CRITICAL SPEED AND CRITICAL STROKE RATE COULD BE USEFUL PHYSIOLOGICAL AND TECHNICAL CRITERIA FOR COACHES TO MONITOR ENDURANCE PERFORMANCE IN COMPETITIVE SWIMMERS

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The purposes of this study were to determine whether the concepts of critical swimming speed (CSS) and critical stroke rate (CSR) could be reliable and used by coaches in order to control and monitor endurance performance in competitive swimmers. The results of this study conducted with well-trained swimmers showed that CSS could be determined easily from two common distances and more accurately from 200- and 400-m tests after a correction of minus 1.4 %. Moreover, CSS was well correlated with swimming velocity corresponding to 4 mmol.l^{-1} of blood lactate concentration and could avoid using lactate testing. Furthermore, the concept of a critical stroke rate defined as 'the stroke rate value, which can be theoretically maintained continuously indefinitely without exhaustion' and expressed, as the slope of the regression line between the number of stroke cycles and time seemed to be reliable. Coaches, in order to set not only aerobic training loads but also to control swimming technique, could easily use CSS and CSR.

KEY WORDS: swimming, critical speed, critical stroke rate

INTRODUCTION: Currently, coaches employ critical swimming speed (CSS) as a method for determining the training intensity to improve and monitor the aerobic capacity of swimmers. CSS was defined by Wakayoshi et al. (1992) as the theoretical maximal swimming speed that could be maintained without exhaustion for a long period of time. It can be assessed by the slope of the regression line determined between the test distance and the time needed to cover it at maximum intensity. CSS has been shown to be well correlated with the swimming velocity corresponding to the onset of blood lactate accumulation (V_{OBLA}) and the maximal lactate steady state (Wakayoshi et al., 1992a and 1993). Very often and unfortunately, coaches have not enough time to use lactate testing or to assess a large number of performances in a short period during the training program. Thus, some authors such as Maclaren and Coulson (1998) have suggested using 100- and 200-m tests in order to calculate CSS and monitor aerobic training.

Besides, coaches must also take into account the very similar velocity values with different combinations of stroke length (SL) and stroke rate (SR) achieved by each swimmer. These differences are determined by such factors as anthropomorphic variables, muscular strength, physical conditioning, and swimming economy. It has been acknowledged that biomechanical skill in swimming is of far greater importance for metabolic economy than in running and cycling and that elite swimmers adopt very different combinations of stroke parameters compared to their less proficient counterparts. Several studies showed that efficiency during constant work depends on frequency in many cyclic sports as well as in swimming (Swaine and Reilly, 1983; Weiss et al., 1988; Pelayo et al., 1996 and 1998). Thus, the swimmer has to know whether his spontaneously chosen SR corresponds to the minimal energy cost and he needs to be advised by coaches in the different combinations of stroke rate and stroke length to make the most effective choices in order to develop endurance capacity. The relationships between velocity and stroke rate have been illustrated previously as a stroke rate-velocity curves (Craig et al., 1985). Keskinen and Komi (1993) found a strong positive correlation (r = 0.86) between V and SR. Thus, besides the concept of critical velocity, it was hypothesized that a theoretical stroke rate would exist which could be maintained without exhaustion for a long period of time.

Stroke rate, which could be reported from competitive events or maximal tests, could be plotted as a function of race times. The velocity-time relationship ($V = a / t + b$) could be extended to a stroke rate-time relationship as follows: $SR = a/t + b$. The critical stroke rate

(CSR) is the stroke rate at which one swims indefinitely, and thus SR will approach b. Since SR = n / t, integration yields to n = b.t + a, in which 'n' denotes the number of stroke cycle realized. Accordingly, CSR equals b, i.e., the slope of the regression line between the number of stroke cycles and time.

Hence, the purposes of this study were twofold: i) to investigate the accuracy of the different methodologies using swimming performances and used by coaches in order to determine CSS, ii) to evaluate the existence of a critical stroke rate and its reliability.

