Does net energy cost of swimming affect time to exhaustion at the individual’s maximal oxygen consumption velocity?

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**Aim.** The purpose of the present study was to examine the relationship between time limit at the minimum velocity that elicits the individual’s maximal oxygen consumption (TLim-v VO2max) and three swimming economy related parameters: the net energy cost corresponding to v VO2max (Cv VO2max), the slope of the regression line obtained from the energy expenditure (E) and corresponding velocities during an incremental test (C_slope) and the ratio between the mean E value and the velocity mean value of the incremental test (C_inc). Complementarily, we analysed the influence of Cv VO2max, C_slope and C_inc on TLim-v VO2max by swimming level.

**Methods.** Thirty swimmers divided into 10 low-level (LLS) (4 male and 6 female) and 20 highly trained swimmers (HTS) (10 of each gender) performed an incremental test for v VO2max assessment and an all-out TLim-v VO2max test.

**Results.** TLim-v VO2max, Cv VO2max, C_slope and C_inc averaged, respectively, 313.8±63 s, 1.16±0.1 m·s⁻¹, 13.2±1.9 J·kg⁻¹·m⁻¹, 28±3.2 J·kg⁻¹·m⁻¹ and 10.9±1.8 J·kg⁻¹·m⁻¹ in the LLS and 237.3±54.6 s, 1.4±0.1 m·s⁻¹, 15.6±2.2 J·kg⁻¹·m⁻¹, 36.8±4.5 J·kg⁻¹·m⁻¹ and 13±2.3 J·kg⁻¹·m⁻¹ in the HTS. TLim-v VO2max was inversely related to C_slope (r=-0.77, P<0.001), and to v VO2max (r=-0.35, P=0.05), although no relationships with the Cv VO2max and the C_inc were observed.

**Conclusions.** The findings of this study confirmed exercise economy as an important factor for swimming performance. The data demonstrated that the swimmers with higher and v VO2max performed shorter time in TLim-v VO2max efforts.

**KEY WORDS:** Swimming - Time limit - Oxygen consumption - Energy cost.

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Time limit is defined as the duration during which a certain intensity of exercise can be sustained until exhaustion.¹ Time limit at intensities corresponding to the individual’s maximal oxygen uptake (VO2max) has been mostly studied in running and in cycling but is a new subject of interest in swimming training and performance diagnosis. The first study that assessed time limit in swimming compared cyclists, kayak paddlers, swimmers and runners, performing in their specific ergometers, although not in their performance specific field conditions.² In this study, time limit was performed at the velocity that elicits VO2max (TLim-v VO2max) and was only different between cycling and running. In addition, an inverse relationship between TLim-v VO2max and v VO2max was found in swimming. Afterwards, two studies, also performed in swimming flume, not in normal swimming, characterized swimming TLim-v VO2max and tried to find out the main factors that affected it.³,⁴ The authors addressed that TLim-v VO2max correlated positively with accumulated oxygen deficit and negatively with VO2max, and observed the occurrence of a O₂ slow component in the TLim-v VO2max trial. Arguing

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that exercising in a flume may impose particular mechanical constraints that impair its comparison with free swimming in a conventional pool, Fernandes et al. proposed a new TLim-v VO2max protocol implemented in normal swimming specific conditions. It was shown that TLim-v VO2max is negatively related to v VO2max and to the 3.5 mmol·L⁻¹ anaerobic threshold in high-level male swimmers. In addition, a positive relationship between TLim-v VO2max and O₂ slow component was reported. Also in this research field, Renoux examined the effect of 12-week training program on TLim-v VO2max and v VO2max and designed an intermittent training regimen to develop those parameters. The training program allowed an improvement in v VO2max although such evolution was not seen for TLim-v VO2max. Complementarily, it was observed an inverse relationship between those parameters.

Despite these last studies, no report was published relating time limit and one major swimming performance determinant: swimming economy (C), has been well reported since the ‘70s for different workloads and for distinct swimming levels. Hence, SE has been considered a fundamental parameter of swimming science applied to training and could be one of the main contributors for an improved TLim-v VO2max effort. Meanwhile, several authors have been determining C by simply estimating the contribution of aerobic metabolism, through the monitoring of O₂ at submaximal (or even maximal) intensities. The negligence of the anaerobic contribution to the overall energy requirement in the referred models can be justified by the difficulties imposed by the assessment of the glycolytic system when performing in normal swimming conditions, i.e., in a swimming pool. As TLim-v VO2max duration and intensity are closely related to the 400 m freestyle event, in which the anaerobic contribution is approximately 20% of the total energy expenditure, it was proposed to bridge that

difficulty and assess C based on data from aerobic and anaerobic energy pathways.

