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Assessment of Fatigue Thresholds in 50-m All-Out Swimming

Susana M. Soares, Ricardo J. Fernandes, J. Leandro Machado, José A. Maia, Daniel J. Daly, and João P. Vilas-Boas

Context: It is essential to determine swimmers' anaerobic potential and better plan training, understanding physiological effects of the fatigue. ***Purpose:*** To study changes in the characteristics of the intracyclic velocity variation during an all-out 50-m swim and to observe differences in speed and stroking parameters between these changes. ***Methods:*** 28 competitive swimmers performed a 50-m front-crawl all-out test while attached to a speedometer. The velocity–time ($v[t]$) curve off all stroke cycles was analyzed per individual using a routine that included a wavelet procedure, allowing the determination of the fatigue thresholds that divide effort in time intervals. ***Results:*** One or 2 fatigue thresholds were observed at individual level on the $v(t)$ curve. In males, when 1 fatigue threshold was identified, the mean velocity and the stroke index dropped ($P < .05$) in the second time interval (1.7 ± 0.0 vs 1.6 ± 0.0 m/s and 3.0 ± 0.2 vs 2.8 ± 0.3 m/s, respectively). When 2 fatigue thresholds were identified, the mean velocity of the first time interval was higher than that of the third time interval ($P < .05$), for both male (1.7 ± 0.0 vs 1.6 ± 0.1 m/s) and female (1.5 ± 0.1 vs 1.3 ± 0.1 m/s) swimmers. ***Conclusion:*** One or 2 fatigue thresholds were found in the intracyclic velocity-variation patterns. Concurrently, changes in velocity and stroke parameters were also observed between time intervals. This information could allow coaches to obtain new insights into delaying the degenerative effects of fatigue and maintain stable stroke-cycle characteristics over a 50-m event.

Keywords: aquatic exercise, metabolism, speed decline, anaerobic transition zone, stroke parameters

The importance of the ATP-PC and glycolytic energy pathways during competitive swimming is generally accepted. In fact, as the majority of swimming events last less than 2 minutes, success largely depends on anaerobic energy production.[1] With this in mind, a number of tests have been developed to evaluate swimmers' anaerobic potential, but none have fully satisfied either researchers or coaches, as they were mainly indirect. The most direct measurements—muscle biopsy[2] and magnetic nuclear resonance[3]—are expensive, invasive, and/or limited in providing information on total anaerobic energy production in exercises that involve more than a single muscle or muscle group.[2] The results obtained with indirect tests commonly represent a mechanical expression of jumping,[4] running,[5] or cycling effort,[6] but information on physiological changes, fatigue, and changes in stroke pattern is not provided. Coaches still cannot obtain specific information to help determine training and competitive strategy.

The gold standard for anaerobic potential evaluation is the Wingate Anaerobic Test (WAT).[7] The WAT has several limitations and is very unspecific for swimming even when performed using arm-cranking ergometers,[8] since rotational arm-cranking movement is quite different from swimming patterns.[9] In-water swimming tests attempting to mimic the WAT (30-s all-out tests) were developed using tethered swimming (in both adolescent[10] and international-level swimmers[11]), but once more they were not able to provide information on fatigue onset and consequent technical changes.

Although all energy systems are active at the start of an effort, the domination of the ATP-PC in all-out short anaerobic efforts is well accepted. It is not clear when ATP-PC domination ends and glycolysis starts. Various authors indicate different limits, particularly 1 to 5 seconds,[12] 7 to 10 seconds,[13] 5 to 15 seconds,[14–16] and 10 to 20 seconds.[17] When this bioenergetic approach is applied to training, it is assumed that from 8 to 12 seconds a gradual rise in the contribution of glycolysis occurs,[12] indicating the depletion of the ATP and PC affecting swimming technique. Some evidences exists that stroke frequency, stroke length, and stroke index change concurrently with a drop in swimming velocity,[18] but it is not clear when exactly these changes occur. This knowledge is fundamental to allow coaches to design more efficient training and competitive strategies.

