Comparison of anaerobic threshold, oxygen uptake and heart rate between specific table tennis procedure and conventional ergometers

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Abstract: The purposes of this study were to: 1) compare the oxygen uptake (VO_2) and heart rate (HR) corresponding at anaerobic threshold intensity measured during graded incremental exercise tests (GTX) in table tennis-specific protocol (ST), treadmill (TT), cycle ergometry (CE) and arm crank ergometry (AE); 2) correlate the AnT intensity among ST, TT, CE and AE; verify the use of VO_2 and HR at AnT and the AnT intensity for predicting the table tennis performance. Eleven Brazilian table tennis male players of national level (19.4±0.7 years; body mass: 70.8±3.9 kg) participated to the study. The athletes underwent four maximal graded incremental exercise tests performed in ST using a Tibhar RoboPro Plus ball throwing machine and on TT, CE and AE; and also a simulated tournament among players to estimate the table tennis performance ranking. During graded incremental exercise tests, blood samples were collected after each 3-min exercise stage to determine the anaerobic threshold, which corresponded to 3.5 mmol/L fixed blood lactate concentration. VO_2 and HR were also measured during GTXs. The AnT corresponded 42.8±5.6 balls·min^{-1} to ST, 131.9±6.6 W to CE, 64.5±6.1 W to AE and 11.1±0.3 km·h^{-1} to TT. The VO_2 and HR at AnT measured in ST (37.2±1.7 ml·kg^{-1}·min^{-1} and 182.8±7.2 bpm, respectively) were similar to values obtained in CE (29.8±1.9 ml·kg^{-1}·min^{-1} and 157.2±7.1 bpm) and TT (36.3±1.0 ml·kg^{-1}·min^{-1} and 166.0±10.2 bpm), but it was significantly different to AE (18.2±1.1 ml·kg^{-1}·min^{-1} and 132.7±4.7 bpm). AnT in ST was only significantly correlated with AE (r= .89), while VO_2 at AnT in ST was significantly correlated with values measured in CE (r= .92) and TT (r= .81). However, the variables measured during maximal graded incremental exercise tests in ST, CE, AE and TT were not statistically correlated with the table tennis performance ranking analyzed by Spearman correlation test. The results did show that there are differences among the results from table tennis-specific test and from conventional ergometers (i.e., CE, TT and AE); few significant correlations among them; and any parameter did show significant correlation with table tennis performance. These results indicate the importance of using table tennis-specific test to evaluate the anaerobic threshold in table tennis players and that the parameters measured cannot predict the table tennis performance.

Key words: table tennis, aerobic endurance, table tennis performance, mechanical ball thrower

1. INTRODUCTION

Several investigations have reported the importance of specificity in physical fitness evaluation (Basset and Boulay 2000; Müller et al. 2000; Roels et al. 2005; Tordi et al. 2001). However, measurement of endurance capacity in sports is generally carried out on laboratory ergometers, such as conventional cycles and/or treadmills, which are inaccurate to measure specific training adaptations (Forbes and Chilibeck 2007).

Both studies measuring physical ability and the application of specific-test in table tennis players are scarce, (Morel and Zagatto 2008; Zagatto et al. 2008, 2009, 2011). In table tennis only two studies have compared aerobic capacity measured with table tennis-specific test (ST) using a balls thrower machine (i.e. robot) and conventional ergometers (Zagatto et al.

2009; Morel and Zagatto 2008). However, the values measured during ST were not significant and positively correlated with values measured during cycle, arm crank (Zagatto et al. 2009) and treadmill (Morel and Zagatto 2008). In these studies the aerobic capacity was determined using lactate minimum test and abrupt increase of lactatemia (Zagatto et al. 2009; Morel and Zagatto 2008).

The onset of blood lactate accumulation (OBLA) protocol, which estimates the aerobic-anaerobic transition by fixed lactate concentration during graded incremental exercise test (GTX) (Heck et al., 1985, Pereira et al., 2002), have been widely applied for endurance evaluation, training prescription and performance prediction (Heck et al., 1985, Pereira et al., 2002, Zagatto et al., 2004) due to its easiness for application in high performance training routine. Such procedure could result in different findings for specific

test evaluations. In addition, comparison of other physiological variables (e.g., gas exchange and heart rate) between ST and conventional ergometers, on anaerobic threshold intensity, as well as their correlations with table tennis performance have not been investigated yet.

Thus, the purposes of this investigation were to: 1) compare among table tennis-specific test (ST), treadmill (TT), cycle ergometry (CE) and arm crank ergometry (AE), the VO_2 and HR values corresponding to anaerobic threshold intensity measured during maximal graded incremental exercise tests (GTX); 2) correlate the AnT intensity among these ergometers; 3) verify the use of VO_2 and HR at AnT and the AnT intensity for predicting the table tennis performance. Our hypotheses are that significant differences to physiological responses among the ST, CE, AE, and TT will be verified, and that table tennis performance will be mostly associated with variables obtained during ST.

