Use of perceived exertion in determining critical velocity in deep water running

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ABSTRACT

The linear relation between exercise intensity and the increase rate of the neuromuscular activity assessed by electromyography allows the estimation of the fatigue threshold, which would be the intensity that could be maintained indefinitely without presenting increase on the electromyography signals along time. It has been hypothesized that the subjetive perception of exertion would behave similarly to the neuromuscular activity and that a perceived exertion threshold (PET) identified similarly to the electromyographic fatigue threshold could coincide with the critical velocity (CritV). Thirteen individuals from both genders (23.0 ± 2.5 years), in a 15 m long x 2.5 m deep swimming pool performed three deep water running exhaustive tests for the determination of the parameters of the critical velocity model, reporting the perceived exertion (6-20 points in Borg scale) each 15 m. For the PET identification, the straight lines inclination coefficients of the increase on the perceived exertion in time (ordinate) and the velocities used (abscissa) were adjusted into a linear function that provided a point in the velocity axis where, theoretically, the perceived exertion would be indefinitely stable. The CritV was estimated through the equations used in the critical velocity model. For comparison purposes of the CritV and PET estimations and their associations, the repeated measures analysis of variance ANOVA was used ($p < 0.05$) and the Pearson correlation was calculated. The data obtained for the CritV determination fulfilled the criteria adopted for the model's validity and CritV and PET presented no statistical difference (0.23 ± 0.02 m/s x 0.24 ± 0.03 m/s), being significantly correlated ($r = 0.85$). These results suggest that the PET seems to represent the maximum exercise intensity in which the physiological and psychophysical variables would attain stability and that this index may be used in the CritV determination.

Key words: Perceived exertion. Critical velocity. Deep water running.

INTRODUCTION

Perceived exertion scales were created with the objective of establishing relations between the subjetive perception of exertion and the external load or physiological stress objective data. According to Borg(1), the exertion perception is a result of the integration of afferent signals originated from both the skeletal muscles (peripheral) and from the cardiorespiratory system (central). During the performance of high-intensity exercises(2), in other words, exercises performed at intensities above the critical power (CritP), the metabolic acidosis seems to be an etiological agent common to both types of sensorial activities(3,4). The decrease on the tissue pH causes muscular fatigue and the decrease on the blood pH is associated with a ventilation increase. Both responses require higher afferent neuromotor activity for both skeletal muscles and ventilatory muscles(3,5), which would be subjectively perceived by the individual as a progressive effort to maintain the same muscular work rate. Thus, it seems that the exertion perception involves both feedback and feed forward(5).

Studies show that the electromyographic activity of the knee extensor muscles undergoes progressive increase along time in high-intensity exercises in cycle ergometer(6,7). The electromyographic activity increase rate is proportional to the exercise intensity. The linear relation between exercise intensity and electromyographic activity increase rate allows the estimation of the fatigue threshold, which is the intercept of the linear regression in the intensity axis. The fatigue threshold would be the exercise intensity that could be maintained indefinitely without alterations on the neuromuscular activity, in other words, without increases on the electromyographic signals along time. In the present study, it has been hypothesized that the subjetive perception of exertion would behave similarly to the neuromuscular activity objective data. Thus, a perceived exertion threshold could be estimated through procedure similar to the electromyographic fatigue threshold.

Le Chevalier *et al.*(7) suggest that the fatigue threshold coincides with the CritP determined through the inclination of the work-time linear relation in ergometer adapted for unilateral knee extension exercise. This intensity was originally described as that in which the exertion of isolated muscles is maintained without exhaustion(8). Moritani *et al.*(9) extended this concept to the cycle ergometer. In modalities such as running(10) and swimming(11,12), the work is replaced by distance and the power by velocity. One adopts, through this conversion, a linear relation between the respective pairs of variables. Thus, the critical velocity may be estimated (CritV).

The CritV corresponds to a limit exertion intensity that could be maintained with $\dot{V}O_2$(13) and lactate(14) steady state. Above this intensity, these variables reach peak values, thus predicting the exhaustion occurrence. The occurrence of exhaustion in running at supra-CritV coincides with the full exhaustion of the anaerobic running capacity (AnaerRC). The AnaerRC is described as the maximum distance to be covered at the expense of the anaerobic metabolism.

