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Research article

Anaerobic capacity may not be determined by critical power model in elite table tennis players

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Abstract

The aim of the present study was to verify the applicability of anaerobic work capacity (AWC) determined from the critical power model in elite table tennis players. Eight male international level table tennis players participated in the study. The tests undertaken were: 1) A critical frequency test used to determinate the anaerobic work capacity; 2) Wingate tests were performed using leg and arm ergometers. AWC corresponded to 99.5 ± 29.1 table tennis balls. AWC was not related to peak (r = -0.25), mean (r = -0.02), relative peak (r = -0.49) or relative mean power (r = 0.01), nor fatigue index (r = -0.52) (Wingate leg ergometer). Similar correlations for peak (r = -0.34), mean (r = -0.04), relative peak (r = -0.49), relative mean power (r = -0.14) and peak blood lactate concentration (r = -0.08) were determined in the Wingate arm ergometer test. Based on these results the AWC determined by a modified critical power test was not a good index for measurement of anaerobic capacity in table tennis players.

Key words: Anaerobic capacity, table tennis, critical frequency, Wingate test, lactate.

Introduction

Racket sports are characterized by periods of intense effort followed by brief rest periods. The intense efforts use phosphagenic energy sources (ATP;PCr) as the main mechanism to resynthesize energy (ATP) in contrast, during periods of rest, the aerobic energy supply dominates. The major energy (ATP) supplier during long rallies comes primarily from glycolysis (Zagatto, 2004).

The laboratory methodology for measuring anaerobic power and capacity is not as well developed as protocols available for measuring aerobic variables. Various approaches researchers have been used including the maximal accumulated oxygen deficit (MAOD) (Hill and Smith, 1993), the Wingate cycle ergometer test (Beneke et al., 2002), the Wingate arm ergometer test (Hawley and Williams, 1991), and tethered swimming (Papoti et al., 2003; 2007) to determine the anaerobic capacity. However, a great number of these protocols need expensive equipment and present specific application limitations in field evaluations, especially with respect to racket sports.

The critical power concept (critP), initially developed by Monod and Scherrer (1965), seems to be an appropriate theoretical model, and is the only method that can evaluate aerobic and anaerobic parameters without high cost, using non-invasive procedures. It is based on the hyperbolic relationship between different exercise intensities and their respective exhaustion times. This model has an aerobic component called critical power (critP) and an anaerobic component called anaerobic work capacity (AWC) (Bishop et al., 1998). AWC theoretically represents a finite supply of energy and is used only at intensities greater than critical power, such that fatigue would be a consequence of total AWC depletion (Bishop et al., 1998; Monod and Scherrer, 1965). AWC is considered by many authors to be an index of anaerobic capacity (Bulbulian et al., 1996; Green et al., 1994; Hill and Smith, 1993; Papoti et al., 2003). Nebelsick-Gullet et al. (1988) compared AWC determined by the critical power model with the 30 second Wingate test and concluded that AWC provided a valid estimation of anaerobic capacity. Green et al. (1994) adapting the model to a cycle ergometer, corroborated these findings, confirming that AWC can be used to estimate the anaerobic capacity. The ability to adapt the critical power model in studies using differing ergometers and different sports such as the cycling (Bishop et al., 1998), swimming (Papoti et al., 2003), running (Bosquet et al., 2006) and table tennis (Zagatto and Gobatto, 2002; Zagatto, 2004), makes this model extremely viable. Despite this, in most adaptations of the critical power model, only the aerobic parameter has been validated. In contrast, the anaerobic component of critP has not been validated (Dekerle et al., 2002; Papoti et al., 2005), thus lessening its general acceptance by sports scientists.