With this in mind, Soares et al[19] used wavelets to analyze the intra-stroke-cycle force-to-time ($F[t]$) curve in a 30-second tethered swimming test, concluding that changes occurred in the frequency content of the $F(t)$ curve might be associated with anaerobic fatigue thresholds. However, tethered swimming is different from free swimming, and some bias may exist when using this testing condition.

Free-swimming velocity patterns have recently been analyzed using nonchronometric approaches during in-water tests similar to the WAT. Smolka and Ochmann[20] developed an anaerobic efficiency test (using 100-m freestyle swimming at maximal intensity), purportedly based on the classic WAT. Nevertheless, the test had some limitations, as it was conducted in a 25-m swimming pool involving turns, disturbing the analysis of the time progression of speed; it was much longer than the WAT; and the swimming speed was collected by 5 cameras for manual video digitizing (highly time consuming).

Potentially, the analysis of fatigue via the decrease in velocity (or power) over time during an all-out exercise could provide important information concerning not only the anaerobic potential of a swimmer but also the dynamics of the ATP-PC cycle to lactic

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Soares and Maia are with the Faculty of Sport, Center for Research, Education, Innovation and Intervention in Sport (CIFI2D), and Fernandes, Machado, and Vilas-Boas, the Faculty of Sport, Center for Research, Education, Innovation and Intervention in Sport (CIFI2D), Porto Biomechanics Laboratory (LABIOMEP), University of Porto, Porto, Portugal. Daly is with the Dept of Kinesiology, KU Leuven, Leuven, Belgium. Address author correspondence to Susana Soares at susana@fade.up.pt.

transition. Furthermore, changes in swimming technique could be examined simultaneously, to observe how fatigue influences technical competence and performance. Using modern technology such as instantaneous speed meters together with data-analysis procedures (such as frequency analyses—wavelets), it might now be possible to obtain more information on a swimmer's anaerobic potential dynamics to better control training and competition. The purpose of the current study was to explore the potential of a swim-specific velocity test for anaerobic potential assessment to determine if changes over time in the intracyclic velocity variation can be considered fatigue thresholds and determine if there are differences in speed and stroking parameters in the time intervals between fatigue thresholds, as well as in the mean stroke intracycle velocity-variation profile.

Methods

Subjects

Twenty-eight competitive swimmers, 15 male (18.8 ± 2.4 y, 69.9 ± 7.0 kg, and 1.8 ± 7.5 m) and 13 female (16.5 ± 2.4 y, 58.5 ± 7.2 kg, and 1.7 ± 3.3 m), with training experience of 9.5 ± 2.7 and 7.9 ± 3.1 years (respectively), took part in this study. All swimmers were volunteers, and an informed-consent form was signed by parents or swimmers before participation. No potential conflicts of interest exist. All the procedures were approved by the local ethics committee in accordance with the Helsinki Declaration.

Experimental Protocol

An all-out 50-m front-crawl test was performed in an indoor heated (28°C) long-course swimming pool. To determine the instantaneous velocity–time ($v[t]$) curves, swimmers were connected to an electromechanical speedometer measuring the rotational velocity of a pulley over which a fine nylon line passed.[21] The line was attached to the swimmer at a central point of the lumbar region, and the pulley was coupled to an incremental rotation sensor generating 500 impulses per rotation (registered using in-house-developed acquisition software with LabVIEW 7.1). In addition, the software also calculates the maximal, mean ± SD, and minimum velocity; the coefficient of variation (CV = [SD/mean] × 100); the distance covered; and the total swimming time for each participant. The further processing of the individual instantaneous $v(t)$ curves was performed using a MATLAB (version 7.0) routine (described in detail elsewhere),[22] including a continuous wavelet analysis (frequency content) of the signal, distinguishing separated time intervals with distinct frequency properties.[22] The frequency of the main lobe of each time interval was used to perform comparisons between temporal regions. Points separating regions (time intervals) of different spectral characteristics are referred to as fatigue thresholds. Finally, the mean $v(t)$ profiles for all strokes in each of the regions were obtained for each individual swimmer.

