

Research article

Can the *curriculum* be used to estimate critical velocity in young competitive swimmers?

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Abstract

The aims of the present study were to assess critical velocity using the swimmer *curriculum* in front crawl events and to compare critical velocity to the velocity corresponding to a 4 mmol·l⁻¹ of blood lactate concentration and to the velocity of a 30 min test. The sample included 24 high level male swimmers ranged between 14 and 16 years old. For each subject the critical velocity, the velocity corresponding to a 4 mmol·l⁻¹ of blood lactate concentration and the mean velocity of a 30 min test were determined. The critical velocity was also estimated by considering the best performance of a swimmer over several distances based on the swimmer *curriculum*. Critical velocity including 100, 200 and 400 m events was not different from the velocity of 4 mmol·l⁻¹ of blood lactate concentration. Critical velocity including all the swimmer events was not different from the velocity of a 30 min test. The assessment of critical velocity based upon the swimmer *curriculum* would therefore seem to be a good approach to determine the aerobic ability of a swimmer. The selection of the events to be included in critical velocity assessment must be a main concern in the evaluation of the swimmer.

Key words: Training, evaluation, aerobic ability, critical power.

Introduction

A number of field tests have been developed to help swimming coaches monitoring their training. For instance, Smith et al. (2002) reported that the first level of evaluation should be the competitive performance itself. The use of the individualized swimming distance versus time performance curve, based on a series of criterion effort has appeared attractive and appealing for physiological assessment in swimming (Wakayoshi et al., 1992). The critical swimming velocity concept (CV) could provide the basis to analyze the effects and trends brought about through training, predict future competitive performance and provide recommendations for continued directional training (Dekerle, 2006).

The critical velocity concept is an extension of the critical power concept originally introduced by Monod and Scherer (1965). Attempting to understand the local work capacity of one muscle or one muscle group, Monod and Scherer (1965) highlighted the fact that local work and time to exhaustion were linearly related. Further, the slope of the relationship, called critical power, was defined as a threshold of local fatigue, while the y-intercept

value corresponded to a reserve of energy. Critical power was mathematically defined as the power that can be maintained indefinitely. A distance-time relationship equivalent to the work-time equation of Monod and Scherer (1965) was proposed by Hughson et al. (1984). The slope of the relationship (CV) was interpreted as a maximal rate of energy turnover by aerobic metabolism and was defined as the velocity that can be maintained indefinitely without exhaustion (Dekerle et al., 2005; Fernandes and Vilas-Boas, 1999; Wakayoshi et al., 1992).

Since Wakayoshi et al. (1992) have recovered the critical power concept for swimming, creating the CV concept (aerobic ability indicator), several distances have been used by several authors for its determination (Dekerle et al., 2002; Fernandes and Vilas-Boas, 1999; Soares et al., 2004; Wakayoshi et al., 1993). At a lower level, the y-intercept value (anaerobic swimming capacity indicator) was being similarly recuperated, though its informative usefulness related to anaerobic potential is still in discussion (e.g. Soares et al., 2004; Vilar et al., 2004). Recently, some authors (Abe et al., 2006; Fernandes et al., 2008) have introduced the concept of anaerobic critical velocity, based upon sprint swimming distances and the respective time durations. Anaerobic critical velocity seems to represent the functional anaerobic capacity of swimmers. However, this new concept is outside the main aim of the present paper and will not be considered. Critical velocity only will be analyzed as an aerobic ability indicator.

Wakayoshi et al. (1993) and Dekerle et al. (2002) have used 200 and 400 m distances in the determination of CV and Fernandes and Vilas-Boas (1999) have concluded that the distances of 200 and 800 m seem to be the best in enabling CV estimation. However, the use of only two performances to assess critical velocity would be unreliable (Dekerle, 2006). This concern has to be considered when using the distance – time relationship to predict performance or monitoring the effects of training. To enable the use of different distances in the determination of CV and in the subsequent comparison of results from different studies we must be sure that the results are sufficiently similar not to negatively influence training planning and not to lead to misinterpretations of science. It can be noticed that the determination of CV has been shown to be reliable if exhaustion times are variable and physiological responses at CV have also been shown to be reproducible (Hinckson and Hopkins, 2005; Vandewalle

et al., 1997). Nevertheless, Wright and Smith (1994) established that a long swimming distance, of approximately 15 min duration, should be included as one of the distances used to compute CV, in order to avoid overestimation of this parameter.

