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THE BEHAVIOUR OF KINEMATIC PARAMETERS DURING A TIME TO EXHAUSTION TEST AT VO_2MAX IN ELITE SWIMMERS

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SUMMARY

The aim of this study was to analyse, in swimming pool conditions, the behaviour of kinematic parameters - stroke rate (SR), stroke length (SL) and stroke index (SI) - during a time to exhaustion test performed at the minimum velocity that elicits maximal oxygen uptake (TLim-vVO_2max) in elite freestyle swimmers. Eleven swimmers from the National Portuguese Swimming Team (five male and six female) performed an intermittent incremental test for vVO_2max assessment and an all-out swim at vVO_2max to determine TLim-vVO_2max and to analyse the evolution of the kinematic parameters throughout the test. SR increased and SL (and SI) decreased during the TLim-vVO_2max test, as a general tendency. When the differences in SR, SL and SI between each 12.5% section of the test were tested, a significant increase in SR and a decrease in SL and SI was verified at 25% [(74.00 (25.83m)], 50% [(148.10 (51.66m)] and 87.5% [(259.15 (90.41m)] of the TLim-vVO_2max duration. These data showed a reduction of the propelling efficiency throughout such a test. These findings could be useful when designing training programmes, namely of middle distance swimmers, taking into consideration maximum aerobic speed, time to exhaustion and propelling efficiency.

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INTRODUCTION

The assessment of the time required for a swimmer to reach exhaustion at the minimum velocity that elicits maximal oxygen uptake (TLim-vVO_2max) is a recent topic of interest. The procedure developed by Billat et al (1994) seems to be relevant to assess various determinants of training and performance in endurance athletes. While swimming has been considered to be among the endurance sports, it seems relevant to examine swimmers' ability to sustain intensities that elicit their VO_2max.

TLim-vVO_2max in free swimming was firstly studied in swimming flume (Billat et al, 1996) and later investigated in conventional pools (Renoux, 2001; Fernandes et al, 2003). TLim-vVO_2max seems to be

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ABBREVIATIONS:

BxB	breath-by-breath
HR	heart rate
SI	stroke index
SL	stroke length
SR	stroke rate

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related to factors that determine fatigue, namely the energy cost of swimming (Fernandes et al, 2005). Similarly, some simple biomechanical parameters, i.e., stroke rate (SR), stroke length (SL) and stroke index (SI), have been shown to reflect signs of fatigue during training (Toussaint and Berg, 1992; Keskinen and Komi, 1993), SI being considered a valid indicator of swimming efficiency (Costill et al, 1985). TLim-vVO_2max concept seems to characterise closely the 400m freestyle performance (Fernandes et al, 2003) and the changes in the SR, SL and SI seem to reflect the changes of stroke performance. Thus, the combination of these two sources of information could bring new knowledge about technical ability in swimming events. The purpose of this study was to analyse the SR, SL and SI during the course of a typical TLim-vVO_2max freestyle effort, performed in normal swimming pool conditions, using top-level swimmers.

METHOD

Subjects

The subjects were 11 elite freestyle swimmers (5 male and 6 female) of the National Portuguese Swimming Team. The mean (SD) values for their physical characteristics, weekly training frequency and physiological parameters are presented in Table 1.

TABLE 1: Mean (SD) values for the physical characteristics, weekly frequency of training and physiological parameters of the subjects.

Parameters	Swimmers (n=11)
Age (years)	17.51 (1.69)
Body mass (kg)	66.02 (10.04)
Height (cm)	173.2 (9.6)
Training units (session/week)	8.8 (0.4)
vVO_2max (m/s)	1.46 (0.08)
TLim-vVO_2max (s)	202.73 (70.77)
DLim-vVO_2max (m)	296.01 (103.32)

Study Protocol

The testing sessions took place in a 25m indoor swimming pool and in-water starts and open turns were used. The swimmers performed an incremental set of freestyle to assess vVO_2max. The increments were 0.05m/s per each 200m stage with 30s resting intervals until exhaustion. Initial velocity was established according to the swimmers' individual performance on the 400m freestyle minus 7 increments of velocity (Fernandes et al, 2003). VO_2 was measured breath-by-breath (BxB) using a portable gas exchange system ($K4b^2$, Cosmed, Italy). The swimmers breathed through a respiratory snorkel and valve system rebuilt to enable BxB data collection, which has shown to be a valid tool to carry out measurements of swimmers' cardiorespiratory responses (Keskinen et al, 2003). Velocity was controlled using a visual pacer (TAR. 1.1, GBK-electronics, Aveiro, Portugal) with successive flashing lights, 2.5m apart, on the bottom of the pool.

