

The test battery was unable to significantly discriminate between the two performance levels in any junior male or female age group, although multiple regression analysis yielded significant models for junior males ($P=0.000$) and females ($P=0.000$) accounting for 74% and 47% of the variance in swimming performance respectively. In junior males, arm span, waist circumference, torso to waist ratio and CMJ were significant predictors of performance ($P<0.05$) and in junior females, arm span, sitting height, sitting height percentage and CMJ were significant predictors of performance ($P<0.05$). Several of the characteristics identified as important for junior swimming performance are those that individually differentiate between performance level in senior swimmers (in males, torso to waist ratio and CMJ and in females, sitting height and sitting height percentage). Hence, some characteristics possessed by elite junior swimmers may also be important for elite senior swimming performance. All regression analyses were unable to explain 100% of the variance in swimming performance indicating that some of this variance must be attributed to other factors such as more detailed physiological measures, swimming technique, psychological and/or environmental characteristics. It seems likely that the inclusion of swimming specific tests in the battery would provide additional predictive power to this analysis, although further multidisciplinary research is required to establish any contribution these factors may have to elite swimming performance.

CONCLUSION

The characteristics that predict swimming performance differ from junior to senior level in both males and females. A longitudinal approach to this type of research would provide valuable information about the importance of certain characteristics to performance during growth and development and at senior level. This type of approach suggests that an appropriate multidisciplinary test battery combined with multivariate analyses could be useful as an important predictive and diagnostic tool for talent identification and development in elite junior swimmers.

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ASSESSMENT OF TIME LIMIT AT LOWEST SPEED CORRESPONDING TO MAXIMAL OXYGEN CONSUMPTION IN THE FOUR COMPETITIVE SWIMMING STROKES

Ricardo Fernandes¹, Carla Cardoso¹, José A. Silva¹, Sónia Vilar¹, Paulo Colaço¹, Tiago Barbosa², Kari L. Keskinen³, J. Paulo Vilas-Boas¹

¹University of Porto, Faculty of Sport, Porto, Portugal

²Department of Sports Sciences, Polytechnic Institute of Bragança, Portugal

³Finnish Society for Research in Sport and Physical Education, Helsinki, Finland.

Time limit at lowest speed of maximal oxygen consumption (TLim- $\dot{V}O_{2max}$) was characterized in the 4 swimming strokes, and related with $\dot{V}O_{2max}$ and anaerobic threshold (AnT). 23 elite swimmers performed an incremental protocol for $\dot{V}O_{2max}$ assessment. 48 hours later, TLim- $\dot{V}O_{2max}$ was assessed. $\dot{V}O_2$ was directly measured BxB (K4 b2, Cosmed, Italy) and AnT was assessed individually (YSI 1500L Sport, USA). TLim- $\dot{V}O_{2max}$ values were 238.8 ± 39.0 , 246.1 ± 51.9 , 277.6 ± 85.6 and 331.4 ± 82.7 s in crawl, backstroke, butterfly, and breaststroke (no differences observed). No correlations were found between TLim- $\dot{V}O_{2max}$ and $\dot{V}O_{2max}$, and AnT. However, inverse relationships were observed between TLim- $\dot{V}O_{2max}$ and $\dot{V}O_{2max}$ ($r=-0.63$, $p<0.01$) and $vAnT$ ($r=-0.52$, $p=0.01$), pointing out that the higher the velocities commonly related to aerobic proficiency, the lower the TLim- $\dot{V}O_{2max}$.

Key Words: time to exhaustion, competitive strokes, oxygen consumption, anaerobic threshold.

INTRODUCTION

Time limit at lowest speed of maximal oxygen consumption (TLim- $\dot{V}O_{2max}$) was studied both in swimming flume (1, 2, 3) and in normal swimming pool conditions (4, 6, 13). While no studies have been carried out based on other swimming techniques than front crawl, the purpose of this experiment was to characterize, and compare, TLim- $\dot{V}O_{2max}$ in the four competitive strokes, as well as to observe its relationships with two major performance determinants: $\dot{V}O_{2max}$ and anaerobic threshold (AnT). Complementarily, knowing that top-level swimmers have their specificities (11) and that TLim- $\dot{V}O_{2max}$ was never assessed in elite swimmers, the pertinence of this study is clearly stated.

