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ORIGINAL ARTICLE

Physiological characteristics of badminton match play

Oliver Faude · Tim Meyer · Friederike Rosenberger · Markus Fries · Günther Huber · Wilfried Kindermann

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Abstract The present study aimed at examining the physiological characteristics and metabolic demands of badminton single match play. Twelve internationally ranked badminton players (eight women and four men) performed an incremental treadmill test [$VO_{2peak} = 50.3 \pm 4.1$ ml min^{-1} kg^{-1} (women) and 61.8 ± 5.9 ml min^{-1} kg^{-1} (men), respectively]. On a separate day, they played a simulated badminton match of two 15 min with simultaneous gas exchange (breath-by-breath) and heart rate measurements. Additionally, blood lactate concentrations were determined before, after 15 min and at the end of the match. Furthermore, the duration of rallies and rests in between, the score as well as the number of shots per rally were recorded. A total of 630 rallies was analysed. Mean rally and rest duration were 5.5 ± 4.4 s and 11.4 ± 6.0 s, respectively, with an average 5.1 ± 3.9 shots played per rally. Mean oxygen uptake (VO_2), heart rate (HR), and blood lactate concentrations during badminton matches were 39.6 ± 5.7 ml min^{-1} kg^{-1} (73.3% VO_{2peak}), 169 ± 9 min^{-1} (89.0% HR_{peak}) and 1.9 ± 0.7 mmol l^{-1}, respectively. For a single subject 95% confidence intervals for VO_2 and HR during match play were on average 45.7–100.9% VO_{2peak} and 78.3–99.8% HR_{peak}. High average intensity of badminton match play and considerable variability of several physiological variables demonstrate the importance of anaerobic alactacid and aerobic energy production in competitive badminton. A well-developed aerobic endurance capacity seems necessary for fast recovery between rallies or intensive training workouts.

Keywords Metabolic profile · Energy metabolism · Racquet sports · Ambulatory spirometry · Intermittent exercise

O. Faude (✉) · T. Meyer · F. Rosenberger · M. Fries · W. Kindermann
Institute of Sports and Preventive Medicine, Faculty of Clinical Medicine, University of Saarland, Campus Bldg. B 8.2, 66123 Saarbrücken, Germany
e-mail: oliver.faude@uni-paderborn.de

O. Faude · M. Fries
Olympic Training Center Rheinland-Pfalz/Saarland, Saarbrücken, Germany

G. Huber
Badminton World Training Center, Saarbrücken, Germany

T. Meyer
Institute of Sports Medicine, University Paderborn, Paderborn, Germany

Introduction

Knowledge about cardiovascular, metabolic, and respiratory demands in certain types of sports provides the basis for adequate performance assessment and evidence-based design of training regimens. In addition to heart rate monitoring and blood lactate determinations, gas exchange measurements offer the opportunity to directly evaluate the physiological profile of discipline-specific performance (Meyer et al. 2005). Such an approach has originally been used in laboratory settings for endurance sports such as running (Costill 1970), cycling and rowing (Hagerman et al. 1988) or even in soccer players while dribbling a ball on a treadmill (Reilly and Ball 1984). However, recent research has demonstrated that there are considerable differences in physiological responses during intermittent high intensity exercise compared to continuous endurance exercise of the same average intensity (Christmass et al. 1999; Ferrauti et al. 2001). Racquet and field sports are characterised by intermittent activity and cannot be appropriately simulated in a laboratory. Therefore, it is necessary to assess physiological profiles and energy patterns of such sports during field tests (Meyer et al. 2005; Smekal et al. 2001).

Recent technological advancements generated lightweight ambulatory metabolic devices allowing for an accurate evaluation of racquet sports such as badminton under field test conditions. So far, "physiological profiling" has recently been conducted in soccer (Ferrauti et al. 2006), tennis (Ferrauti et al. 2001; Smekal et al. 2001), and badminton (Faccini and Dal Monte 1996). These studies reported average and maximal physiological values but no measures reflecting the sport-specific exercise dynamics. This might be due to the fact that the utilized metabolic systems were working on a mixing chamber principle analysing data every 10 or 15 s. Because mean rally times in tennis or badminton last between 5 and 10 s (Cabello Manrique and Gonzalez-Badillo 2003; Glaister 2005; Smekal et al. 2001), it is questionable if mixing chamber systems can adequately reflect the intermittent nature of such sports. Roecker et al. (2005) emphasized that a breath-by-breath (BBB) analysis of respiratory data is most specific to analyse VO_2 kinetics during exercise with sudden changes in work load. This procedure enables the calculation of moving averages of sampling windows adequately reflecting the temporal structure of the specific sports.

