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Research article

Validity of critical frequency test for measuring table tennis aerobic endurance through specific protocol

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Abstract
The aim of this study was to validate critical frequency specific test (crit*f*) for the estimation of the aerobic endurance in table tennis players. Methods: Eight male international-level table tennis players participated of this study. Specific tests were applied by using a mechanical ball thrower to control the intensity of the exercise. The crit*f* was determined by applying three or four series of exercises to exhaustion (Tlim). The crit*f* was evaluated by using lactate steady state test (90, 100, and 106 % of crit*f* intensity). The other specific test was an incremental protocol used to determine the anaerobic threshold (AnT_{BI}) and the onset of blood lactate accumulation (OBLA) using a ball thrower. Results: The crit*f* (39.87 ± 3.31 balls·min^{-1}) was not significantly different among AnT_{BI} (48.11 ± 7.36 balls·min^{-1}) and $OBLA_{3.5}$ (49.36 ± 12.04 balls·min^{-1}) frequencies and it was correlated with AnT_{BI} parameter (r = 0.78). At frequencies of the 90 and 100% of crit*f* a dynamic equilibrium was verified in lactate concentration between the eighth and twentieth minutes. However, this dynamic equilibrium was not found at 106% intensity. Conclusion: The data indicate that in table tennis the crit*f* model can be used for measuring the aerobic endurance.

Key words: Anaerobic threshold - Aerobic endurance - Blood lactate - table tennis.

Introduction

Racket sports are characterized by effort and rest periods. During these effort periods the movements of inferior limbs are rapid and powerful whereas, the movements of upper limbs are rapid only. Overall, the aerobic system is the predominant mechanism of resynthesis of energy (ATP) in these sports, but in effort periods the phosphagenic system (ATP-PCr) is the main mechanism to resynthesis of ATP (Zagatto et al., 2008). The measurement of the aerobic and anaerobic capacities and power are very important in sports to verify the physical aptitude status of athletes and to determine ideal exercise prescription. Despite the fact that the ATP-PCr is the main mechanism to resynthesize of ATP in effort periods in rackets sports, the aerobic system is responsible for the recovery between effort periods (rally) and is also the main tool for the prescription of exercises (i.e., anaerobic threshold). The aerobic endurance, called, anaerobic threshold (AnT) or maximal lactate steady state (MLSS) by some investigators, has been used as a main tool for the prescription of the intensity of the exercise, in both aerobic and anaerobic sports. However, despite the importance of verifying the aerobic endurance with precision, few studies have measured this aerobic component using specific protocols for racket-sports. Nevertheless, the majority of investigations that applied specific tests were performed in tennis, badminton and squash (Chin et al., 1995; Girard et al., 2005; 2006; Smekal et al., 2000; Wonisch et al., 2003). However, there have been few applications of specific procedures in table tennis (Morel and Zagatto, 2008; Zagatto and Gobatto, 2007; Zagatto et al., 2008).

The use of blood lactate concentration ([Lac]) has been the main physiological parameter used for determining aerobic endurance. However, the measurement of blood lactate currently requires invasive and expensive techniques to analyze the samples (Heck et al., 1985; MacIntosh et al., 2002). Monod and Scherrer (1965) proposed the critical power model (critP) as a non-invasive procedure to estimate the aerobic endurance by measuring the time of exercise until exhaustion. The critical power model has been described as a good procedure for measuring the aerobic endurance (Dekerle et al., 2002; Toubekis et al., 2006; Wakayoshi et al., 1993). Several investigations have been adapted to the original critical power model for other sports and ergometers, such as swimming (Dekerle et al., 2002; Di Prampero et al., 2008; Toubekis et al., 2006; Wakayoshi et al., 1993), cycle ergometer (Bishop et al., 1998; Pringle and Jones, 2002), running (Bosquet et al., 2006), kayaking (Clingeleffer et al., 1994) and recently table tennis (Morel and Zagatto, 2008 ; Zagatto and Gobatto, 2007; Zagatto et al., 2008). Although the critical power model has been adapted for table tennis and so-called critical frequency (crit*f*), the validity of this procedure adapted for table tennis has not yet been verified. Therefore, the purpose of this investigation was to verify the validity of the critical power model adapted to table tennis (critical frequency test) to measure the aerobic endurance in a specific protocol using a mechanical ball thrower.