In addition, all tests were video recorded from above water using a JVC GR-SX1EG SVHSC panning camera placed 2 m from the lateral wall of the pool and 3 m above water level at the 25-m point. From video, the time of hand entry and exit of all arm cycles was obtained. These data were then synchronized to the velocity traces using MATLAB. To validate the anaerobic character of the test, the maximal lactate concentration ($[La^-]$) was determined. At the end of each test, a 5-μL blood sample was taken from the ear lobe and analyzed (Lactate Pro, Arkray, Inc) at 1 and 3 minutes of recovery and each 2 minutes thereafter (until the maximal value was found). The fatigue index for velocity breakdown was calculated using the WAT formula: $FI = ([v_{max} - v_{min}] \times 100)/v_{max}$.[23]

Statistical Analyses

Descriptive statistics were reported as mean ± SD, and normality was analyzed using the Shapiro-Wilk test. Furthermore, dependent and independent *t* tests and analysis of variance (ANOVA) were used (with a Bonferroni post hoc procedure). Effect sizes are presented as percentage of total variance explained (η^2). The significance level was set at 5%. SPSS 19.0 was used in all analysis.

Results

Table 1 shows the velocity parameters for the 50-m all-out front-crawl test along with the maximal posttest $[La^-]$.

Female swimmers had a higher number of curves with 2 fatigue thresholds (n = 10; 77%), and male swimmers had balanced percentages of 1- and 2-threshold curves (n = 7, 47%, vs n = 8, 53%, respectively).

Frequency contents of the main lobe for each time interval between fatigue thresholds were statistically compared within gender and time interval (Table 2). For both male and female swimmers, 1-threshold curves showed a higher signal frequency in the first time interval than in the second ($P = .001$, $\eta^2 = .940$, and $P = .042$, $\eta^2 = 0.918$, respectively).

In 2-threshold curves, male swimmers had a sequential decline from the first to the third time interval ($P = .001$, $\eta^2 = .735$). In female swimmers, a decline was evident when moving from the first to the third time interval ($P = .015$, $\eta^2 = .499$) and from the second to the third interval ($P = .002$, $\eta^2 = .668$) but not from the first to the second interval ($P > .05$).

The time instant coincident to the occurrence of the fatigue thresholds and respective representation in percentage of the total 50-m time are presented in Table 3 for both 1- and 2-threshold curves.

No differences ($P > .05$) were observed in time of threshold occurrence between male and female swimmers. Furthermore, when

Table 1 Maximal, Mean, and Minimum Velocity, Fatigue Index, and Blood Lactate Concentration During a 50-m All-Out Front-Crawl Test (n = 28), Mean ± SD

	Velocity (m/s)				
	Maximal	Mean	Minimum	Fatigue index (%)	Blood lactate concentration (mmol/L)
Males (n = 15)	1.7 ± 0.1*	1.7 ± 0.1*	1.6 ± 0.1*	10.5 ± 4.6	11.3 ± 2.0*
Females (n = 13)	1.5 ± 0.1	1.4 ± 0.1	1.3 ± 0.1	9.7 ± 5.1	7.3 ± 1.6

*Higher than females, $P < .05$.

Table 2 Frequency Content of the Main Lobe for Each Time Interval Based on the Position and Number of Frequency Thresholds, Mean ± SD

	Male Swimmers' Interval			Female Swimmers' Interval		
Thresholds	1st	2nd	3rd	1st	2nd	3rd
1[a]	5.0 ± 0.5[b]	2.5 ± 0.7	—	4.8 ± 0.8[b]	2.2 ± 0.9	—
2	4.6 ± 1.6[b,c]	2.9 ± 0.8[c]	1.9 ± 0.3	4.2 ± 1.7[c]	3.3 ± 0.7[c]	2.2 ± 0.8

[a] One fatigue threshold define just 2 time intervals, 1 at left and 1 at the right of the threshold. [b] Different from 2nd interval. [c] Different from 3rd interval.

