Incremental test proposal based on the rating of perceived exertion to determine metabolic thresholds and mechanical parameters of free style

Manoel Carlos Spiguel Lima[1], Pedro Balikian Junior[1,2], Cláudio Alexandre Gobatto[3], Jair Rodrigues Garcia Junior[1] and Luiz Fernando Paulino Ribeiro[4]

ABSTRACT

The Rating of Perceived Exertion (RPE) is non-invasively determined and used together with lactacidemic analysis as indicator of intensity during incremental test. In field, especially in swimming, due to the difficulty of sample collection, alternative protocols have been used to estimate the anaerobic threshold. Thus, the study aims were: to prescribe one incremental test based on Borg's scale; to estimate metabolic thresholds determined through analysis lactate methods [settling bi-segmented (V_{LT}), fixed concentration-3.5 mM ($V_{3.5mM}$) and maximal distance ($V_{Dmáx}$)]; to relate the RPE attributed in each stage with a heart rate (HR) and swimming mechanical parameters [stroke rate (SR), and stroke length (SL)]; to analyze the utilization of the Borg's scale in regularity of velocity increment in test and relate the metabolic thresholds with the critical velocity (CV). Twelve swimmers (16.4 ± 1.3 years old) were subjected to two maximal efforts (200 and 400 meters), the data was used to determine the CV, velocity in 400 meters (V_{400m}) and critical stroke rate (CSR); and one incremental test with an initial intensity based in RPE, respectively, 9, 11, 13, 15 and 17; the HR, lactacidemia ([Lac]) and the times of four cycles strokes and the distances of 20 m and 50 m, were monitored in all stages. Subsequently, the velocity of the SR, SL, V_{LT}, $V_{3.5mM}$ and $V_{Dmáx}$ stages were calculated. ANOVA and correlation of *Pearson* were used to analyze the results. Significant differences were not found among VC, $V_{Dmáx}$ and V_{LT}, however the $V_{3,5mM}$ was lower than all velocities ($P < 0.05$). Significant relationships ($P < 0.05$) were found among VC versus V_{400m}, $V_{Dmáx}$, $V_{3.5mM}$; V_{400m} versus $V_{3.5mM}$ and $V_{Dmáx}$; $V_{Dmáx}$ versus V_{LL}; in incremental test among the RPE versus velocity, [Lac], HR, SR and SL ($P < 0.05$). Our conclusion was that RPE is a reliable tool for velocity control of stages during incremental test in swimming.

Keywords: Heart rate. Blood lactate concentration. Stroke rate. Stroke length.

INTRODUCTION

The lactacidemia response obtained in incremental protocols is a widely used variable in the prescription of exercise intensity in cyclic sports with aerobic predominance. Moreover, it seems to be the best variable in order to identify the exercise suitable intensity[1]. Besides the blood lactate analysis, other intensity parameters are usually concomitantly collected during the incremental test, namely: heart rate, oxygen consumption ($\dot{V}O_2$) and Subjective Perceived Exertion (RPE)[2-3]. The SPE is a non-invasive and practical method for aerobic exercise intensity evaluation[3-4]. It is considered an useful tool for the exercise intensity prescription[3-4] and a trustful variable for fatigue quantification during test of graduated exercise[5]. However, there is some judgment about its trustfulness during incremental exercise test in treadmill[6].

There is a consensus that the most trustful methodology in order to determine the intensity of the anaerobic threshold is the lactate maximal steady phase estimate (LMSP), confronting evaluation protocols and methodologies that use the blood lactate in the physical exertion[7-8]. Such protocol requires continuous tests of approximately 30 minutes, performed at different days, which makes its applicability in laboratory or field difficult. In the latter, there is more difficulty due to the lack of or limitation in temperature and humidity control, movement velocity, the manipulation of blood samples materials and the communication with the athletes, especially when the procedures are performed in a pool.

Researchers have been developing alternative protocols in a trial to diminish the presented problems and improve the tests applicability. They highlight the use of the critical velocity model (CV)[9-10], the determination of the anaerobic threshold through steady concentration of blood lactate (OBLA)[11-12] and analysis of the swimming mechanical behavior (stroke rate and length), joined with physiological variables[13-15]. Costill *et al.*[16] presented the concept of stroke index (SB) as a good predictor of the maximal oxygen consumption in trained swimmers. Dekerle *et al.*[9], based on the CV concept, used the relation between stroke rate (SR) and time, and developed the critical stroke rate term (CSR), representing a stroke rate in which the swimmer could swim for a long period of time without exhaustion. In a recent study, Papoti *et al.*[14] were able to determine strength and SR at maximal intensity and in the anaerobic threshold using data acquisition system during exertion in tied swimming.

The SPE response was also observed applying the Borg 6–20 scale, with linear increase according to power, heart rate (HR) and $\dot{V}O_2$ in an incremental test[17]. Other researchers have demonstrated that the SPE may be used in order to estimate the lactate threshold (LT)[18-19] and that it is not affected by the gender[20-21], training stage[22-23] and exercise type[18]. Thus, the SPE was proposed as being a valid measurement in order to determine the exercise intensity[4,21,24-25] and a useful tool in the training prescription.

In swimming pools, it is difficult to precisely control the stages velocity during an incremental test the same way it is done in the swimming flume. The alternative incremental protocols for lactecidemia responses analysis require light adjustment in the bottom of the pool or that an evaluator completes the pool's edge distance in order to maintain the established velocities.