As the anaerobic metabolism mobilization is the main source of H^+ ions accumulation in tissues and hence the decrease on the pH in the organism, one may infer that the AnaerRC exhaustion rate would be the responsible for the increase on the perceived exertion in high-intensity exercises. Thus, the maximum intensity able to be maintained without increases on the perceived exertion along time should coincide with the CritV. Therefore, the objective of the

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present study is to compare CritV obtained in the deep water running with the perceived exertion threshold (PET) that we have proposed as alternative way to determine the maximal exercise intensity that allows stabilization of the physiological and psychophysical variables.

METHODS

Subject

Thirteen young individuals from both genders with 23.0 ± 2.5 years of age, 170 ± 12 cm of height and 64.3 ± 15.3 kg of body mass participated in this study. All individuals signed the free consent form in order to participate in the study. None of them presented previous experience with deep water running.

Familiarization with deep water running and Borg scale

The swimming pool used in this study was 15 m long and 2.5 m deep, with water temperature kept near to 28°C. It was considered as favorable for the deep water running practice because the individuals could not touch the ground while maintaining their heads out of water.

The volunteers underwent two to four sessions of deep water running familiarization. These sessions were aimed at instructing them the correct deep water running technique with the objective of presenting reliable results during tests for the determination of the parameters of the critical velocity model and PET. The deep water running technical instructions were given by two appraisers. One of them remained out of the swimming pool while the other monitored movements in the underwater environment. Once participants wore floating vests, their relaxed bodies trended to be positioned vertically in relation to the bottom of the swimming pool, with heads above the surface. During running, the trunk should simulate traditional running in order for the body to start dislocating. The incursions amplitude of hip, knees and ankles joints should be large and fingers should be united in the sagittal plane in order to simulate swimming strokes. Their elbows should lie along their trunks. Each familiarization session lasted about 20 minutes. The exercise intensity was selected by the participant himself. They were advised to select a comfortable intensity. At the end of each session, shortly after a rest period, the participants were asked to cover 60 m at maximum water displacement velocity. When the deep water running technique seemed to be effective and the performance in both consecutive 60-m tests was not over than 5% different, the participants were able to start the tests to determine CritV, AnaerRC and PET.

Still during familiarization, instructions about the use of the Borg 15-points scale(1) were given to be used in further stage. The scale was presented to participants during the deep water running practice, and they attributed a numerical value in the corresponding scale to their general exertion perception in that moment. The scale presents verbal attributes next to the numbers to facilitate the selection so that participants would familiarize with the use of the scale and memorize the relation between the verbal attributes and the numerical values they should report (example: 7-very, very light; 17-very intense).

Tests to determine CritV and AnaerRC

All tests used to determine the parameters of the critical velocity model were performed in different days. Before each test, the participant performed quick warm-up exercise in rhythm freely selected. The tests intensities (0.25 to 0.35 m/s) were established individually, so that exhaustion would only occur within range of one to ten minutes(15). In order to control velocity, cones were placed at the border of the swimming pool each 5 m. Sound signals, performed with the aid of a whistle, indicated the moment in which the individual should be aligned with the cone. When reaching the end of the swimming pool, the participant turned around to perform the same exercise all the way back with no interruption. The voluntary abdication or the incapacity of maintaining the rhythm indicated for more than two cones were considered as exhaustion. In case two consecutive errors of rhythm were made, the participant was encouraged to correct them in the next cone. If the errors were successfully corrected, the test was carried out until one of the exhaustion criteria occurred. If a participant could not correct the rhythm requested, the distance covered by the last two cones (10 m) was deduced from the total distance covered. This variable, the test total time and the mean velocity were adjusted to the equations predicted through the critical velocity model in order to estimate CritV and AnaerRC. These equations are described below:

Time = AnaerRC/(velocity – CritV) (equation 1)

Distance = AnaerRC + (CritV. time) (equation 2)