It was the purpose of the present study to describe physiological characteristics as well as energetic requirements of badminton match play by means of ambulatory gas exchange measurements using a BBB approach.

Materials and methods

Study design and the employed procedures are in accordance with ethical standards and the Declaration of Helsinki. The study was approved by the local ethics committee. Each subject gave written informed consent before the start of the study.

Subjects and general design

Twelve internationally ranked badminton players (eight females, four males, world ranking position between 49 and 164) participated in this study. Anthropometric and performance characteristics of these subjects are presented in Table 1. All subjects were medically screened (medical history, physical examination, resting as well as exercise ECG) to ensure that there were no contraindications to study participation.

Players performed an exhaustive incremental ramp-like exercise test on a treadmill for the determination of maximal ergometric parameters. Additionally, they played a simulated badminton match. The tests were separated by at least three and a maximum of 21 days. Both tests were performed with simultaneous gas exchange measurements.

Incremental exercise test

The incremental ramp exercise test was performed on a motorized treadmill (Woodway, Lörrach, Germany) at a constant incline of 0.5%. After running three minutes at 2.0 m s^{-1}, velocity was increased every minute by 0.25 m s^{-1} (women) or 0.30 m s^{-1} (men), respectively, to arrive at a total ramp time of about 10 min (Buchfuhrer et al. 1983). Subjects were verbally encouraged until volitional exhaustion. Capillary whole-blood samples (20 µl) were taken from the hyperemized earlobe before the start, at the end as well as 2 and 4 min after cessation of exercise and analyzed for lactate concentrations (automated enzymatic-amperometric method, Greiner BioChemica, Flacht, Germany). Heart rate was recorded from a written ECG at the end of each stage. Gas exchange measurements were carried out continuously throughout the test. Peak oxygen uptake (VO_{2peak}) was determined as the highest oxygen uptake (VO_2) averaged over 30 s during the test.

Badminton match play

Altogether, six badminton matches were played according to the current rules of the Badminton World Federation (http://www.internationalbadminton.org/statues.asp). To ensure that athletes were highly motivated, matches were included in a regular internal ranking competition. Opponents were matched for performance ability and gender. After an individual warm-up of about 10 min, subjects played a match of two 15 min with 2 min rest in between. Both players wore a

Table 1 Anthropometric data and performance characteristics of the subjects

	Age (years)	Height (cm)	Weight (kg)	VO_{2peak} (ml min^{-1} kg^{-1})	World ranking position
Females ($N = 8$)	21.8 ± 2.1	166 ± 5	59.8 ± 6.8	50.3 ± 4.1	122 ± 35
Males ($N = 4$)	21.3 ± 1.7	177 ± 2*	70.3 ± 5.5*	61.8 ± 5.9*	87 ± 29

Data as mean ± SD

VO_{2peak} peak oxygen uptake

*Significantly different from females

Table 2 Badminton match characteristics

Rally time (s)	Rest time (s)	Work density	Number of shots per rally	Shots per rally time (s^{-1})	EPT (%)
5.5 ± 4.0	11.4 ± 6.0	0.51 ± 0.34	5.1 ± 3.9	0.92 ± 0.31	31.2 ± 2.8

Data as mean ± SD

EPT effective playing time

portable metabolic device around their neck (MetaMax 3b, Cortex Biophysik, Leipzig, Germany) as well as a chest-belt for telemetric heart rate recording (Polar Electro, Kempele, Finland). The metabolic systems weighed 600 g. After warm-up, during the 2 min break as well as after the match capillary blood samples were taken for lactate determination.

Additionally, rally times, rest times between rallies, the number of shots per rally, and the actual score were recorded in a standardized match protocol. From these data, the following parameters were calculated: (1) the work density (rally time divided by rest time); (2) the effective playing time (EPT; rally time divided by rally + rest time expressed in per cent); (3) shot frequency (number of shots per rally time in shots per second).

Subjects refrained from intensive exercise for three days prior to match play. On the test day, all subjects received a similar breakfast and lunch, respectively. During the 2 min break, water intake was allowed ad libitum. Subjects drank on average 0.13 ± 0.08 l still mineral water.

