

Physiological profile and energy expenditure of high level badminton players.

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Introduction. Badminton is one of the most popular sports in the world. It is characterized by short duration-high intensity intermittent actions and various performance factors, such as technical, tactical, and conditional aspects. Despite the well-known popularity of badminton, information on physiological players' profile and energy expenditure during this activity are still very limited. Few papers present in the literature focused on heart rate (HR), while only two investigations included also pulmonary oxygen uptake (\dot{V}_{O_2}) measurement. The actual badminton scoring system consists of 3 games up to 21 points ("3x21") but recently, the Badminton World Federation is introducing a new scoring system with 5 games up to 11 points ("5x11"). It is reasonable to assume that under the "5x11" scoring system, overall match duration and exercise and resting periods may be affected, thus determining a change in the physiological demands during competitions. Then, a feedback from cardiorespiratory and metabolic engagement during "5x11" may provide important information for badminton practitioners and trainers.

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).

Methods: *Participants:* fourteen high level badminton athletes competing at national and international level, were recruited for the study. *Experimental procedures:* participants performed an intermittent incremental square-wave test on a treadmill ergometer for the maximal aerobic power assessment, during which cardiorespiratory data (\dot{V}_{O_2} ; expiratory ventilation, \dot{V}_E ; heart rate, HR) were collected on a breath-by-breath basis together with blood lactate concentration ($[La^-]_b$). On different days, participants were paired up to play against each other playing the "3x21" or the "5x11" match, in random order. Cardiorespiratory and metabolic variables were collected during all matches. In addition, from \dot{V}_{O_2} and respiratory quotient data, total and per minute energy expenditure (EE) were calculated. 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. Overall match duration, games duration, rally time, rest time, effective playing time (EPT), shots per rally, work density, and shot frequency were recorded to determine the temporal structure of the games. In addition, frequency of rally and rest time distribution were calculated. Data are expressed as mean \pm standard deviation. On a third day, in a subgroup of eight athletes, the metabolic expenditure of three different playing intensities (LOW, MODERATE and HIGH) was estimated by a wearable multisensors (WMS) and compared to the minute energy expenditure (EE kJ/min) derived by IC, being considered as the reference value. At the end of each game, the rate of the perceived exertion (RPE) at general, muscular and respiratory level was also assessed. Moreover the HR- \dot{V}_{O_2} relationship was also assessed and compared with the one obtained in laboratory during a standard treadmill test

Results. STUDY 1: comparing the three play intensities, \dot{V}_{O_2} of HIGH resulted to be significant higher than LOW. \dot{V}_E and HR were significantly higher at MODERATE and HIGH compared to LOW intensity and $[La^-]$ was significantly higher in HIGH than LOW and MODERATE intensity. The slope of HR- \dot{V}_{O_2} relationship didn't change in the field tests with respect to the laboratory test but the intercept significantly increased.

STUDY 2: the \dot{V}_{O_2} , \dot{V}_E and HR measured during “3x21” were similar to the data measured during “5x11” ($72 \pm 8\%$ and $73 \pm 8\%$; $62 \pm 23\%$ and $61 \pm 21\%$; $86 \pm 5\%$ and $85 \pm 6\%$, respectively). The minute EE measured during each game of “3x21” was significantly lower than the first three games of “5x11” (about -11%, $P < 0.05$) but the mean value of minute EE required to complete the whole match is similar between the two scoring systems (50.1 ± 7.6 kJ/min and 50.7 ± 7.1 kJ/min, for “3x21” and “5x11” respectively). The metabolic expenditure of a single game is significantly lower in the “5x11” scoring rule (about -50%, $P < 0.05$) however, at the end of the match the total EE is similar to “3x21” (1782 ± 553 kJ and 1627 ± 267 kJ, for “3x21” and “5x11” respectively). The duration of each game was shorter during “5x11” compared to “3x21” ($P < 0.05$). However, the total time necessary to complete a match was similar (1910 ± 193 s and 1987 ± 338 s for “5x11” and “3x21”, respectively). 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. Lastly, EPT was $32 \pm 3\%$ and $30 \pm 3\%$, 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 ($P < 0.05$).

STUDY 3: 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. From the lowest to the hardest intensity practice, general RPE values were 9.9 ± 1.9 , 13.7 ± 1.9 and 15.0 ± 2.3 a.u.; 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., being the values referred to LOW significantly lower compared to MIDDLE and HIGH ($P < 0.05$ for both comparisons). 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. 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.

Discussion and conclusions. STUDY 1: main findings of the present study is that the \dot{V}_{O_2} /HR relationship differs when assessed with a treadmill test or during executing a match simulation. It could be noted that HR begins to rise immediately at the beginning of the game even when the intensity is low, probably due to a nervous system strategy that over-activate the cardiac activity. The main consequence of this result is represented by the fact that, if the HR/ \dot{V}_{O_2} relationship has been assessed with an intermittent square-wave incremental test, monitoring HR during field activities is not able to provide accurate information on the metabolic events that support the specific tasks. 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.

STUDY 2: our data show no difference in \dot{V}_{O_2} , \dot{V}_E , HR and blood lactate accumulation between “3x21” and “5x11”. Therefore, the high intensity demand of the game is maintained in both scoring system. These data suggest that also cardiovascular and metabolic strain are comparable between the two scoring system. For temporal structure, it is possible that more time under the “5x11” is needed to change tactical habits that can influence the structure of matches.

STUDY 3: The results of this study suggest that the combination of accelerometer signals to HR monitoring seems to provide 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 may depend on the characteristics of the badminton activity that is composed by several rapid movements and direction changes that weights on the accelerometer signals introducing a bias in the algorithm computation. These results suggest caution in the use of this kind of devices for the metabolic expenditure estimation if a task-specific calibration of the algorithm lacks.