Considering reports of increases linearly related between the swimming velocity, swimming physiological parameters and SPE[26],

1. Faculdade de Educação Física da UNOESTE, Presidente Prudente, SP.
2. Departamento de Educação Física da UNESP, Presidente Prudente, SP.
3. Departamento de Educação Física da UNESP, Rio Claro, SP.
4. Departamento de Educação Física da UESC, Ilhéus, BA.

Received in 21/10/05. Final version received in 17/3/06. Approved in 15/5/06.

Correspondence to: Manoel Carlos Spiguel Lima, Faculdade de Educação Física da UNOESTE, Laboratório de Fisiologia do Exercício – Grupo de Estudo em Fisiologia do Exercício (GEFE) Campus II – Bloco B1, Rod. Raposo Tavares, km 572, Bairro Limoeiro – 19067-175 – Presidente Prudente, SP. Tel.: (18) 229-2000 (ramal 2137). E-mail: manu@unoeste.br

the use of the latter instead of the velocity control could simplify the anaerobic threshold evaluation (AT) and associated indices during incremental tests.

Almost all the studies that relate the physiological variables with the SPE, previously determines the stages exertion intensity of the incremental test (velocity, load, etc.) so that the individuals could be later interviewed and attributed the SPE parameters of each stage. Nevertheless, we did not find report of studies that use the SPE in order to establish the intensities of the incremental stages. Thus, our aims were: (1) to determine the intensity of the incremental test stages using the SPE and to analyze the possibility to estimate metabolic thresholds; (2) to analyze the use of the SPE in the control of velocity increase during the stages, joined with the physiological and mechanical responses, during the incremental protocol; (3) to observe the correlations between the SPE, physiological and mechanical variables (stroke rate (SR) and stroke length (SL)) and (4) to verify possible correlations between the different estimation methods of the metabolic thresholds.

METHODOLOGY

Subjects

The study group was consisted of 12 swimmers with age range between 15 and 19 years, trained with 5-6 weekly sessions, daily volume between 4,000 and 8,000 m, with regular training for at least 3,5 years and participation in national and state competitions. The anthropometrical and body composition measures are presented in table 1.

The swimmers received previous information on the experimental procedures and eventual risks and later the clarified consent form was presented and signed by their parents or responsible ones. The protocol and the procedures were approved by the Medical Ethics Committee of the Oeste Paulista University. The evaluated subjects were familiarized with the invasive and non-invasive procedures used, since during the previous training period periodic evaluations were performed in order to determine the training intensities and eight athletes had participated in previous experiments with the same procedures. The 15 points (6-20) Subjective Perceived Exertion Scale (SPE) was presented to the athletes with the instructions prior to all tests, according to the recommendations by Borg[27]. During 6 months of training the coach used the SPE from one to two times a week in order to quantify the training overload and the athletes performed incremental tests with questions about the SPE after each stage.

TABLE 1
Anthropometrical measures and body composition of the swimmers (n = 12)

	Height (cm)	Body mass (kg)	Body fat (%)
Average ± SD	178.7 ± 8.2	71.7 ± 8.8	7.4 ± 2.1
Length (min-max)	166-194	55.8-88.5	4.2-10.3

Experimental procedures

All evaluations were performed in Olympic swimming pool of 50 m with water temperature between 27° and 28°C. The swimming style was the crawl with free warm-up, and tests performance at the athletes training time. The volunteers were asked to avoid intense extra physical activity sessions, not to intake alcoholic drinks during the experimental period and to have their meals two hours prior the test. The swimmers were submitted to maximal sprints at the 200 and 400 m distances, randomly performed with 24 hours of interval between both, and to an incremental test with 200 m stages performed 48 hours after the second maximal sprint.

Critical velocity (CV) and critical stroke rate (CSR)

In order to determine the CV, the time (T200 and T400) of two maximal sprints of 200 and 400 m were registered, which were plotted in a linear regression model between time-distance, resulting in a line whose inclination was considered as the individual CV[10].

A central lane measuring 20 meters of distance was marked in the pool before the maximal exertion, in order to isolate the lapping impulses. The 50 m partials (T50), the time of the 20 m partials (T20) and the time of 4 stroke cycles (T4c) were registered with the aid of digital timers (Casio®), being later used for the length (SL) and stroke rate (SR) calculation. The critical stroke rate (CSR)[9] was determined from the linear regression model between SR (min^{-1} cycles) and distance, while the SL was determined by the division tof the velocity by the SR.

The heart rate was monitored with Polar frequency meters, S810 model (Polar Electro Oy, Finland). In the end of each sprint the volunteers visualized the Borg's scale (SPE) in order to obtain the real Subjective Perceived Exertion (SPEr).

Incremental test

The incremental protocol consisted of 5 200 m sprints, with 90 seconds pauses for blood samples. The initial intensity and the intensity increases were determined with previous visualization of the 6-20 scale[27] of SPE. Thus, the subjective intensity of the test beginning was named prescribed SPE (SPEp) for each of the sprints: 9 (very light), 11 (light), 13 (slightly intense), 15 (intense-heavy) and 17 (very intense). T200, T50, T20, T4c, HR and SPEr were registered, which were later used for the calculation of the velocity of each sprint (V), of SR and SL. After each stage, blood samples from the ear lobes were collected in heparinized capillars, which were immediately transferred to 1,5 mL Eppendorff tubes containing 50 µl of NaF 1% solution and stored in ice for later lactacidemia determination ([Lac]). The reading was performed in electro-enzymatic apparel, YSL 1500 SPORT model (Yellow Springs Co., EUA).