METHODS

Subjects

Twenty-three elite swimmers (15 males of 19.4 ± 2.1 yy, 178.1 ± 6.2 cm and 71.8 ± 7.4 kg, and 8 females of 17.2 ± 1.4 yy, 166.0 ± 3.7 cm and 59.7 ± 4.3 kg) from the Portuguese National Swimming Team volunteered to participate in this study and signed an informed consent form.

Test protocol

Each subject performed, in their best technique, an individualized intermittent incremental protocol for $v\dot{V}O_{2max}$ assessment, with increments of $0.05\text{ m}\cdot\text{s}^{-1}$ each 200 m stage and, 30 s intervals, until exhaustion (4). $\dot{V}O_2$ was directly measured using a telemetric portable gas analyzer (K4 b², Cosmed, Italy) connected to the swimmers by a respiratory snorkel and valve system (9, 14). Expired gas concentrations were measured breath-by-breath. Swimming velocity was controlled using a visual pacer (TAR. 1.1, GBK-electronics, Aveiro, Portugal) with flashing lights on the bottom of the pool. $\dot{V}O_{2max}$ was considered to be reached according to primary and secondary traditional physiological criteria (8). $v\dot{V}O_{2max}$ was considered to be the swimming velocity correspondent to the first stage that elicits $\dot{V}O_{2max}$. If a plateau less than $2.1\text{ ml}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$ could not be observed, the $v\dot{V}O_{2max}$ was calculated as proposed by Kuipers et al. (9): $v\dot{V}O_{2max} = v + \Delta v \cdot (n\cdot N^{-1})$, (Eq. 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 lactate concentrations ($[La^-]$) analysis were collected from the earlobe at rest, in the 30 s rest interval, at the end of exercise and during the recovery period (YS11500L Sport auto-analyser - Yellow Springs Incorporated, Yellow Springs, Ohio, USA). Those data allowed to assess individual AnT, that was determined by $[La^-]$ /velocity curve modeling method (least square method) (5). HR was monitored and registered continuously each 5 s through a heart rate monitor system (Polar Vantage NV, Polar Electro Oy, Kempele, Finland). Forty-eight hours later, subjects swam until exhaustion at their pre-determined velocity, to assess TLim- $v\dot{V}O_{2max}$. This protocol consisted in two different phases, all paced: (i) a 10 min warm-up at an intensity correspondent to 60% $v\dot{V}O_{2max}$, followed by a short rest (20 s) for earlobe blood collection, and (ii) the maintenance of that swimming $v\dot{V}O_{2max}$ until volitional exhaustion or until the moment that the swimmers were unable to swim at the selected pace. TLim- $v\dot{V}O_{2max}$ was considered to be the total swimming duration at the pre-determined velocity. HR was registered continuously using the same procedure previously described.

Statistical analysis

Mean (\pm SD) computations for descriptive analysis were obtained for all variables (all data were checked for distribution normality with the Shapiro-Wilk test). One-way Anova, with a Bonferroni post-hoc test, was also used. A significance level of 5% was accepted.

RESULTS

Data concerning the variables obtained in the incremental test: $\dot{V}O_{2max}$, $[La^-]_{max}$, HRmax, AnT (velocity and $[La^-]$ values) and $v\dot{V}O_{2max}$, and the parameters assessed in the Time Limit test: TLim- $v\dot{V}O_{2max}$, $[La^-]_{max}$ and HRmax, are reported in Table 1 for each competitive stroke. The values of $\dot{V}O_{2max}$ obtained in the incremental test are in accordance with those previously published for elite front crawl swimmers for a number of authors (1, 3, 7). Studies that aim to compare $\dot{V}O_{2max}$ in elite front crawl, backstroke, butterfly and breaststroke swimmers are very scarce, so it is difficult to make valid comparisons. However, the observation of no differences between $\dot{V}O_{2max}$ values between techniques is in accor-