Gas exchange measurements

During all matches subjects breathed through a Hans-Rudolph mask. Exhaled air was analyzed for oxygen (electrochemical cell) and carbon dioxide concentrations (infrared analyzer) for each breath. Minute ventilation was recorded digitally using a Triple-V sensor. Raw gas exchange data were stored on the data logger of the metabolic system and downloaded on a PC after the matches. About 5 s moving averages were calculated for gas exchange data during match play. This sample time interval was chosen because it adequately reflects the structure of the game as it was observed by Cabello Manrique and Gonzales-Badillo (2003) during international tournaments as well as in the present study (Table 2).

The metabolic system had been checked by the manufacturer within the last 4 weeks prior to the tests and was certified for accuracy. Additionally, the system was calibrated according to the manufacturer's instructions prior to each test. Volume calibration was carried out using a 3-l syringe. To calibrate gas analyzers, a standard gas ($FO_2 = 12.0\%$ and $FCO_2 = 5.04\%$) as well as environmental air ($FO_2 = 20.93\%$ and $FCO_2 = 0.03\%$) was used.

Calculations and statistics

Gross energy expenditure (EE) during match play was calculated according to the following equation:

$$\text{EE}\ (\text{kcal min}^{-1}) = 0.550\ \text{VCO}_2\ (\text{l min}^{-1}) + 4.471\ \text{VO}_2\ (\text{l min}^{-1})$$ (Jeukendrup and Wallis 2005).[1]

Data are presented as means and standard deviations (SD). Comparisons between female and male players as well as between players who won their matches compared with the losing players were carried out using the Mann–Whitney *U*-test. For analysis of physiological variations during badminton match play, average heart rate and oxygen uptake values as well as 95% confidence intervals (95% CI) were calculated for each single player. The level of statistical significance for the α–error was set at $P < 0.05$.

Results

Ramp exercise test

Ramp tests lasted an average of 9:02 ± 1:10 min and mean maximal running velocity was $4.43 \pm 0.51\ \text{m s}^{-1}$. Peak values for blood lactate concentrations, heart rate, and respiratory exchange ratio were $6.8 \pm 1.2\ \text{mmol l}^{-1}$, $190 \pm 7\ \text{min}^{-1}$, and 1.09 ± 0.12, respectively. Peak oxygen uptake is presented in Table 1.

Match characteristics

The six matches played resulted in a total of 630 rallies (92–119 rallies per match) for statistical analyses. Table 2 shows the average characteristics of badminton match play for all 630 rallies played. 86.7% of all rallies lasted for 9 s or less with a rally time between 3 and 6 s occurring most frequently. Only, 3.2% of all rallies lasted longer than 15 s (Fig. 1). In contrast, rest time was mostly situated between 6 and 15 s (87.1%).

Physiological characteristics

Mean physiological responses during badminton match play are given in Table 3. Oxygen uptake relative to body weight, minute ventilation and energy expenditure were significantly higher in the male subjects. Blood lactate con-

[1] The original publication by Jeukendrup and Wallis (2005) contains an error. The equation is given as EE = 0.550*VCO2 – 4.471*VO2. Retracking of the mathematical deduction resulted in the equation used in the present manuscript. The equation is proposed for calculating gross energy expenditure during moderate to high intensity exercise (50–75% VO2max).