Determination of the lactate threshold velocity through the visual inspection method (V_{LT})

Individual swimming velocity ($m.s^{-1}$) data and lactate concentration (Lac) (mM) were plotted in order to determine the lactate threshold velocity (V_{LT}) Two groups of distinct points were obtained through visual analysis of those points and from the sudden increase of the lactacidemia due to the swimming intensity increase. Thus, with the bi-segmentation of the groups of points, two lines were determined through linear regression and the intersection point of the two segments was obtained being equal to the two equations of the lines ($y_1 = y_2$). Thereby, the x indices corresponding to the inflexion point were found, as well as the V_{LT} velocity indices.

Determination of the action of the anaerobic threshold velocity through the maximal distance method (V_{Dmax})

In order to determine the anaerobic threshold through the maximal distance method (V_{Dmax}), the lactate-velocity curves suffered polynomial correction of third order (software STATISTIC 6.0). A line between the first and last points was traced and, with the aid of a ruler, the maximal perpendicular distance between the line and the curve was traced. The intersection of this point in the polynomial curve of third order originated the V_{Dmax} and the corresponding [Lac][28].

Determination of the anaerobic threshold velocity through the 3,5 mM steady concentration ($V_{3,5mM}$)

In order to determine the anaerobic threshold intensity corresponding to the 3,5 mM steady lactate concentration ($V_{3,5mM}$), the mathematical calculation of linear regression was used with the results obtained in the incremental protocol sprints. The lactate concentration indices above or below 3,5 mM were used in order to interpolate the results with their respective velocities[8].

SPEr, SR, SL and HR in the different threshold methods

The SPEr, SR and HR parameters in the intensities referring to V_{Dmax}, CV, and $V_{3,5mM}$ were determined through the mathematical method of linear regression using the results obtained in the sprints obtained in the incremental protocol for each subject through interpolation.

Statistical analysis

The differences significance between the intensities obtained with the different protocols was determined through variance analysis (one way ANOVA). The *Pearson* correlation coefficient was used in order to establish the correlations between the variables and the intraclass correlation coefficient was used to test the agreement between the SPEp and SPEr. The significance index of $P < 0,05$ was adopted and the STASTISTIC 6.0 (Statsoft) software was used.

RESULTS

In tables 2 and 3 the velocities and the stroke rates obtained with invasive and non-invasive methods are presented. It may be observed that only the $SR_{3,5}$ of 26,71 ± 3,27 cycles.min^{-1} and SR_{v400} of 35,11 ± 4,21 cycles.min^{-1} were significantly different ($P < 0,05$) from the critical stroke rate (CSR) of 30,82 ± 3,91 cycles.min^{-1} (datum not presented in table 3).

TABLE 2
Comparison between the averages of the 400 meters performance velocities (V_{400}), critical velocity (CV), anaerobic threshold velocity through the Dmax method (V_{Dmax}), lactate threshold velocity through the visual inspection method (V_{LT}) and anaerobic threshold velocity through the 3,5 mM steady concentration method ($V_{3,5mM}$)

Velocity ($m.seg^{-1}$)	V_{400m} (n = 12)	CV (n = 12)	$V_{Dmáx}$ (n = 9)	V_{LT} (n = 9)	$V_{3,5mM}$ (n = 12)
Average ± SD	1.37 ± 0.05*	1.28 ± 0.05	1.31 ± 0.07	1.30 ± 0.09	1.22 ± 0.06†
Length (min-max)	1.28-1.44	1.20-1.34	1.19-1.44	1.10-1.41	1.13-1.29

* † Significant differences between the remaining studied velocities $P < 0.05$.

TABLE 3
Comparison between the averages of the stroke rate (SR) in the 400 meters velocity (SR_{v400}), in the critical velocity (SR_{cv}), in the anaerobic threshold velocity through the Dmax method (SR_{VDmax}), in the lactate threshold velocity through the visual inspection method (SR_{LT}) and in the anaerobic threshold velocity through the 3,5 mM steady concentration method ($SR_{3,5mM}$)

SR ($cycle.min^{-1}$)	SR_{V400}	SR_{CV}	SR_{VDmax}	SR_{LT}	$SR_{3,5mM}$
Average ± SD	35.11 ± 4.21*	28.57 ± 3.91	31.04 ± 4.36	30.55 ± 4.83	26.71 ± 3.27†
Length (min-max)	27.25-43.32	23.08-35.36	26.15-39.82	23.43-40.30	21.43-31.86

* † Significant differences between the remaining SR studied $P < 0.05$.

In table 4 the correlations between the intensities of the different protocols and with the performance in the 400 m distance (V_{400}) are presented.

The individual correlations between SPEp and the variables determined during the incremental test, velocity (V), lactate concentration ([Lac]), heart rate (HR), stroke length (SL) and stroke rate (SR) varied between r = 0,95-0,99; r = 0,84-1,00; r = 0,94-1,00; r = –0,78-–1,00 and r = 0,90-0,99; respectively. Significant individual correlations were also found between the SR and the variables determined during the incremental test (V, [Lac], SL, and HR) and varied between r = 0,92-0,99; r = 0,91-1,00; r = –0,88-–1,00 and r = 0,91-1,00; respectively.