In this regard, the main purpose of this study was to analyse the relationship between TLim-v VO2max and SE. For that we considered three SE profile related parameters: 1) the C at v VO2max (Cv VO2max); 2) the slope of the regression line obtained from the relationship between energy expenditure values (E) and corresponding velocities in an incremental test (Cslope) and 3) the ratio between the mean value and the mean velocity value of the incremental test (Cinc). It was hypothesized that TLim-v VO2max should be negatively affected by Cv VO2max, Cslope and Cinc. Complementarily, given that C differs according to the subjects’ level, we observed the influence of Cv VO2max, Cslope and Cinc on the TLim-v VO2max by swimming level, in both low-level and high-level groups. For better comparison between the two groups, we also assessed the C at the swimming velocity of 1.2 m·s⁻¹ (C1.2).

Materials and methods

The subjects (n=30) were divided into two groups: 1) a group of 10 low-level swimmers (LLS) triathletes and Physical Education students and 2) a group of 20 highly trained competitive swimmers (HTS). The groups were matched for gender being 4 males and 6 females in the LLS group and 10 swimmers of each gender in the HTS group. The criterion to be included in the HTS group was a personal best in the 400 m freestyle event under 4:40 and 4:40 for male and female, respectively. Mean and standard deviation (mean±SD) values for physical characteristics and swimming frequency of training are described in Table I. All subjects volunteered to participate in this study and signed a written informed consent, where the experimental protocol was described. The Ethics Committee of our Faculty approved the experimental protocol.

All the test sessions took place in a 25 m indoor swimming pool, during the final of the winter general preparatory training period. The water was maintained at 27.5 °C for all experiments. Briefly, each subject performed an individualized intermittent incremental protocol for freestyle v VO2max assessment, with increments of 0.05 m·s⁻¹ each 200 m stage and 30 s rest intervals until exhaustion. VO2 was directly measured using a metabolic cart (SensorMedics 2900 oximeter, Yorba Linda, CA, USA) mounted on a spe-
chial chariot running alongside the pool and connected to the swimmer by a 1.8 m hose, and a respiratory valve with low airflow resistance and small dead space. This extended hose was shown to do not affect VO2max results. Expired gas concentrations were averaged every 20 s. Swimming velocity was controlled using a visual pace (TAR. 1.1, GBK-electronics, Aveiro, Portugal) with flashing lights on the bottom of the pool.

VO2max was considered to be reached according to primary and secondary traditional physiological criteria, namely the occurrence of a plateau in VO2 despite an increase in swimming velocity, high levels of blood lactic acid concentrations ([La-] ≥ 8 mmol·L⁻¹), elevated respiratory exchange ratio (R≥1), elevated heart rate (HR >90% of [220-age]) and exhaustive perceived exertion (controlled visually and case to case). VO2max was considered to be the swimming velocity correspondent to the first stage that elicits VO2max. If a plateau less than 2.1 mL·min⁻¹·kg⁻¹ could not be observed (7 cases reported), the v VO2max was calculated as proposed by Kuipers et al.; v VO2max = v + Δv·(n/N), 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 preset protocol time (in seconds) for this step.

Capillary blood samples for [La-] analysis were collected from the earlobe at rest (after previous local hyperemia with Finalgon®), in the 30 s rest interval between each exercise step and at the end of exercise (YSI1500LSport auto-analyser, Yellow Springs Incorporated, Yellow Springs, OH, USA). HR was monitored and registered continuously each 5 s through a heart rate monitor system (Polar Vantage NV, Polar Electro Oy, Kempele, Finland). The E values for each exercise step were obtained through the addition of the net VO2 values (difference between the averaged value of the last minute of exercise and the resting value) and the values that result from the transformation of the net [La-] (difference between last step [La-] and the previous step) into O2 equivalents. For this last procedure, we used the proportionality constant of 2.7 mL O2·kg⁻¹·mM⁻¹ which was latter verified for capillary blood. The energetic contribution of high-energy phosphates was considered negligible.

