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TIME LIMIT AT THE MINIMUM VELOCITY OF $\dot{V}O_{2MAX}$ AND INTRA-CYCLIC VARIATION OF THE VELOCITY OF THE CENTRE OF MASS

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The purpose of this study was to analyse the relationship between time limit at the minimum velocity that elicits maximal oxygen consumption (TLim-v$\dot{V}O_{2max}$) and intra-cyclic variations of the velocity of the centre of mass (dv) in the four competitive swimming techniques. Twelve elite male swimmers

swam their own best technique until exhaustion at their previously determined $v\dot{V}O_{2max}$ to assess TLim-$v\dot{V}O_{2max}$. The test was videotaped in the sagittal plan and the APAS software was used to evaluate the horizontal velocity of the centre of mass (Vcm) and its intra-cyclic variation (dv) per swimming technique. Results pointed out that the strokes that presented higher intra-cyclic variations also presented larger values of TLim. Intra-cyclic speed fluctuations (dv) decreased during the TLim test in the four strokes studied, probably due to fatigue.
Key words: VO_2, intra-cyclic velocity variations, time limit, centre of mass.

INTRODUCTION

Time to exhaustion at minimum intensities corresponding to maximal oxygen uptake ($v\dot{V}O_2$máx) is a relatively new topic of interest in swimming training and performance diagnosis (2). It is commonly new as Time Limit at $v\dot{V}O_2$máx (Tlim-$v\dot{V}O_2$máx).

Previous studies of Time Limit in swimming were mainly conducted in swimming flume (3, 5, 6). However, the swimming flume can impose mechanical constrains that may compromise generalisation of results to free swimming conditions. So, a new protocol to assess Time Limit to the minimum speed corresponding to $\dot{V}O_2$máx (Tlim-$v\dot{V}O_2$máx) in normal swimming-pools was recently proposed (7).

Despite Tlim-$v\dot{V}O_2$máx in swimming remains a recent research topic, different influencing factors were already checked (3, 5, 6, 7) in literature. Among these, energy cost (8, 9) and stroke parameters (12) were the first biomechanical related parameters already exploited. Meanwhile, intra-cyclic fluctuations of the swimmer's velocity are among the most relevant performance determining biomechanical factors (1,11,15). Nevertheless, this parameter was never related to Tlim-$v\dot{V}O_2$máx in the literature at our disposal. The aim of the present study was to explore the relationship between TLim-vVO_2máx and intra-cyclic variations of the centre of mass velocity (dv) in the four competitive swimming techniques.

METHODS

Subjects

Twelve elite male swimmers (19.8 ± 3.5 y, 70.1 ± 8.0 kg and 178.3 ± 6.5 cm) were volunteered to serve as subjects. All the swimmers were informed about the characteristics and the purposes of the study.

Test protocol

Tests were conducted in a 25m indoor swimming pool. First, all subjects performed an intermittent incremental protocol for freestyle $v\dot{V}O_{2max}$ assessment. The test used increments of 0.05 m/s each 200m stage, with 30s intervals until exhaustion. $\dot{V}O_2$ was directly measured by a portable gas analyser (K4 b^2 Breath by breath Pulmonary Gas Exchange System – COSMED, Italy) connected to the swimmers by a specific respiratory snorkel for swimming (10, 14). Expired air was continuously measured during the entire test and averaged every 5s. $v\dot{V}O_{2max}$ was considered to be the swimming velocity corresponding to the first stage that elicits $\dot{V}O_{2max}$.

Forty-eight hours late, the subjects swam their own best technique until exhaustion, at their previously determined $v\dot{V}O_{2max}$ to assess TLim-$v\dot{V}O_{2max}$. This protocol considered in three different phases, all paced through a visual light pacer (TAR.1.1, GBK – electronics, Aveiro, Portugal) used to control swimming velocity: (i) a 10 minutes warm-up at an intensity corresponding to 60% $v\dot{V}O_{2max}$, followed by a short rest period (20s) for blood collection; (ii) a 50 m distance performed at progressive velocity, allowing the swimmers to reach their individual $v\dot{V}O_{2max}$, and (iii) the maintenance of that swimming $v\dot{V}O_{2max}$ until exhaustion. TLim was considered to be the total swimming duration at $v\dot{V}O_{2max}$ (7).