TABLE 4
Correlations between the 400 meters performance velocities (V_{400}), critical velocity (CV), anaerobic threshold velocity through the Dmax method (V_{Dmax}), lactate threshold velocity through the visual inspection method (V_{LT}) and anaerobic threshold velocity through the 3,5 mM steady concentration method ($V_{3,5mM}$)

	V_{400}		VC		V_{Dmax}		V_{LT}	
	r	n	r	n	r	n	r	n
VC	0.89*	12	–	–	–	–	–	–
V_{Dmax}	0.61*	9	0.69*	9	–	–	–	–
V_{LT}	0.47	9	0.58	9	0.92*	9	–	–
$V_{3,5mM}$	0.84*	12	0.80*	12	0.42	9	0.43	9

* Significant correlations $P < 0.05$.

Figure 1 shows that there was not significant difference between the prescribed Subjective Perceived Exertion (SPEp) and the real (SPEr) during the incremental test effort. Besides that, the intraclass correlation coefficient (95% of reliable interval – RI) presented high results for agreement analysis (R = 0,972; RI = 0,84-0,99; $P < 0,0001$) These results reveal excellent agreement between SPEp and SPEr.

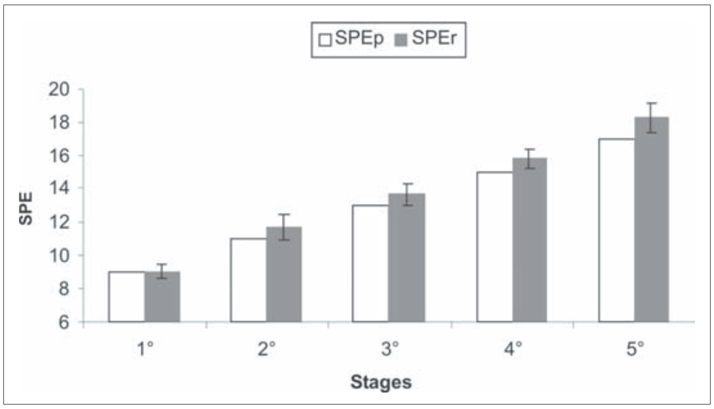

***Figure 1** – Comparison between prescribed Subjective Perceived Exertion (SPEp) and real (SPEr) in the incremental test stages. The differences in each stage were not significant.*

Figure 2 shows the determination coefficients between the SPEp and the heart rate, lactate concentration and velocity variables.

Figure 3 shows the determination coefficients between the SPEp and the stroke length and rate mechanical variables, during the incremental test.

DISCUSSION

Velocity control during the incremental test

The stages velocity during the incremental test linearly increased with the SPEp (figure 2c) and the individual correlations varied between r = 0,95 and 0,99. Therefore, the determination of the subjective intensities using the SPE is reliable in order to establish suitable velocity parameters during the incremental test. Nevertheless, no supporting reference to the presented methodology in our study was found, once the majority of the research uses laboratory tests and/or other sports, and determines the intensities (velocity in treadmill and load in the cycle ergometer) for the physiological data and SPE obtaining, which limits our comparisons.

Similarly to our study, Ueda and Kurokawa[26] evaluated six men and four women in the swimming flume, analyzed the correlations between physiological variables ($\dot{V}O_2$, HR, [Lac]) with the SPE dur-

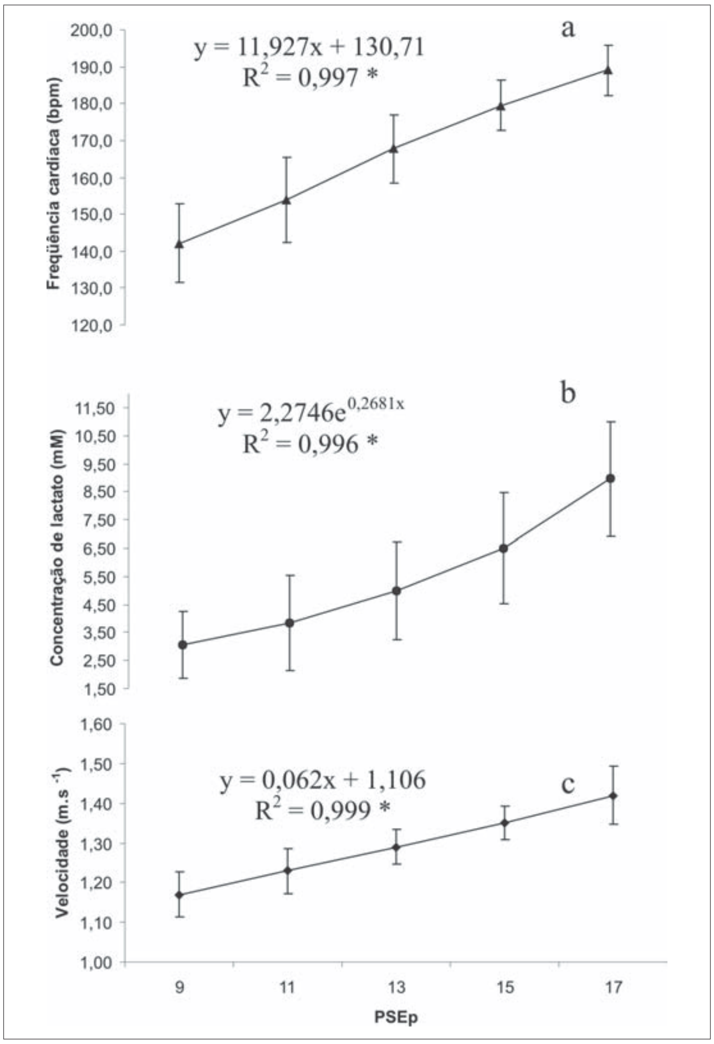

***Figure 2** – Determination coefficient between SPEp and **(a)** heart rate, **(b)** lactate concentration and **(c)** sprint velocity. * P < 0.05.*