Velocity = CritV + [AnaerRC. (1/time)] (equation 3)

PET estimation

During the three exhaustive tests, the individuals were instructed to report the perceived exertion according to the Borg 15-points scale(1), each 15 m covered. The angular coefficient of the linear regression between time as independent variable and individual perceived exertion values attributed during each test was determined through linear regression. The angular coefficients of all straight lines (perceived exertion increase rate) obtained with this procedure were used to estimate the parameters of the linear linear regression in function of the mean velocity of the three tests. PET was identified through the projection of this straight line on the velocity axis (x), in other words, it corresponded to the velocity in which the perceived exertion increase rate was "0". Figures 1 and 2 exemplify these procedures in a representative individual.

Statistical treatment

CritV and AnaerRC were estimated through equations 1, 2 and 3 and through the linear and non-linear regression procedures. The respective standard error of estimate (SEE) and the determination errors (r^2) associated to each equation were also estimated. The comparison between the CritV estimations provided by the three equations and the PET value was performed through repeated measures analysis of variance (ANOVA). The same statistical tests were adopted to compare the AnaerRC estimations. The Scheffé *post hoc* test for multiple comparisons was used to identify differences between means. The Pearson correlation coefficient was used to verify associations between CritV and PET estimations. The significance level adopted in all analyses was of $p < 0.05$.

RESULTS

Table 1 shows the velocity mean values, distance and time of the three exhaustive tests used to determine CritV and AnaerRC.

TABLE 1
Mean values (± SD) of velocity in exhaustive rectangular tests, distance and duration. Results are listed in increasing order of velocity used in each test

Velocity ($m.s^{-1}$)	Distance (m)	Time (s)
0.26 ± 0.02	184.6 ± 68.7	699.1 ± 274.5
0.31 ± 0.02	85.4 ± 29.5	271.2 ± 83.4
0.35 ± 0.03	49.3 ± 19.5	142.7 ± 58.3

Figure 1 shows that the increase on the perceived exertion along each test occurred linearly. In some cases, visual inspection showed that the first perceived exertion value reported did not fit to the linear tendency of the next points used in the linear regression.

When this occurred, the first point was excluded from the analysis. There were other occasions in which the last points repeated on 20, which is the maximum value. This generally occurred in the longest test. These points also weakened the linearity tendency of the rest of the curve. Thus, these points were also rejected so that the linear portion of the curve was described with better fitting of the regression equation. The PET obtained, according to example of a case shown by figure 2, was of 0.24 ± 0.03 m/s.

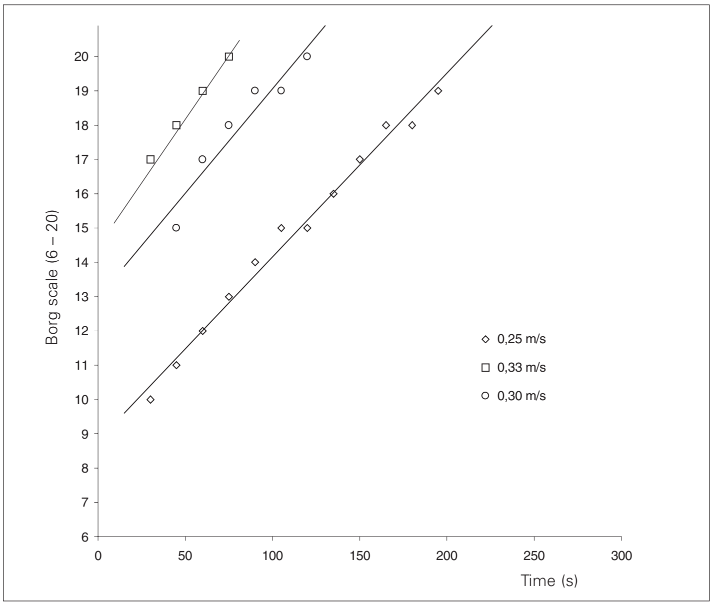

***Fig. 1** – Increase on the perceived exertion along time in three exhaustive rectangular tests from a representative subject*

