Table Tennis: Cardiorespiratory and Metabolic Analysis of Match and Exercise in Elite Junior National Players

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Purpose: The aim of the study was to determine the cardiorespiratory and metabolic characteristics during intense and moderate table tennis (TT) training, as well as during actual match play conditions. Methods: Blood lactate concentration (Lac), heart rate (HR, beats per minute [bpm]), oxygen uptake (VO2), and energy expenditure (EE) in 7 male participants of the German junior national team (age: 14 ± 1 y, weight: 60.5 ± 5.6 kg height: 165 ± 8 cm) were examined during six training sessions (TS) and during an international match. The VO2 was measured continuously with portable gas analyzers. Lac was assessed every 1 to 3 min during short breaks. Results: Mean (peak) values for Lac, HR, VO2, and EE during the TS were 1.2 ± 0.7 (4.5) mmol∙L–1, 135 ± 18 (184) bpm, 23.5 ± 7.3 (43.0) mL·kg–1·min–1, and 6.8 ± 2.0 (11.2) METs, respectively. During match play, mean (peak) values were 1.1 ± 0.2 (1.6) mmol∙L–1, 126 ± 22 (189) bpm, 25.6 ± 10.1 (45.9) mL·kg–1·min–1, and 4.8 ± 1.4 (9.6) METs, respectively. Conclusions: For the first time, cardiorespiratory and metabolic data in elite junior table tennis have been documented demonstrating low cardiorespiratory and metabolic demands during TT training and match play in internationally competing juniors.

Keywords: racquet sports, lactate, oxygen uptake, energy

Table tennis is characterized by intermittent movement patterns with varying energetic demands lasting for 10 to 25 min per match duration.1 Match play conditions and exercise cannot easily be simulated in controlled laboratory settings and therefore need to be determined during actual competition and exercise. These
results can be used as scientifically based source to adjust training protocols to the characteristic demands of the sport. However, when compared with other racquet sports like tennis\textsuperscript{2,3} or badminton\textsuperscript{4,5} very limited data are available regarding the cardiorespiratory and metabolic demands during match play and training in table tennis.

Zagatto and coworkers\textsuperscript{6} recently analyzed the heart rates and blood lactate concentrations of Brazilian table tennis players, ranging from 1.8–2.2 mmol\cdot L\textsuperscript{-1}. However, in this investigation blood samples for the determination of blood lactate concentration were collected before and after each set. Within this period of time, lactate concentration may vary according to intensity. Thus, the movement pattern fluctuates widely throughout a match, and a more frequent sampling of blood, such as in short breaks, and would allow assessing metabolic changes during match and exercising more precisely.

In addition, heart rate analysis has previously been performed in order to describe and estimate the metabolic demands during competition and training in table tennis\textsuperscript{6} and tennis.\textsuperscript{2,7,8} However, heart rate may be influenced by other factors, such as psychological stress and mental concentration,\textsuperscript{9} as well as fluid loss\textsuperscript{10} and, therefore, may lead to an inaccurate estimation of metabolic demands. To resolve this, breath-by-breath measurements of oxygen uptake via portable devices are used in other racquet games to evaluate respiratory data even when workloads change rapidly.\textsuperscript{2,5,11,12} To the best of our knowledge, no comparable data during competitive table tennis match or training have been available to date.

The integration of portable oxygen uptake measurement, heart rate monitoring, and frequent blood lactate measurements allows quantifying the cardiorespiratory and metabolic demands during match play and exercise and should help improve training and match strategies in table tennis. To our knowledge, there have been no published studies that have examined these parameters during table tennis match play and different training protocols in elite junior table tennis players. The aim of the present study was to assess the cardiorespiratory and metabolic demands of table tennis match play as well as training in elite junior national table tennis players.

Methods

Participants

Seven members of the male German junior national team (age: 14 ± 1 y, weight: 60.5 ± 5.6 kg, height: 165 ± 8 cm) living at the German Table Tennis Federation’s training headquarters participated in this study. The players were accustomed to frequent international tournament participation. These seven players were chosen to participate, as they were the best German players within their age group at that time. The players and their guardians were informed about the design of the study, and, before the start of the study, both signed an informed consent document that was in accordance with the university’s research ethics review board. Before testing, all participants were fully familiarized with the laboratory and exercise procedures. On the test days, they were asked to report to the training facility well hydrated, at least 1 h after eating a light meal, and not to have performed strenuous exercise at least 24 h before testing.
Experimental Design

Six training sessions were planned and monitored by the head coach of the German Junior National Team. The training sessions started at 8 AM and lasted approximately 80 min. To ensure different exercise intensity, the training sessions were designed with technical drills at low intensity as well as high-intensity drills. All sessions began with a 15 min warm-up integrating jogging, stretching, and exercises with racquet and ball. Thereafter, the head coach implemented different technical drills at low intensity to improve stroke precision. This part of the session lasted 35 min. The next sessions included high-intensity drills with short breaks and time pressure between rallies, such as, playing 200 balls. All sessions ended with a cool-down integrating jogging and stretching.