The use of only two distances in the assessment of the CV is due, naturally, to worries related to swimmer evaluation by coaches. From a theoretical point of view, the more distances that are included the better, because this minimizes possible errors, increasing the strength of the regression line equation. However, it is not always possible to carry-out an experimental protocol to determine the CV including various distance bouts. This situation would require expensive time, which could be a main concern for coaches. An alternative approach is to apply the best performance of a swimmer in several distances using the same technique to assess CV based on the swimmer *curriculum*. With this approach, critical velocity may be assessed without additional experimental tests. It only requires the use of the best performance of a swimmer in competition in several distances, i.e., the swimmer *curriculum*. Fernandes and Vilas-Boas (1999) have already used this approach to assess critical velocity. However, Fernandes and Vilas-Boas (1999) used the competition distance and the correspondent official time on the distances of 50, 100, 200, 400, 800 and/or 1500 m. In the present study we aimed to determine CV including all the swimmer events but also to use different combinations of distance – time plots. Moreover, in the study of Fernandes and Vilas-Boas (1999) only the most recent times were analyzed and the authors did not refer to the time gap between all the events. In the present paper we wanted to investigate if the personal best times, independently of the moment when they took place, produced the same results in young swimmers.

The critical velocity assessment that was developed is a non-invasive test to evaluate the aerobic ability (Toussaint et al., 1998; Toubekis et al., 2006). Several authors attempted to associate this intensity to maximal lactate steady state and to the velocity corresponding to 4 mmol·l⁻¹ of blood lactate concentration (V4) (e.g. Deckerle et al., 2005; Toubekis et al., 2006). Another test widely used in swimming to assess aerobic capacity is the 30 minutes test (t30) (Colantonio and Kiss, 2007; Olbrecht et al., 1985). Both CV and t30 are non-invasive tests and seem to be valid and practical methods for the evaluation of the endurance capacity of young swimmers (Toubekis et al., 2006).

Taking into account the above considerations, we hypothesized that CV can be estimated based only on swimmer best performances (*curriculum*). Further, it is suggested that CV based on the *curriculum* can be a good and time-saving approach to help coaches monitor training, namely to an understanding of whether critical velocity is related to V4 and velocity of t30, since these two parameters are widely used in swimming training.

Therefore, the aims of the present study were: to assess CV in young swimmers using the swimmer *curriculum* in front crawl events and to compare this *curriculum*-based CV to the velocity corresponding to a 4 mmol·l⁻¹ of blood lactate concentration (V4) and to the velocity of a 30 min test (Vt30).

Methods

Subject

A sample of 24 male swimmers of high national level was used in this study. The mean (\pm standard deviation) of their age, height and body mass were 15.04 \pm 0.20 years, 1.71 \pm 0.07 m and 64.81 \pm 8.34 kg, respectively. Their mean (\pm standard deviation) best times for 50, 100, 200, 400, 800 and 1500 m freestyle were respectively: 26.65 \pm 0.52, 56.64 \pm 1.36, 243.03 \pm 3.08, 258.71 \pm 5.84, 548.36 \pm 18.80, 1047.97 \pm 37.51 seconds. The participants were age-group swimmers and were selected to join technical and conditional evaluation.

Technical information

The participants' parents and coaches provided their written informed consent and the procedures were approved by the institutional review board.