Table 3 Time Corresponding to Occurrence of Male and Female Swimmers' Fatigue Thresholds, Mean ± SD, and Time Expressed in Percentage (%) of the Total Swim Time

		2 Thresholds	
	1 threshold	1st	2nd
Time (s), male	11.6 ± 1.3[a,b]	8.5 ± 1.7[b]	15.4 ± 2.4
Total time (%), male	40.0 ± 4.5	30.2 ± 5.9	54.7 ± 9.1
Time (s), female	13.3 ± 2.1[a]	9.3 ± 1.4[b]	16.9 ± 2.8
Total time %, female	42.9 ± 6.7	28.5 ± 5.2	51.6 ± 9.4

[a] Different from 1st threshold of 2 threshold curves. [b] Different from 2nd threshold of 2 threshold curves.

considering both curve types, the threshold of the 1-threshold curves occurs later than the first thresholds of the 2-threshold curves, both in male ($P = .002$, $\eta^2 = .736$) and in female swimmers ($P = .002$, $\eta^2 = .768$). That same threshold occurs sooner than the second threshold of the 2-threshold curves, but only for the male swimmers ($P = .002$, $\eta^2 = .764$). When considering 2-threshold curves only, male ($P = .001$, $\eta^2 = .925$) and female swimmers ($P = .001$, $\eta^2 = .944$) reach the second threshold later than the first.

The mean intracyclic velocity pattern for the stroke cycles performed before and after each fatigue threshold is shown in Figure 1 and in a quantitative way in Table 4. Changes in the draw of the velocity pattern of the mean stroke cycle are observed after each threshold (represented by dotted lines).

Due to technical limitations (failure of the video cameras) occurring during image collection, identification of the different stroke cycles that compose the total $v(t)$ curve was not possible for all swimmers. Figures and tables for the intracyclic velocity variation of female swimmers with $v(t)$ curves for 1 threshold could not be made.

Discussion

This study explored the possibility of a swim-specific all-out test to explain the dynamic of the anaerobic potential. The nature of the anaerobic effort was shown by the maximum blood lactate value attained during effort recovery. Using wavelet analysis, changes in the frequency content of the intracyclic velocity signal were observed and fatigue thresholds were determined. One or 2 thresholds were observed in different swimmers, probably indicating more abrupt or progressive transitions between exertion capabilities, something understandable if we consider that literature reveals diverse duration times of the ATP-PC and respective start of glycolysis. Furthermore, differences existed in velocity and stroking parameters in the time intervals between thresholds, but unexpectedly not in the mean stroke intracycle velocity-variation profile, meaning that the swimmers were able to deal with stroke frequency and stroke length to maintain velocity. Looking at the mean curves presented in Figure 1, a reduction of the intracyclic velocity-variation profile was expected, but individual changes of the CV values in different and contradictory directions might have influenced this outcome. Further research should be conducted to investigate the velocity variations with the fatigue.

The use of a cable speedometer in the current study produced a continuous $v(t)$ curve during a 50-m maximal test, from which the frequency content could be analyzed. First, an instantaneous $v(t)$ curve was found, evidencing a first drop after the performer achieved maximal power. Fatigue was evident when a swimmer was no longer able to maintain the same power. A similar pattern was expected in the $v(t)$ curve produced in the 50-m all-out front-crawl swimming test. The first observation on the frequency content of the instantaneous $v(t)$ curve of each swimmer was that it is possible to determine not only 1 but, in some cases, 2 fatigue thresholds, a quite new and important result for training purposes. In addition, unexplained sex differences were observed, revealing that some distinct training strategies might be needed. Second, despite the fact that the mathematical procedure seems accurate, it is important to demonstrate that the thresholds could really isolate time intervals that were different in their characteristics, allowing for a specific intervention for both training and 50-m race strategy. Data taken from time intervals defined by the thresholds were the frequency content of the curve that remained at the left and at the right of the threshold and the time, velocity, and stroke parameters observed for these intervals. The frequency content differences were always significant between the time intervals of the 1-threshold curves, both for male and for female swimmers, validating the existence of the observed thresholds for those curves. Nevertheless, differences were not as consistent for the 2-threshold curves. For male swimmers the frequency content of the 3 time intervals was different. For females, the frequency content of the first time interval was not different from that of the second but was from that of the third. These results point out that possibly the differences in frequency content alone are not enough to confirm the existence of the fatigue thresholds.