Methods

Subjects

Eight male table tennis players of international level (mean ± SD – age 18 ± 3 years, body mass 67.0 ± 10.7 kg, height 1.76 ± 0.10 meters, body fat 14.7 ± 7.1 %, and body mass index 21.7 ± 2.9 kg·m^{-2}) participated in this study. The players were fully informed of the nature and

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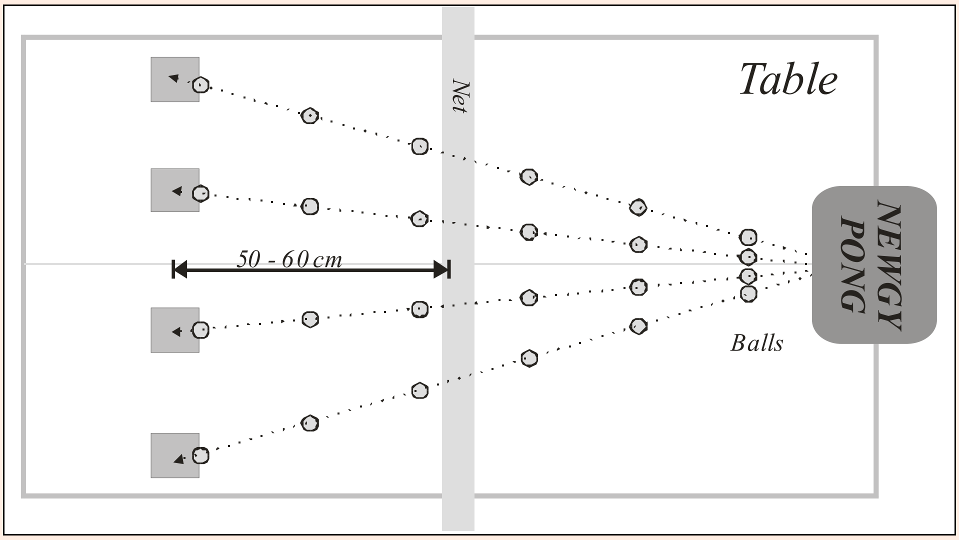

Figure 1. Illustration scheme of table tennis and the contact areas for the balls shot by the equipment NEWGY PONG 2000 in the specific tests for table tennis.

possible risks of the investigation before giving their written informed consent. The experimental procedure was approved by the Ethics Committee of São Paulo State University, Brazil.

Experimental design

Three sport-specific protocols were applied (critical frequency, lactate steady state test and incremental test) simulating forehand offensive strokes with ball shots from a mechanical ball thrower (*NEWGY-PONG* 2000, Newgy, CANADA). Prior to each sport-specific test a 4 minute warm-up exercise at moderate intensity (35 balls·min^{-1}) was performed by subjects**.** The tests started five minutes after the end of the warm-up period.

Description and adaptation of the mechanical ball thrower

The *NEWGY-PONG* 2000 (Newgy, Canada) mechanical ball thrower has adjustments from 0 to 10 for speed control, lateral ball oscillation, and thrower frequency. Lateral ball oscillation was adjusted (setting 3) so that balls were shot systematically to different areas of the table tennis table (between the two extremities) so that the ball contacted the table between 50 and 60-cm away from the net (Figure 1). Ball speed was constant at to "setting 5". Only ball frequency (exercise intensity) was changed for each effort (Zagatto et al., 2008).