VO_2max was considered to be reached according to primary and secondary conventional physiological criteria (Howley et al, 1995), namely the occurrence of a plateau in VO_2 despite an increase in swimming velocity, high levels of [La-] ($\geq$ 8 mmol l^{-1}), elevated respiratory exchange ratio ($R \geq 1.0$), elevated heart rate [HR > 90% of (220 – age)], and exhaustive perceived exertion (controlled visually and case to case). vVO_2max was considered to be the swimming velocity correspondent to the first stage that elicits VO_2max. If a plateau less than 2.1ml min^{-1} kg^{-1} could not be observed, the vVO_2max was calculated as follows (Kuipers et al, 1985):

$$vVO_2max = v + \Delta v \ . \ (n \ N^{-1}),$$

where v is the velocity corresponding to the last stage accomplished, Δv is the velocity increment, n indicates the number of seconds that the subjects were able to swim during the last stage and N the pre-set protocol time (in seconds) for this step.

Capillary blood samples for [La-] analysis were collected from the earlobe at rest, in the 30s rest interval, at the end of exercise and during the recovery period (YSI1500LSport auto-analyser - Yellow Springs Incorporated, Yellow Springs, Ohio, USA). HR was monitored and registered continuously each 5s through a heart rate monitor system (Polar Vantage NV, Polar Electro Oy, Kempele, Finland).

Forty-eight hours later, all subjects swam an all-out swim at their previously determined vVO_2max to assess TLim-vVO_2max. This protocol consisted of two different phases, each paced with the referred visual light-pacer: (i) a 10 min warm-up at an intensity correspondent to 60% vVO2max and (ii) the maintenance of that swimming vVO_2max until volitional exhaustion or until the moment the swimmers were unable to swim at the selected pace. TLim-vVO_2max was considered to be the total swimming duration at the pre-determined velocity. Distance limit (DLim-vVO_2max) also was registered as the distance performed (in meters) during the TLim-vVO_2max test.

SR was registered by the counting of the number of strokes in each 25m, SL was calculated by dividing velocity by SR, and the product of SL by the velocity allowed to assess SI (according with Craig and Pendergast, 1979, and Costill et al. 1985).

Statistical Analyses

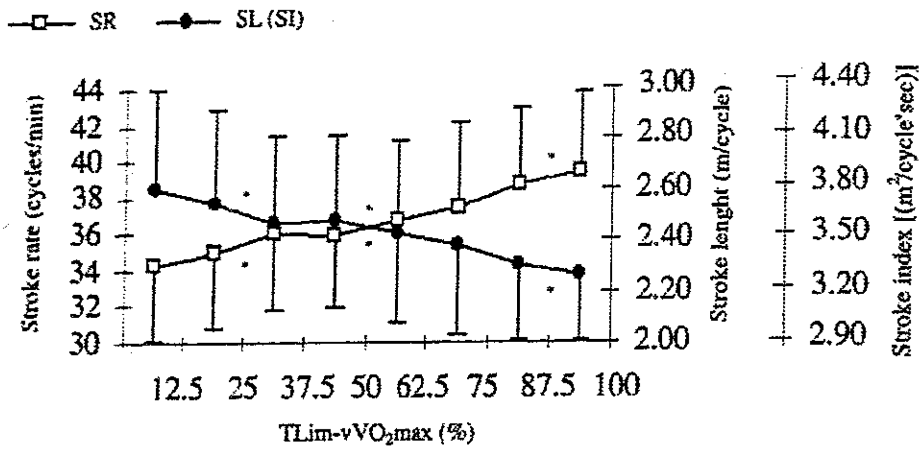
As the distances obtained in the TLim-vVO_2max test (DLim-vVO_2max) were different between swimmers, each DLim-vVO_2max was divided in 8 sections in order to make inter-subjects comparison. Then, the values of the stroking parameters, in each length, were converted to each 12.5% of the TLim-vVO_2max test.