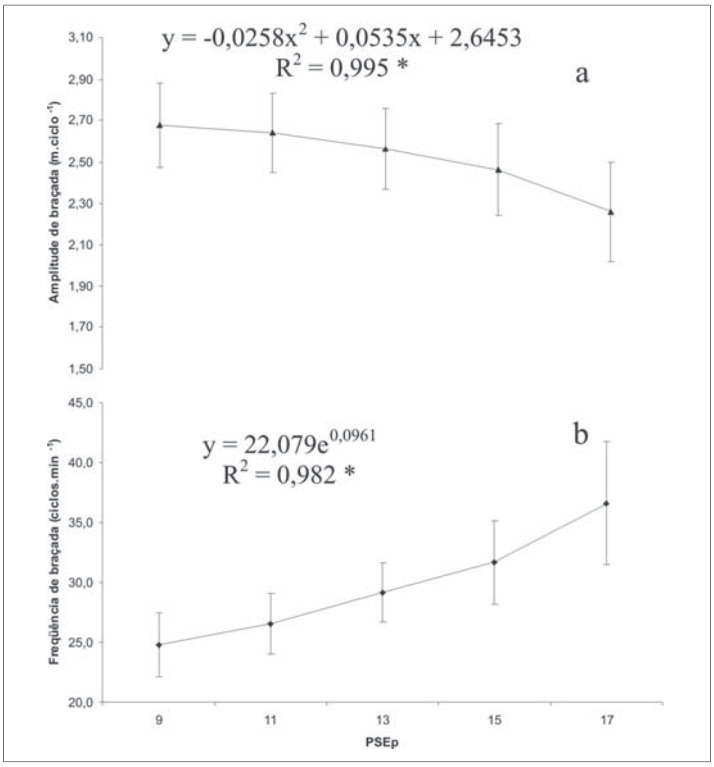

***Figure 3** – Determination coefficient between SPEp and **(a)** stroke length and **(b)** stroke rate. * P < 0.05.*

ing incremental test, and observed linear increase between the intensity (arrest) and SPE r = 0,991 for men and r = 0,998 for women). Kang *et al.*[21] verified during running and cycling incremental test, linear increase between SPE and the ergometers intensities. Agreeing with the previous study, but using a new exertion perception scale (OMNI) though, Robertson *et al.*[29] and Utter *et al.*[30] found positive correlations between the load and the effort SPE during incremental exercise in treadmill and cycle ergometer. Utter *et al.*[25] evaluated sixty-seven individuals (33 men and 34 women) in treadmill incremental test with the purpose to validate the OMNI exertion perception scale. They reported significant linear increase ($P < 0{,}01$) between OMNI and 6-20 Borg's scale with the maximal oxygen percentage (%$\dot{V}O_2$max) (R^2 = 0,74 and 0,77) for men and (R^2 = 0,72 and 0,73) for women, respectively, and between the OMNI and SPE scales (R^2 = 0,92) for both sexes. Garcin and Billat[2] obtained high correlation between $\dot{V}O_2$max velocity (v$\dot{V}O_2$max) with the SPE (r = 0,91) in twelve well-trained runners during incremental test on 400 meters track.

In another interesting study, Marriott and Lamb[31] performed two rowing ergometer tests in nine male rowers. The first incremental test (estimation test) was performed in order to obtain the SPE, HR data and average power of each stage performed until the voluntary fatigue. The second test (production test) was performed with intensities using the SPE 6-20 scale in irregular order (15, 11, 17, 13 and 19). The results demonstrated correlation coefficients between SPE and average power (watts) in the estimation and production tests (r = 0,96 and r = 087, respectively, $P < 0{,}01$). The lowest correlation obtained in the production test was possibly due to the SPE intensities irregularly established. In a similar study, Eston *et al.*[32] performed treadmill test with 16 men and 12 healthy women, finding in the graduated exercise test (estimation) significant correlation coefficient between %$\dot{V}O_2$max and SPE (r = 0,91 for men and r = 0,87 for women), and in the production test (with SPE indices of 9, 13 and 17) with correlation coefficients between %$\dot{V}O_2$max and SPE of r = 0,93 for men and r = 0,89 for women. These results corroborate the results of our study which presented individual correlations of r = 0,95 to 0,99 between the SPEp and velocity (m.s^{-1}) during the incremental test.

Determination of metabolic thresholds

The incremental test using the SPEp made the metabolic thresholds estimation possible, as well as the analysis of the correlation coefficient between the used methods (tables 2 and 3). Significant correlations between the $V_{3,5mM}$ and CV, V_{Dmax} and $V_{LT,}$ and between V_{Dmax} and CV (r = 0,80; r = 0,92 and r = 0,69; respectively, $P < 0{,}05$) were found. It was not possible to identify the metabolic thresholds in three athletes, due to the atypical disposition of the lactate-velocity curve points used for the V_{LT} and V_{Dmax} estimation, through visual inspection after the curves adjustments. On the other hand, the $V_{3,5mM}$ was obtained through linear regression for all subjects. Thus, the non-estimation of the V_{LT} and V_{Dmax} thresholds for the three subjects was not due to the proposed protocol, but to the obtained data instead.

