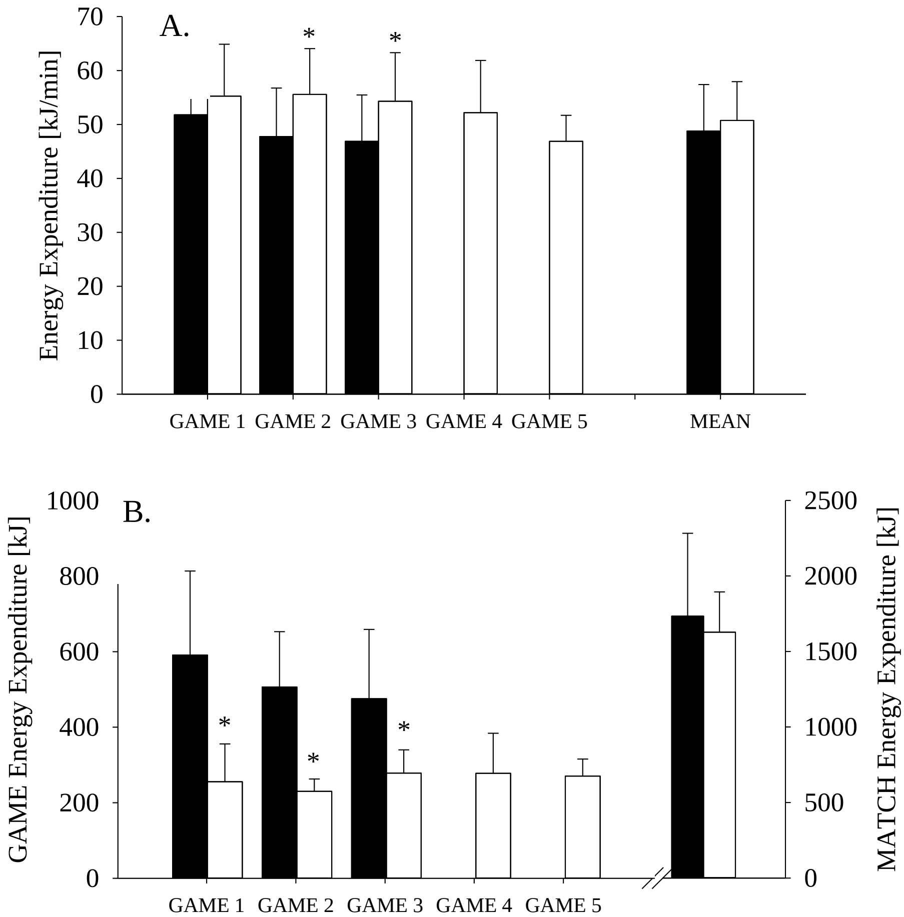


Figure 8. Mean energy expenditure (EE) measured during the classical "3x21" and during "5x11" scoring rule. Black bars and refer to "3x21" and "5x11" RPSS, respectively. *P<0.05 vs "3x21".

STUDY 3

Validation of multisensors system

Minute EE of the three different intensity practices calculated by IC were about 53.9 ± 7.3, 62.3 ± 13.7 and 64.3 ± 12.8 kJ/min for LOW, MODERATE and HIGH intensity, respectively. The two-way ANOVA analysis demonstrated that EE/min significantly increased from LOW to MODERATE playing intensities but no change was found between MODERATE and HIGH game. In all conditions WMS metabolic expenditure estimation was higher than the one obtained by IC (+59%, +41% and +38% for LOW, MODERATE and HIGH, respectively; P < 0.001) but this bias remained constant among each intensity indeed, there were no differences among the regression lines at each intensity of practice.

Regarding the reported RPE after LOW, MIDDLE and HIGH intensity, the general perceived efforts were 9.9 ± 1.9, 13.7 ± 1.9 and 15.0 ±2.3 a.u., respectively; muscular values amounted to 9.1 ± 1.5, 13.2 ± 2.2 and 14.5 ± 2.8 a.u. and respiratory perception was 10.7 ± 2.5, 14.8 ± 2.2 and 15.5 ± 2.7 a.u., from the lightest to the hardest practice, respectively. All the RPEs (general, muscular and respiratory) in LOW were significantly lower than MIDDLE and HIGH (P<0.05); on the contrary, no differences emerged when comparing MIDDLE to HIGH RPE values.