Cv VO2max was assessed as the ratio obtained by E and the corresponding v VO2max that elicits VO2max. Cv was considered as the slope of the regression line obtained by the overall relationship established between E and the corresponding velocities in the incremental test and C inc was assessed as the ratio obtained by the mean E value and the mean velocity value of the incremental test. The CV was also assessed as a swimming velocity commonly achieved by both LLS and HTS.

The second test session occurred 48 h later. All subjects swam at their previously determined v VO2max to assess TLim-v VO2max. This protocol consisted of three different phases, all paced: 1) a 10 min warm-up at an intensity correspondent to 60% v VO2max, followed by a short rest (20 s) for earlobe blood collection; 2) a 50 m distance performed at progressive velocity, allowing the swimmers to reach their individual v VO2max, and 3) the maintenance of that v VO2max until volitional exhaustion or until the moment that the swimmers were unable to swim at the selected pace. TLim-v VO2max was considered the total swimming duration at the previously determined v VO2max.

[La-] were assessed at rest, during the 20 s rest intervals and immediately after exercise. The lactate production (Δ[La-]) was determined as the difference between the maximal values measured after the test and those measured after the warm-up. HR was registered continuously using the same procedure previously described.

Swimmers were instructed to use a surface open turn, always performed to the same lateral wall side, without gliding. In-water starts were also used. Swimmers were verbally encouraged to perform as long as possible during the tests. Both tests were carried out in the same conditions for each subject (i.e. water and air temperature, and time of the day) and all were instructed not to exercise hard before and between the evaluations.

Statistical analysis

Mean and SD computations for descriptive analysis were obtained for all variables for the two performance level groups and for the entire group of subjects (all data where checked for distribution normality with the Shapiro-Wilk test). Pearson’s correlation coefficient and unpaired Student’s t-test were also used. All statistical procedures were conducted with SPSS 10.05 and the significance level was set at 5%.

Results

Data concerning the variables obtained in the incremental test: VO2max, [La-]max, HRmax, v VO2max, E
**TABLE II.**—Mean±SD values for $\dot{V}O_{2\text{max}}$ (absolute and relative), $[La]_{\text{max}}, HR_{\text{max}}, vV0_{2\text{max}}, CV_{\text{O2}}, CV_{\text{Lact}}, C_{\text{slo}}$, $C_{\text{inc}}, C_{1.20}$ (incremental test) and TLIm-v $V0_{2\text{max}}, \Delta[La]$ (TLim test), for the two swimming level groups.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Low-level swimmers (n=10)</th>
<th>Highly trained swimmers (n=20)</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V0_{2\text{max}}$ (ml·min$^{-1}$·kg$^{-1}$)</td>
<td>52.1±6.5</td>
<td>69.9±9.3</td>
<td>0.002</td>
</tr>
<tr>
<td>$V0_{2\text{max}}$ (L·min$^{-1}$)</td>
<td>3.18±0.71</td>
<td>4.28±0.91</td>
<td>0</td>
</tr>
<tr>
<td>$[La]_{\text{max}}$ (mmol·L$^{-1}$)</td>
<td>9±2.9</td>
<td>8±1.9</td>
<td>0.107</td>
</tr>
<tr>
<td>$HR_{\text{max}}$ (b·min$^{-1}$)</td>
<td>187.2±8.3</td>
<td>190.4±7.6</td>
<td>0.307</td>
</tr>
<tr>
<td>$vV0_{2\text{max}}$ (m·s$^{-1}$)</td>
<td>1.16±0.1</td>
<td>1.4±0.06</td>
<td>0</td>
</tr>
<tr>
<td>$CV_{\text{O2}}$ (J·kg$^{-1}$·min$^{-1}$)</td>
<td>13.2±1.9</td>
<td>15.5±2.2</td>
<td>0.007</td>
</tr>
<tr>
<td>$C_{\text{slo}}$ (J·kg$^{-1}$·min$^{-1}$)</td>
<td>28±3.2</td>
<td>36.8±4.5</td>
<td>0</td>
</tr>
<tr>
<td>$C_{\text{inc}}$ (J·kg$^{-1}$·min$^{-1}$)</td>
<td>10.9±1.8</td>
<td>13.1±2.3</td>
<td>0.008</td>
</tr>
<tr>
<td>$C_{1.20}$ (J·kg$^{-1}$·min$^{-1}$)</td>
<td>13.6±2.2</td>
<td>11.7±2.3</td>
<td>0.04</td>
</tr>
<tr>
<td>TLIm-v $V0_{2\text{max}}$ (s)</td>
<td>313.8±63</td>
<td>237.3±54.6</td>
<td>0.002</td>
</tr>
<tr>
<td>$[La]_{\text{max}}$ (mmol·L$^{-1}$)</td>
<td>10.6±1.9</td>
<td>9.3±1.8</td>
<td>0.095</td>
</tr>
<tr>
<td>$\Delta[La]$ (mmol·L$^{-1}$)</td>
<td>6.8±2.2</td>
<td>8.2±1.6</td>
<td>0.049</td>
</tr>
</tbody>
</table>