Physiological variables behavior during the incremental test

The heart rate (HR) responded linearly with the SPEp increase (R^2 = 0,999; figure 2a) during the incremental test, and the individual correlations varied between r = 0,94 and 1,00. Similar data were presented by Ueda and Kurokawa[26] who found significant correlation between arrest (N) and HR, $\dot{V}O_2$ and HR; SPE and HR for men (r = 0,99; 0,99 and 0,99) and women (r = 0,99; 0,99 and 0,99; respectively). In the study by Marriott and Lamb[31], the correlation coefficient in the SPE estimation test (incremental test) was of r = 0,95 and in the production irregular test (using the SPE for intensity determination) was of r = 0,75.

Demura and Nagasawa[33] evaluated 10 healthy students in cycle ergometer, and analyzed the physiological responses with the

SPE parameters during incremental test until fatigue and in an active recovery of 25 minutes. The results showed significant correlations between HR and SPE during the test (r = 0,99) and in the recovery (r = 0,97).

Other studies showed significant correlations between the SPE and metabolic demand measured through the oxygen consumption and HR[17,34], however, the HR may be directly influenced by several factors, among which we may highlight medication, measuring difficulty[35], room temperature influence[36] and the lower number of heart beats in water in comparison to land[37]. Such factors may generate imprecision in the intensity control during the exercise.

The lactate concentration is considered the most sensitive local factor of metabolic stress[19] and reflects in the SPE increase during exercise[22,24]. According to other studies[26,38], one may observe that the lactecidemia response during the incremental test correlated with the SPEp (r = 0,84-1,00 and r^2 = 0,996; P < 0,05, figure 2b). However, even facing the significant correlations, we should mention that the SPE is influenced by central (oxygen consumption, ventilation and HR) and local parameters (lactate concentration). Thus, the best correlations between lactate and SPE are found during incremental tests[26,38]. In recent study, Green *et al.*[3] did not find correlation between lactate and SPE during test with steady load with duration of sixty minutes in cycle ergometer. The researchers evaluated physically active subjects of both sexes, and the results showed decrease of the lactacidemia and SPE increase, confirming that there is dissociation between lactate and SPE, and that other factors significantly contribute to the SPE increase in continuous tests with steady load. Mercer[38] conducted a study in order to analyze the SPE reproducibility related to the blood lactate in fourteen women divided in two groups according to their physical ability (high $\dot{V}O_2$max and moderate $\dot{V}O_2$max). The SPE relation with the lactate threshold (SPE_{LT}), the steady 2 mM lactate concentration (SPE_2), 2,5 mM ($SPE_{2,5}$) and 4 mM (SPE_4) were determined, and the intraclass correlation coefficient for the group with high $\dot{V}O_2$max of r = 0,97; r = 0,97; r = 0,97 and r = 0,72; and for the moderate $\dot{V}O_2$max group of r = 0,83; r = 0,96; r = 0,96 and r = 0,90 respectively, were found. No significant differences between the groups in relation to the SPE_{LT}, SPE_2, $SPE_{2,5}$ and SPE_4 were found.

In another study, Kolkhorst *et al.*[39] evaluated ten subjects during incremental test in treadmill in order to analyze the effect of different inclinations (+5%, 0% and –5%) in SPE response related to the 2mM and 4mM lactate steady concentrations. The lowest SPE was related to the 2 mM steady lactate concentration during the incremental test with +5% inclination comparing to the 0% and –5% inclinations (P < 0,05). On the other hand, the SPE related to 4mM steady lactate concentration was not different between incremental tests with +5%, 0% and –5% inclinations. The authors reported that there were not significant differences between the relative oxygen consumption and the respiratory coefficient (RC) in the three different inclinations related to the 2 mM and 4 mM concentrations. On the other hand, the HR related to 2 mM in the incremental test with –5% inclination was significantly higher than 0% and +5% (P < 0,05), as well as the treadmill velocity related to the steady 2 mM and 4 mM lactate concentration was lower during the +5% test comparing to the remaining inclinations (P < 0,05). These results showed a possible correlation between the SPE, HR and treadmill velocity, however, the authors did not perform correlations between these variables, which limits the comparison with our results.

Mechanical variables behavior during the incremental test

In this study significant individual correlations were found between HR and the velocity (V), lactate concentration ([Lac]), stroke length (SL) and heart rate (HR) variables which varied between r = 0,92-0,99; r = 0,91-1,00; r = –0,88-–1,00 and r = 0,91-1,00; respectively. During the incremental test, the increase between the SPEp and the SR was exponential and the significant determination coefficient (R^2 = 0,98) (figure 3b). In the study by Wakayoshi *et al.*[15] conducted with tem well-trained swimmers in the swimming flume, significant linear correlations were found between cubic velocity and SR of r = 0,89 (P < 0,05) at r = 0,99 (P < 0,01) during the swimming savings test, which used 5 or 6 submaximal intensities. The CSR calculated using the 200 and 400 meters distances was not significantly different from the SR determined in 30 minutes continuous test (SR_{30}), there was significant correlation (r = 0,86; P < 0,01) between the two frequencies, though. The authors reach to the conclusion that CSR underestimated in 3,9% the SR_{30} and that the CV and CSR indices may be used for the aerobic training load control and the swimming technique.

Dekerle *et al.*[9] and Wakayoshi *et al.*[40] define the CSR as a stroke rate that may be kept for a long period of time without fatigue. In an evaluation of the 8 male well-trained swimmers, Dekerle *et al.*[9] observed that the $\dot{V}O_2$ and the SR did not change in sub-thresholds of 30% to 60% of the velocity of the $\dot{V}O_2$max. Contrarily, significant increases in the $\dot{V}O_2$ and SR were found in supra-threshold intensities of 80% and 100% of the $\dot{V}O_2$max velocity. Thus, it was demonstrated that the anaerobic intensity emphasizes swimming technique damage in order to maintain the required velocity. Therefore, such intensity would be impossible for the swimming technique training with the aim to improve the mechanical efficiency. It was also stated that the suitable SR or intensity to the improvement of the swimming technique should be anaerobic sub-threshold or CSR.