The Wingate test designed for the cycle ergometer (Beneke et al., 2002) has also been adapted for the arm ergometer (Hawley and Williams, 1991), tethered swimming (Papoti et al., 2003) and other protocols, and has been used to assess the capacity of glycolytic and ATP-PCr energy systems in athletes (Vandewalle et al., 1987). Vandewalle et al. (1987) showed that the peak power output obtained in the Wingate test represented the maximal rate of ATP-PCr catabolism and that the mean power output represented primarily glycolytic metabolism or the 'anaerobic capacity'. Many authors confirm the utility of the Wingate test as a protocol for evaluating anaerobic capacity (Beneke et al., 2002; Hawley and Williams, 1991); it is ideal for evaluating power in sprint and jump athletes, and power in other sports such as table tennis.

The use of a specific non-invasive, low cost protocol for evaluating anaerobic capacity in table tennis is of great importance as it can reproduce specific motor patterns. However, confirmation of its validity is necessary. The aim of the present study, therefore, was to verify AWC applicability (critP model) in table tennis. Thus,

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AWC determined by the critical power test (specifically adapted for table tennis), was correlated with variables from both cycle and arm Wingate tests.. Our hypothesis being that AWC (critP) can be used to determine anaerobic capacity in table tennis players.

Methods

Subjects

Eight male international level table tennis players (age: 18±3 years, body mass: 67.0 ± 10.7 kg, height: 1.76 ± 0.10 metres, body fat: 14.7 ± 7.1%, and body mass index: 21.7 ± 2.9 $kg\cdot m^{-2}$) participated in the study. The study was approved by the Research Ethics Committee of the Bioscience Institute, São Paulo State University (UNESP), Rio Claro Campus, Brazil and the athletes signed an informed consent form prior to testing.

Experimental approach to the problem

The critical frequency test (crit*f*) (critical power model adapted for table tennis) was used to determine anaerobic work capacity (AWC) in a table tennis specific test; and Wingate tests were used in both cycle (W_{cycle}) and arm crank ($W_{arm\ crank}$) ergometers to determine peak (highest power output in the initial 5-s) and mean power output (W, $W\cdot kg^{-1}$) (over 30-s).

The tests for the crit*f* protocol were conducted using a table tennis table and mechanical ball thrower; Wingate tests were performed on a Monark 894-E cycle ergometer (Monark, Sweden) (W_{cycle}) and a Cybex UBE 2462 (Cybex, Owatonna, MN) arm ergometer ($W_{arm\ crank}$). Verbal encouragement was used in all tests to maintain a maximum effort (Wingate tests). Twenty-four hours rest was permitted between tests, and testing was conducted over a maximum period of 2 weeks. Prior to each test the ergometer was used as a warm-up exercise for 4 minutes at moderate intensity (35 $balls\cdot min^{-1}$ for critical frequency test, 85 watts for cycle ergometer and 49 watts for arm ergometer). During warm-up (Wingate tests) 2 to 3-s duration flat-out sprints were performed at the beginning of the 4th minute of warm up**.** Tests were started five minutes after the end of the warm-up period.

Procedures

Description and adaptation of the mechanical ball thrower, used in the critical frequency test

The *NEWGY-PONG* 2000 (Newgy, Canada) mechanical ball thrower has adjustments between 0 to 10 for speed control, lateral ball oscillation, and launch 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 from the net (Figure 1). Ball speed was maintained constant corresponding to Setting 5. Only ball frequency was changed for each effort; hence the term ‘critical frequency test’.

To minimize interference from learning before a specific test, participants were submitted to two familiarization sessions (performed on consecutive days) with the same ball speed and lateral oscillation as the test, and with varying ball shot frequency. Each familiarization session lasted 10 minutes.