Oxygen uptake, respiratory exchange ratio, and heart rate were monitored telemetrically during the training sessions. Samples for blood lactate measurement and ratings of perceived exertion were collected every 1 to 3 min. In addition, lightweight multi-sensor devices were placed on the upper arm to estimate energy expenditure during the training sessions.

Three sets of an international match were analyzed, which was organized by the head coach of the German Junior National Team and carried out according to the current rules of the Table Tennis World Federation. The match play was arranged so that two players from different countries played against each other. To ensure high individual motivation, the winner of the match play qualified for a future international tournament. Both players of a match were equipped with a portable respiratory device, but only the German players’ respiratory data (oxygen uptake and respiratory exchange ratio) were analyzed. To estimate the energy expenditure during match play, all German players wore lightweight multisensor devices. Samples for blood lactate analysis and ratings of perceived exertion were collected from all seven players, every 1 to 3 min, depending on the match situation. The heart rate of all players was recorded continuously using 5 s intervals during the match.

The respiratory data were collected with an open portable breath-by-breath spirograph (Cosmed K4B2, Italy) using standard algorithms with dynamic account for the time delay between the gas consumption and volume signal. The system was calibrated before each test using calibration gas (15.8% O₂, 5% CO₂ in N; Praxair, Germany), targeting the range of anticipated fractional gas concentration, and a precision 1 L syringe (Zan, Germany). The participants breathed through a Hans-Rudolph mask and a turbine flowmeter during all matches and training sessions. Exhaled air was analyzed for oxygen (electrochemical cell) and carbon dioxide concentrations (infrared analyzer) for each breath. All cables and tubing were attached with tape and straps to ensure a wide range of motion for the players’ arms and upper body. Heart rate was recorded online using short-range telemetry (Polar S 710, Finland). Twenty microliters of capillary blood from the right ear lobe was analyzed for blood lactate concentration (Eppendorf Ebio plus, Germany). All blood samples were analyzed in duplicate and the mean of the two measures was used for statistical analysis. Simultaneously, while collecting blood, the participants were asked to rate their sensation of perceived exertion on the 15 grade scale of Borg ( Borg, 1982).

The Sense Wear Pro 3 armband (Body Media, USA) was used for continuously assessing energy expenditure during training and match play situations. The device
was worn on the subject’s upper playing arm and recorded biaxial acceleration, heat production, and galvanic skin response. Energy expenditure was calculated using Inner View software (version 6.1, Bodysense, Pittsburgh, USA). For reasons of comparability, energy expenditure is expressed as metabolic equivalents (METs). The Sense Wear Pro 3 armband has been validated against doubly labeled water and/or indirect calorimetry and also under intense exercise.

**Statistical Analysis**

All data were calculated with conventional procedures and presented as mean values and standard deviation (SD). In our laboratory setting, the routinely measured coefficient of variation in repeated measures for the blood lactate measurements is 1.2% at 12 mmol·L⁻¹. The technical error measurements (%TEM) for oxygen uptake, heart rate, and ratings of perceived exertion are 3.2%, 1.9%, and 4.8%, respectively. The data for each variable (blood lactate concentration, oxygen uptake, energy expenditure, and heart rate) during the training sessions were averaged and a paired t test was calculated in order to analyze differences between the training sessions and the match. The ratings of perceived exertion were compared between match and training using the Wilcoxon signed-rank test. An alpha of P < .05 was used for statistical significance. The effect size, Cohen’s d, defined as (difference in means)/standard deviation, was calculated for all variables between training and match play. Thresholds for small, moderate, and large effects were 0.20, 0.50, and 0.80, respectively.

**Results**

Mean values for blood lactate concentrations, heart rate, oxygen uptake, respiratory exchange ratio, energy expenditure as well as ratings of perceived exertion and the effect sizes are presented in Table 1.