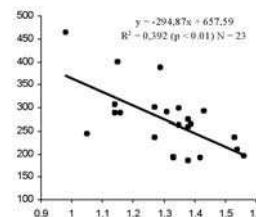
dance with Troup (15). The obtained values of HRmax are in agreement with the literature since that, for this kind of intensity of exercise (aerobic power zone), values ranging from 180 to 200 $\text{b}\cdot\text{min}^{-1}$ are consensual (12). Likewise, the $[La^-]_{max}$ mean values are in agreement with the typical requirements for $\dot{V}O_{2max}$ swimming intensities (8). While no significant differences were observed between competitive strokes in TLim- $v\dot{V}O_{2max}$, pooled data were correlated with $\dot{V}O_{2max}$ ($\text{ml}/\text{kg}/\text{min}$) and AnT (mmol/l), being observed no significant interrelationships. However, moderate inverse correlation values were observed between TLim- $v\dot{V}O_{2max}$ and $v\dot{V}O_{2max}$ ($r=-0.63$, $p=0.001$, Figure 1A) and $vAnT$ ($r=-0.52$, $p=0.012$, Figure 1B).

Table 1. Mean (\pm SD) values for $v\dot{V}O_{2max}$ (absolute and relative), $[La^-]_{max}$, HRmax, AnT (velocity and $[La^-]$ values) and $v\dot{V}O_{2max}$ (incremental test), and TLim- $v\dot{V}O_{2max}$, $[La^-]_{max}$ and HRmax (Time Limit test), for each competitive stroke. Significant differences are shown through pairs of (1), (2), (3), (4), (5), (6), (7), (8), (9) and (10), $p \leq 0.05$.

Parameters	Front crawl (n = 8)	Backstroke (n = 5)	Butterfly (n = 4)	Breaststroke (n = 6)
$v\dot{V}O_{2max}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	64.28 \pm 10.27	66.78 \pm 11.40	53.95 \pm 4.82	63.21 \pm 8.14
$\dot{V}O_{2max}$ ($\text{l}\cdot\text{min}^{-1}$)	4.34 \pm 1.32	4.69 \pm 1.11	3.57 \pm 0.54	4.33 \pm 0.71
$[La^-]_{max}$ ($\text{mmol}\cdot\text{l}^{-1}$)	8.34 \pm 3.02	11.22 \pm 3.63	8.22 \pm 1.60	9.13 \pm 1.99
HRmax ($\text{b}\cdot\text{min}^{-1}$)	182.50 \pm 5.73	190.00 \pm 6.60	179.25 \pm 6.50	190.83 \pm 7.33
AnT ($\text{mmol}\cdot\text{l}^{-1}$)	2.59 \pm 0.97 ⁽¹⁾	4.56 \pm 2.10	5.56 \pm 2.30 ⁽¹⁾	3.03 \pm 1.50
$vAnT$ ($\text{m}\cdot\text{s}^{-1}$)	1.33 \pm 0.10 ⁽²⁾	1.25 \pm 0.06 ⁽³⁾	1.21 \pm 0.07 ⁽⁴⁾	1.01 \pm 0.08 ^(5,6)
$v\dot{V}O_{2max}$ ($\text{m}\cdot\text{s}^{-1}$)	1.45 \pm 0.08 ⁽⁵⁾	1.35 \pm 0.04 ⁽⁷⁾	1.29 \pm 0.03 ^(5,8)	1.10 \pm 0.07 ^(6,7,8)
TLim- $v\dot{V}O_{2max}$ (s)	243.17 \pm 30.49	246.08 \pm 51.93	277.63 \pm 85.64	331.43 \pm 82.73
$[La^-]_{max}$ TLim ($\text{mmol}\cdot\text{l}^{-1}$)	6.92 \pm 2.53 ^(9,10)	10.65 \pm 2.40 ⁽⁹⁾	9.04 \pm 0.91	10.76 \pm 1.34 ⁽¹⁰⁾
HRmax TLim ($\text{b}\cdot\text{min}^{-1}$)	180.00 \pm 6.44	176.60 \pm 8.56	179.50 \pm 4.44	185.67 \pm 7.97

$\dot{V}O_{2max}$: maximal oxygen consumption; $[La^-]_{max}$: maximal blood lactic acid concentrations; HRmax: maximal heart rate; AnT: anaerobic threshold; $vAnT$: velocity corresponding to anaerobic threshold; $v\dot{V}O_{2max}$: lowest speed of maximal oxygen consumption; TLim- $v\dot{V}O_{2max}$: time limit at $v\dot{V}O_{2max}$; n: number of subjects.