The test was videotaped in a sagittal plan, with two cameras (JVC SVHS), that provided, after mixing and editing, a dual-media image of the swimmer (17). The APAS software (Ariel Dynamics Inc, USA) was used to evaluate the horizontal velocity of the centre of mass (Vcm) and its intra-cyclic variation (dv) per swimming technique. A complete cycle of all techniques was analyzed, in the first and last laps of the TLim test, as well as in all the intermediate 100m laps.

Statistical analysis

Means and standard deviations of all variables were calculated. The variation coefficient (VC) of the intra-cyclic time distribution of instantaneous horizontal swimming velocity of the centre of mass was also calculated within a stroke cycle. Linear regressions were computed between variables, as well, its coefficients of determination and correlation. The level of statistical significance was set at $p \leq 0.05$.

RESULTS AND DISCUSSION

Figure 1 presents the regression line computed between the intra-cyclic fluctuations of the velocity of the centre of mass and the time duration of the TLim test, irrespectively of the swimming technique used.

Through the observation of the regression line of the Figure 1 it is recognizable that the swimmers with higher dv values perform longer at $v\dot{V}O_{2max}$. However, previous results available in literature support the hypothesis that dv should be taken as an indicator of energy cost of locomotion, inversely related to swimming economy and to the maximal velocity attainable by a given swimming technique (4, 13, 16).

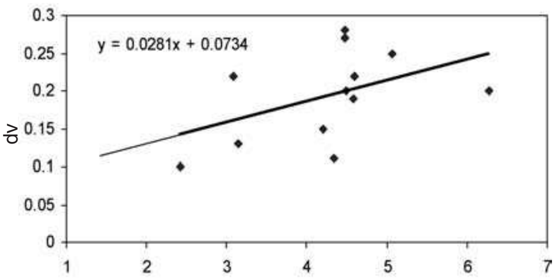

Figure 1. Relationship between TLim and dv for pooled data (r = 0.528, p = 0.078).

The apparent incongruence of the late finding with literature lead us to admit the hypothesis of a swimming technique specific effect on the relationship searched, suggesting the need of a stroke by stroke analysis. The results of such approach are presented in Figure 2. The Table 1 summarises the values of the correlation coefficients computed between TLim and dv.

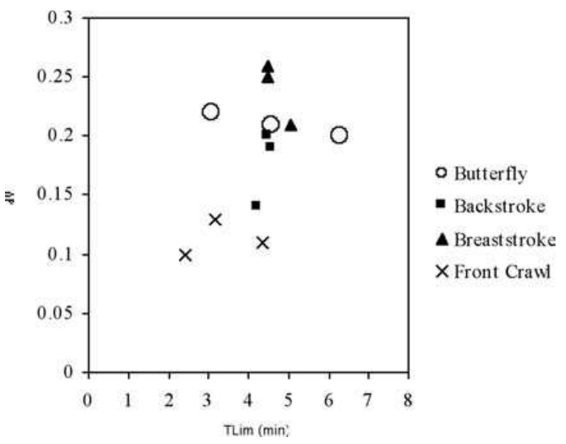

Figure 2. Relationship between TLim and dv for each swimming technique.

Table 1. Coeficients of correlation between TLim and dv.

Stroke	r	p
Buterfly	-0.296	0.809
Backstroke	0.911	0.271
Breaststroke	- 0.945	0.212
ront Crawl	0.195	0.875

No statistical significant correlations were obtained between TLim-v$\dot{V}O_{2max}$ and dv values for the different techniques, probably due to the reduced number of subjects of the particular samples. Nevertheless, the r values obtained for backstroke and breaststroke were quite high (0.911 and -0.945, respectively).

It is possible to observe that the technique that presented smaller values of dv - the front crawl - is also characterised by low TLim results. The technique that showed larger intra-cyclic fluctuations of the CM velocity was the breaststroke, also the one that delivers the higher values of TLim. Very interesting to note was that the simultaneous swimming techniques were characterized by inverse relationships between both variables, while the alternated ones showed a direct one. So, both backstroke and butterfly assume intermediate dv / TLim relationships in the interval between the boundaries defined by front crawl and breaststroke.

In our opinion, the reason for such controversial results should be searched in relevant co-variants not controlled in this study, namely the relative anaerobic energy contribution at v$\dot{V}O_{2max}$ for each technique. It maybe the case that different muscular activity and particular biomechanics of different swimming techniques imposed different energy partitions, for instance a more anaerobic v$\dot{V}O_{2max}$ for the front crawl and the backstroke, imposing less TLim durations despite a more economic mechanics (lower dv) in comparison with butterfly and breaststroke. Further investigation is needed to clarify this particular issue.