The presented results in figure 3b show significant determination coefficient between SL and SPEp (R^2 = 0,995), and negative individual correlations ranging from r = –0,88 to –1,00 for the SR and SL. Keskinen *et al.*[41] did not find significant differences between the SR determined in 25 and 50 meters swimming pool, however, the SL was significantly longer in the 25 meters pool, with differences ranging from 1,8% up to 8,2% during the 200 meters progressive sprints. The SR in the aerobic and anaerobic threshold determined in both pools, did not present significant difference either. An issue to be considered in the study is that the authors makes use of the velocity obtained in the progressive sprints and relates SR and SL. The velocity in the 25 meters pool was slightly higher comparing to the 50 meters one, which may be due to the bigger amount of laps, which seems to cause the overestimated result of the SL in the 25 meters.

One of the few longitudinal studies of the analysis of swimming mechanical parameters was performed by Wakayoshi *et al.*[42]. The aerobic training effect was observed for six months in the velocity variables (V), SR, SL and [Lac] in eight swimmers. The pre and post-tests consisted of a 400 meters maximal sprint (Vmax) and three submaximal ones in the 85%, 90% and 95% velocities of the Vmax obtained in the first 400 meters sprint. Significant increase in the threshold velocity was observed (VOBLA) and maximal velocity (Vmax) between the pre and post-training (P < 0,05). The increase of the post-training V85%, V90% and V95% was due to the increase of the SR and decrease of the SL. Nonetheless, the Vmax increased facing a SL increase, being the SL increase more visible in the final 150 meters (6th, 7th and 8th stage of 50 meters). As expected, the [Lac] in the Vmax was significantly lower in the post, comparing to the pre-training.

CONCLUSION

The SPE is a reliable parameter in the control of the exercise intensity during incremental test in swimming, with no need of velocity control during each stage of the test in a pool. Moreover, the test made the estimate of the metabolic thresholds used in the study possible. It is important to mention that the athletes were familiarized with the SPE for a 6 months period, which seems to have contributed for a good intensity control using the SPE. Nevertheless, the number of studies using the intensity determination and establishing increases with the SPE during the incremental test is scarce. Further research with the aim to obtain data which may confirm the established proposal is still needed. Thus, the intensity determination methodology through the SPE in the incremental tests will be able to be applied in athletes of different previous knowledge of the 6-20 scale and different physical ability levels. A reliability and reproducibility test is still necessary in order to reassure the efficiency of the proposed model.

All the authors declared there is not any potential conflict of interests regarding this article.