**Table 1 Blood lactate concentration, heart rate, oxygen uptake, respiratory exchange ratio, energy expenditure, and ratings of perceived exertion during table tennis training and during match conditions**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Training</th>
<th>Match Situation</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood lactate (mmol·L⁻¹)</td>
<td>1.2 ± 0.7 (4.51)</td>
<td>1.1 ± 0.2 (1.62)</td>
<td>0.21</td>
</tr>
<tr>
<td>Heart rate (bpm)</td>
<td>135 ± 18 (184)</td>
<td>125 ± 22* (189)</td>
<td>0.49</td>
</tr>
<tr>
<td>Oxygen uptake (mL·kg⁻¹·min⁻¹)</td>
<td>23.5 ± 7.3 (43.0)</td>
<td>25.6 ± 10.1 (45.9)</td>
<td>0.23</td>
</tr>
<tr>
<td>Respiratory exchange ratio</td>
<td>0.86 ± 0.03 (1.02)</td>
<td>0.86 ± 0.06 (1.07)</td>
<td>0.00</td>
</tr>
<tr>
<td>Energy expenditure (MET)</td>
<td>6.8 ± 2.0 (11.2)</td>
<td>4.8 ± 1.4* (9.62)</td>
<td>1.15</td>
</tr>
<tr>
<td>Ratings of perceived exertion</td>
<td>13.5 ± 2.4 (19)</td>
<td>11.8 ± 2.6* (16)</td>
<td>0.67</td>
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<tr>
<td>(Borg’s scale)</td>
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*Note.* Data is expressed as mean ± SD (max). *Indicates significant differences (P < 0.05) between the training session and match.
Blood lactate concentration, oxygen uptake, respiratory exchange ratio did not differ between training and match play. Peak values for all variables during training were achieved when playing 200 balls without break (Figure 1). Heart rate (effect size = 0.49), energy expenditure (effect size = 1.15) as well as ratings of perceived exertion (effect size = 0.67) were lower during match play compared with the training sessions ($P < .05$).

The matches lasted $37 \pm 2$ min. Average values of all seven players for lactate, heart rate, oxygen uptake, respiratory exchange ratio, and energy expenditure during match play are presented in Table 1. Mean kinetics of energy expenditure, rating of perceived exertion and lactate concentration are presented in Figure 2. In general, lactate values remained below 2.0 mmol·L$^{-1}$ lactate during match conditions.

**Discussion**

The present study provides a novel insight into cardiorespiratory and metabolic responses to training and match play situation in table tennis. Although the sample size is rather small and might therefore limit the interpretation of the data, it must be considered that, for the first time, gas analysis and frequent lactate values of internationally competing junior table tennis players were collected during training and actual match conditions. According to blood lactate concentration, heart rate,

![Figure 1 — Blood lactate concentration during training. Values above 2 mmol·L$^{-1}$ were achieved when playing 200 balls without a break.](image)
The frequent collection of lactate values in the present study revealed similar values for the matches (1.1 ± 0.2 mmol·L⁻¹) and training sessions (1.2 ± 0.7 mmol·L⁻¹), indicating a small contribution of energy production from lactic pathways. The match analysis conducted by Zagatto and coworkers also showed similar mean lactate concentration of 1.8 ± 0.7 mmol·L⁻¹ when measures less frequently. The blood lactate concentrations in the present study are clearly below values from previous investigations in other racquet sports, which reported values during high-level badminton match play between 3.8 and 4.7 mmol·L⁻¹ and squash 6.8 to 9.2 mmol·L⁻¹. Although we did not conduct time motion analysis, it may be hypothesized that racquet sports, such as tennis, badminton, and squash, are characterized by a greater range of movement, combined with longer sprint distances and more jumps, when compared with table tennis. Strokes in table tennis are predominately performed by the upper body and over a shorter range of
motion. Therefore, the amount of motor unit recruitment involved in table tennis is most likely lower compared with the other disciplines, which in turn leads to lower cardiorespiratory activation in order to comply with energetic demands.

