Journal of Physical Education and Sport ® - JPES, 11(2), Art # 33, pp.215-220, 2011
E- ISSN 2066-2483 P-ISSN 1582-8131 © JPES

Original Article

Aerobic evaluation of young swimmers using the critical velocity test a brief report

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Published online:: June 30 2011
(Accepted for publication June 20 2011)

Abstract
Critical velocity is the maximal swimming velocity that could be maintained for a long time without exhaustion. As it is considered to be well related with the exercise intensity corresponding to the individual anaerobic threshold, critical velocity has been used to monitor the swimmer's aerobic performance. However, studies conducted in age-group swimmers are scarce and some literature does not use a long distance test as required for obtaining reliable critical velocity results. The aim of the present study was to assess critical velocity in 11-14 years old swimmers in order to characterize their aerobic capacity. So, 56 girls and 62 boys performed 200 and 800m front crawl tests at maximum intensity, being critical velocity assessed by the slope of the regression line between the test distances and the respective times. Critical velocity values were 1.21±0.06, 1.28±0.05 and 1.25±0.06 m/s for the girls, boys and total group, with significant differences being observed between gender groups. As expected, these results were lower than the values presented in the literature for older swimmers. However, some of these studies that reported significantly higher critical velocity values used short distances tests for its assessment, which could lead to the overestimation of the final results. It is suggested the use of the individual critical velocity converted in 100m time to implement specific training series for aerobic capacity development, as well as for the more precise definition of training volumes and intensities. Thus, the used critical velocity test could be considered a useful training strategy used to increase swimmers conditioning.
Key words: Swimming, aerobic threshold, critical velocity, age-group

Introduction

Swimming is an individual and cyclic sport in which both conditional and biomechanical factors are determinant for the swimmer's performance. In fact, di Prampero et al. (1974) proposed a swimming performance equation, in which swimming velocity (v) is directly dependent of both the energy input from aerobic and anaerobic pathways ($\dot{E}$) and of the swimming technique, expressed as the ratio established between propelling efficiency (ep) and body drag (D):

$$v = \dot{E} \cdot (ep \cdot D^{-1}) \qquad (1)$$

To increase the effectiveness of the training process and to predict swimmer's performance, coaches often implement training control and evaluation strategies. In fact, coaches often evaluate the adequacy of the training exercises and programs, as well as the development of the swimming performance determinant factors. To evaluate the swimmer's aerobic conditioning, one of the most used parameters is the anaerobic threshold, which gives important information regarding the level of development of the swimmer's aerobic capacity (Heck et al., 1985; Simon, 1997; Pyne et al., 2001). However, despite the fact that there are many different tests available to assess anaerobic threshold (for a detailed review see Svedahl and MacIntosh, 2003 and Faude et al., 2009), several researchers use the invasive, time consumable and expensive procedure of blood collection for lactate concentration analysis.

In order to overcome the above referred constraints, Wakayoshi et al. (1992a) developed and adapted for swimming the concept of critical power introduced by Monod and Scherrer (1965) for the total work done by one muscle or one synergistic muscle group, presenting the critical velocity (CV) test. These authors defined CV as the theoretic maximal swimming velocity that could be maintained for a long period of time without exhaustion, being a parameter closely related to the anaerobic threshold concept. In fact, CV is considered a valid method for the evaluation of swimmer's aerobic capacity through the assessment of the velocity corresponding to a regime of physiological aerobic steady state (Wakayoshi et al., 1992a; Wakayoshi et al., 1992b; di Prampero et al., 2008).

After the pioneer studies of Wakayoshi and co-workers, several researchers assessed the front crawl CV as an indicator of the swimmer's functional aerobic capacity (e.g. Ginn, 1993; Wright and Smith, 1994; Fernandes and Vilas-Boas, 1999; Hill and Smart, 2001; Dekerl et al., 2002). However, these studies were mainly conducted in male adult swimmers involved in high frequency and load training regimens. Thus, taking into account the scarcity of data concerning the determination of CV in age-group swimmers, the purpose of this

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study was to assess CV in a large group of male and female swimmers of 11-14 years old in order to characterize the swimming aerobic capacity of these age-group swimmers.