Mean and SD computations for descriptive analysis were obtained for all variables (all data were checked for distribution normality with the Shapiro-Wilk test). A one-way repeated measures ANOVA was also used to compare the evolution of the kinematic parameters from one section to the next. A significance level of 5% was accepted.

Results

In Figure 1 it is possible to observe that SR increased and SL (and SI) decreased during the TLim-vVO_2max test, as a general tendency. When the differences in SR, SL and SI between each 12.5% section of the test duration were tested, a significant increase in SR and a decrease in SL and SI was verified at 25% [(74.00 (25.83m)], 50% [(148.10 (51.66m)] and 87.5% [(259.15 (90.41m)] of the TLim-vVO_2max.

FIGURE 1: Mean (SD) values for SR, SL and SI during the TLim-vVO_2max test (n=11), * $p<0.05$.



DISCUSSION

Since the pioneering study by East (1970), the analysis of the stroke kinematic parameters is one of the major points of interest in the biomechanical investigation of swimming. Following the previous studies that related TLim-vVO_2max and some metabolic parameters (e.g. Billat et al, 1996; Renoux, 2001; Fernandes et al, 2003), it was tried in this study to go further in this analysis and observe the behaviour of SR, SL and SI during a typical TLim-vVO_2max effort.

The present results have some similarity with a previous study of Marinho et al (2004), where an increase in SR and a decrease in SL during the TLim-vVO_2max test were observed (with significant changes after 100m during the swim, corresponding to 33.3% of the test duration). However, the subjects of that study were not elite swimmers and a less sensitive oximeter (Sensormedics 2900, Yorba Linda, USA), with 20 sec VO_2 averaged data, was used. In the present study all subjects were crawl specialists of the Portuguese National Swimming Team and the analysis of VO_2 kinetics was performed BxB. These facts may explain some of the observed differences between the two studies.

The present data suggest that the changes observed in SR, SL and SI in the three points mentioned above are critical in the TLim-vVO_2max effort. High-speed swimming overloads the human neuromuscular system and may deteriorate the stroke performance during the event, which was already shown in previous studies (Keskinen and Komi, 1993; Wakayoshi et al, 1995; Laffite et al, 2004). Wakayoshi et al

(1996) and Dekerle et al (2005) also observed the existence of a biomechanical boundary, very closely related to the swimming intensity corresponding to anaerobic threshold, beyond which the SL becomes compromised. The reduction in the mechanical propulsive efficiency is possibly due to the increased local muscular fatigue, which seems to reduce the swimmers' ability to maintain the "feel for the water" (Wakayoshi et al, 1996). This reduction in the quality of stroke technique, represented by the decrease in SL and SI, and consequent increase in SR to maintain the swimming velocity, is associated with a lower capacity of force production to overcome water resistance (Craig et al, 1985). Monteil et al (1996) have already verified changes in forces distributions and propelling efficiency throughout the different phases of the stroke cycle because of fatigue. It could be hypothesised that swimmers have to modify their coordination because the task constraints are maintained, whereas the swimmers have not the same capability to develop the corresponding speed (Dekerle et al, 2003). Further investigations should be conducted in this topic, namely in what concerns other major measures of swimming technique such as intra-cyclic velocity variations.

The findings of the present study can be useful in designing training programs based on intermittent exercises (Renoux, 2001). Distances beyond which the SL becomes compromised should be designed with especial care and swimmers and coaches should pay special attention to their stroking technique. Alves (2000) suggests that the decrease in SL during a 400m freestyle event could be due to reduced rolling of the body and to the incapacity to create a large amount of propulsive force at the end of the arm stroke, i.e., in the upsweep. Coaches could use TLim-vVO_2max and vVO_2max data combined with the analysis of the stroking parameters. This would allow setting not only VO_2max training loads but also to control stroking technique during training, as suggested by Clipet et al (2003). For example, the swimmers could swim an aerobic training set using a specific and controlled individual SR to cover each length.

In conclusion, this study showed that TLim-vVO_2max typical effort appeared to be characterised by a reduction of the propelling efficiency. Results of this study could help swimming coaches to draw up individualised training programmes for a given swimmer by taking into consideration maximum aerobic speed, time limit and propelling efficiency.

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