The analyses of the differences in time, velocity, and stroke parameters are also needed to provide additional information on the fatigue thresholds. The time and velocity parameters always changed after the fatigue threshold when 1 threshold was found. Stroke parameters also changed, with the exception of stroke length, which remained stable during the entire 50-m all-out swim. In the 2-threshold curves, results were the same for male and female

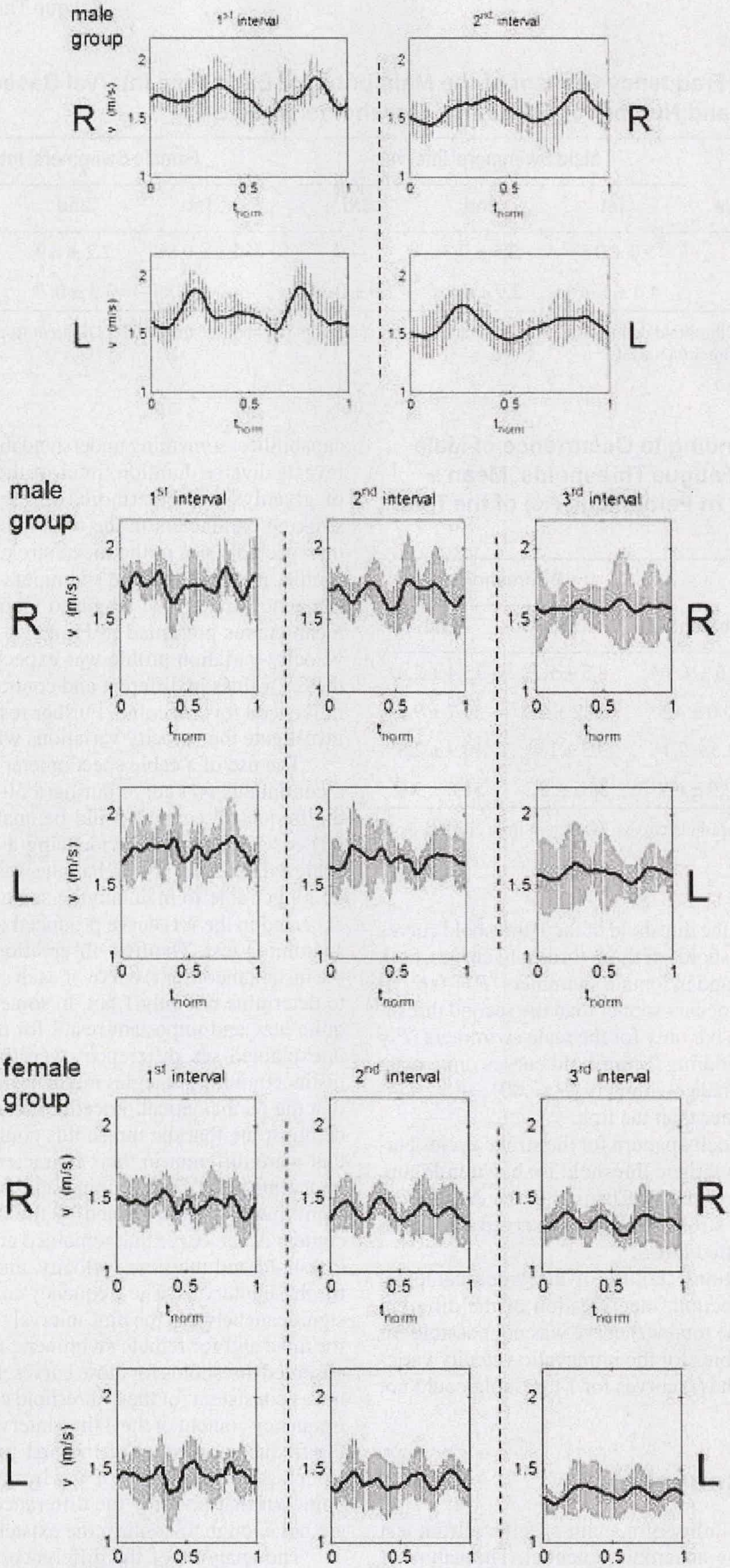

Figure 1 — Intracyclic velocity variation for mean right (R) and left (L) stroke cycles, before and after the fatigue thresholds (represented by the dotted line). Plots for males with velocity–time curves where 1 fatigue threshold was identified (top panel), and plots for males (middle panel) and females (bottom panel) with velocity–time curves where 2 fatigue thresholds were identified. Vertical lines over intracyclic velocity represent the SD calculated point by point. The curves are normalized to percentage arm-cycle time and start at hand entry.

Table 4 Total Time Analyzed and Respective Representation in Percentage of the Total 50-m Time, Stroke Length, Stroke Frequency, Stroke Index, and Mean Velocity per Each Time Interval and the Coefficient of Variation Defined in the 1- and 2-Fatigue-Threshold Velocity–Time Curves, Mean ± SD

		Interval		
		1st	2nd	3th
Total time analyzed (s)	1 threshold male[a]	7.4 ± 1.6[c]	15.2 ± 2.2	—
	2 thresholds male	4.0 ± 2.3[d]	5.4 ± 2.5[d]	11.3 ± 3.4