Material and Method

Participants

One hundred and eighteen young swimmers (62 males and 56 females), selected by FINA ranking tables to a training campus, participated voluntarily in this study. A medical examination at the beginning of the training season revealed that all subjects were in good general health. The local Ethics Committee approved the procedures and the swimmers' parents were fully aware of the evaluation protocol. The subjects' main anthropometric and training characteristics are shown in Table 1.

Table 1. Characteristics of the participants.

Parameters	Girls (n = 56)	Boys (n = 62)
Age (years) *	12.0 ± 0.7	13.1 ± 0.8
Body mass (kg) *	46.9 ± 6.7	54.7 ± 7.7
Height (cm) *	158.4 ± 6.2	167.0 ± 7.9
Years of swimming practice	4.2 ± 1.5	4.2 ± 1.2
Training session (n.wk^{-1})	6.3 ± 0.7	6.4 ± 0.7

Values are mean ± SD. *n*, number of subjects, *, difference between the gender groups ($P \leq 0.001$).

Instruments and Procedures

Briefly, after a 1000 m warm-up at low to moderate intensity, each swimmer performed a 200 and a 800 m front crawl tests at maximum intensity with in-water starts and flip turns. Between tests, subjects swam 3 x 400 m (with 1 rest min interval) for active recovery, which, in addition with passive rest, led to a rest period higher than 1h. All tests were conducted in a 25 m indoor swimming pool, 1.90 m deep, with a water temperature of 27.5ºC. The times of the 200 and 800 m front crawl bouts were registered by stopwatches (Seiko®) operated by experienced coaches and researchers. As proposed before (cf. Wakayoshi et al., 1992a), CV was assessed as the slope of the regression line established between the two test distances and the respective time needed to cover them at maximum intensity. CV, represented as *a* in the above-refereed regression line (and expressed in m/s), was calculated from the distance (*y*) in function of the time (*x*) relationship, and *b* is y-interception value, according to the following equation:

$$y = ax + b \qquad (2)$$

Descriptive analyses were obtained and data were checked for distribution normality using the Kolmogorov-Smirnov test. Student's independent t-test was used to analyze differences between gender groups. A significance level of 5% was accepted.

Results

Figure 1 presents a representative scattergram showing the distribution of distance (vertical axis) and time (horizontal axis) variables for the CV assessment of one swimmer (the line equation and determination coefficient - r^2 - are also shown). As explained before, in this example the CV value is 1.327 m/s.

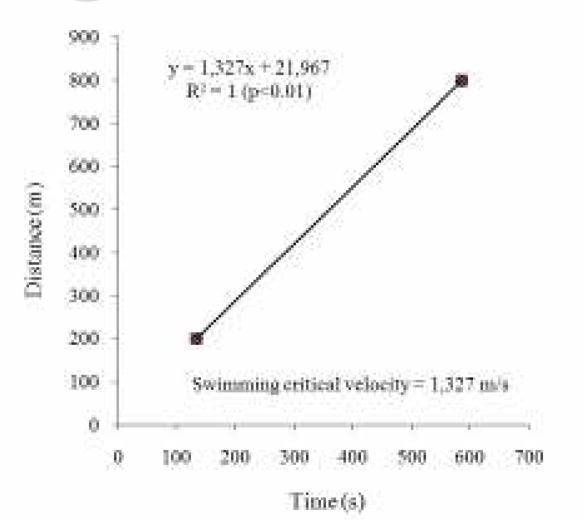

Figure 1. Example of a regression line established between the test distances of 200 and 800 m and the time spent in its achievement at maximum swimming velocity.

In the total sample, the r^2 values of the regression analysis between distance and time allowed to identify a very strong linearity in the relationship between these parameters, being higher than 0.999 ($p<0.01$). It is also possible to observe a low variance coefficient in the CV values (~0.05).
Data concerning the different variables obtained in female and male groups, as well as in the total sample are presented in Table 2. The CV value converted in 100 m time (CV_{100t}), for direct application in aerobic capacity development training workouts, was also assessed. Significant differences were found between gender groups in all the analyzed variables.