The low concentration of blood lactate during match and training in our study is supported by low average oxygen uptake. During exercise and match play, oxygen uptake averaged 20–25 mL·kg⁻¹·min⁻¹, peaking to values of 45 mL·kg⁻¹·min⁻¹ and corresponding to 9–10 METs as measured by the multisensory devices. Unfortunately, no comparable data regarding oxygen consumption and energy expenditure are available for table tennis. In other racquet games, these values are considerably higher. Faude et al.⁵ investigated oxygen uptake values of 43.8–53.3 mL·kg⁻¹·min⁻¹ for females and 55.7–63.4 mL·kg⁻¹·min⁻¹ for male badminton players, corresponding to 12 METs. In tennis, Ferrauti et al.² measured average oxygen uptake values of 25.6 mL·kg⁻¹·min⁻¹, equivalent to 600 kcal/h, in six male tennis players. Forty minutes of racquetball, for example, showed slightly higher mean oxygen consumption values (25.8–28.9 mL·kg⁻¹·min⁻¹) in 14 recreational players.²¹

Oxidative metabolism during these short recovery periods is likely sustained to resynthesize muscle phosphates.²²,²³ Due to the fact that lactate concentrations are low during matches, it may be assumed that energy is mainly derived from anaerobic alactic and aerobic pathways. On average, respiratory exchange ratios during table tennis match and training did not exceed 0.87, indicating a higher involvement of lipid oxidation in table tennis during exercise and matches as compared with other racquet sports. In contrast, Faude et al.⁵ reported higher respiratory exchange ratios of 0.99 ± 0.07 during badminton. In addition, participants during the first 30 min of a 2 h tennis match showed values reaching 0.95.² The greater values observed in these investigations could be explained by a higher contribution of carbohydrate oxidation due to a greater range of motion.

The moderate cardiorespiratory and metabolic demands during match and exercise are confirmed by moderate levels of perceived exertion. During match, the perceived exertion was rated 11.8 ± 2.6 by the players, which represents “fairly light” on the Borg scale.²⁴ During high-intensity table tennis specific drills, the ratings were 14.1 ± 3.0, representing “somewhat hard” to “hard.” Nevertheless, since RPE reflects a subjective parameter some limitations should be considered. The participants in this study were among the top-ranked junior players in Germany, facing a great amount of competitive stress, and need to qualify for national team ranking. It is known that highly motivated participants may underestimate perceived exertion in comparison with their individual work capacity.²⁵ In addition, fatigue and sickness as well as anxiety and depression, could lead to an overestimation.²⁵ However, none of these symptoms were reported from any player during this study. Finally, winning or losing a rally could also influence the player’s rating. In light of this, frequent rating in short time sequence, such as every 1 to 3 min, minimizes the possible influence on RPE scores because of success or disappointment. However, the possible difference in stress level between an actual real competition and simulated competition needs to be considered as a study limitation. In order to ensure a high level of motivation and a potential high level of psychological pressure, the winner of the match play in the present study would qualify to participate in a future international tournament. Since we did not assess stress hormone levels we can only speculate if the simulated competition in fact could reproduce the psychological stress of real match situation.
The authors are aware that a larger sample size including a senior cohort would have provided greater scope for cross comparisons. However, the data in this study were collected from the best German junior table tennis players at the time. These players live and train at the German Table Tennis federation’s head quarters in a controlled environment. Generally, it is very difficult to recruit elite senior German table tennis players. Since they belong to the best in the world they face a high number of competitions and high amount of traveling and therefore lack of time in participating in this type of studies. Therefore, increasing the number of nonelite players would have implied integrating technically “weaker” players, which could have potentially distorted the data outcome. Further, when comparing match performance a round-robin tournament or all-play-all tournament is in which each contestant meets all other contestants in turn would increase the power of analysis. In the present study however we were fortune to have the possibility to arrange a competitive setting in which elite junior players from different countries participated against each other.

Practical Applications and Conclusion

The present data from elite junior table tennis players revealed moderate cardiorespiratory and metabolic demands during match and training, indicating that endurance capacity may not be a limiting factor for junior table tennis players. Nevertheless, junior players competing at international level face regular high training loads, as well as competitive psychological stress. In this case, an elevated level of physical fitness may improve recovery and the ability to resist fatigue from frequent match and training. Since table tennis training and match play revealed low to moderate cardiorespiratory and metabolic demands, supplementary conditioning programs with higher physical demands should be added to the regular table tennis training in order to increase the players’ physical fitness. In this context, the table tennis specific drills with long high-intensity rallies, such as playing 200 balls, activated aerobic and anaerobic pathways and could be beneficial in increasing the players’ endurance capacity. This requires further investigation to fully explore the issue.

Acknowledgments

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References