A scatter plot of EE/min values obtained by MS and IC in each game intensity was reported in figure 9.

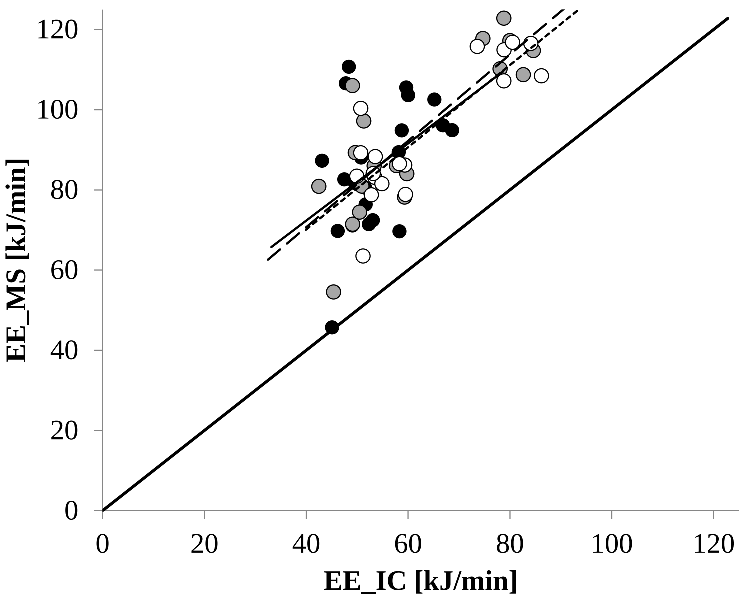


Figure 9. Energy Expenditure estimated by MS against the values measured by IC are plotted at each game simulation intensity. Black, grey and white circles refer to LOW, MODERATE and HIGH intensity, respectively. The identity line is represented by the fat continuous line. Regression line during LOW, MODERATE and HIGH intensity: $EE\_MS_{LOW} = 0.96 \cdot EE\_IC_{LOW} + 33.85$, $R^2 = 0.19$; $EE\_MS_{MODERATE} = 1.08 \cdot EE\_IC_{MODERATE} + 27.66$, $R^2 = 0.66$ and $EE\_MS_{HIGH} = 1.02 \cdot EE\_IC_{HIGH} + 29.16$, $R^2 = 0.72$, respectively. P = n.s. among regression lines.

The values obtained by WMS were constantly higher compared to the reference values and the error residuals seemed to be inversely proportional to the intensity level. The distribution of the error at increasing exercise intensity against the mean values of the two methods is plotted on the Bland-Altman plot in Figure 10. The mean overestimation accounted for about 30 kJ/min and the distribution of the difference increased with the rise of the mean EE. A Student *t* test on the regression line confirmed a proportional bias in the estimated EE ($P<0.05$).