The observed inverse relationships between TLim- $v\dot{V}O_{2max}$ and $v\dot{V}O_{2max}$, and/or $vAnT$, confirms previous findings obtained in national level freestyle swimmers (4, 6), and point out that, whatever the swimming techniques the higher the swimming velocities commonly related to aerobic proficiency, the lower the TLim- $v\dot{V}O_{2max}$. This observation seems to be justified by the fact that higher swimming velocities indicates more strenuous efforts, with probably more pronounced recruitment of anaerobic energy pathways, leading to earlier fatigue stages and, consequently, to lower TLim- $v\dot{V}O_{2max}$. However, no relationship was found between TLim- $v\dot{V}O_{2max}$ and $[La^-]_{max}$, in opposition with some previous findings (3, 6).



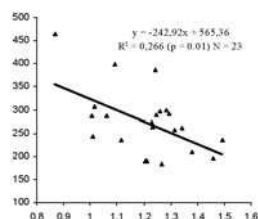


Figure 1. Relationship between $T_{Lim-v\dot{V}O_2max}$ (A panel), and $v\dot{V}O_2max$ (B panel).

CONCLUSIONS

$T_{Lim-v\dot{V}O_2max}$ did not differ between swimming strokes, pointing out that the phenomenon is similar in all four strokes. $T_{Lim-v\dot{V}O_2max}$ was lower in the swimmers who presented higher $v\dot{V}O_2max$ and $vAnT$, which could be explained by the higher anaerobic rate in that specific exercise effort. $\dot{V}O_2max$ and $[La^-]$ values are poor predictors of $T_{Lim-v\dot{V}O_2max}$ performance.

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OXYGEN UPTAKE AND VENTILATORY THRESHOLD IN SWIMMING

Pedro Morais, Carla Cardoso, Vera Faria, Sónia Rocha, Leandro Machado, Ricardo Fernandes, J. Paulo Vilas-Boas
University of Porto, Faculty of Sport. Porto, Portugal

The purpose of this study was to identify, in terms of percentage of maximal oxygen uptake ($\% \dot{V}O_2max$), the intensity of swimming associated with a non linear increase of minute ventilation (V_e), also described as ventilatory threshold (VT). Twenty nine trained swimmers participated in our study: 15 males and 14 females. Each subject performed an intermittent incremental protocol of 200m stages, with increases of $0.05m \cdot s^{-1}$, and 30s intervals between each stage. VT was assessed by $V_e/\dot{V}O_2$ curve modelling method (least square method). It was assumed VT to be the intersection point, at the maximal fit situation, of a combined pair of regressions (linear and exponential). The analysed values of $\dot{V}O_2$ and V_e were cropped by direct oximetry. The present study demonstrated that the non linear increase of V_e corresponding to VT in a specific swimming situation seems to happen at $84.3 \pm 8.7 \%$ $\dot{V}O_2max$.

Key Words: ventilatory threshold, oxygen uptake, minute ventilation, evaluation.

INTRODUCTION

The concept of whole body maximal oxygen uptake ($\dot{V}O_2max$) has received much attention in the specialized literature, especially on its relevance to endurance performance and adaptation to training, being frequently viewed as one of the most relevant factors of performance [2]. However, di Prampero et al. [9] observed that, besides $\dot{V}O_2max$, other parameters are crucial for the athlete endurance performance, such as motor economy and the capability to sustain a high percentage of $\dot{V}O_2max$ ($\% \dot{V}O_2max$) along the exercise. On the same perspective, Svendsen et al. [17] support that an athlete with a