$V0_{2\text{max}}$: maximal oxygen consumption; $[La]_{\text{max}}$: maximal blood lactate acid concentrations; $HR_{\text{max}}$: maximal heart rate; $vV0_{2\text{max}}$: minimum velocity at $V0_{2\text{max}}$; $CV_{\text{O2}}$: net equivalent oxygen consumption (lobaric plus anaerobic) of energy expenditure at $V0_{2\text{max}}$; $C_{\text{slo}}$: energy cost at $V0_{2\text{max}}$; $C_{\text{inc}}$: slope of the regression line obtained from the relationship between $E$ and corresponding velocities in the incremental test; $C_{1.20}$: ratio obtained by the mean $L$ value and the velocity mean value of the incremental test; $\Delta[La]$; energy cost at the swimming velocity of 1.2 m·s$^{-1}$, TLIm-v $V0_{2\text{max}}$: time limit at $V0_{2\text{max}}$; $\Delta[La]$, lactate production.

$V0_{2\text{max}}$, $CV_{\text{O2}}$, $C_{\text{slo}}$, $C_{\text{inc}}$, $C_{1.20}$ and the parameters assessed in the Time Limit test: TLIm-v $V0_{2\text{max}}$, $[La]_{\text{max}}$ and $\Delta[La]$ are reported in Table II. In each level group, no differences by gender were observed regarding the TLIm-v $V0_{2\text{max}}$ performance: mean±SD values were 242.6±59.1 and 231.9±52.3 in HTS, and 321.5±70.7 and 308.7±63.8 in LLS, respectively for male and female swimmers. The relationship between $E$ and swimming velocity in the incremental test for $V0_{2\text{max}}$ assessment is shown in Figure 1 for all subjects. The last 1 or 2 steps were performed at competitive intensities, i.e., at or above $V0_{2\text{max}}$, which are intensities similar to that of the 400 m event.² The individual $E$ vs velocity determination coefficients ranged from $r^2=0.48$ (P<0.05) to $r^2=0.99$ (P<0.01), with a mean $r^2$ value of 0.62±0.03.

Figure 2 shows a weak, although significant, inverse relationship between TLIm-v $V0_{2\text{max}}$ and $V0_{2\text{max}}$ ($r=-0.35$, P<0.05), i.e., as a group, the swimmers that obtained the highest $V0_{2\text{max}}$ seem to reach the exhaustion earlier. When considering the HTS and LLS (and also the subgroups divided by gender), no significant relationship between TLIm-v $V0_{2\text{max}}$ and $V0_{2\text{max}}$ was noted. For the entire sample, it was also observed a moderate significant relationships between $V0_{2\text{max}}$ and $CV_{\text{O2}}$ ($r=0.23$, P<0.01), $C_{\text{slo}}$ ($r=0.22$, P<0.001) and $C_{\text{inc}}$ ($r=0.44$, P<0.05).

As can be observed in Figure 3, TLIm-v $V0_{2\text{max}}$ and
Cslope were inversely correlated both when the entire group (r=-0.77, P<0.001) and the two level groups: HTS (r=-0.68, P<0.001) and LLS (r=-0.61, P=0.05) were considered. However, no significant correlations were found between TLim-v V̇O₂max and Cslope(r=-0.25, P=0.18), and C slope (r=-0.15, P=0.43). Complementarily, despite the moderate and negative correlation observed between v V̇O₂max and Cslope (r=-0.47, P<0.01), TLim-v V̇O₂max did not correlate with Cslope (r=0.2, P=0.3).