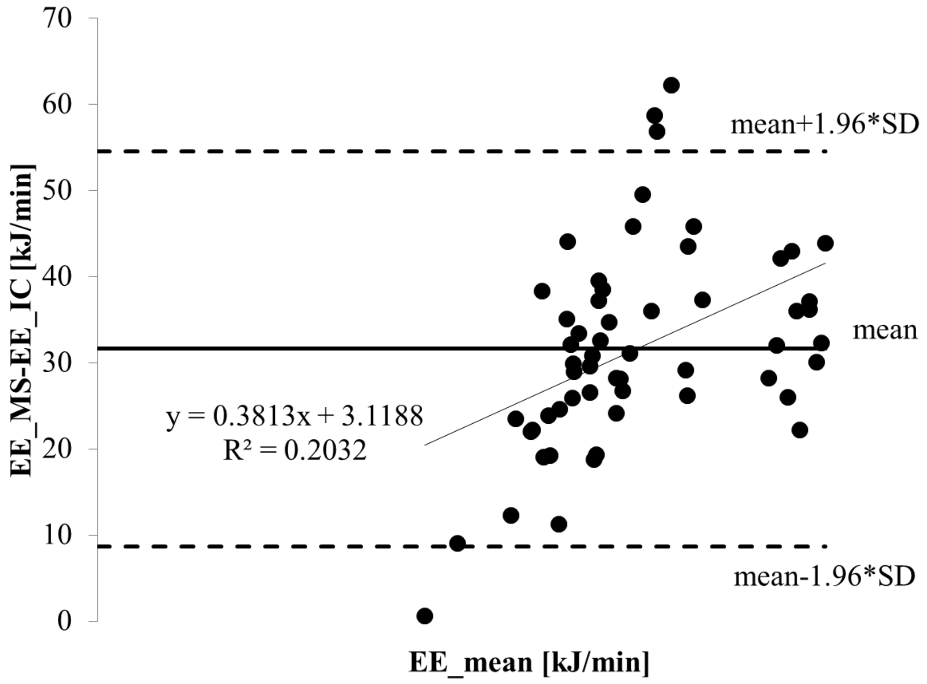


Figure 10. Bland Altman plot depicting the error distribution against the mean of the EE expenditure measured by IC and estimated by MS.

Discussion

STUDY 1

One of the aim of the present study concerns the comparison of the HR and $\dot{V}_{O_2}$relationships obtained by a treadmill incremental test in laboratory settings to the one obtained on field while playing rallies at increasing intensity. The measure of cardio-respiratory parameters during playing badminton would provide information on the metabolic events that support the activity however, the device necessary to measure this kind of variables results to be cumbersome and obstructive to the practice thus, a different approach that could give similar information should be adopted. HR is known to be linearly related to $\dot{V}_{O2}$ (Astrand PO, 1977) thus allowing to estimate the physiological demand of a specific task by the measure of heart rhythm but only when the HR-$\dot{V}_{O_2}$ratio is known (Esposito et al., 2004). If during match simulations a correspondence of the relation between HR and $\dot{V}_{O_2}$obtained during treadmill test and field sessions is valid, estimation of oxygen uptake would be obtained by monitoring the only HR also during training or match situations when a direct measure isn't allowed. An accurate definition of this relationship is usually done in the laboratory by a direct assessment of individual oxygen uptake and HR during a incremental treadmill test. Noticeably, the monitoring of HR directed to give metabolic information could be adopted only when a correspondence between the HR-$\dot{V}_{O_2}$ratio obtained in laboratory setting is similar to that evaluated on field. The main findings of the present study is that the relationship between HR and $\dot{V}_{O_2}$ differs when assessed with a treadmill test or during executing a match simulation. In this latter case HR it could be noted that HR begin to rise immediately at the beginning of the game even when the intensity is LOW. This behavior could be explained by a nervous system strategy that over-activate the cardiac activity probably to favor a prompt reaction to the opponent's shots since the very beginning of the game. The main consequence of this result is represented by the fact that monitoring HR during field activities is not able to provide accurate information on the metabolic events that support the specific tasks.

STUDY 2

The temporal structure of badminton matches played under the traditional “3x21” scoring system in our study is similar to that found by others studies and summarized in a recent review (Phomsoupha & Laffaye, 2015) (Table 2). BWF introduced this “3x21” RPSS in 2006 in substitution of the old “sideout” scoring system where games were played to 15 points (11 for women). This variation resulted in a change of some aspects of temporal structure and activity profile (Chen & Chen, 2008). In particular, a significant decrease in the average overall match duration and a significant increase in the average number of shots has been observed (Phomsoupha & Laffaye, 2015). Recently, BWF is testing a new RPSS of 5 games up to 11 points (“5x11”) that could also influence game characteristics. The results of our study show that most of game characteristics are similar between the “3x21” and “5x11” scoring system. As expected, single games are significantly shorter in “5x11” with respect to “3x21” however total match duration is similar between conditions. The EPT and rallies played are significantly lower during the “5x11”. EPT depends on rally time and total match duration, therefore it is influenced by work and rest duration. Mean rally and rest time and total match duration is similar between condition, consequently the difference in EPT depends on others factors. In the “3x21”, when the leading score reaches 11 points, players have a 60 seconds interval. At the end of each game players have 2-minute interval. Consequently, in a 3 games match a total of 6 minutes of interval are permitted. In the “5x11” players have 2-minute interval between games and an extra 60 second interval only in the fifth game, when leading score reaches 6 points. In this case 9 minutes of interval are possible. In this study participants were asked to play a complete match (3 games in “3x21” and 5 games in “5x11”) so rest interval regulated by the laws of badminton may explain the difference in EPT.