To minimize interference from learning before the sport-specific test, the participants performed two familiarization sessions (done on consecutive days) at the same ball speed and lateral oscillation as applied in the test, and at varying ball shot frequencies. Each familiarization session lasted approximately 10 minutes.

Experimental procedures

*Critical frequency test (crit*f*):* All the athletes performed three or four trials (separated by at least 2 hours and no more than 2 exercises per day) on a table tennis table. Exercise frequencies (intensities) corresponded to approximately 48, 56, 65, and 72 (balls.min^{-1}) and were performed until technical or voluntary exhaustion (technical exhaustion occurred when four consecutive errors occurred in the offensive strokes developed with aid of coach). Exhaustion time (Tlim) was recorded. The crit*f* was obtained by linear regression techniques between ball frequency (*f*) and the inverse of the Tlim ($Tlim^{-1}$), corresponding to linear coefficient (y-intercept) (Figure 2).

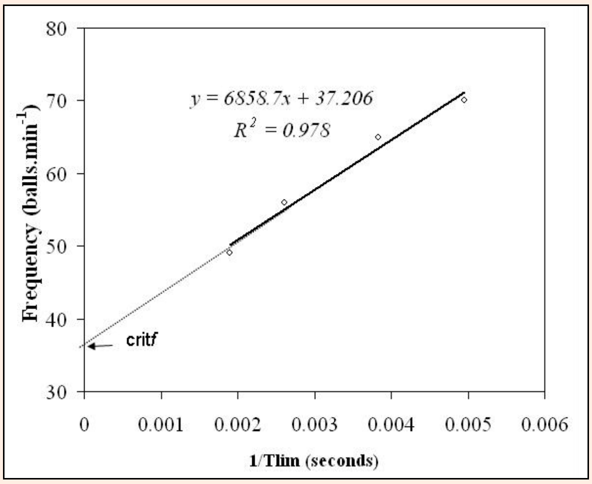

Figure 2. Represents the linear relationship between ball shot frequencies versus inverse of exercise time (1/Tlim) used to determine the critical frequency (crit*f*). The crit*f* corresponded to linear coefficient between frequency and the inverse of time.

Lactate steady state test: A sport-specific continuous test was applied after crit*f* to verify the blood lactate behavior in intensities below crit*f* (90% of crit*f*), at crit*f* (100% of crit*f*) and upper crit*f* (106% of crit*f*). The test lasted 20 minutes at constant workload intensity. Capillary blood samples were taken from the ear lobe (25 µl) every four minutes of constant load to determine the blood lactate