No significant correlations were found between TLim-v V̇O₂max and absolute V̇O₂max (r=-0.16), relative V̇O₂max (r=-0.30), Ev V̇O₂max (r=-0.33), [La⁻]max (r=0.2) and HRmax (r=0.2), obtained in the incremental test (P>0.05). Likewise, no significant relationships (P>0.05) were reported between TLim-v V̇O₂max, [La⁻]max (r=0.05) and Δ[La⁻] (r=-0.2).

Discussion

To our knowledge, this is the first study that analyse the relationship between TLim-v V̇O₂max and SE. The used experimental approach seems to be pertinent because it combines two of the primary areas of interest in swimming training and performance diagnosis: the speed at maximal aerobic power (and the respective duration of sustained effort) and Cslope. Complementarily, this study has the advantage of been made with two level groups, to be conducted in normal swimming conditions and to consider both aerobic and anaerobic energy pathways to estimate the overall metabolic power in swimming performance. In this regard, although some authors remain defining C as the oxygen uptake at a given absolute exercise intensity, it was considered fundamental to quantify the contribution of the two main energy sources: 1) oxidative phosphorylation and 2) anaerobic glycolysis.

Considering that TLim-v V̇O₂max has an effort duration and intensity very similar with the 400 m freestyle event, it was tried to assess C relating the more traditional aerobic energy measurements with the assessment of anaerobic energy contribution, which has been proved to be significantly present in efforts lasting from 2-4 min.

Both HTS and LLS presented mean values of V̇O₂max similar to those previously described by others: higher values in HTS, like those found in well trained swimmers and moderate values in LLS, in accordance with the data for recreational and non-specialized swimmers. As expected, v V̇O₂max and Ev V̇O₂max were higher in HTS compared with LLS, which seems to reflect the superior training and performance level of the HTS group.

The TLim-v V̇O₂max values reported in this study for each group were similar to the data reported in swimmers of the same level. In fact, low-level athletes seem to present higher TLim-v V̇O₂max val-
ues than the high-level athletes, in different sports, and particularly in swimming.\textsuperscript{1,5} This subject will be addressed latter in the discussion. No differences between genders were observed in this parameter, indicating that the level groups were matched for gender regarding TLim-v VO\textsubscript{2max}.

From the present results and from the available data provided by the literature,\textsuperscript{2,3,5} it is likely that the individual performance in TLim-v VO\textsubscript{2max} test does not depend directly on the swimmers' VO\textsubscript{2max}. Despite the importance of the evaluation of VO\textsubscript{2} kinetics in swimming, VO\textsubscript{2max} by itself seems not to be considered anymore as one of the main performance determinants in this sport.\textsuperscript{7,11,29} This simply denotes that other factors rather than aerobic power may be taken into account, particularly in specific TLim-v VO\textsubscript{2max}-like efforts. Until this moment, the literature points out that the TLim-v VO\textsubscript{2max} in swimming seems to be direct and positively influenced by accumulated oxygen deficit,\textsuperscript{3} as well by the oxygen slow component,\textsuperscript{5} and inversely related to v VO\textsubscript{2max}.\textsuperscript{2,5,6} which was confirmed by the results of the present study, and to the 3.5 mmol/L\textsuperscript{-1} anaerobic threshold.\textsuperscript{5}

The first study that analysed swimming TLim-v VO\textsubscript{2max}, hypothesized that v VO\textsubscript{2max} depended on the C, even though no relationship between efficiency or C and TLim-v VO\textsubscript{2max} was reported until then.\textsuperscript{2} The data of the present study contributes, for the first time, with new insights into this topic.

Firstly, it was noted a linear increase in the individual \(\bar{E}\) values with swimming velocity. This is an open subject in the literature because other authors found out a cubic \textsuperscript{9,11,27} relationship between those two parameters. These cubic relationships seem to be explained by the fact that the total \(\bar{E}\) rate appears to adjust reasonably to the theoretical model, in which the power to overcome drag will equal the drag forces times the velocity and, thus, varies as a function of the cube of velocity.\textsuperscript{11} Despite this formulation and the late findings, the literature suggests a linear/v relationship.\textsuperscript{8,20,30} One possible explanation may be that, at higher velocities, swimming efficiency can increase, namely by the possible reduction of intra-cyclic speed fluctuations.\textsuperscript{20,31} Naturally, it is likely that, at even faster velocities, efficiency can drop once again (assuming a "U" inverted shape for the efficiency/velocity function),\textsuperscript{32} imposing that, considering even higher swimming speeds, C can increase relatively more than expected by the proposed model.