	2 thresholds female	4.8 ± 1.6[d]	6.3 ± 1.9[d]	11.2 ± 3.0
Total time analyzed (% of 50-m time)	1 threshold male[a]	25.2 ± 5.7	51.6 ± 6.7	—
	2 thresholds male	13.9 ± 7.7	19.0 ± 8.6	39.3 ± 11.8
	2 thresholds female	14.7 ± 5.2	19.3 ± 5.89	34.0 ± 8.9
Stroke length (m)	1 threshold male[a]	1.8 ± 0.1	1.8 ± 0.2	—
	2 thresholds male	1.8 ± 0.1[b]	1.8 ± 0.2	1.8 ± 0.2
	2 thresholds female	1.7 ± 0.1	1.7 ± 0.1	1.7 ± 0.1
Stroke frequency (cycles/s)	1 threshold male[a]	1.0 ± 0.1[c]	0.9 ± 0.	—
	2 thresholds male	1.0 ± 0.1[b]	1.0 ± 0.1[b]	0.9 ± 0.1[b]
	2 thresholds female	0.9 ± 0.1	0.9 ± 0.1	0.8 ± 0.1
Stroke index (m^2/s)	1 threshold male[a]	3.0 ± 0.2[a]	2.8 ± 0.3	—
	2 thresholds male	3.1 ± 0.3[b]	3.0 ± 0.4[b]	2.9 ± 0.4[b]
	2 thresholds female	2.4 ± 0.2	2.3 ± 0.2	2.2 ± 0.2
Mean velocity (m/s)	1 threshold male[a]	1.7 ± 0.0[c]	1.6 ± 0.0	—
	2 thresholds male	1.7 ± 0.0[b,d]	1.7 ± 0.1[b]	1.6 ± 0.1[b]
	2 thresholds female	1.5 ± 0.1[d]	1.4 ± 0.1	1.3 ± 0.1
Coefficient of variation (%)	1 threshold male[a]	15.3 ± 2.5	15.5 ± 4.3	—
	2 thresholds male	13.0 ± 1.7	13.5 ± 2.1	14.2 ± 1.2[b]
	2 thresholds female	13.5 ± 1.7	13.2 ± 1.5	12.4 ± 1.2

Note: Due to technical problems (failure of the video cameras) during image collection, the identification of the different stroke cycles that compose the total velocity–time curve was not possible for all swimmers. As a result there are no figures and tables presented for the intracyclic velocity variation of female swimmers with velocity–time curves for 1 threshold.