For each subject the CV, the V4 and the Vt30 were determined. The CV was assessed considering the best performance recorded in several distances, based on the swimmer *curriculum*. The personal best in the 50, 100, 200, 400, 800 and 1500 m freestyle was registered for each swimmer. The mean (\pm standard deviation) time gap between the swimmers personal records (the difference between the oldest and the most recent personal best) was 5.0 \pm 1.2 months. The CV was calculated using the slope of the distance-time relationship, plotting the swimming performances over time (Wakayoshi et al., 1992) (Figure 1). The standard error of CV (slope of the equation line) was calculated to determine the strength of the regression line equation.

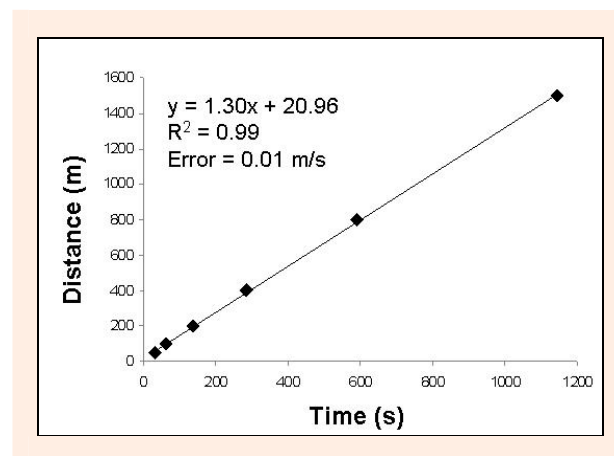


Figure 1. An example of the assessment of CV50to1500 for one swimmer of the sample (CV50to1500 = 1.30 m/s). The regression equation, the R² value between the distance and the event time and the standard error of CV are also presented.

We considered three critical velocities based on the swimmer *curriculum*: (i) the velocity corresponding to the regression of 50, 100 and 200 m (CV50/100/200), (ii) the velocity corresponding to the regression of 100, 200 and 400 m (CV100/200/400) and (iii) the velocity corresponding to the regression of 50, 100, 200, 400, 800 and 1500 m (CV50to1500).

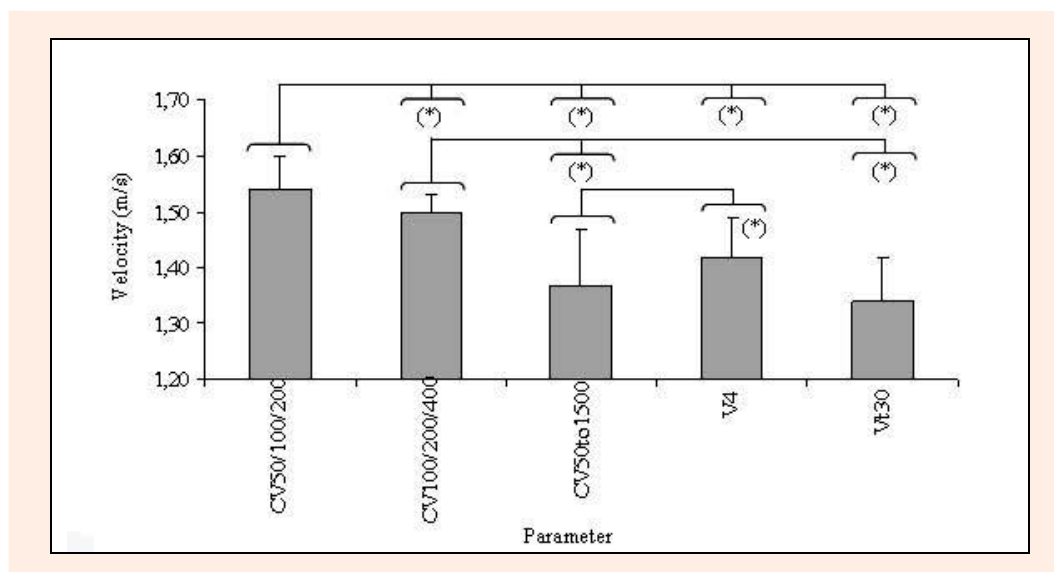


Figure 2. Mean \pm SD values for the velocities that were considered in the study and statistical differences between the values of each velocity. * $p \leq 0.05$.