Critical frequency test to determine anaerobic work capacity in table tennis

Athletes were submitted to 3 or 4 repetitions until exhaustion (separated by a minimum break of 2 hours and no more than 2 repetitions per day) with the mechanical ball thrower simulating forehand attacks at shot frequencies

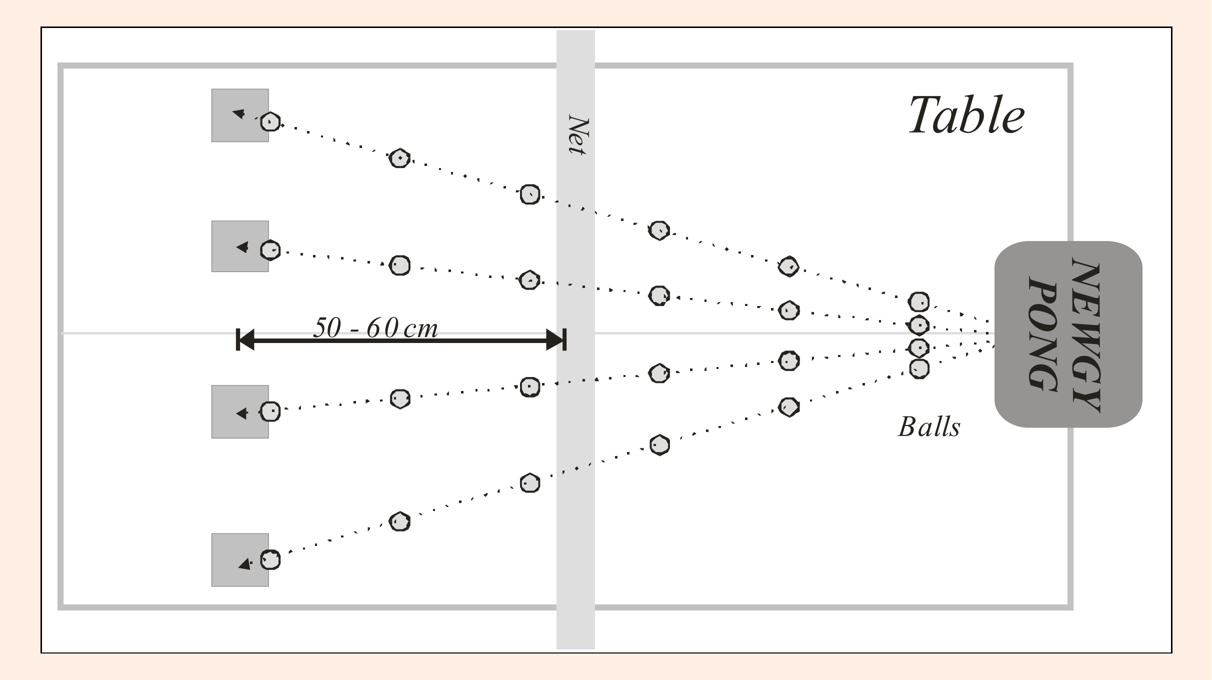

Figure 1. **Representative procedures of a specific table tennis test for determination of AWC using a mechanical ball thrower. The figure demonstrates the mechanical ball thrower (NEWGY PONG 2000), with the projections of ball displacement, and the areas the balls made contact on the table tennis table. Ball contact was adjusted to occur between 50 and 60-cm beyond the net, adjustment of the equipment resulted in four fixed areas of ball contact with the table.**