Table 2. CV, CV_{100t} and time duration of the 200 and 800 m front crawl tests, in female, male and total group of swimmers.

Parameters	Girls (n = 56)	Boys (n = 62)	Total group (n = 118)
CV (m/s) *	1.21 ± 0.06	1.28 ± 0.05	1.25 ± 0.06
CV_{100t} (s) *	82.7 ± 4.3	78.2 ± 2.8	80.3 ± 4.2
200 m (s) *	147.6 ± 7.9	138.5 ± 6.1	142.8 ± 8.3
800 m (s) *	645.0 ± 31.6	606.5 ± 23.9	624.9 ± 33.7

Values are mean ± SD. *n*, number of subjects, *, difference between the two gender groups ($P \leq 0.001$).

The CV values ranged between 1.10 - 1.34 m/s for the female group, and between 1.20 - 1.40 m/s for the male group. CV presented an overall high and very high inverse relationships with 200 and 800 m tests (r = -0.67 and r = -0.93, respectively, both for < 0.001).

Discussion

Since the enhancing of swimmer's performance can no longer be obtained only by the increasing of training volume and by the use of nonspecific methodologies (Costill, 1999; Olbrecht, 2000), more objective and specific training sets are required to improve the quality of the training process, aiming develop performance. This is especially true for young swimmers engaged in the beginning of the specialization stage. Therefore, the increase knowledge about performance-determinant factors, the use of performance diagnosis and training methods are essential (cf. Smith et al., 2002). Moreover, assessments in young swimmers should be less expensive, less invasive, less complex and less time consuming in comparison to the ones carried-out in adult swimmers (Fernandes et al., 2008).

Given that high percentage of the training volume in swimming is dedicated to the development of the swimmer's aerobic capacity (Maglischo, 2003), coaches need objective data that allow them to better quantify the proper intensities to develop the aerobic performance. Anaerobic threshold is a worldwide parameter used to evaluate aerobic capacity, and data obtained are frequently used to more accurately define exercise workloads and intensities at aerobic regimens (Heck et al, 1985; Simon, 1997; Pyne et al., 2001; Smith et al., 2002). However, to avoid blood collection related with the assessment of anaerobic threshold (an invasive and expensive method), coaches often implement simple non-invasive distance tests, namely the 30 and 60 min continuous swimming test - T30 and T60 (Olbrecht et al., 1985) - and the 2000 (Touretski, 1993) and 3000 m swim test (Madsen, 1982). However, these tests contain significant limitations preventing coaches to use them, particularly when testing young swimmers. In fact, as they are monotonous tests that imply lower levels of motivation, they could underestimate the final result. Additionally, as the tests are carried out in training conditions (with swimmers performing very close from each other), the final result of the swimmers that followed the line leader are adulterated due to the drafting phenomena (cf. Silva et al., 2008). Moreover, as referred by Smith et al. (2002), the typical mean velocities resulting from these tests are unlikely to be uniform, thereby reflecting different levels of physiological intensity.

In opposition to the above-referred tests, CV is a methodology that is emerging, due mostly to its operativeness: it is a simple, not expensive and non-invasive method. CV value is considered closely related to the velocity corresponding to anaerobic threshold and to the aerobic training (Wakayoshi et al., 1992a Wakayoshi et al., 1992b), allowing evaluating the maximal velocity of a swimmer in a regime of physiological aerobic balance (Wakayoshi et al., 1993; Barden and Kell, 2009). These conclusions were based in the high correlation values observed between CV and: (i) the swimming velocity corresponding to 4 mmol/l of blood lactate concentrations (Wakayoshi et al., 1992a, b; Wright and Smith, 1994; Ikuta et al., 1996; Vilas-Boas et al., 1997; Fernandes and Vilas-Boas, 1999; Toubekis et al., 2006), a standard value for anaerobic threshold proposed by Mader et al. (1978); (ii) the mean velocity of the T30 (Fernandes and Vilas-Boas, 1999; Dekerle et al., 2002; Greco et al., 2007), which is closely related to anaerobic threshold (Stegmann and Kindermann, 1982; Olbrecht et al., 1988) and (iii) the velocity corresponding to the maximum lactate steady state (Hill and Smart, 2001; Wakayoshi et al., 1993; Dekerle et al., 2005).