2. METHODS

2.1 Subjects

Eleven male table tennis players of national level [age 19.4($\pm$0.7) yr; body mass 70.8($\pm$3.9) kg; and peak oxygen uptake 43.9($\pm$1.5) ml·kg^{-1}·min^{-1}] participated in this study. All had over four years of systematic regular training and participated in competitions, being technically representative samples of table tennis players. Subjects were informed of experimental risks and signed an informed consent document prior the investigation. The investigation was approved by the Ethics Committee of University for use of human subjects. For athletes under 18 years of age, the consent document was signed by parents or guardian.

2.2. Experimental Procedures

Subjects completed five testing sessions accomplished in two weeks, with minimum of 48 hours between sessions. Three visits to the laboratory were needed for graded incremental exercise tests (GTX) on cycle ergometry (CE), arm crank ergometry (AE) and treadmill (TT); and two sessions were needed for GTX on table tennis-specific test (ST) and to determine table tennis performance ranking in simulated tournament.

Graded incremental exercise test (GTX)

Maximal graded incremental exercise tests (GTX) were performed on cycle ergometry (CE), arm crank ergometry (AE), treadmill (TT) and on table tennis-specific test (ST). All GTXs consisted of 3-minute effort stages (20-s pause between stages) and accomplished until voluntary exhaustion.

Cycle ergometry

GTX test was accomplished on mechanical braked cycle ergometry Monark 894E (Monark, Stockholm, Sweden) with initial intensity of 103 W and incremented by 15 W after each complete stage until

voluntary exhaustion. The participants were informed to maintain fixed cadence of 60 rpm.

Arm crank ergometry (AE)

To apply the GTX on arm crank ergometry, mechanical braked cycle ergometry Monark 894E (Monark, Stockholm, Sweden) was adapted to upper limbs. The initial intensity was 29 W and incremented by 15 W after each exercise stage until voluntary exhaustion. Similar to CE, the cadence was also maintained constant at 60 rpm.

Treadmill (TT)

Treadmill GTX was performed on motorized treadmill (Inbramed ATL, Inbrasport, Porto Alegre, Brazil) with initial speed at 8 km·h^{-1} and incremented by 1.5 km·h^{-1} every 3-min effort stage until exhaustion. The slope was maintained constant at 1%. Test ended with voluntary exhaustion of the participant.

Table tennis-specific procedure (ST)

The ST was applied on table tennis court simulating forehand offensive strokes in ball shots from a mechanical ball thrower Robopro Plus Tibhar (robot) (Tibhar, Saarbruecken, Germany). All subjects were instructed to perform constant and regular strokes.

The robot had adjustment from 0 to 9 arbitrary units for ball-thrower frequency (f). The modification of 1 arbitrary unit resulted in frequency changes of approximately 10 balls.min^{-1}. Because of this high range in original equipment control with increase of only one arbitrary unit, an alternative control was built, allowing the increment in f correspondent to approximately one-ball.min^{-1} to each arbitrary unit increase. The robot had also adjustments for ball speed and lateral ball oscillation. Ball speed and lateral ball oscillation were maintained constant, corresponding to setting 4 (approximately 35 km.h^{-1}) and setting 5, respectively. Balls were shot systematically on two locations of the table (laterally at 30-40 cm from the central line - maximal equipment range), so that the ball contacted the table between 50 and 60-cm away from the net, simulating the stroke of an opponent (Morel and Zagatto 2008, Zagatto et al, 2011). Only ball frequency (exercise intensity) was changed in the test and it was adjusted by real frequency of shots.

After equipment adjustment, ST was applied with initial frequency at 30 balls.min^{-1} and incremented by approximately 4 balls.min^{-1} until voluntary exhaustion.

Figure 1 shows the ergometers used in the graded incremental exercise tests.

Measurement of physiological responses in GTXs.

In all GTXs, a pause of 20-s after every stages was standardized in order to collect blood samples (25 μL) from the ear lobe for lactatemia ([La$^-$]) analysis into an electrochemical lactate analyzer YSI 1500 SPORT (YSI, Yellow Springs, OH, USA). Blood samples were

also taken at 3, 5 and 7 minutes after the test. During all GTXs the oxygen uptake (VO_2) was measured every three breath cycles by a portable metabolic system (MedGraphics VO2000, Medical Graphics Corp., St. Paul, MN, USA). The gas analyzer was always calibrated before each test following manufacturers' recommendations. Heart rate (HR) values were continuously recorded with gas exchange (Polar, Kempele, Finland) and interconnected with portable metabolic system. In all GTXs, gas exchanges and HR samples were averaged every 30 seconds, and the highest values reached were regarded as peak values. Rating of perceived exertion (RPE) (Borg, 1982) was also measured after exercise stages. The anaerobic threshold was considered as the intensity of fixed lactate concentration corresponding to 3.5 mmol·L⁻¹ (OBLA) (Morel and Zagatto 2008; Zagatto et al. 2008). Figure 2 shows an anaerobic threshold determination.