Figure 3 show the behaviour of dv and Vcm values in different moments of TLim test for each technique.

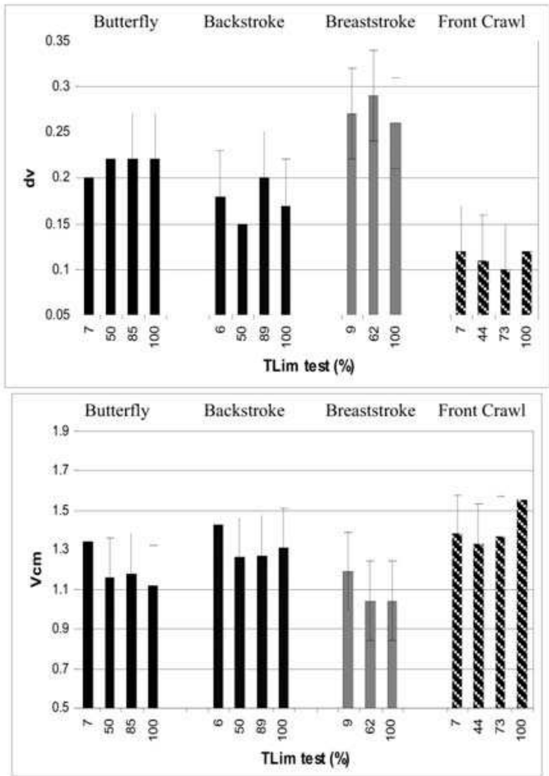

Figure 3. dv and Vcm values during TLim test in the four competitive techniques.

The techniques that present smaller dv values, Backstroke and Front Crawl, have larger values of Vcm, probably because dv allows for higher swimming economy and this one favours higher Vcm.

CONCLUSION

The results of the present research pointed out that the relationship between intra-cyclic speed fluctuations and TLim-v$\dot{V}O_{2max}$ may be strongly influenced by other co-variables, and that it should be searched, preferably, considering each swimming stroke independently. Butterfly, and breaststroke, the swimming techniques with higher speed fluctuations per stroke cycle are characterized by a tendency to an inverse relationship between speed fluctuations and TLim-v$\dot{V}O_{2max}$. The inverse tendency was perceived to the alternated techniques, and for the pooled data.

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RELATIONSHIPS BETWEEN ENERGY COST, SWIMMING VELOCITY AND SPEED FLUCTUATION IN COMPETITIVE SWIMMING STROKES

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The purpose of the study was to analyse relationships between total energy expenditure ($\dot{E}_{tot}$), energy cost (EC), intra-cycle variation of the horizontal velocity of displacement of centre of mass (dv) and mean swimming velocity (v). 17 Portuguese elite swimmers (4 at Freestyle, 5 at Backstroke, 4 at Breaststroke and 4 at Butterfly) were submitted to an incremental set of nx200-m swims. Bioenergetical and biomechanical parameters presented significant interrelationships. For pooled data, the relationship between $\dot{E}_{tot}$ and v was $r=0.59$ ($p<0.01$), between EC and dv was $r=0.38$ ($p<0.01$) and the polynomial relationship, between dv and v was $r=0.17$ ($p=0.28$). Individual evaluation and identification of biomechanical critical points may help the swimmers to become more efficient at a certain swimming velocity.

Key Words: competitive strokes, energy expenditure, energy cost, speed fluctuation, velocity.

INTRODUCTION
In swimming science, economy of movement is an interesting field of research. Several investigations have been conducted to understand the role of bioenergetics and its repercussions in performance. Most of those studies focused exclusively on the contribution of aerobic system to produce energy for movement even though all competitive swimming events also require significant contribution from anaerobic energetic system to cover total energy expenditure. Particularly in swimming, environmental factors have hindered the measurement of cardiorespiratory variables within the actual field setting. However, machinery to explore human aerobic energetics during field conditions has become available with the improvement of miniaturized metabolic measurement systems.
Intra-cycle variation of horizontal velocity of centre of body mass (dv) is a widely accepted criterion for biomechanical description of swimming techniques. There is a positive relationship between high dv and increased energy cost, especially in Breaststroke (12) and Butterfly stroke (2). In Backstroke and Freestyle the relationship was not so evident (1). In this perspective, it is important to obtain a better understanding of the relationship between the energy cost and dv in the competitive strokes.
Some investigators suggested the possibility of high dv being related with lower swimming velocities (e.g., 2, 12). It was