The high linearity of the relationship distance/time observed was also verified in other studies with older swimmers (Wakayoshi et al., 1992a; Wakayoshi et al., 1992b; Wrigth and Smith, 1994; Fernandes and Vilas-

Boas, 1999; Brickley et al., 2004). The accentuated linearity verified in this study and in the specialized literature, confirms that it is possible to assess CV through simplified calculations, namely using two distances. However, as suggested before by Wright and Smith (1994), it is fundamental not to suppress a long distance (of approximately 15 min duration), because it may lead to an overestimation of the final result. Dekerle et al. (1999) also suggest that swimming CV should be calculated from performances ranging from 200 to 2000 m, i.e., from exhaustion times ranging from 2 to 30 min. The disrespect of this premise seems to be the reason why some authors argue that CV represents a higher intensity than anaerobic threshold (cf. Martin and Whyte, 2000; di Prampero et al., 2008; Espada and Alves, 2010). In fact, Martin and Whyte (2000) evidenced that the shorter the predictive trials, the higher the slope of the distance-time regression.

The CV results obtained in the present study, showing lower values than older swimmers (Wakayoshi et al., 1992a; Wright and Smith, 1994; Ikuta et al., 1996; Vilas-Boas et al., 1997; Fernandes and Vilas-Boas, 1999; Espada and Alves, 2010), are in accordance with literature that followed the above-referred assertion of Wright and Smith (1994). Given that swimming performance increases with age and maturation status, it seems reasonable that young swimmers achieved higher times at the 200 and 800 m tests and, therefore, obtained lower CV values. Conversely, significantly higher CV values were found in the studies that used shorter distances for CV assessment: (i) Abe et al. (2006) used distances between 75 and 150 m and found high correlation values with anaerobic performance; (ii) Di Prampero et al. (2008) found significant relationships between CV and aerobic power using distances between 50 and 200 yards; and (iii) Fernandes et al. (2008), using 12.5, 25 and 50 m tests in front crawl, obtained strong inverse relationship between the CV and the 100 m performance time, and its first and second 50 m partials. Moreover, some studies pointed out to that CV value overestimate the intensity of anaerobic threshold, which may be due to the use of (short) distances of 100 or 200 m, and 400 m in its assessment (Wakayoshi et al., 1992b; Wakayoshi et al., 1993; Ginn, 1993; Hill et al., 1995; Ikuta et al., 1996; MacLaren and Coulson, 1999; Greco et al., 2007; Espada and Alves, 2010). Moreover, the CV obtained are similar to those observed in older but less proficient swimmers, as reported in triathletes by Martin and Whyte (2000).

The high inverse relationship between CV and 200 and 800 m tests durations seems to be also in accordance with literature, particularly when correlating CV and the 400 m test (Wakayoshi et al., 1992a; Wakayoshi et al., 1992b; Wakayoshi et al., 1993; Espada and Alves, 2010). These results may be easily explained by the fact that these parameters provide 100% of the information needed to generate CV (they are co-variants). Complementarily, it is not surprising that CV relates better with the 800 m effort, since CV is indicative for the capacity of the aerobic energy system (Toussaint et al., 1998), which is more predominant in longer events (as the 800 m in comparison with the 400 m effort).

It is important to highlight that there are many reasons for trying to quantify the intensity of exercise corresponding to anaerobic threshold, including the assessment of health-related cardiovascular or pulmonary fitness, and the evaluation of training programs and categorization of the intensity of exercise. It is expected that the CV protocol presented in this study, conducted with both short and long distance tests, could be well accepted and applied by coaches in their training control and young swimmers' evaluation programs. We keep on saying that reliable and systematic control and evaluation is a precious tool to increase the training efficiency through the correct establishment of training volumes and intensities. This protocol could be easily applied in one training session.

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