To determine the swim velocity at $4 \text{ mmol}\cdot\text{l}^{-1}$ of blood lactate concentration (V4), each subject performed 2x200 m front crawl, at 80% and at 100% of their maximum speed (according to their best time at 200 m front crawl), with 30 minutes of passive recovery between bouts (Mader et al., 1976; Michielon et al., 2006; Silva et al., 2007). One, three and five minutes after each bout, 32 micro-litres of capillary ear lobe blood samples were collected and analysed with an Accusport Lactate Analyser (Boehringer, Mannheim, Germany). The highest value of blood lactate concentration was used. Before each subject's test a calibration of the Accusport was performed with several YSI 1530 Standard Lactate Solutions ($2.5, 5.0, 10.0$ and $15.0 \text{ mmol}\cdot\text{l}^{-1}$). V4 was determined by linear interpolation of the points relating blood lactate and swimming speed.

To determine the Vt30, each subject performed a 30 min all-out test in front crawl, trying to swim the greatest distance possible. The mean velocity during the 30 min test was considered to be the Vt30 (Colantonio and Kiss, 2007; Olbrecht et al., 1985). This test was carried out individually, i.e., each swimmer performed alone in a single lane.

Statistics

The normality and homocedasticity assumptions were checked respectively with the Shapiro-Wilk and the Levene Tests. A repeated-measures analysis of variance with Bonferroni adjustment was used to analyze the differences between the mean values of each velocity

(CV50/100/200, CV100/200/400, CV50to1500, V4 and Vt30). The Spearman correlation coefficient was used to evaluate the associations between each velocity that was considered. The statistical significance was set to $p \leq 0.05$ for all analysis. Data are presented as mean and standard deviations (SD).

Results

In Figure 2 the mean values of the CV50/100/200, CV100/200/400, CV50to1500, V4 and Vt30 are presented. One can note that the highest velocity was obtained using the CV with 50, 100 and 200 m personal best times. On the other hand, the velocity obtained during the 30 min all-out swimming presented the lowest value. When we compare the values for each velocity, it is possible to observe that only the CV including 100, 200 and 400 m was not different from the V4, and the CV including all the swimmer freestyle events was not different from the Vt30.

Mean (\pm standard deviation) error of CV50/100/200, CV100/200/400 and CV50to1500 were 0.04 ± 0.001 , 0.03 ± 0.003 and $0.01 \pm 0.001 \text{ m}\cdot\text{s}^{-1}$, respectively.

In Table 1 the correlations between each velocity are presented. We can observe that there was no relationship between CV50/100/200, CV100/200/400 and CV50to1500. Moreover, CV100/200/400 was not related to V4 and Vt30. On the other hand, both CV50/100/200 and CV50to1500 were positively related to V4.

Table 1. Correlations between each of the velocity that were considered.

	CV50/100/200	CV100/200/400	CV50 to 1500	V4	Vt30
CV50/100/200	----	.43	-.17	.73 *	.47
CV100/200/400		----	.61	.39	.07
CV50to1500			----	.72 *	.44
V4				----	.69 *
Vt30					----

* $p \leq 0.05$.

Discussion

The aims of the present study were to assess critical velocity using the swimmer *curriculum* in front crawl events and to compare critical velocity to the velocity corresponding to a 4 mmol·l⁻¹ of blood lactate concentration and to the velocity of a 30 min test in young swimmers.

The main finding of this work was that the CV using 100, 200 and 400 m was not different from V4 and that the CV including all the swimmer freestyle events was not different from Vt30. Moreover, CV50/100/200 and CV50to1500 presented a positive relationship with V4.