As for total rallies played, the difference between the two scoring system may be explained by BWF rules. In fact, in “3x21” the score can go above 21, to a maximum of 30 points, whereas in “5x11” the games end no later than 11 points. Therefore, it is possible to play an higher number of rallies during the “3x21”. Data on physiological characteristics of badminton matches are still lacking. The only study published after the introduction of the “3x21” observed an average $\dot{V}_{O2}$ value corresponding to 73±6.5% of $\dot{V}_{O2peak}$, HR data of 89±4.6% of maximal heart rate, blood lactate accumulation of 1.9 ± 0.7 mmol·l^{-1} and EE values of 53.3±12.7 kJ·min^{-1} (Faude et al., 2007). These data are similar to those observed in this study.

Our data show no difference in oxygen uptake, ventilation, HR and blood lactate accumulation between “3x21” and “5x11”. Therefore, the high intensity demand of the game is maintained in both scoring system. Total energy expenditure was lower during each game for “5x11” in accord with shorter game duration, however total energy expenditure for the whole match was similar between conditions. During “5x11” EE expenditure per minute was higher with respect to “3x21” probably due to the slightly higher shots frequency, however there was no difference between scoring system when considering a complete match. These data suggest that also cardiovascular and metabolic strain are comparable between the two scoring system.

STUDY 3

To our knowledge this is the first study that evaluate the performance of a portable multisensors for monitoring the energy expenditure during the practice of badminton games. The use of this wearable devices has been recently introduced to support the monitoring of activity in order to have a better insight into the metabolic events that sustain specific tasks. Even if this approach is widely used in daily living (Butte, Ekelund, & Westerterp, 2012; Rampichini S., 015) and in several team sport games (Dellaserra, Gao, & Ransdell, 2014; Walker, McAinch, Sweeting, & Aughey, 2016), their accuracy in estimating energy expenditure is still not satisfying. In the present study different intensity levels have been performed in order to evaluate the performance of the device either at light and at more intense practices. Both EE and RPE values assessed at the three activity intensities increased significantly form LOW to HIGH games demonstrating that a real growth in the energy demand and perception of effort occurred. The results of this study show that the combination of accelerometer signals to HR monitoring provides and energy expenditure data that overestimates the reference value at each playing intensity. Indeed, in all the game, the values estimated by WMS were higher compared to the data obtained by the reference approach. These results could depend on the characteristics of the badminton activity that is composed by several rapid movements and direction changes that heavily influence the accelerometer signals. The branched algorithm used to estimate energy expenditure is based either on HR values and on the activity index, a parameter that derived from the accelerometer signal. As the algorithm for the energy expenditure estimation has been validated on activities (Brage et al., 2007) with no changes in the movements direction, it is reasonable to hypothesized that badminton, being composed by rapid and continuous changes of direction, needs a different computational model. On this study the bias between WMS energy expenditure and the reference value amounts to about 30 $kJ \cdot min^{-1}$ and shows to be constant along the increase of the activity intensity. These results suggest caution in the use of this kind of devices for the metabolic expenditure estimation because the algorithm usually used for the estimation has been done on different activities and doesn't fit the tasks performed during badminton game.

Conclusions

One of the main findings of the present project allows, by the STUDY 1, to conclude that the HR-$\dot{V}_{O_2}$ relationship assessed in laboratory setting with a standard treadmill test can't be transposed to field conditions. If a correspondence between HR and $\dot{V}_{O_2}$ during performing specific badminton tasks is necessary, an individual task-oriented protocol able to match HR monitoring to metabolic information should be executed on field.

The results of STUDY 2 suggest that in comparison with "3x21" scoring rule, the "5x11" allows a lower number of rallies. Even if a single game of "5x11" is shorter compared to "3x21" either the total duration of the match and the total energy expenditure of the whole match are similar demonstrating that cardiovascular and metabolic strain are comparable between the two scoring system. Only number of rallies played and EPT were the significantly different between the two scoring systems. It is possible that more time under the "5x11" is needed to change tactical habits that can influence the structure of matches and, eventually, the energetic profile.

In conclusion, from the third study emerged that caution in the use of multisensor devices has to be taken when the metabolic expenditure is the main goal. A task-specific model should be implemented to better fit the EE estimation to the measured one.

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