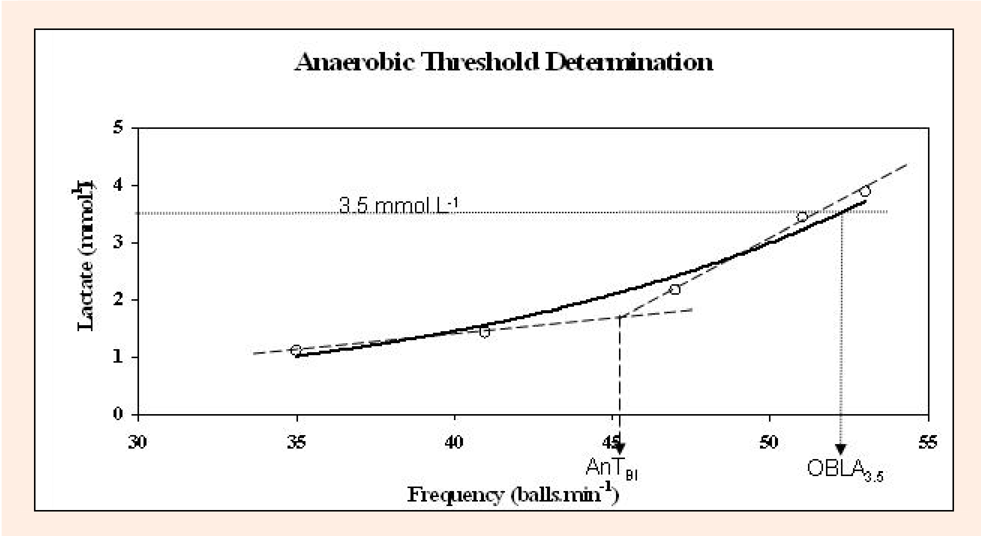

Figure 3. Determination of frequency corresponding of anaerobic threshold determined in specific protocol through visual inspection of abrupt increase of [Lac] using bi-segmented linear regression model (AnT_{BI}) (Dash lines) and the $OBLA_{3.5}$ determined by fixed blood lactate concentration corresponding to 3.5 mmol·L^{-1} (short dot lines).

concentration during the test. The lactate steady state was defined as highest work rate that could be maintained without an increase of blood lactate by more than 1.0 mmol.L^{-1} between the 8th and the 20th min of constant load of the lactate steady state test (Gobatto et al., 2001).

Incremental test: The sport-specific incremental test consisted of an initial frequency of 34 balls·min^{-1} and increments of 5 balls·min^{-1} every 3 minutes until voluntary exhaustion. After each exercise stage blood samples (25 µl) were collect from the ear lobe to determine the lactatemia. Blood samples were also taken at 1, 3, 5 and 7 minutes after exercise.

Determination of anaerobic threshold (AnT) and Onset of blood lactate accumulation (OBLA) intensities: Anaerobic threshold (AnT_{BI}) was determined by visual inspection of abrupt increase of the lactate concentration response using bi-segmented linear regression model (determined by three specialists in physiology of exercise) and the onset of blood lactate accumulation was corresponded to 3.5 mmol.L^{-1} fixed blood lactate concentration ($OBLA_{3.5}$) (Figure 3).

Blood sample analysis: Blood samples (25 µL) were collected from a participant's ear lobe and transferred to 1.5 mL Eppendorf tubes containing 50 µL NaF (1% sodium fluoride). The homogenate was injected (25 µL) into an electrochemical lactate analyzer (Yellow Springs Instruments model 1500 Sport, Ohio, USA). The electrochemical lactate analyzer was calibrated after every five blood samples analysis using a standard-5.0 mmol.L^{-1} lactate solution. Blood lactate concentrations are expressed in millimoles per liter (mmol.L^{-1}).

Statistical analysis

Data are expressed as mean ± SD. Significant differences for crit*f*, AnT_{BI} and $OBLA_{3.5}$ were tested by one-way ANOVA. Newman-Keuls *post hoc* test was performed if statistical significance was obtained to identify which variables differed. Relationships between variables were examined by using a Product Moment Linear Correlation Analysis. The intensity of lactate steady state was determined by variation lower than 1.0 mmol·L^{-1} between the 8th and 20th minutes of constant exercise. The program *STATISTIC for Windows 6.0* (Statsoft, Inc. 2001) was used for statistical analysis. In all cases, the statistical significance was set at $p < 0.05$.

Results

The Tlim obtained in the exercise frequencies (48, 56, 65 and 72 balls·min^{-1}) corresponded to 578.57 ± 203.95 s, 342.67 ± 109.70 s, 259.60 ± 38.90 s, and 188.83 ± 60.47 s, respectively. The crit*f* was determined by linear regression between intensity of exercise and Tlim^{-1} and corresponded to 39.87 ± 3.31 balls·min^{-1}. The coefficient of determination (R^2) of regression was 0.88 ± 0.11. A dynamic equilibrium of lactate was found at frequencies of 90% of crit*f* (lactate mean value correspondents at 2.88 ± 1.19 mmol·L^{-1} and variation of lactatemia equivalent to 0.27 mmol·L^{-1}) and 100% of crit*f* (lactate mean value correspondents at 3.51 ± 0.34 mmol·L^{-1} and variation of lactatemia equivalent to 0.75 mmol·L^{-1}). However, there was no lactate equilibrium at the frequency of 106 % of crit*f* (lactate mean value correspondent at 3.80 ± 1.80 mmol·L^{-1} and variation of lactatemia equivalent at 1.46 mmol·L^{-1}). The relationship between lactate concentration and exercise time verified by constant workloads at given frequencies of crit*f* are showed in Figure 4.