Fig 1. The figure shows the exercises performed in cycle ergometry (1a), arm crank ergometry (1b), treadmill (1c), which were considered as conventional ergometers, and the exercise in table tennis-specific procedure (1d).

Table 1. Oxygen uptake, heart rate and rating of perceived exertion values at OBLA measured in GTXs on table tennis-specific procedure (ST), cycle ergometry (CE), arm crank ergometry (AE) and treadmill (TT).

	ERGOMETERS			
	ST	**CE**	**AE**	**TT**
VO_{2PEAK} (ml·kg⁻¹·min⁻¹)	37.2(±1.7)	29.8(±1.9)	18.2(±1.1)[a,b]	36.3(±1.0)[c,b]
VO_{2PEAK} (%VO_{2PEAK})	94.0(±1.9)	72.2(±3.8)[a]	67.1(±3.6)[a]	83.2(±2.2)
OBLA (%) of maximal intensity	90.9(±3.1)	73.6(±2.9)	71.5(±3.8)[a]	82.9(±2.1)
HR_{OBLA} (bpm)	182.8(±7.2)	157.2(±7.1)	132.7(±4.7)[a]	166.0(±10.2)[c]
HR_{OBLA} (%HR_{PEAK})	91.3(±3.2)	78.3(±3.4)	66.5(±2.3)[a]	82.7(±5.0)[c]
RPE_{OBLA}	16.6(±1.2)	13.0(±0.9)	14.1(±0.6)	14.48(±0.6)

Results are mean(±SEM). Significant differences (P<0.05) in relation: a) to ST; b) to CE; c) to AE.
VO_{2OBLA}: Oxygen uptake at OBLA; HR_{OBLA}: heart rate at OBLA; RPE_{OBLA}: Rating of perceived exertion at OBLA

Table tennis performance ranking determination by simulated tournament
Table tennis performance ($TT_{PERFORMANCE}$) was considered as the ranking estimated through a tournament between the study subjects. The competition was run in an elimination format with repechage, where each athlete could lose one match and still be able to attain first place. The athlete was eliminated from the tournament after losing two matches.

2.3. *Data Analysis*
All data analysis was performed using the STATISTICA 7 package. Results are shown in means (±standard error of the mean). Initially Shapiro-Wilk's test was used to analyze variables normality and all scores showed normality. One way ANOVA with repeated measures was used for comparison among parameters intra ergometers. Significant F-ratios were followed by post-hoc comparison using Newman-Keul's procedure. The product-moment correlation test was used for analyses of association between physiological variables determined in all ergometers and the Spearman correlation test was applied to analyze the association between physiological variables

and table tennis performance ranking. In all cases, statistical significance was set at $P < 0.05$.

3. RESULTS

The OBLA intensities obtained during GTXs corresponded to 42.8(±5.6) ball·min⁻¹ in ST, 64.5(±6.1) W on AE, 131.9(±6.6) W on CE and to 11.1(±0.3) km·h⁻¹ on TT. The results of VO_2, HR and rating of perceived exertion correspondent at OBLA, as well as the value at OBLA as a percentage of the maximal intensity obtained in specific and conventional ergometers are shown in table 1. All parameters, except the RPE at OBLA, shown significant differences among ergometers. However, these differences were observed, practically, by lower values measured on AE.

Table 2 shows the significant product-moment correlations among physiological responses at ST with CE, AE, and TT.

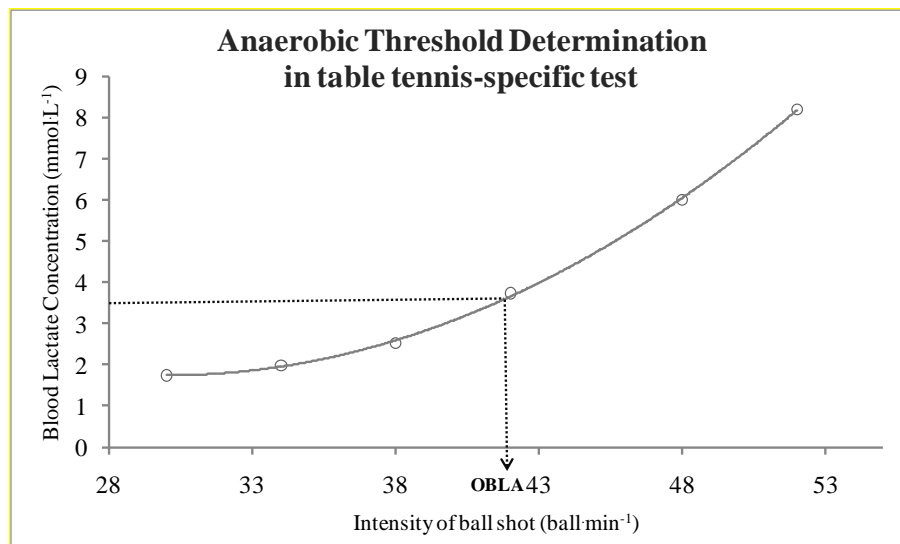The table tennis performance ranking was not significantly correlated with any measured parameter.

