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CRUCIAL SWIMMING VELOCITY PARAMETERS IN 2000 M FRONT CRAWL PERFORMANCE

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ABSTRACT

Purpose. The authors tried to point out the crucial factors determining swimming results in a 2000m front crawl race. Basic procedures. Two groups of subjects: G1 (16.8 ± 0.77 years) and G2 (14.7 ± 0.49 years) of 15 swimmers each took part in two incremental tests for assessing aerobic endurance of arms in arm cranking (VO2 max AR) and of legs in cycling (VO2 max LG). The applied procedure made it possible to simultaneously determine the anaerobic threshold AT (WL1 AR and WL1 LG) and the maximal oxygen uptake [l. min–1] (VO2 max AR and VO2 max LG). The 2000m front crawl race was recorded by means of a digital camcorder. On the basis of analysis of two complete cycles of swimming strokes, the stroke rate (SR), arm coordination index (IdC) and stroke phases (E, PL, PS, R) were computed. Main findings. The results of the hierarchic regression analysis showed that the factors connected with the front crawl technique, especially the coordination index (IdC) and stroke rate (SR), played a significant role among all the determinants of swimming velocity. On the other hand, no significant influence of stroke length (SL) on swimming velocity was found. Among the examined physiological indices swimming velocity was dependent only on the anaerobic threshold level (WL1 AR). Conclusions. Swimming velocity over the 2000m distance is determined mostly by the stroke rate (SR), coordination index (IdC) and anaerobic threshold level (WL1 AR).

Key words: swimming, stroke parameters, oxygen uptake, anaerobic threshold

Introduction

The front crawl is the most common stroke in swimming events. It is the fastest swimming technique, and it is also used by swimmers in swimming marathons and triathlons. The front crawl stroke is constantly refined affecting the swimmer’s velocity in the water. The development of the stroke is possible thanks to scientific data obtained from direct measurement of swimming parameters in aquatic conditions. Numerous studies point to the great significance of morphological and physiological determinants of the swimmer’s body in attaining the highest results in the crawl [1–7]. The front crawl stroke at a specific velocity (V) requires application of an effective swimming technique in which the stroke length (SL) and stroke rate (SR) of the motor cycles of arms are matched with the swimmer’s training level. The SL and SR depend on the swimming distance and swimming velocity.

The strategy of long-distance swimming consists in maintaining the steady and possibly the highest speed of motion. Each change of swimming velocity, e.g. acceleration, entails increased hydrodynamic resistance of the water in proportion to the swimmer’s squared velocity (Hollander et al. [8]). The world elite swimmers usually maintain a steady swimming velocity over the entire swimming distance; however, they also tend to modify the stroke parameters (SR and SL) as their fatigue increases [9–12]. Recent studies into the front crawl stroke, apart from analyzing swimming velocity, SR and SL, have also concentrated on the index of arm coordination (IdC) [13–16]. According to Chollet et al. [13] the index affects swimming velocity to a great extent.

The 2000m swimming test [17] was used in the study with regard to the specific characteristics of muscle work in swimming involving to a large extent aerobic metabolism. Swimming velocity over this distance is similar to the speed in a 1500m front crawl race or in long-distance swimming events (swimming marathons). In experienced swimmers it corresponds to exercise intensity above the maximal lactate steady state [18]. Swimming with such intensity for several minutes may even exceed the critical swimming velocity (Vcrit) [19]. It is only possible, however, in highly trained ath-
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M. Strzała, A. Tyka, P. Krężałek, Velocity parameters in the front crawl stroke

In consideration of the above observations it seemed necessary to examine relationships between selected somatic variables (body weight-length and structural indices) and physiological variables (VO₂max and anaerobic threshold WLT) and long-distance front crawl swimming velocity. Also the effect of swimming technique parameters on swimming velocity was determined.

Material and methods

Thirty well-trained swimmers from a school of sport championship at a high national and international level took part in the study. They were divided into two fifteen-member age groups G1 (16.8 ± 0.77 years) and G2 (14.7 ± 0.49 years) (Tab. 1). All subjects featured the level of biological development at 4–5° on the Tanner scale. In G1, 9 subjects featured a mesomorphic body build and 6 subjects had an ectomorphic body build; in G2, 10 and 5 subjects, respectively, according to Carter–Heath [2]. The total body length (TBL) was measured from the tips of the fingers with the arms stretched up above the head down to the pointed toes. The lean body mass (LBM) was calculated using the formula of Slaughter et al. [20]. All statistical correlations, tests of statistical significance, analyses of variance and hierarchical analysis of regression were made with the aid of SPSS software package (Version 12, USA). In the hierarchical analysis of regression were made with the aid of SPSS software package (Version 12, USA).