Secondly, we reported positive relationships between \(C_{\text{slope}}\) (and CV VO\textsubscript{2max}) and v VO\textsubscript{2max} and an inverse relationship between TLim-v VO\textsubscript{2max} and v VO\textsubscript{2max} (Figure 2). This last finding, previously reported in running and cycling \textsuperscript{1,2} and in swimming \textsuperscript{3,5,6} and the lower TLim-v VO\textsubscript{2max} values obtained by the high-level athletes, seem to suggest that the lower level of maximal aerobic metabolic rate of the less proficient swimmers may be associated with a large capacity to sustain that exercise intensity. In this sense, it must be realized that LLS performed the incremental test at lower absolute velocities than HTS, denoting that they could not perform at higher velocities (and longer) due to lower energetic capacity and to lower mechanical efficiency in late test steps.\textsuperscript{13} The reduction in the technical ability due to fatigue in LLS is well described,\textsuperscript{4,13,18} namely that advanced swimmers are able to swim with a greater distance per stroke than poorer swimmers at a given velocity.\textsuperscript{13,27} Thus, the fact that HTS presented significantly higher absolute v VO\textsubscript{2max}, CV VO\textsubscript{2max} and \(\Delta[La]\) values than LLS seems to suggest that the TLim-v VO\textsubscript{2max} effort made by the HTS was a more strenuous one. So, the use of a higher percentage of anaerobic capacity in the TLim-v VO\textsubscript{2max} test by the HTS can be, at least, one of the explanations for the reduced time at this specific effort, due to a more deleterious intracellular ambient (with accumulation of waste products), which could contribute to an earlier fatigue stage.\textsuperscript{2,3,33} However, we did not found any relationship between TLim-v VO\textsubscript{2max}, C, VO\textsubscript{2max} and \(\Delta[La]\).

For better comparison of the two level groups, it was considered the C\textsubscript{1,20} specific value, which was similar to those previously described.\textsuperscript{8,14,28} The HTS and LLS' C\textsubscript{1,20} values allowed the observation, for this velocity, that HTS had a lower C than LLS. This suggests that HTS require less energy for the same absolute velocity and/or they have highly efficient stroking mechanics or lower drag values (Table II and Figure 1).

Thirdly, it was verified the existence of a strong and inverse relationship between TLim-v VO\textsubscript{2max} and \(C_{\text{slope}}\), both when the entire group and each performance level groups were considered (Figure 3). This means that the swimmers with a lower SE slope profile, irrespective of their performance level, can sustain longer swimming exercise at v VO\textsubscript{2max}. Similar results were presented before relating C and the 400 m swimming distance.\textsuperscript{13,15,29} This fact seems to suggest that technical ability, considered as the ratio between drag and pro-
pelling efficiency, is a fundamental parameter in TLim-v \( VO_{2\text{max}} \) (and in swimming in general). In this regard, the better the swimming technique is, more metabolic power is devoted to move the body forward (overcoming drag) and less is wasted in giving to masses of water a kinetic energy change. Complementarily, it was observed that the aerobic metabolism did not directly influence the TLim-v \( VO_{2\text{max}} \), being, probably, the anaerobic performance capacity a very relevant parameter to these specific type of efforts, as suggested earlier.

The fact that the HTS presented a \( C_{\text{slope}} \) greater than LLS seems to contradict some data present in the specialized literature. However, it must be realized that the velocities performed in the incremental test were very different between the two level groups and, assuming that there is a strong link between the anaerobic capacity and SE profiles, it keeps suggesting that the HTS seems to reach more severe steps in the incremental test with higher anaerobic energy contribution.

Conclusions

This study confirmed SE as an important performance-influencing factor, appearing that the swimmers with higher \( C_{\text{slope}} \) and \( VO_{2\text{max}} \) performed less in TLim-v \( VO_{2\text{max}} \) efforts. Despite aerobic processes mainly supply TLim-v \( VO_{2\text{max}} \), the contribution of the anaerobic energy system might play an important role in this kind of workload in swimming. For a better knowledge of the complex group of factors that influence TLim-v \( VO_{2\text{max}} \), it is suggested a combined metabolic (with focus on anaerobic assessments) and biomechanical approach, relating some important technical parameters (e.g. stroke rate or stroke length) to the studied metabolic parameters.

References

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