The critical velocity was at first thought to correspond to a sustainable intensity and has been compared to parameters such as the maximal lactate steady state (the highest intensity that can be maintained without any drift in the blood lactate concentration) and the onset of blood lactate accumulation (intensity corresponding to a 4 mmol·l⁻¹ of blood lactate concentration during an incremental test) (Dekerle et al., 2006). However, swimmers can hardly maintain CV for longer than 30-40 min (Dekerle et al., 2006) and CV has been shown to be close to Vt30 (Colantonio and Kiss, 2007; Dekerle et al., 2002; Fernandes and Vilas-Boas, 1999) and higher than maximal lactate steady state and V4 (Dekerle et al., 2005; Denadai et al., 2000; Martin and Whyte, 2001; Rodriguez et al., 2003; Wakayoshi et al., 1992; 1993). All these data must be interpreted with care, since it does not seem possible that swimmers could sustain this intensity indefinitely. However, the studies cited above which argue that CV does not represent a steady state threshold were based on wrong assumptions, omitting the premise of always including a long distance in the CV assessment (Fernandes and Vilas-Boas, 1999; Wright and Smith, 1994). In fact, Fernandes and Vilas-Boas (1999) and Toubekis et al. (2006) reported CV values lower than V4 and Greco et al. (2007) reported that CV was significantly higher than Vt30 in males and females.

The present study showed CV values based on 50, 100 and 200 m higher than V4 and Vt30 and CV values based on 100, 200 and 400 m higher than Vt30 and similar to V4. Moreover, CV based on all the events presented similar values of Vt30 and lower values than V4. Thus, it seems important to note that the value of CV is dependent on the exhaustion times used to plot the relationship (Dekerle et al., 2006; di Prampero et al., 1999; Fernandes et al., 2008; Toubekis et al., 2006), considering the influence of energy cost in swimming. This phenomenon is noted in our study as well. It seems logical that critical velocity would decrease when including more long-distance events. When including the 1500 m the CV would decrease since the aerobic component is very high while at the 50 m this component is very low (Gastin, 2001). Further, Wright and Smith (1994) established the fact that a long swimming distance, of approximately 15 min duration, should be included as one of the distances used to compute CV, in order to avoid overestimation of this parameter. Therefore, the suggestion of Wakayoshi et al. (1993) and Dekerle et al. (2002) to use the distances of

200 and 400 m to assess CV should be treated with caution.

Additionally, according to the specialized literature (Jacobs, 1986; Stegmann et al., 1981; Urhausen et al., 1993), the V4 does not represent the individualized lactate threshold in trained swimmers, since those values are usually lower than 3 mmol·l⁻¹. However, the velocity corresponding to 3.5 mmol·l⁻¹ of blood lactate concentration could better be used in trained swimmers (Heck et al., 1985). Thus, the problem did not seem to be the low values of Vt30 (well related with the CV obtained with all competition distances) but the fact that both V4 and critical velocity assessments not including a long distance could overestimate the anaerobic threshold.

In an attempt to make the determination of CV quick and easy for coaches, the suggestion to base this assessment on only two performances seems pertinent (Wakayoshi et al., 1993; Fernandes and Vilas-Boas, 1999; Dekerle et al., 2002). However, including only two performances to determine CV would decrease its level of reliability, although the use of a long distance would help in correcting for this (Fernandes and Vilas-Boas, 1999; Wright and Smith, 1994). We were able to note that including more distance-time events would decrease the estimation error of critical velocity. Indeed, it was found an error of only 0.73% in the CV50to1500 whereas CV50/100/200 and CV100/200/400 presented an error of 2.60% and 2.00%, respectively. This situation has to be considered when using the distance-time relationship to predict the performance or monitoring effects of periods of training. This point of view reinforces the main concern of the present study. An alternative approach to the assessment of CV based on experimental tests is to use the swimmer *curriculum* to determine CV. Using this methodology one can assess CV based on all the performances that are available for a given swimmer.