LBM was calculated using the formula of Slaughter et al. [20]. All statistical correlations, tests of statistical significance, analyses of variance and hierarchical analysis of regression were made with the aid of SPSS software package (Version 12, USA). In the hierarchical analysis of regression were made with the aid of SPSS software package (Version 12, USA).

Laboratory tests and swimming exercise test

The swimmers performed two incremental tests for assessment of aerobic capacity of arms (VO₂max AR) and legs (VO₂max LG). The VO₂max AR test was performed on an 834E-Ergomedic cycloergometer (Monark, Sweden) modified for arm cranking in a sedentary position, and the incremental VO₂max LG test on the ER 900 Jaeger ergometer (Germany). The VO₂max LG was preceded by a warm-up (WU) at the intensity of 45% VO₂max, after which the exercise intensity was increased by 30 watts every three minutes. The intensity of the warm-up in VO₂max LG amounted to 150 W in G1 and to 120 W in G2. The VO₂max AR test was preceded with a warm-up of intensity of 90 W in G1 and 60 W in G2, after which the exercise intensity was increased by 18 W and 12 W, respectively, every three minutes. The incremental tests were performed at 70 rpm⁻¹ in VO₂max LG and 60 rpm⁻¹ in VO₂max AR. The indices of respiratory exchange were determined using the 919ER MEDIKRO meter (Finland). During the last 30 seconds of each load segment in VO₂max AR and VO₂max LG tests blood samples were drawn from the earlobe and the blood lactate concentration (La) was marked with the aid of PLUS DR LANGE Miniphotometer (Germany). The applied research procedure in both incremental tests made it possible to estimate the anaerobic threshold AT (WLT AR and WLT LG) with the Dmax lactate method [21, 22] as well as the maximal oxygen uptake [1 l min⁻¹] (VO₂max AR and VO₂max LG).

The 2000m swimming race with the start from the water was held in a 50m-long pool. The swimmers’ movements were recorded by means of a GRV 9800 JVC digital camcorder (Japan) at 50 frames per second, from the side of the pool about one meter below the water surface. In biomechanical analysis the movements of the swimmer’s arms are cyclic. According to Chollet et al. [13] a movement cycle of the arm starts and ends with the arm’s entry into water (E). Each cycle was divided into four phases: E (Entry), PL (Pull), PS (Push), and R (Recovery). The propulsive phases were PL and PS; non-propulsive phases were E and R.

The following parameters were used in assessment of the swimming technique: stroke rate (SR), index of coordination (IdC) and stroke length (SL) understood as body’s translocation during one complete cycle. SL was calculated on the basis of the arm stroke rate and mean swimming velocity (V). The above mentioned parameters were marked for each swimmer after each 20m leg of the swimming distance, with the exception of the 5m distance before each turn. The analysis covered two complete stroke cycles. The duration of the swimming race and its individual legs was measured with a stopwatch with an accuracy of 0.01 s. The leg movement quantity (LQ) was calculated from the same footage as the arm movements. The leg movements were classified as six-stroke movements (performed for one complete cycle of arm movements), four-stroke movements and two-stroke movements. The front crawl indices were calculated from the footage after 8, 18, 28, and 38 pool lengths of the 2000 m swimming distance. After each 500 m a 30s break was taken to draw a blood sample (arterialized blood) to mark lactate concentration (La). The arm movements in the front crawl were divided into four stroke phases (following Chollet):
1) E (entry) – the time from the hand’s entry into the water until the commencement of the arm’s movement backwards; non-propulsive phase;
2) PL (pull) – the time from the commencement of the arm’s movement backwards until its positioning vertically downwards; propulsive phase;
3) PS (push) – the time from the positioning of the arm downwards until its drawing out of water; propulsive phase;
4) R (recovery) – the time from drawing the arm out of water until its re-entry; non-propulsive phase.

To assess the interaction of arms in propulsion the index of coordination (IdC) was calculated (similarly to the contribution of all stroke phases) as percentage of the entire cycle duration:

$$IdC = \frac{t_{PL} - t_{PL}}{T_c} \cdot 100\%$$

where IdC – coordination index of arms,

$t_{PL}^1$ – time of commencement of phase PL for the first arm,
$t_{PL}^2$ – time of commencement of phase PL for the second arm,
$T_c$ – time of the entire cycle.