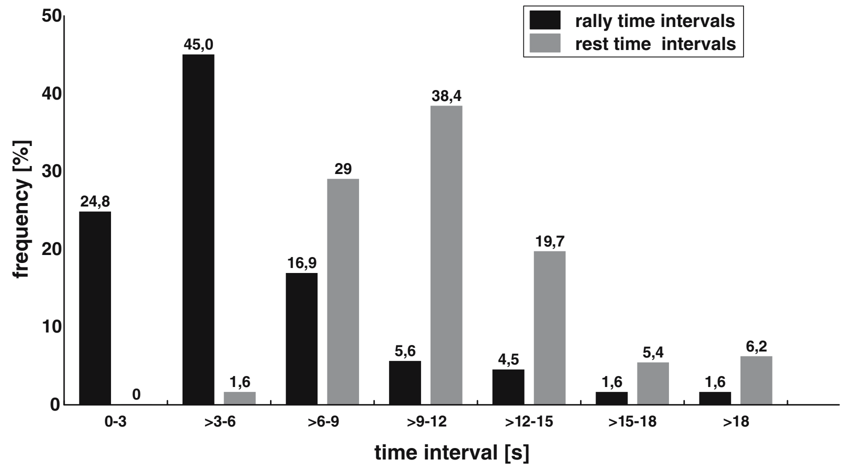

Fig. 1 Rally and rest time interval distribution during badminton match play

Table 3 Average physiological responses of badminton match play

	Total ($N = 12$)	Females ($N = 8$)	Males ($N = 4$)
HR (min^{-1})	169 ± 9	170 ± 10	166 ± 6
HR (% HR_{peak})	89.0 ± 4.6	88.4 ± 5.1	90.3 ± 3.7
Lactate (mmol l^{-1})	1.9 ± 0.7	1.9 ± 0.9	1.9 ± 0.1
VO_2 (ml min^{-1} kg^{-1})	39.6 ± 5.7	36.4 ± 2.8	46.0 ± 4.5*
VO_2 (% VO_{2peak})	73.3 ± 6.5	72.6 ± 7.2	74.8 ± 5.3
RER	0.99 ± 0.07	0.99 ± 0.08	0.99 ± 0.06
V_E (l min^{-1})	72.2 ± 18.1	61.1 ± 8.7	94.3 ± 6.4*
b_f (min^{-1})	45.7 ± 5.9	44.9 ± 5.9	47.4 ± 5.9
EE (kJ min^{-1})	53.3 ± 12.7	45.9 ± 6.7	68.0 ± 7.5*
EE (kJ kg^{-1} min^{-1})	0.84 ± 0.12	0.77 ± 0.06	0.97 ± 0.10*

Data as mean ± SD

HR heart rate, *VO_2* oxygen uptake, *RER* respiratory exchange ratio, V_E minute ventilation, b_f breathing frequency, and *EE* energy expenditure

*Significantly different from females

centrations varied between 0.9 and 3.5 mmol l^{-1}. Figure 2 shows an example of oxygen uptake and heart rate kinetics from a representative subject. For a single subject 95% CIs for VO_2 and HR during match play were on average 45.7–100.9% VO_{2peak} and 78.3–99.8% HR_{peak} (Fig. 3). No significant differences were observed between players winning versus losing the match ($P > 0.41$).

Discussion

The results of this descriptive study revealed a high average intensity of badminton match play. Considerable fluctuations in several physiological variables represent the intermittent nature of the sport. The findings demonstrate the importance of alactacid as well as aerobic energy production in badminton.

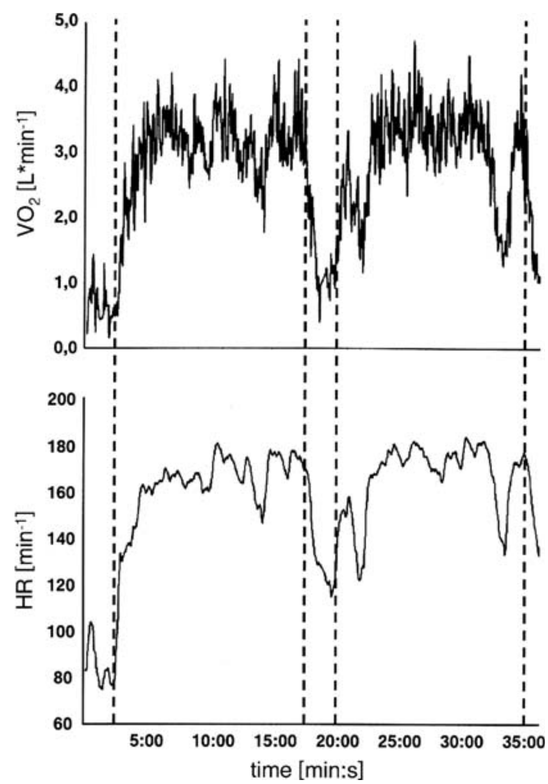

Fig. 2 Oxygen uptake (VO_2, *top*) and heart rate (HR, *bottom*) responses of a representative subject (5 s-moving average). The dashed lines represent the start and the end of the two 15 min match intervals

Match characteristics

In the present study, an average total match duration of 30 min with 2 min rest in between was chosen. This is very similar to real match play conditions, since the rally point scoring system has been introduced. For instance, average match duration in the World Cup 2006 in Madrid was 33.6 min for women's and men's singles (http://www.internationalbadminton.org/results.asp). Although average rally time (5.5 vs. 6.4 s) and the number of shots played per rally