Fig 2. Determination of anaerobic threshold in table tennis-specific test using fixed lactate concentration corresponding to 3.5 mmol·L^{-1} (OBLA).

Table 2. Significant product-moment correlations to physiological responses at submaximal intensities between the ST and the conventional ergometers.

ST	VO_{2OBLA}	VO_{2OBLA} at VO_{2PEAK}	OBLA	OBLA at maximal intensity
CE	.92			.93
AE		.82	.89	.83
TT	.81			.77

4. DISCUSSION

The main findings of the study were the significant differences of VO_{2OBLA} and HR_{OBLA} among the ergometers and also the not significant correlation of VO_{2OBLA} and HR_{OBLA} measured in all ergometers with table tennis performance. The significant differences obtained among ergometers were basically found for lower values by AE. The result obtained in ST was not different to TT results for all parameters, while CE was only lower than ST to VO_{2OBLA} as a percentage of peak oxygen uptake. Nevertheless, the similar values verified between ST, TT, and CE should be attributed to greater active body mass in ST due to muscle activities of lower and upper limbs, as reported by Forbes and Chilibeck (2007).

In table tennis there are few studies that compared results measured in specific and conventional tests (Morel and Zagatto, 2008; Zagatto et al., 2008), being found more studies in rackets sports such as squash (Girard at al., 2005), tennis and badminton. In squash, Girard et al. (2005) found higher value of VO_2 at respiratory compensation point in specific tests than treadmill, while Smekal et al. (2000) observed the same results for VO_2 and pulmonary ventilation corresponding to individual anaerobic threshold intensity. However, the results of VO_2 were not verified by Girard et al. (2006) in tennis. The VO_{2OBLA} corresponding to a percentage of VO_{2PEAK} showed

higher values in ST (94.0±1.9% of VO_{2PEAK}) than in CE and in AE and these highest responses in ST should be attributed to the players mechanical limitation against the high throwing frequency of the robot, which made impossible to reach the real physiological VO_{2PEAK}, thus, overestimating VO_{2OBLA} as a percentage of VO_{2PEAK}.

Although the present study did not investigate the effect of training, the subjects were table tennis athletes. Therefore, specific adaptation occurred with training, mainly muscle adaptations, could be verified by few significant correlations between variables measured in ST with conventional ergometers, being the main correlations VO_2 and OBLA as a percentage of maximal intensity.

In general, the table tennis training prescription is still performed empirically. Probably, due the reduced number of researches that restricts scientific information about specific procedures, physiological profile and characteristics of table tennis matches for the trainers and coaches (Zagatto et al., 2010). The anaerobic threshold is an important testing widely used for evaluating, prescribing and monitoring the sport training, and to know that it is necessary to use specific test for evaluating the aerobic conditioning of table tennis players instead of using conventional ergometers is a relevant finding.

Table tennis performance was evaluated as the ranking determined by simulated tournament among the

subjects. Contrary to our initial hypothesis, no significant correlations between ST variables and table tennis performance were found. Our results showed that anaerobic threshold and also the parameters at anaerobic threshold measured in specific and conventional table tennis ergometers cannot predict the table tennis performance and showed to be not a determinant factor for sporting success. Smekal et al. (2000) also did not verify the correlation between physiological parameters and tennis ranking performance, also verified by Wilkinson et al. between maximal oxygen uptake and performance ($r = -.70$).

Despite the importance of measuring the aerobic threshold for evaluating the aerobic endurance and for monitoring and prescribing the training, the aerobic threshold is unable to be used as unique sports performance predictor.

5. CONCLUSIONS

In conclusion, our findings describe that there are different responses of anaerobic threshold and physiological parameters at anaerobic threshold when measured with specific and conventional table tennis ergometers. The ST is a test using movements and strokes similar to those performed in matches, respecting the sport ecological validity. It seems ideal to be applied in the training program for optimizing performance (Muller et al. 2000), which should be used during table tennis training routine, however it cannot predict the table tennis performance.

6. ACKNOWLEDGMENTS

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