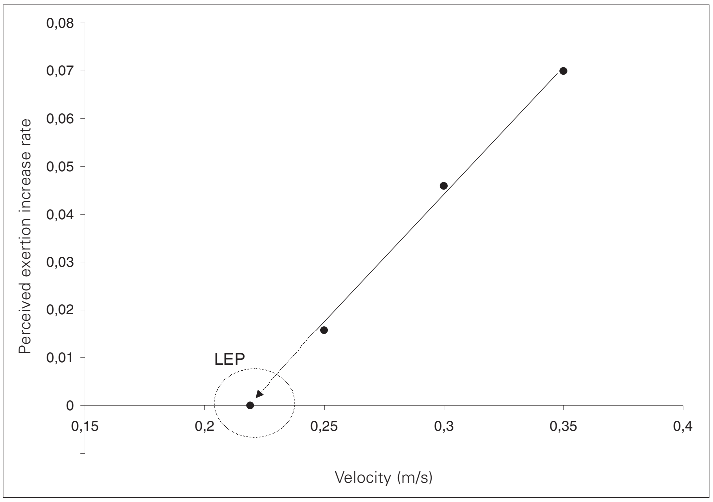

***Fig. 2** – Perceived exertion threshold (PET) determination through linear relation between perceived exertion increase rate and deep water running velocity from a representative subject*

Table 2 shows the mean values obtained for CritV, AnaerRC, the respective SEE and r². Significant differences were observed between the AnaerRC estimations ($p < 0.05$). The estimation provided by equation 1 was different from that provided by equation 3 ($p < 0.05$). The CritV estimations were compared between each other, along with the PET value (figure 3). No significant differences between each other were detected, although a tendency ($p = 0.054$) for this difference was observed, according to the preestablished significance level.

TABLE 2
Critical velocity (CritV), anaerobic running capacity (AnaerRC), standard error of estimate (SEE) and determination coefficient (r^2) provided by equations (1, 2 and 3) predicted through the critical power model (mean ± SD)

Equation	CritV		AnaerRC		r^2
	m/s	SEE	m	SEE	
1	0.23 ± 0.02	0.005 ± 0.000	19.1 ± 7.8*	3.3 ± 2.6	0.983 ± 0.026
2	0.24 ± 0.03	0.009 ± 0.006	17.0 ± 7.5	3.9 ± 2.7	0.999 ± 0.001
3	0.25 ± 0.03	0.025 ± 0.041	15.0 ± 7.6	2.7 ± 1.4	0.965 ± 0.042

***** Significant difference in relation to equation 3.

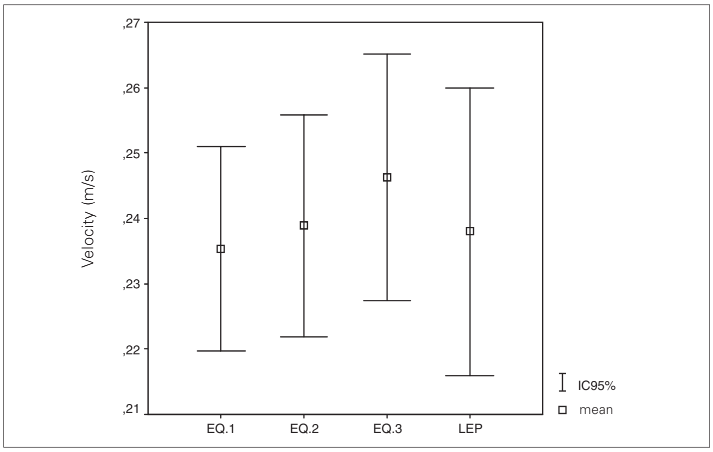

***Fig. 3** – Mean values of CritV estimated through the three equations of the critical velocity model and PET*

Table 3 contains the correlation matrix between CritV and PET estimations. All correlations were high, but the correlations between PET and the different CritV estimations, which ranged between 0.85 and 0.88, are emphasized.