The AnT_{BI} was determined by three specialists in exercise physiology through a visual inspection following bi-segmented linear regression and were obtained, among them, a results variation of 2.86 ± 2.59% for [Lac] and 0.79 ± 0.36% for intensity (shot frequency). The AnT_{BI} occurred at frequency of 48.11 ± 7.36 balls·min^{-1} and the [Lac] at AnT_{BI} was 3.09 ± 1.65 mmol·L^{-1}. The $OBLA_{3.5}$ determined by fixed blood lactate concentration occurred at frequency of 49.36 ± 12.04 balls·min^{-1}. The maximal frequency obtained in the incremental test was 58.81 ± 12.76 balls·min^{-1}.

The crit*f*, AnT_{BI} and $OBLA_{3.5}$ were not significantly different [$F(1,6) = 3.03$; $p = 0.72$]. However,

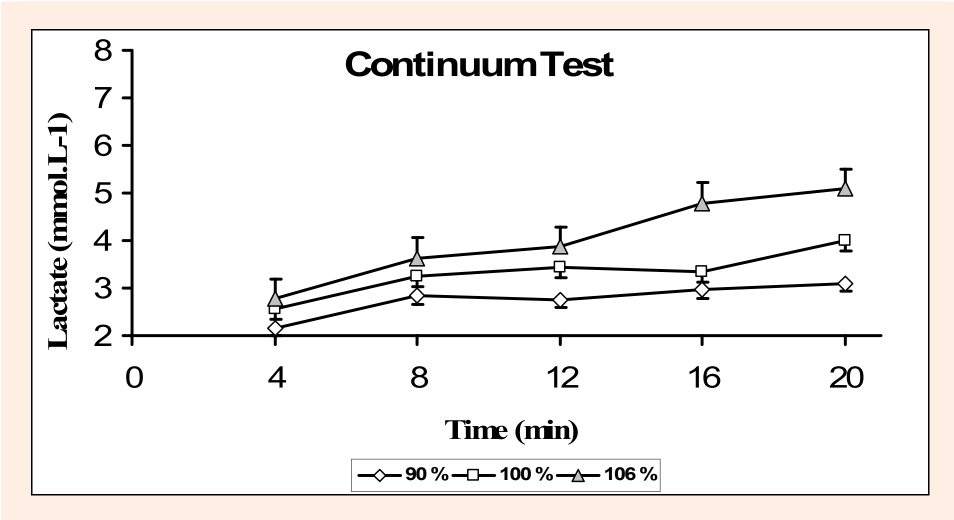

Figure 4. The relationship between blood lactate concentration and time of exercise in the lactate steady state test. The vertical bars indicate SEM.

despite the lack of significant differences between these variables, the AnT_{BI} and the $OBLA_{3.5}$ were 20.7% and 23.8% higher than crit*f*, respectively. The crit*f* was significantly correlated with the AnT_{BI} ($r = 0.78$; $p = 0.03$) and also with the frequency at exhaustion ($r = 0.79$, $p = 0.02$), but not with $OBLA_{3.5}$ ($r = 0.42$; $p = 0.34$). The AnT_{BI} was also correlated with frequency at exhaustion ($r = 0.94$; $p = 0.002$).