[a] 1-fatigue threshold defines just 2 time intervals, 1 at left and 1 at the right of the threshold.

[b] Different ($P < .05$) from females.

[c] Different ($P < .05$) from 2nd interval.

[d] Different ($P < .05$) from 3rd interval.

swimmers. Neither time, velocity, nor stroke parameters were significantly different after the first fatigue threshold's occurrence. Differences were observed in the transition from the first to the third and from the second to the third time interval in time. Moreover, the mean *v* clearly dropped in the third interval compared with the first. Those results suggest that after the fatigue of the first energy-supplying system (ATP-PC), swimmers have 2 possible strategies to cope: a brisk drop (1 threshold) in mean velocity, revealing a possible change to a predominant involvement of the glycolytic system, or a more progressive transition to the glycolytic system, with the 2 thresholds defining a transition zone. It is also possible to hypothesize that the transition zone could be a strategy of swimmers with lower glycolytic power, who might try to extend the participation of the ATP-PC system, mixing it more and sooner with glycolysis under pronounced power regimens. Thus, the transition zone could be a zone with a higher mix of anaerobic participation. In this zone there are no differences in the kinematic parameters. This hypothesis needs further investigation and, if confirmed, may become a powerful tool for coaches in the future.

The degenerative effects of fatigue on performance during all-out short efforts have been studied by several authors[24] who observed decreases in time, velocity, and stroke parameters, some corresponding with those of the current study. Changes in velocity occurring in parallel with alterations in stroke parameters have been related to changes in coordination in swimming technique.[25] Is also clear that fatigue induces degeneration in arm-stroke coordination, requiring a conscientious intervention for technique optimization under severe fatigue conditions. Seifert et al[25] used the index-of-coordination concept,[26] and others from the group found that the index did not change significantly during the long 400-m front-crawl event.[27] Other authors observed a drop in velocity and stroke parameters such as stroke frequency after the first 50 m of a 200-m swim.[28] In the current study, even before looking at the quantitative data, visual inspection of the curves (Figure 2) shows that the mean stroke-cycle pattern clearly changes after the fatigue threshold. At the beginning of the 30-second maximal test, the swimmer demonstrated a complex movement of the propulsive and resistive segments, leading to several acceleration changes, resulting in more obvious peaks in the *v*(*t*) profile per stroke and in a higher mean velocity. By the end of the test, when fatigue had set in, the propulsive movements and resistive actions were more stable and smoother, resulting in fewer acceleration peaks and lower values for mean velocity. This seems to indicate that the fatigue thresholds were clearly identified and, therefore, have a mechanical basis resulting in a power-input impairment.

The appearance of fatigue thresholds should be discussed in relation to the energy-delivery systems. Some authors claim that the ATP-PC cycle can deliver energy from 1 to 20 seconds during all-out exercise[17] and that afterward glycolysis ensures that energy is maintained, somewhat suggesting a border between those 2 anaerobic energy systems. As reviewed by McMahon et al,[29] the precise mechanism responsible for fatigue during brief high-intensity exercise remains controversial, although evidence indicates that within 10 seconds of exercise a reduction in phosphocreatine occurs. In the same 10 seconds, as observed in a study using 31P-NMR, free hydrogen ions also decline.[30] As velocity is expected to decrease, it would be logical to find a fatigue threshold in the boundary between the ATP-PC cycle and lactic energy systems at around 10 seconds. Examining the results of the current study, it can be seen that the unique or the first threshold appears early in time (between 9 and 12 s). This result well matches the time duration for ATP-PC-cycle function during an all-out effort, particularly in well-trained athletes.[17] Moreover, Smolka and Ochmann[20] found a similar time for the swimmers to attain (8.48 s) and maintain (3.93 s) maximal velocity during the first 25 m of 100-m front-crawl swimming. The second threshold that occurred in some *v*(*t*) curves does not have such an intuitive explanation. Its occurrence can express a mixed transition period from ATP-PC cycle to glycolytic dominance, as mentioned before, probably explaining previously observed changes in coordination.[25] Another possible explanation for the threshold's occurrence could be the learning effect, as in a short-course swimming pool, 9 to 12 seconds is more or less the time needed to reach the turn in a 50-m all-out front-crawl bout. Thus, swimmers could just be used to decelerating at approximately this time, when the displacement is produced by simply pushing off the wall with the legs. None of these explanations could be proven with the results of the current work, indicating that further research needs to be carried out in the field of anaerobic swimming performance.