It seems that CV50to1500 is a good approach to determine Vt30, which has been shown to be close to CV obtained using experimental tests during training sessions (Dekerle et al., 2002). This tendency was already confirmed using competition times by Fernandes and Vilas-Boas (1999). CV50/100/200 and CV100/200/400 presented significantly higher values than CV50to1500. Therefore, these values must be used carefully when designing training sets (Wright and Smith (1994). Although CV100/200/400 was not different from V4, CV100/200/400 was not related to this velocity.

Furthermore, we observed that there was no relationship between CV50/100/200, CV100/200/400 and CV50to1500. Once again one must take into account that the inclusion of different distance-time events could produce very diverse CV results. The CV was found to vary according to different distances. For instance, the change of 50 to 400 m (CV50/100/200 vs. CV100/200/400) was sufficient to produce different values of critical velocity.

The CV has been shown in swimming to be a good indicator of the capacity of the aerobic energy system (Toussaint et al., 1998). Greco and Denadai (2005) and Toubekis et al. (2005) confirmed this finding in young swimmers. CV is lower than the end velocity of an

incremental test, traditionally associated to maximal aerobic velocity and it is highly related to V4 (Wakayoshi et al., 1992; 1993) and maximal lactate steady state (Dekerle et al., 2005). Altimari et al. (2007) suggested that anaerobic threshold velocity obtained from fixed lactate blood concentration of $3.5 \text{ mmol}\cdot\text{l}^{-1}$, as well as the critical velocity obtained through larger distances seems to be the most reliable indices of prediction of the aerobic performance in the adolescent swimmers. In the present study we found that CV50/100/200 was related to V4, presenting a positive relationship between each parameter ($r = 0.73$). The same relationship occurred between CV50to1500 and V4 ($r = 0.72$), indicating that the swimmers with higher CV50to1500 presented higher V4 values. This assumption could be important in designing training sets in swimming teams, where the individuals are usually divided into training groups of similar level.

However, should personal best times be used to design training sets, some concerns must be emphasized. The first is related to the selection of the events to be analyzed and the second is related to the chosen technique. Freestyle may comprise events from 50 to 1500 m but the other strokes are limited to 50, 100 and 200 m events. It would be interesting therefore to conduct this study assessing CV in relation to different stroke techniques, rather than only in front crawl. The third concern is related to the data available for each swimmer because sometimes swimmers do not compete in all the events. On the other hand, some of the performances must be updated, which should be considered during the assessment of CV. In the present study the mean time gap between events personal records was 5.0 ± 1.2 months. In further investigations, it would be interesting to relate this time gap and critical velocity. However, in this study we analyzed only young swimmers and usually their personal best times correspond to the most recent official times. Thus, future analysis should extend the scope of this study to adult swimmers to test for significant similarities or differences. Moreover, it seems pertinent to compare CV for given distances obtained in competition and training contexts.

Conclusion

We have found that the assessment of CV based upon the swimmer *curriculum* seems to be a good approach to determine aerobic ability in young swimmers. Using personal best times was shown to be an alternative method to circumvent the difficulties of conducting experimental tests during training sessions. It also permitted the obtaining of accurate values with which to design training intensity sets. The assessment of CV based on the entire swimmer events presented the best way to predict the velocity of a 30 min all-out swim, while the CV based on the 100, 200 and 400 m events was shown to be similar to the V4. Therefore, the decision over the selection of events to be included in the estimation of critical velocity must be a main concern in the evaluation of the swimmer.

Acknowledgments

The authors would like to thank the important contribution of the Portuguese Swimming Federation staff for the data collection. This study was supported by FCT (SFRH/BD/40243/2007).

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Key points

- Critical velocity using 100, 200 and 400 m events was not different from the velocity of 4 mmol·l⁻¹ of blood lactate concentration.
- Critical velocity using all the swimmer events was not different from the velocity of a 30 min test.
- The assessment of critical velocity based upon the swimmer *curriculum* seemed to be a good approach to determine the aerobic capacity of a swimmer.
- The decision on the events to be analysed must be a main concern in the evaluation of the swimmer critical velocity.

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