METHOD:

First Part. Ten well-trained competitive swimmers (8 males and 2 females; aged 18.6 ± 1.9 years) volunteered for this study. Mean height, body mass and arm span were 1.78 ± 0.11 m, 63 ± 9 kg, and 1.83 ± 0.12, respectively. During a 10-day period, the best average velocity (V_{50}, V_{100}, V_{200}, V_{400}, and V_{2000}) was recorded for each swimmer on 50-, 100-, 200-, 400-, and 2000-meter front crawl tests. During each test, stroke rate (SR_{50}, SR_{100}, SR_{200}, SR_{400}, and SR_{2000}) was measured three times across the length of the pool using a Seiko frequency-meter (base 3) and expressed in cycles per minute. All the swimmers also performed a 30-min test and V_{30min} and SR_{30min} were measured. All the combinations of the distance tests (from 50- up to the 2000-m) were used in order to calculate the slope (CSS) of the regression between time and distance. Furthermore, all the distance tests (from 50- up to the 2000-m) were used in order to calculate the slope (CSR) of the regression line between the number of stroke cycles and time. At the end of the 2000-m and 30-min tests, blood was sampled from fingertips into capillary tubes for lactate determination $[La]_s$. Blood samples were analyzed using Dr Lange's photometric method. The swimming velocity correspondent to 4 $mmol.l^{-1}$ of blood lactate concentration (V_4) was determined individually, by inter or extrapolation, based on the regression line computed between the $[La]_s$ values reported in 2000-m and 30 min tests (Fernandez and Vilas-Boas, 1998).

Second Part. Nine well-trained competitive swimmers (6 males and 3 females; aged 16.1 ± 1.1 years) volunteered for this study. Mean height, body mass and arm span were 1.77 ± 0.07 m, 64.1 ± 4.6 kg, and 1.81 ± 0.8, respectively. During a 10-day period, the best average velocity (V_{200} and V_{400}) and stroke rate (SR_{200} and SR_{400}) were recorded for each swimmer on a 200- and 400-meter front crawl tests. CSS and CSR were calculated from the pre-cited methodologies but CSS was decreased of 1.4 % according to the results of the first part of the study. Then, the swimmers had to perform two tests. The first (T_{CSS}) consisted to a 30 min swim at CSS regulated by an aquatic row of lights connected to a speed programmer. Spontaneously stroke rate was measured throughout this test. In a second 30 min swim test (T_{CSR}), the stroke rate set at the critical stoke rate was imposed by means of a beeper fitted in the swim cap. In fact, an acoustic metronome was placed under the swim cap and set at the imposed rate. This method has been previously used by Chollet et al. (1996). Spontaneously velocity was measured each 50-m throughout the test. In T_{CSS} and T_{CSR}, and capillary blood samples for lactate determination were taken at rest and 3 minutes post-exercise during passive recovery and analyzed using Dr Lange's photometric method.

Statistical Analyses. All data are reported as means ± SD. The relationships between time and distance, between the number of stroke cycles and time, and between V_4 and different CSS were examined using simple regression. A non-parametric procedure, the Wilcoxon test was used to test differences between the different CSS calculated values in the first study, between CSR calculated and measured values in the different 30 min tests, and between blood lactate values. A 95% level of confidence was accepted for all comparisons.

RESULTS AND DISCUSSION:

First Part. The velocities measured in the 50-, 100-, 200-, 400-, 2000-m tests are reported in Table 1 and V_{30min} was 1.30 ± 0.05 $m.s^{-1}$.

Table 1 **Velocity Values Reported in the Different Tests and CSS Values Expressed in % of V**

Distance tests	50-m	100-m	200-m	400-m	2000-m
V ($m.s^{-1}$)	1.73 ± 0.09	1.63 ± 0.09	1.50 ± 0.08	1.42 ± 0.09	1.32 ± 0.05
CSS (% of V)	76.5	81.4	87.9	93.1	100.2

$[La]_s$ values measured in the test of 30 min and 2000-m were 3.68 ± 1.58 and 4.17 ± 1.28 $mmol.l^{-1}$, respectively. Hence, V_4 was 1.32 ± 0.06 $m.s^{-1}$. The swimming velocity corresponding to 4 $mmol.l^{-1}$ of blood lactate concentration (V_4) was not significantly different to V_{2000} and V_{30min}, and with the values of CSS calculated from the slope of the regression between 200- and 400-m and between 2000- and the other distances. V_4 was significantly correlated with all values of CSS calculated from two distances except from 50- and 100-m, and 100- and 200-m [(50- and 200-m; r= .63), (50- and 400-m; r= .88), (100- and 400-m; r= .88), (200- and 400-m; r= .90)]. Moreover, all values of CSS calculated from 2000-m and the other distances are also correlated with V_4. Method comparison analysis demonstrated that V_4 is overestimated by 8.3, 4.5, 3.0, and 1.4 % when the combinations of 50- and 200-m, 50- and 400-m, 100- and 400-m, and 200- and 400-m were used to calculate CSS, respectively.