TABLE 3
Correlation matrix of the estimations of CritV resulting from the application of the three equations of the critical velocity model and PET

	Equation 1	Equation 2	Equation 3	PET
Equation 1	1.00			
Equation 2	0.98	1.00		
Equation 3	0.92	0.98	1.00	
PET	0.85	0.88	0.88	1.00

Note – All correlations are significant ($p < 0.05$).

DISCUSSION

There are no published studies that estimated CritV and AnaerRC in deep water running in literature. Most works on the modality, unlike the present study, use the static deep water running model, in which the individual remains attached to the border through the floating vest, and the exertion intensity is controlled by the steps frequency or through physiological markers, such as the heart rate. To review these studies, Wilder and Brennan(16), and Reilly *et al.*(17) are recommended.

The parameters of the critical velocity model were determined in modalities related to the deep water running and their physiological meaning was established. According to Wakayoshi *et al.*(11,18) and Kokubun(12), the CritV obtained in swimming is not different from the anaerobic threshold, calculated through fixed concentration of 4 mM of blood lactate in test with progressive velocities. The correlation between both variables in the studies mentioned was high (r = 0.85 to 0.89). Besides, the CritV seems to be coincident with the maximal lactate steady-state directly measured(12,18). In running, Sid-Ali *et al.*(14) and Hill and Ferguson(13) found similar results with regard to the meaning of CritV. In the second study, it was additionally demonstrated that the CritV is the maximal intensity possible to be maintained without the elevation of the $\dot{V}O_2$ up to its maximum value. The meaning of AnaerRC is not fully clear, once the expected correlation between this index and the peak plasma lactate after exhaustive test was not confirmed by Housh *et al.*[19]. Still, the AnaerRC would theoretically be an indicative of anaerobic capacity[20].

Albuquerque da Silva (data not published) showed that, in the deep water running, the CritV is not significantly different from the anaerobic threshold, determined through the fixed concentration of 3.5 mM in incremental test. The correlation between these variables ranged from 0.79 to 0.90, depending on the equation used in the CritV estimation. Therefore, the physiological meaning of CritV in the deep water running seems to agree with that established in other modalities.

The CritV estimations are not different from each other in the present study. Besides, the mean SEE ranged from 2 to 10% of the CritV. According to Hill[21], these are important conditions in which the parameter's validity and accuracy are assured. However, a significant difference was observed (p = 0.05) between the AnaerRC estimations. The SEE associated to this variable ranged from 14 to 23%. Both factors made the AnaerRC validity and accuracy infeasible as indicative of anaerobic capacity, according to criteria elaborated by Hill and Smith[20]. Still, the adjustment of the experimental data to all equations was satisfactory, considering the high values of r^2, above 0.96 on mean.

Much has been discussed on the neurophysiological mechanisms responsible for the exertion perception. Cafarelli[5] summarizes the discussion into three thinking lines with their respective explanatory hypotheses. Hypothesis 1 supports the feed forward primacy and the theory that a "copy" of the motor impulses is transmitted to the sensorial cortex, carrying the information about the degree of muscular activation. This information would be the main constituent of the exertion perception. Hypothesis 2 supports that the feedback coming from chemical and mechanical receptors in the joints, tendons, parts of the cardiorespiratory system and the skeletal muscles would produce the peripheral sensation, translated into exertion perception in high levels of the central nervous system. Hypothesis 3 proposes that the afferent muscles would be compared to the efferent motors and that this comparison of information would cause immediate compensations by counterbalancing the fatigue. This hypothesis supports that the sensorial cortex monitors both the efferent and the afferent signals in order to generate the exertion perception.