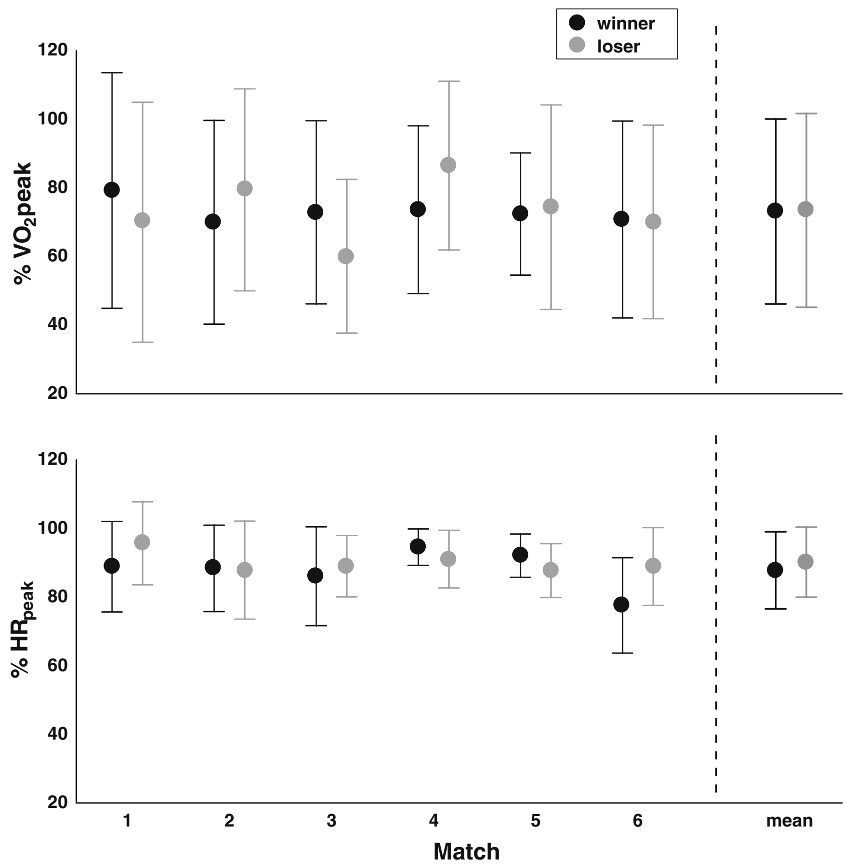

Fig. 3 Oxygen uptake (VO_2, *top*) and heart rate (HR, *bottom*) responses during badminton matches. Data as mean and 95% confidence limits for each single subject as well as average values (*bold lines*)

(5.1 vs. 6.1) were slightly lower than it was recently observed during international tournaments (Cabello Manrique and Gonzalez-Badillo 2003), work density, shots per real time and EPT were very similar. In addition, the distribution of rally and rest time intervals was nearly the same as it was observed by Cabello Manrique and Gonzales-Badillo (2003) during high level competition. Therefore, it seems tenable that the data obtained in the present study may largely reflect real badminton conditions. However, it is obvious that exercise intensity during simulated match play with players wearing a gas mask and the metabolic system on their shoulders is presumably lower than in real badminton competition. Therefore, real exercise intensity might be slightly underestimated.

Physiological characteristics

The results of the present study revealed a high average intensity of badminton match play. Faccini and Dal Monte (1996) observed lower values (35.7 ml min^{-1} kg^{-1} corresponding to 60.4% VO_{2max}) in seven nationally ranked male Italian players. The reasons for this discrepancy are not clear. Although these authors have obtained video tapes of their matches, data to describe match characteristics are only presented rudimentarily. However, VO_{2peak} values in the present study may have been slightly underestimated as indicated by maximal lactate and heart rate values of the subjects ramp exercise. Therefore, average match intensity expressed relative to VO_{2peak} might have been slightly overestimated. Nevertheless, VO_{2peak} values in the present study are within the upper range of values reported for badminton players in other studies [43.8–53.3 ml min^{-1} kg^{-1} for females and 55.7–63.4 ml min^{-1} kg^{-1} for males, respectively (Faccini and Dal Monte 1996; Ghosh et al. 1993; Majumdar et al. 1997; Miao and Wang 1988)].