Discussion

The critical frequency test was shown to be a good method to aerobic endurance evaluation in a table tennis sport-specific test, and of lactate concentration was found to stabilize at 100% of crit*f* intensity and significantly correlate with crit*f* and AnT_{BI}. The critical power model made some adaptations to the original model described by Monod and Scherrer (1965), for application to swimming (Wakayoshi et al., 1993), cycle ergometer (Bishop et al., 1998; Jenkins and Quigley, 1990; 1992; Pringle and Jones, 2002), running (Bosquet et al., 2006; Smith and Jones, 2001), and kayaking (Clingeleffer et al., 1994), with valid and reliable results. The critical power model has been validated and correlated with the aerobic endurance determined by ventilatory threshold (Moritani et al., 1981), fatigue threshold (DeVries et al., 1982), individual anaerobic threshold (McLellan and Cheung, 1992), onset of blood lactate accumulation (OBLA) (Papoti et al., 2005; Wakayoshi et al., 1993) and maximal oxygen uptake (Jenkins and Quigley, 1992), showing it to be a good tool for assessing the aerobic parameter. Wakayoshi et al. (1993) adapted the critP concept for swimming and called it critical swimming. Wakayoshi et al. (1993) found high correlation between critical swimming and anaerobic threshold and showed that in exercise 100% intensity of critical swimming a dynamic equilibrium occurred between the production and the disposal of blood lactate. However, this dynamic equilibrium did not occur when the intensity of exercise was increased by only 2%. Similar result was found by Jenkins and Quigley (1990) on the cycle ergometer. In the present study we adapted the critical power model for table tennis using a mechanical ball thrower (robot) to control the exercise intensity (frequency). This adaptation for table tennis was initially reported by Zagatto and Gobatto (2002; 2007), but these researchers did not validate this test. The values of crit*f* (39.87 ± 3.31 shots·min^{-1}) found here were similar to the ones previously obtained by Zagatto and Gobatto (2002) (39.9 ± 1.3 shots·min^{-1}), but in this investigation higher values of AWC (99.46 ± 29.11 balls and 50.9 ± 6.9 balls, respectively) and linear coefficient ($R^2 = 0.88 \pm 0.11$, and $R^2 = 0.77 \pm 0.06$, respectively) were obtained. Table tennis requires a larger contribution of the ATP-CP system in effort periods (Faccini et al., 1989; Zagatto et al., 2008) and the difference found in AWC in these studies could be due a better ability of the athletes in this study.

Many investigations use approximately four trials in the critical power test, but other authors have used only two trials (Housh et al., 1990; Wakayoshi et al., 1993). Housh et al. (1990) investigated the number of workloads necessary to accurately determine the critical power. These authors found that critical power could be measured using only two trials. However, it should be noted that a possible mistake in Tlim in one or two of the workloads applied could have negative effects in the determination of the critical power and AWC results. In the present investigation, three or four trials were used for critical frequency determination. Nevertheless, the number of workloads used did not influence the results. The duration of the time trial could also influence the results of the critical power model (Bishop et al., 1998; Poole, 1986). Poole (1986) reported that the ideal duration of trials that result in Tlim between 2 and 10 minutes. Workloads that generate a Tlim higher than 10 minutes can overestimate the AWC, and effort that generate short Tlim can overestimate the critP. The Tlim used in the present study respected the relation described by Poole (1986) with Tlim variation between 3 and 9 minutes (188.33 ± 60.47 s to 578.57 ± 203.95 s).