Several works have attempted to establish perceptive responses to exertion performed at metabolic thresholds (ventilatory, lactate)[22-24], to regulate lactacidemia in tests with variable loads through perceived exertion[25], and also to control other variables such as the heart rate and exercise intensity with the use of perceived exertion scales[26]. Particularly, about the determination of the metabolic thresholds that has been objective of this study, the use of the exertion perception has presented some problems. The results from Mahon *et al.*[24] indicate that the perceived exertion rated by the Borg[1] 15-points scale at the ventilatory threshold intensity presents significant inter-individual variability, besides being significantly different when children and adults were compared. However, a study by Hill *et al.*[22] demonstrated that the training affects the ventilatory threshold in adults, but does not modify the associated exertion perception. Weltman[27] gathered findings that emphasize that the 14 and 16-17 exertion perception is associated to the blood lactate fixed concentrations of 2.0 and 4.0 mM, frequently indicated as indicative of lactate and anaerobic thresholds, respectively. The approach presented in this study is different from the works mentioned above with regard to the detection of one of the thresholds – CritV – once we did not intend to establish a fixed value for the perceived exertion at this intensity. The proposal was to search for an original application for the Borg[1] scale, which takes into consideration the perceived exertion variation rate as alternative to the CritV individualized determination. Indeed, as verified in our results, the perceived exertion value may change along a rectangular exercise, what invalidates the attempt of establishing a fixed value associated to the exertion intensity in high-intensity exercise.

For the same step frequency, the perceived exertion is significantly higher in the deep water running than in the field running[28]. This probably occurs because in this situation, the $\dot{V}O_2$ and the heart rate are quite higher in the deep water running. Both variables seem to be relevant in the prediction of the perceived exertion in deep water running through the multiple regression analysis[29]. Other important variables are the minute-ventilation and ventilatory frequency (central) and the legs movement velocity (peripheral). This information, integrated in the sensorial cortex and in the respiratory centers, probably determines the evolution of the perceived exertion in exhaustive rectangular tests and, thus, would influence the PET estimation.

In the present study, PET provided good CritV indirect estimation, once both presented values close to each other, and the correlation between each other ranged from 0.85 to 0.88. It was presupposed that the perceived exertion would be increased in exhaustive tests (figure 1) along with the use of the AnaerRC. Therefore, the maximum intensity in which, theoretically, no increase on the perceived exertion would occur, would coincide with the intensity in which AnaerRC would not be used. In this context, the PET was determined based on the intersection of the linear regression of the relation between the perceived exertion increase rate and the velocity used in exhaustive tests (figure 2). One supposes that the regions from the central nervous system responsible for organism's perceptive representation is sensitive to the anaerobic reserve depletion, represented by the AnaerRC. In fact, this hypothesis is in agreement with Caffareli[5], Kostka and Cafarelli[3], and Robertson *et al.*[4], who established through their findings that H^+ accumulation, both in the exercised muscles and blood, would be the main responsible for the increase on the perceived exertion. Most H^+ accumulation in exercise is direct result of the anaerobic metabolism mobilization.

The role the feed forward plays in the perceived exertion manifestation cannot be ignored, once the electromyographic activity that indicates the motor drive for the muscular activation increases along high-intensity rectangular exertions[6]. This increase may be attributed to the incapacity of the motor stimuli at the beginning of the exercise to remain effective until the end of the exercise due to alterations on the peripheral cellular environment (ADP and H^+ accumulation). The increase on the electromyographic activity would be a result of the communication between efferent and afferent information, whose comparison and integration would modulate the perceived exertion. The coincidence between the fatigue threshold and CritP[7] reinforces this hypothesis 3.

From the practical point of view of the use of metabolic thresholds for the prescription of aerobic exercises, the PET identification seems to be promising, once the results of this study suggest that the increase on the exertion perception would somehow be determined through the use of the anaerobic capacity. A limitation of this study was the lack of an objective measure of the use and depletion of the anaerobic energetic supplies concomitantly to the perceived exertion data collecting. Although the PET identifies the same metabolic threshold already described through other methods based on the heart rate, ventilation and on the blood lactate concentration, it showed to be a useful tool for the prescription and control of the aerobic training. The use of any equipment or the employment of invasive procedures would be useless. However, its physiological meaning and applicability on the aerobic training deserve further investigations.

CONCLUSIONS

The results of the present study suggest that the perceived exertion may be used in the CritV determination. The PET was not significantly different in relation to the CritV ($p > 0.05$). Besides, the correlations between both variables were quite high (r = 0.85 to 0.88). Thus, PET seems to represent the maximum exercise intensity where physiological and psychophysical variables would find stability. New studies must be conducted in order to assess the PET validity in other experimental conditions.

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

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