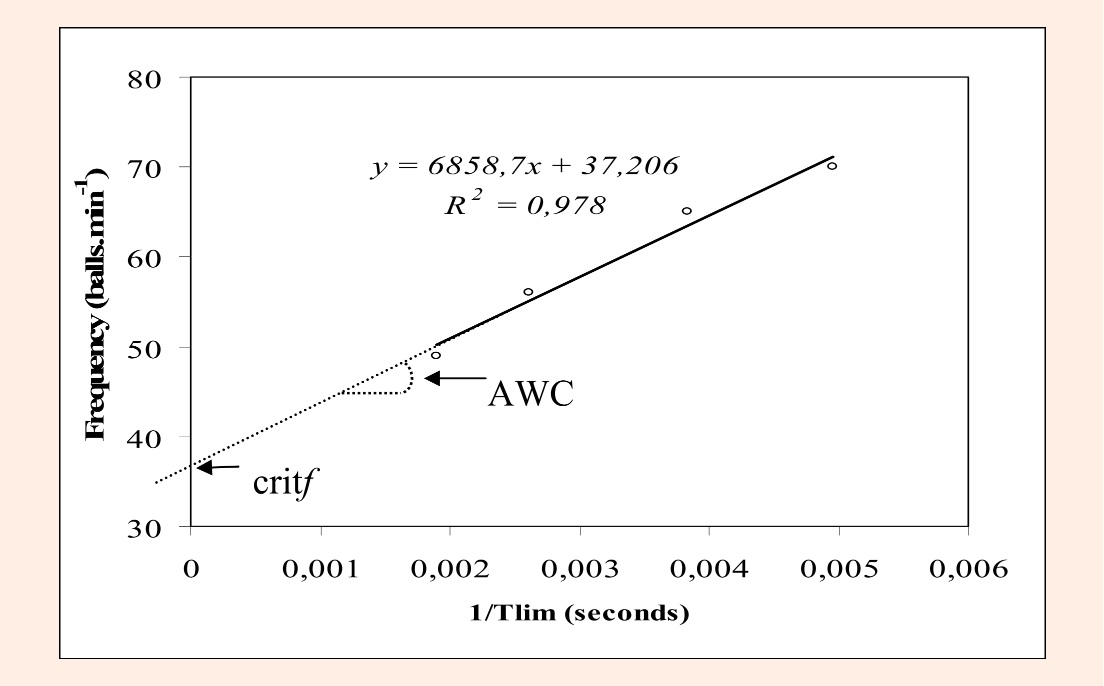

Figure 2. **Represents the linear relationship between ball shot frequency versus inverse of exercise time (1/Tlim) used to determine the anaerobic work capacity (AWC) in the specific model (crit*f* applied to table tennis). AWC corresponded to an angular coefficient between frequency and the inverse of time. (The data in Figure 2 corresponds to participant 4).**

(intensities) of approximately 48, 56, 65, and 72 balls·min^{-1}. The balls were released at a constant frequency throughout a repetition, and each repetition frequency was randomly defined.

Lateral ball oscillation and ball speed were constant throughout the test, corresponding to setting 3 and 5 respectively on the *NEWGY-PONG* 2000 mechanical ball thrower. Test termination occurred when 4 consecutive errors occurred in the attacks or the participant voluntarily stopped due to exhaustion. At this moment, exhaustion time (Tlim) was recorded. After each repetition, blood samples (25µL) were collected from the ear lobe at 1, 3, and 5 minute intervals to determine blood lactate concentration.

The relationship between ball frequency (*f*) and the inverse of the Tlim (1/Tlim) was obtained by linear regression techniques. Using this regression model, the linear and angular coefficients corresponded to crit*f* and AWC, respectively (Figure 2).

The Wingate cycle ergometer test (W_{cycle})

The Wingate Cycle Ergometer Test (W_{cycle}) consisted of exercise performed at maximal power for 30 seconds with an external resistance corresponding to 75g·kg^{-1} body mass. The cycle ergometer (Monark 894-E, Sweden) protocol began without any external resistance, which was added immediately after the test was initiated. Exercise time was recorded only after the external resistance was applied. After 30 seconds of all-out effort, blood samples were collected at 1, 3, 5 and 7 minutes for analysis of blood lactate concentration. Pedal revolution rate was determined by Monark Anaerobic Test Software. Values were obtained at 5 second intervals, these were: peak (in the initial 5-s period), mean (30-s), relative peak, relative mean power outputs, and a calculated fatigue index.

The Wingate arm crank test ($W_{arm\ crank}$)

The Wingate arm crank test ($W_{arm\ crank}$) was performed using an isokinetic arm ergometer (Cybex UBE 2462, Owatonna, MN) and consisted of 30 seconds maximal effort at a constant 120 rpm rotation speed. Values were determined every 5 seconds with peak (in the initial 5-s period), mean (30-s), relative peak, relative mean power outputs, and a calculated fatigue index. Samples were collected at 1, 3, 5, and 7 minutes intervals after the test for the analysis of blood lactate concentration.