The average intensity of simulated badminton competition in the present study is similar to values which were estimated for soccer [~70–75% VO_{2max}, (Stolen et al. 2005)]. Ferrauti et al. (2006) analysed gas exchange data in ten amateur soccer players during match play and observed an average oxygen uptake (VO_2) of 38 ml min^{-1} kg^{-1} corresponding to 62–77% of an estimated maximal oxygen uptake. This resulted in an average energy expenditure of ~890 kcal h^{-1}, a value quite similar to the one observed in the present study (~480 kcal per 30 min in four male subjects). During tennis match play considerably lower values were reported. For instance, Ferrauti et al. (2001) measured an average VO_2 of 25.6 ml min^{-1} kg^{-1} (~54% VO_{2max}) resulting in nearly 600 kcal expended per hour in six male tennis players. Similar average VO_2 values were reported by Smekal and colleagues (2001) in 20 male tennis players of the two highest leagues in Austria. A reason for the lower average intensity observed during tennis might be about 25% lower values for effective playing time (~25% vs. 31.2%) and stroke frequency (0.75 vs. 0.92 shots per second) as it was found by Smekal et al. (2001). The high average intensity in badminton is also underlined by heart rate data which are within the upper range of previously reported values ranging from 80 to 91% of maximal heart rate (Cabello Manrique and Gonzalez-Badillo 2003; Docherty 1982; Majumdar et al. 1997).

In contrast to previous studies which reported blood lactate concentrations during high level badminton match play between 3.8 and 4.7 mmol l^{-1} (Cabello Manrique and Gonzalez-Badillo 2003; Majumdar et al. 1997; Weiler et al. 1997) the present results indicate no large contribution to energy production from lactacid pathways. This might be due to the fact that the values reported in the cited studies were obtained during real high level competition where players have spent slightly greater effort. Playing badminton while wearing a gas mask and the metabolic system may lead to a slight and not avoidable decrease in exercise intensity and, consequently, glycolytic flux rate. Additionally, Weiler et al. (1997) reported 2–3 times higher ratio of adrenalin and noradrenalin to lactate during first league matches compared to badminton training. A higher excretion of catecholamines may increase glycolytic flux and, consequently, also contribute to higher blood lactate concentrations during real competition. Therefore, real exercise intensity and, particularly, anaerobic lactacid energy production might be slightly underestimated in the present investigation.

Despite relatively low blood lactate concentrations average respiratory exchange ratio was quite high. A similar result was obtained by Ferrauti et al. (2001) during tennis match play. During the first 30 min of a 2 h match their subjects reached RER values of 0.95. Also these authors reported considerably higher RER values during tennis compared to continuous running at the same average intensity (~55%VO_{2max}). The high RER observed in the present study could be explained by a nearly 100% carbohydrate oxidation. In addition, an influence of gas exchange kinetics during rest intervals between rallies may be present. High intensity rallies may lead to hyperventilation at the beginning of the breaks. Therefore, ventilatory VCO_2 may exceed metabolic VCO_2 leading to a faster decline in VO_2 compared to VCO_2 and, hence, a temporarily rise in RER.

In addition to the high average intensity, great fluctuations in VO_2 during match play were observed. Whereas oxygen uptake reached maximal aerobic capacity during rallies, it declined temporarily to values lower than 40% VO_{2peak}. Together with low blood lactate concentrations and the average rally duration of 5.5 s, this points to an important contribution of alactacid pathways to energy production. Therefore, a fast resynthesis of phosphocreatine (PCr) stores between rallies seems to be an important factor for optimal physical performance during badminton match play. Tomlin and Wenger (2001) suggested that a well-developed aerobic fitness enhances recovery from high intensity intermittent exercise, particularly through an increased aerobic response during exercise as well as an enhanced PCr regeneration during breaks.

There are obvious differences in physiological and morphological characteristics between genders. For instance, females have a lower lung volume, cardiac output, VO_{2max}, and haemoglobin concentrations as well as a greater body fat content compared to males (Lewis et al. 1986; Sheel et al. 2004). Although there is evidence that physiological responses to exercise, particularly the relative contribution of carbohydrate and lipid metabolism to energy production, may also differ between genders, scientific data do not seem conclusive (Roepstorff et al. 2002). The results of the present investigation showed lower values in minute ventilation, absolute VO_2, and total energy expenditure in the female subjects. In contrast, no influence of gender on blood lactate concentrations, heart rate and percentage of maximal oxygen uptake was observed during badminton match play. Therefore, cardiovascular and metabolic strain seems to be comparable between genders for the investigated situation. However, a concluding statement is not possible from the present results, particularly due to the low number of male subjects studied.

Conclusion

The results of the present study point to the need of a high aerobic capacity in competitive badminton players. Badminton training regimens should be designed to induce the development of a sufficient endurance capacity. Additionally, it might be advisable to reproduce the intermittent nature of the sport, particularly with regard to alactacid energy production to improve badminton specific metabolic pathways.

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