In the current study, relevant information on the anaerobic potential of swimmers was obtained using a 50-m all-out front-crawl swimming test with continuous assessment of the *v*(*t*) curve. It is possible to determine fatigue thresholds on the *v*(*t*) curves using a mathematical procedure that relies on continuous wavelet transformation and to observe concomitant changes in some velocity and stroke parameters between the time intervals defined by fatigue thresholds. These findings open the door to further possibilities to better plan anaerobic training and to better define 50-m race strategy.

Practical Applications and Conclusions

The current study showed the existence of 1 or 2 fatigue thresholds in a maximal 30-second front-crawl effort and some of the degenerative effects on quantitative parameters that sequentially occur. This is the first time that this phenomenon has been observed, and further investigation is needed for the thresholds to be physiologically confirmed. Moreover, the sensibility of the thresholds to the changes induced by training should be tested. For instance, is important to determine if the fatigue thresholds move to the right or to the left in a graphic representation as happens to the known anaerobic threshold, which separates anaerobic and aerobic training zones. Information on these fatigue thresholds would allow coaches to work with swimmers to maintain swimming technique after fatigue, maintaining stroke length and stroke frequency and not losing velocity, a great improvement in anaerobic training quality. The major limitations currently in the field are that the speedometer is not always at the

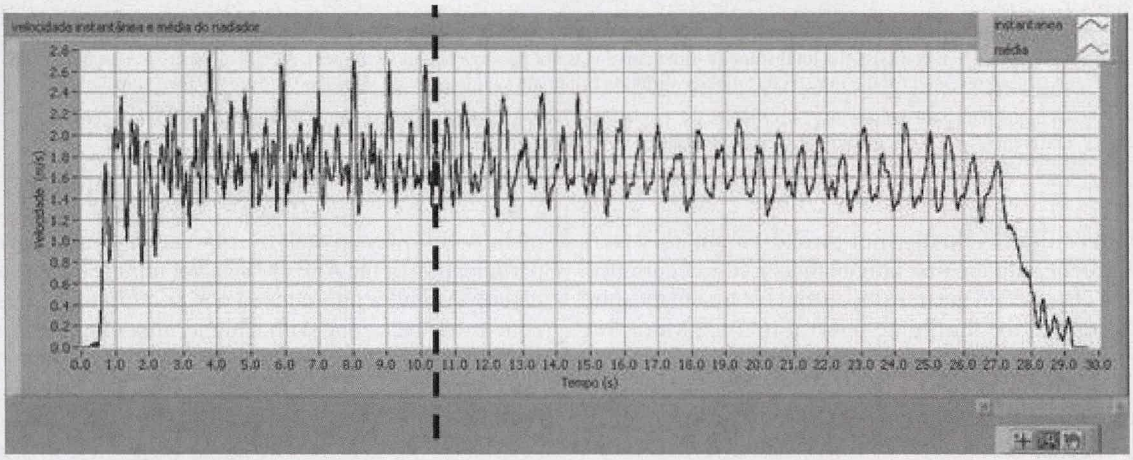

Figure 2 — Individual intracyclic velocity curve obtained by a speedometer. Velocity is in the vertical and time is in the horizontal axis. Figure shows how even before looking at the quantitative data, visual inspection of curve show that the mean stroke-cycle pattern clearly changes after the fatigue threshold (somewhere around the dotted line).

trainer's disposal and the method of analysis (namely the MATLAB routine) is not generally available. Nevertheless, the results are encouraging and further investigation is indicated to optimize and eventually commercialize the method.

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