Blood lactate analyses

Blood samples (25.0 µL) were collected from a participant's ear lobe and transferred to a 1.5 mL Eppendorf tube containing 50µL NaF (1.0% sodium fluoride). The homogenate was injected (25.0 µL) into an electrochemical lactate analyzer (Yellow Springs Instruments model 1500 Sport, Ohio, USA). The electrochemical lactate analyzer was calibrated after every 5 blood samples with standard 5.0 mmol.L^{-1} lactate solution. Blood lactate concentrations were expressed in millimoles per litre (mmol.L^{-1}).

Statistical analysis

Analysis of variance (One way ANOVA) was used to compare blood lactate concentrations and estimate lactate production-removal rates in the critical frequency test, followed by a *post hoc* Newman-Keuls test. Sample normality was evaluated by Kolmogorov-Smirnov & Lilliefors test. The Pearson product moment correlation test was used to establish of the relationship between AWC and variables from the Wingate tests (cycle ergometer and arm crank), and statistical powers (1 - β) were also calculated. Results were analyzed using STATISTICA 6.0 for Windows (Statsoft, Inc. 2001). In all cases a significance

Table 1. Exercise time to exhaustion (Tlim), peak blood lactate concentration (Lac) and estimated lactate production-removal rate (Lac rate) obtained in the crit*f* test. Data are means (SD).

f	48 (balls·min^{-1})	56 (balls·min^{-1})	65 (balls·min^{-1})	72 (balls·min^{-1})
Tlim (s)	578.6 (204.0)	342.7 (109.7)*	259.6 (38.9)*	188.8 (60.5)*
Lac (mmol·L^{-1})	6.2 (2.2)	7.0 (2.3)	8.9 (1.8)	7.0 (2.7)
Lac rate (mmol/L.s).10^2	1.4 (0.9)	2.3 (1.4)	3.4 (3.4)	4.5 (2.7)*

* $p < 0.05$ compared with 48 balls·min^{-1}

level was set at $p < 0.05$. Results were expressed as means together with standard deviations.

Results

Table tennis anaerobic work capacity was 99.5 ± 29.1 balls with an angular coefficient error of 32.6 ± 18.8% and a coefficient of determination (R^2) of 0.88 ± 0.11. Table 1 shows the exercise time to exhaustion (Tlim), peak blood lactate concentration, and estimated lactate production rate at different preset frequencies in the crit*f* test. Tlim at 48 balls·min^{-1} was significantly greater than other frequencies [F(1,6)=11.21; p = 0.001], and the estimated blood lactate production rate at 48 balls·min^{-1} was less than at 72 balls·min^{-1} [F(1,6)= 4.08; p = 0.02].

Peak, mean, relative peak, relative mean power output, and fatigue index in the W_{cycle} and $W_{arm\ crank}$ tests are shown in Table 2.

AWC correlated negatively with peak blood lactate concentration in the W_{cycle} test (Table 3) yet was positively correlated with the fatigue index in $W_{arm\ crank}$ test (Table 4). All other Wingate test variables in both ergometer tests did not show significant correlations with AWC (Tables 3 and 4).

Discussion

The main findings of this study were the poor correlation values obtained between anaerobic work capacity (AWC) (critP) adapted for table tennis and the arm and leg Wingate tests.

Measurement of anaerobic parameters in athletes is extremely important, especially in sports where there is greater participation from glycolytic and phosphagenic energy sources during periods of intense effort, as in the case of table tennis (Zagatto, 2004) and other sports where athletes are required to possess a high anaerobic capacity. However, specific protocols for determining glycolytic and phosphagenic energy sources are difficult to apply in table tennis.