REFERENCES

1. Weltman A. The blood lactate response to exercise. Champaign: Human Kinetics Pub., 1995.
2. Garcin M, Billat V. Perceived exertion scales attest to both intensity and exercise duration. Percept Mot Skills 2001;93:661-71.
3. Green JM, McLester JR, Crews TR, Wickwire PJ, Pritchett RC, Redden A. RPE-lactate dissociation during extended cycling. Eur J Appl Physiol 2005;94:145-50.
4. Engbretson B, Fillinger M, Genson C, Lynch M, Redington M, Shewchuk J. Can the Borg RPE scale be used to prescribe resistance exercise intensity? Med Sci Sports Exerc 2004;36:S4.
5. American College of Sports Medicine. Guidelines for exercise testing and prescription. 6th ed, 2000.
6. Lamb KL, Eston RG, Corns D. Reliability of ratings of perceived exertion during progressive treadmill exercise. Br J Sports Med 1999;33:336-9.
7. Beneke R. Methodological aspects of maximal lactate steady state-implications for performance testing. Eur J Appl Physiol 2003;89:95-9.
8. Heck H, et al. Justification of the 4-mmol/l lactate threshold. Int J Sports Med 1985;6:117-30.
9. Dekerle J, Sidney M, Hespel JM, Pelayo P. Validity and reliability of critical speed, critical stroke rate, and anaerobic capacity in relation to front crawl swimming performances. Int J Sports Med 2002;23:93-8.
10. Wakayoshi K, Yoshida T, Udo M, Kasai T, Moritani T, Mutoh Y, Miyashita M. A simple method for determination critical speed as swimming fatigue threshold in competitive swimming. Int J Sports Med 1992;13:367-71.
11. Mader A. Zur Beurteilung der sportartspezifischen Ausdauerlei-stungsfahigkeit. Sportarzt Sportmed 1976;27:80-8.
12. Sjodin B, Jacobs I, Svendenhag J. Changes in onset of blood lactate accumulation (OBLA) and muscle enzymes after training at OBLA. Eur J Appl Physiol Occup Physiol 1982;49:45-57.
13. Keskinen KL, Komi PV. Stroking characteristics of front crawl swimming during exercise. J Appl Biomech 1993;9:219-26.
14. Papoti M, Cunha AS, Martins LEB, Zagatto AM, Freitas Júnior PB, Gobatto CA. Determinação da força e freqüência de braçada em nado atado utilizando sistema de aquisição de dados. Anais do XI Congresso Brasileiro de Biomecânica, 2005.
15. Wakayoshi K, D´Acquisto LJ, Cappaert JM, Troup JP. Relationship between oxygen uptake, stroke rate and swimming velocity in competitive swimming. Int J Sports Med 1995;16:19-23.
16. Costill DL, Kovaleski J, Porter D, Kirwan J, Fielding R, King D. Energy expenditure during front crawl swimming: predicting success in middle-distance events. Int J Sports Med 1985;6:266-70.
17. Garcin M, Vandewalle H, Monod H. A new rating scale of perceived exertion based on subjective estimation of exhaustion time: a preliminary study. Int J Sports Med 1999;20:40-3.
18. Hetzler RK, Seip RL, Boutcher SH, Pierce E, Snead D, Weltman A. Effect of exercise modality on ratings of perceived exertion at various lactate concentrations. Med Sci Sports Exerc 1991;23:88-92.
19. Steed J, Gaesser GA, Weltman A. Rating of perceived exertion and blood lactate concentration during submaximal running. Med Sci Sports Exerc 1994;26: 797-803.
20. Demello JJ, Cureton KJ, Boineau RE, Singh MM. Ratings of perceived exertion at the lactate threshold in trained and untrained men and women. Med Sci Sports Exerc 1987;19:354-62.
21. Kang J, Holffman JR, Walker H, Chaloupka EC, Utter AC. Regulating intensity using perceived exertion during extended exercise periods. Eur J Appl Physiol 2003;89:475-82.
22. Held T, Marti B. Substantial influence of level of endurance capacity on the association of perceived exertion with blood lactate accumulation. Int J Sports Med 1999;20:34-9.
23. Seip RL, Snead D, Pierce EF, Stein P, Weltman A. Perceptual responses and blood lactate concentration: effect of training state. Med Sci Sports Exerc 1991; 23:80-7.
24. Carton RL, Rhodes EC. A critical review of the literature on ratings scales for perceived exertion. Sports Med 1985;2:198-222.
25. Utter AC, Robertson RJ, Green JM, Suminski RR, McAnulty SR, Nieman DC. Validation of the adult OMNI scale of perceived exertion for walking/running exercise. Med Sci Sports Exerc 2004;36:1776-80.
26. Ueda T, Kurokawa T. Relationships between perceived exertion and physiological variables during swimming. Int J Sports Med 1995;16:385-9.
27. Borg GAV. Escalas de Borg para a dor e esforço percebido. São Paulo: Manole, 2000.
28. Bishop D, Jenkins DG, McEniery M, Carey MF. Relationship between plasma lactate parameters and muscle characteristics in female cyclists. Med Sci Sports Exerc 2000;32:1088-93.
29. Robertson RJ, Goss FL, Boer NF, Peoples JA, Foreman AJ, Dabayebeh IM, et al. Children's OMNI scale of perceived exertion: mixed gender and race validation. Med Sci Sports Exerc 2000;32:452-8.
30. Utter AC, Robertson RJ, Nieman DC, Kang J. Children's OMNI scale of perceived exertion: walking/running evaluation. Med Sci Sports Exerc 2002;34:139-44.
31. Marriott HE, Lamb KL. The use of ratings of perceived exertion for regulating exercise levels in rowing ergometry. Eur J Appl Physiol 1996;72: 267-71.
32. Eston RG, Davies BL, Williams JG. Use of perceived effort ratings to control exercise intensity in young healthy adults. Eur J Appl Physiol 1987;56:222-4.
33. Demura S, Nagasawa Y. Relations between perceptual and physiological response during incremental exercise followed by an extended bout of submaximal exercise on a cycle ergometer. Percept Mot Skills 2003;96:653-63.
34. Skinner JS, Hutsler R, Bergsteinova V, Buskirk ER. The validity and reliability of a rating scale of perceived exertion. Med Sci Sports 1973;5:94-6.
35. Noble BJ, Robertson RJ. The role of RPE in graded exercise testing. In: Noble BJ, Robertson RJ, editors. Perceived exertion. Champaign: Human Kinetics Pub., 1996; 215-55.
36. McArdle WD, Magel JR, Lesmes GR, Pechar GS. Metabolic and cardiovascular adjustment to work in air and water at 18, 25, and 33 degrees C. J Appl Physiol 1976;40:85-90.
37. Kurokawa T, Nomura T, Togashi S, Ikegami H. Cardiorespiratory responses during swimming, running and bicycling in swimmers. Jpn J Phys Fitness Sports Med 1984;33:157-70.
38. Mercer TH. Reproducibility of blood lactate-anchored ratings of perceived exertion. Eur J Appl Physiol 2001;85:496-9.
39. Kolkhorst FW, Mittelstadt SW, Dolgener FA. Perceived exertion and blood lactate concentration during graded treadmill running. Eur J Appl Physiol Occup Physiol 1996;72:272-7.
40. Wakayoshi K, D´Acquisto J, Cappaert JM, Troup JP. Relationship between metabolic parameters and stroking technique characteristics in front crawl. In: Troup JP, Hollander AP, Strasse D, Trappe SW, Cappaert JM, Trappe TA, editors. Biomechanics and medicine in swimming VII. London: Chapman & Hall, 1996;152-8.
41. Keskinen KL, Keskinen OP, Mero A. Effects of pool length on biomechanical performance in front crawl swimming. In: Troup JP, Hollander AP, Strasse D, Trappe SW, Cappaert JM, Trappe TA, editors. Biomechanics and medicine in swimming VII. London: Chapman & Hall, 1996; 216-20.
42. Wakayoshi K, Yoshida T, Ikuta Y, Mutoh Y, Miyashita M. Adaptations to six months of aerobic swim training. Changes in velocity, stroke rate, stroke length and blood lactate. Int J Sports Med 1993;14:368-72.