The mean stroke rate values measured in the 50-, 100-, 200-, 400-, 2000-m tests are reported in Table 2. The coefficient of the regression line between the number of stroke cycles and time for all subjects ranged from 0.99 up to 1.0. CSR calculated from 50- up to the 2000-m tests was 35.9 ± 6,1 $cycles.min^{-1}$ and was not different with SR_{2000}.

Table 2 **Mean (±SD) SR Values in each Event and CSR Values Expressed in % of SR**

Distance tests	50-m	100-m	200-m	400-m	2000-m
SR ($cycles.min^{-1}$)	53.8 ± 5.1	48.9 ± 5.1	44.1 ± 4.5	40.7 ± 5.3	36.4 ± 5.9
CSR (% of SR)	66.6	73.3	81.4	88.1	98.5

Second Part. The mean velocity values reported in the 200- and 400-m tests were 1.33 ± 0,10 and 1.42 ± 0.10 $m.s^{-1}$, respectively. CSS calculated from 200- and 400-m and corrected by 1.4 % was 1.19 ± 0,08 $m.s^{-1}$ and corresponded to 85.5 and 91.1 % of V_{200} and V_{400}, respectively. Mean stroke rate values were 35.1 ± 2.7 and 37.9 ± 2.8 $cycles.min^{-1}$ during the 200- and 400-m tests. CSR calculated from these two tests was 32.6 ± 2.7 $cycles.min^{-1}$. The spontaneously chosen stroke rate measured during T_{CSS} was 32.1 ± 2.3 $cycles.min^{-1}$ and was not significantly different with CSR. In T_{CSR}, the spontaneously adopted velocity by the swimmers was 1.19 ± 0.07 and was not significantly different from CSS. $[La]_s$ values measured in T_{CSS} was 4.65 ± 1.28 $mmol.l^{-1}$, and was not significantly different to $[La]_s$ values measured in T_{CSR} (3.73 ± 0.96 $mmol.l^{-1}$).

The results of the first part of this study emphasized that critical swimming speed could be easily determined from the distance-time model. Results from this investigation reported r^2 > 0.990 for all subjects in each combination of distance tests. Although the relation between time and distance is not strictly linear (Hill, 1995), the present results indicate a good linearity and support previous findings (Wakayoshi et al, 1992b; MacLaren and Coulson, 1998). The use of lactate testing to monitor aerobic training has been well established and the blood lactate concentration of 4 $mmol.l^{-1}$ could represent an index of endurance performance and for setting intensities. This study suggests that CSS could be associated with lactate variables yet does not require invasive procedures nor expansive equipment. However, the

present results are not in accordance with previous data of MacLaren and Coulson (1998) which have shown that CSS can be predict from 100- and 200-m performances. Indeed, the present findings strongly suggest that CSS should be calculated from performances ranging from 200- to 2000-m, i.e., from exhaustion times ranging from 2 to 30 min. Nevertheless, considering the different significant relations, CSS could be determined easily and usefully by coaches from two common distances and more accurately from 200- and 400-m tests after a correction of minus 1.4 %.
Critical stroke rate, defined as 'the stroke rate value, which can be theoretically maintained continuously without exhaustion', is expressed as the slope of the regression line between the number of stroke cycles and time. Results from the first part of the study clearly showed a good linearity according to the $r^2 > 0.99$ for all subjects. Moreover, velocity and stroke rate values reported in the 2000-m test were very closed and well correlated ($r > 0.94$) with CSS and CSR, respectively. Results of the second part of the study confirmed that CSR could be also a good index in order to monitor aerobic training load according to the similar blood lactate concentrations when the subjects swam with a speed set at CSS or a stroke rate set at CSR. In fact, set CSS or CSR lead the swimmer to swim at the same speed and the same stroke rate, and vice versa. These results showed that the stroke length was maintained at a constant level spontaneously throughout T_{CSS} and T_{CSR}. CSS and CSR could be useful criteria in order to control technical and intensity training loads at the same time. Hence, the improvements could be, either to maintain CSS with a lower SR or to maintain CSR with a higher swimming speed. The ability of the swimmer to improve his technique, i.e. his stroke length, particularly in aerobic training load will probably determine success. Indeed, Costill et al, (1985) clearly demonstrated the importance of stroke technique on the energy cost of swimming and its subsequent influence on aerobic performance.

CONCLUSION: Therefore, CSS and CSR calculated from competitive events such as the 200- and 400-m could be used as relevant criteria to evaluate physiological and technical status and to monitor and give advice concerning training. Indeed, coaches have to currently set training loads by defining both intensity and technical parameters.

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