Anaerobic work capacity determined by critP has advantages over other evaluation procedures as it is non-invasive, easy to apply, and low in cost, and in addition specific motor patterns can be adapted to different sports. Although the present study determined blood lactate concentration after the critical frequency test, it is not absolutely necessary as the only variable required is time of effort at each level of exercise intensity. Because of this, the critical power model adapted to table tennis (crit*f* test) was used to determine AWC in international table tennis players.

AWC values and the coefficients of determination (R^2) obtained in the present study (99.5 ± 29.1 balls and 0.9 ± 0.1, respectively) were higher than those found by Zagatto and Gobatto (2002) (50.9 ± 6.9 balls and 0.8 ± 0.1, respectively). The higher AWC values and the closer fitting coefficients of determination are probably due to the athletes participating in the present study having higher performance levels than those in the previous studies. The Tlims values obtained in this study were between 3 and 9 minutes, falling within the limits proposed by Poole (1986) and Bishop et al. (1998), who reported Tlims greater than 10 minutes and below 1 minute which could be an over (Poole, 1986) and an under-estimate (Bishop et al., 1998) of the AWC respectively. Thus our Tlim results were within this suggested range. In relation to 'post-effort' estimated blood lactate production-removal rate, our results did not suggest differences among ball shot frequencies. However, the estimated lactate production-removal rate increased proportionally with a rise in exercise intensity with a significant difference between the higher and lower frequency (72 versus 48 balls·min^{-1}).

AWC has been shown to be sensitive to training (Jenkins and Quigley, 1993), however, its validity remains controversial. Some researchers believe that AWC is a parameter of glycolytic and phosphagenic energy sources (i.e. the anaerobic capacity), correlating it with measaures from the Wingate test (Bulbulian et al., 1996; Nebelsick-Gullett et al., 1988), ATP yield (Green at al., 1994), and maximal accumulated oxygen deficit (Hill and Smith, 1993). In contrast, other authors do not support AWC as an indicator of the anaerobic capacity (Dekerle et al., 2002; Papoti et al., 2003; 2005). Bulbulian et al. (1996) found no relationship between AWC and relative power (W·kg^{-1}) obtained in a Wingate test, but found a

Table 2. Values for peak (Ppeak), mean (Pmean), relative peak (Ppeak/kg), relative mean power output (Pmean/kg), fatigue index (FI), and peak blood lactate concentration (Lac_{Peak}) obtained in the W_{cycle} and $W_{arm\ crank}$ tests. Data are means (SD).

	W_{cycle}	$W_{arm\ crank}$
P_{peak} (W)	772.2 (94.1)	374.5 (55.9)
P_{mean} (W)	602.7 (72.3)	272.7 (36.7)
P_{peak}/kg (W·kg^{-1})	11.6 (0.8)	5.7 (0.7)
P_{mean}/kg (W·kg^{-1})	9.1 (0.8)	4.1 (0.5)
FI (%)	42.7 (5.9)	48.8 (5.0)
Lac_{Peak} (mmol·L^{-1})	9.6 (0.9)	7.8 (1.0)

Table 3. Pearson product moment correlation (PM) and statistical power (1-β) values between anaerobic work capacity (AWC) and the variables obtained in the Wingate cycle ergometer test.

	P_{peak}	P_{mean}	P_{peak}/kg	P_{mean}/kg	FI	Lac_{Peak}
AWC	PM	PM	PM	PM	PM	PM
	-.25	-.02	-.49	.01	-.52	-.73 *
	(1-β)	(1-β)	(1-β)	(1-β)	(1-β)	(1-β)
	91.77%	97.26%	77.94%	97.56%	94.85%	54.38%

* $p < 0.05$ for AWC and Lac_{Peak}

significant, albeit a low correlation ($r = 0.41$) with absolute power. Dekerle et al. (2002) did not find a significant correlation between AWC and 25-m test measures in swimming, and suggested that the AWC does not provide a reliable estimation of the anaerobic capacity.