The blood lactate concentration analyzed during the lactate steady state test showed a dynamic equilibrium in production and disappearance of blood lactate at frequencies of 90 and 100 % of crit*f*. Nevertheless, with an increase of only 6% in the frequency (106% of crit*f*), this dynamic equilibrium was not verified. Similar results were also found by Wakayoshi et al. (1993) in swimming and Jenkins and Quigley (1990) on cycle ergometer. The frequency of 106% of crit*f* applied in the lactate steady state test was chose, because of the difficulty in adjusting lower values of the equipment. The MLSS is usually applied in 30 minutes exercises, analyzing the lactate steady state in the last 20 minutes. But, the table tennis match and training consist in intermittent exercise, and the application of 30 minutes exercise would be very difficult for table tennis players perform. Moreover, even with the lactate steady state test lasting 20 minutes, it was very hard for the athletes to continuously perform the exercise for a long duration. Moritani et al. (1981) found a high correlation between anaerobic threshold, determined for ventilatory threshold, and critical power on the cycle ergometer (r = 0.92), also McLellan and Cheung (1992) found a correlation between the critP and the individual anaerobic threshold (IAT) (r = 0.98) on the same ergometer. In the present investigation the crit*f* also significantly correlated with the AnT_{BI} (r = 0.78), but not with $OBLA_{3.5}$. The $OBLA_{3.5}$ was determined using a fixed [Lac] corresponding to 3.5 $mmol.L^{-1}$, as proposed by Heck et al. (1985) who used this concentration when the exercise stage lasted three minutes. However, this protocol determined the anaerobic threshold for fixed [Lac] though mean values and not through individual values, and this could cause more variability in results. Heck el at. (1985) found a range of 2.40 to 4.35 $mmol.L^{-1}$ for [Lac] for this duration of exercise. The lack of correlation between crit*f* and $OBLA_{3.5}$ can be explained by a possible mistake in the utilization of a fixed lactate concentration protocol. The mean lactate concentration in AnT_{BI} was 3.09 ± 1.65 $mmol{\cdot}L^{-1}$ which is lower than 3.5 $mmol{\cdot}L^{-1}$ used in $OBLA_{3.5}$. This difference in lactate shows that the use of a fixed lactate concentration protocol may result in a mistake in the results of aerobic endurance for table tennis. On the other hand, the use of other methods for anaerobic threshold determination could show better results than $OBLA_{3.5}$, as the lactate threshold, individual anaerobic threshold or lactate minimum tests. Morel and Zagatto (2008) investigated also the crit*f* test for table tennis and found similar results, obtaining significant correlation between crit*f* and the lactate minimum (r = 0.69), but not verified significant correlation between crit*f* and $OBLA_{3.5}$. (r = 0.06).

The table tennis is a sport that has few scientific studies and a lack of valid protocols to specifically measure aerobic endurance. Evaluation protocols showed physiological parameters and performance variables that respect the specificity of sports, because the use of non-specific protocols does not represent the same motor pattern performed in a match. The correlation found between crit*f* and AnT_{BI} (r = 0.78) and the dynamic equilibrium of blood lactate at 100% of crit*f* frequency enables the utilization of the crit*f* model for the evaluation of aerobic endurance in table tennis with a specific protocol by a non-invasive technique. The AnT_{BI} and $OBLA_{3.5}$ were 20.7 % and 23.8 % higher than crit*f*, respectively, but not significantly different. Thus, these results should be taken into consideration. The low number of participants due to the difficulty in recruiting high level athletes may be a limitation of the study. The analyses of only forehand strokes may also be a limitation. Forehand, backhand and defensive strokes are performed in a mach may influence the physiological parameters of a match. However, in this study only the forehand strokes were analyzed. The analyses of the physiological characteristics of table tennis should be further investigated using other parameters, such as maximal oxygen uptake in specific situations.

Conclusion

The critical frequency intensity applied in a specific protocol showed a dynamic equilibrium of lactate in long duration exercise and significant correlation with AnT_{BI}, but not with $OBLA_{3.5}$. Therefore, the crit*f* can be a valid procedure that may be used for evaluating the aerobic endurance of table tennis athletes by non-invasive techniques.

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Key points

- In table tennis is need the use of a specific protocol for evaluation of the aerobic endurance.
- The critical frequency test in table tennis seems to represent the intensity of maximal equilibrium of lactatemia.
- The critical frequency test can be used for measuring table tennis aerobic endurance through specific protocol.

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