Table tennis is characterized by force and power movements in the legs combined with fast arm movements. Zagatto (2004) reported that the ATP-PCr energy production system is the one most used during periods of intense effort during a game of table tennis (approximately 3-s), with glycolysis only contributing at higher levels in a few specific instances, mainly during low duration rallies (Künstlinger et al., 1998; Zagatto 2004); both sets of authors also reported low concentrations of blood lactate during a match (≅ 1.6 mmol·L^{-1}). These latter observations corroborate the idea that table tennis has its energy base in the ATP-PCr system during periods of intense effort. Because the sport has this anaerobic characteristic, relationships between AWC from the specific table tennis test and anaerobic measures from the Wingate cycle and arm ergometer tests were expected. However, examination of the literature revealed that, only Zagatto et al. (2004) used the Wingate test in both cycle and arm ergometer mode to measure anaerobic power and capacity in table tennis players. The latter investigation used an isokinetic arm ergometer, and the low values for peak and mean power output in the Wingate arm ergometer seem to be characteristic of table tennis players *per se* and not due to e.g. variations in ergometry measures.

AWC did not correlate with peak, relative peak, mean, or relative mean power output values in either cycle or arm ergometry. Strong negative correlations were found between AWC and fatigue index in the arm ergometer ($r= -0.79$), and peak blood lactate concentration in the cycle ergometer test ($r = -0.73$; Tables 3 and 4 respectively). Although the literature indicates that the Wingate test measures can be used as an index of anaerobic capacity (Beneke et al., 2002; Hawley and Williams, 1991; Vandewalle et al., 1987), and peak blood lactate concentration in the same test can be used to estimate the contribution to exercise metabolism from glycolysis. The negative correlation between AWC and fatigue index in the arm ergometer does not indicate that AWC is a good index of anaerobic capacity. Our hypothesis was that AWC from the critP could be used to determine anaerobic capacity in table tennis, but this was not substantiated.

Some researchers have reported that AWC represents a finite supply of anaerobic energy composed of PCr, O_2 binding to myoglobin, and intra-muscular glycogen stores (Bishop et al., 1998; Monod and Scherrer, 1965). Bishop et al. (1998) reported that total depletion of these energy supplies (called AWC), was responsible for exhaustion during exercise (Bishop et al., 1998; Monod and Scherrer, 1965). However, Araujo et al. (2005) using the critical power model to evaluate AWC in swimming rats reported reductions of approximately 41 ± 15% in soleus muscle glycogen content at exhaustion. These results demonstrate that exhaustion did not coincide with total muscle depletion of any 'anaerobic reserve'. Thus Araujo et al. (2005) concluded that AWC does not represent an anaerobic reserve or supply, but a physiological state or conditioning status with respect to anaerobic exercise. Therefore, AWC as an index of anaerobic capacity in table tennis, determined by a sport-specific protocol, requires better delineation.

Conclusion

Anaerobic work capacity (AWC) measures obtained using a sport-specific protocol from an adapted critical power model was not a good index to evaluate anaerobic capacity in table tennis.

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Table 4. Pearson product moment correlation (PM) and statistical power (1-β) values between anaerobic work capacity (AWC) and the variables obtained in the Wingate arm crank test.

	P_{peak}	P_{mean}	P_{peak}/kg	P_{mean}/kg	FI	Lac_{Peak}
AWC	PM	PM	PM	PM	PM	PM
	-.34	-.04	-.49	-.14	-.79 *	-.08
	(1-β)	(1-β)	(1-β)	(1-β)	(1-β)	(1-β)
	87.90%	96.99%	78.23%	95.05%	66.64%	96.25%

* $p < 0.05$ for AWC and FI.

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Key points

- Anaerobic work capacity (AWC) was not good index of anaerobic capacity in table tennis.
- AWC determined using the table tennis ergometer showed low correlations with the Wingate test measures for cycle and arm ergometry.
- A sport-specific protocol is required for measuring anaerobic capacity in table tennis.

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