In case the propulsive phases overlapped the IdC was positive; when they occurred following an intermission the IdC took negative values.

Results

The swimmers from both groups differed statistically in terms of their body height and total body length (TBL), arms stretch (AS) and body mass (BM and LBM) (Tab. 1). The anaerobic thresholds in both incremental tests also displayed statistically significant differences. In G1, the VO$_{2\max}$ AR the maximal oxygen uptake was higher than in G1; however, the difference was statistically non-significant per kilogram of body mass. The absolute values of VO$_{2\max}$ in the VO$_{2\max}$ LG test did not differ significantly between both groups; however, in terms of relative values they were higher among the younger swimmers.

The mean level of selected parameters of swimming (SR, SL and IdC) over this distance displayed statistically significant differences in both groups, with the exception of swimming velocity (Tab. 2). In the swimming test the swimmers from G2 reached higher SR and IdC (p < 0.05) than swimmers from G1, their SL was, however, lower. No statistically significant differences in post-exercise blood lactate concentration (La) were observed in G1 and G2. The percent contribution of leg actions for each cycle of arm movements amounted to 46.6% of six-stroke movements, 20% of four-stroke movements and 33.4% of two-stroke movements in G1; and 6.7%, 26.7% and 66.6% in G2, respectively.

In the analysis of swimming results over the controlled distance (every 500 m) the SR showed statistically significant differences in G1 and G2 in the 2nd and 3rd legs of the distance; IdC in the 2nd and 4th legs, whereas swimming velocity only in the 1st leg. The SL showed statistically significant differences in both groups of subjects over the entire distance (Tab. 3).

In the statistical analysis of changes of swimming technique in individual legs of the race ANOVA was used for all swimmers. It was noted that the length of arms cycles decreased linearly in both groups: in G1 (F = 12.16, df = 1.14, p < 0.01), and in G2 (F = 12.16, df = 1.14, p < 0.01). The decrease from the 1st to the 4th leg of the distance amounted to 3.87% and 4.64%, respectively. The blood lactate concentration (La) in both groups showed no statistically significant differences and increased linearly: F = 50.64, df = 1.14, p < 0.001 in G1; F = 34.81, df = 1.14, p < 0.001 in G2, which can be indicative of increasing contribution of glycolitic aner-

<table>
<thead>
<tr>
<th>Parameter</th>
<th>G</th>
<th>Age (years)</th>
<th>BH (cm)</th>
<th>BM (kg)</th>
<th>LBM (kg)</th>
<th>VO$_{2\max}$ AR (l min$^{-1}$)</th>
<th>VO$_{2\max}$ AR (l min$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>x, SD</td>
<td>G1</td>
<td>16.8 ± 0.77</td>
<td>182.2 ± 6.05</td>
<td>70.8 ± 5.40</td>
<td>62.5 ± 4.47</td>
<td>3.13 ± 0.38</td>
<td>3.71 ± 0.37</td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>14.7 ± 0.49*</td>
<td>175.7 ± 6.55*</td>
<td>62.4 ± 6.00**</td>
<td>56.2 ± 5.25*</td>
<td>2.83 ± 0.33*</td>
<td>3.56 ± 0.29</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>G</th>
<th>AS (cm)</th>
<th>BTL (cm)</th>
<th>WL$_{LT}$ AR (W)</th>
<th>WL$_{LT}$ LG (W)</th>
<th>VO$_{2\max}$ AR (ml min$^{-1}$)</th>
<th>VO$_{2\max}$ AR (ml min$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>x, SD</td>
<td>G1</td>
<td>187.0 ± 7.79</td>
<td>252.7 ± 9.43</td>
<td>124.80 ± 18.59</td>
<td>210.00 ± 27.77</td>
<td>44.51 ± 6.10</td>
<td>52.75 ± 6.45</td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>180.3 ± 8.13*</td>
<td>243.4 ± 10.51*</td>
<td>104.27 ± 14.42*</td>
<td>178.00 ± 28.83*</td>
<td>45.61 ± 4.94</td>
<td>57.96 ± 6.33*</td>
</tr>
</tbody>
</table>

*p < 0.05, **p < 0.001
Table 2. Statistical analysis of parameters of swimming velocity and the front crawl stroke and blood lactate concentration over the distance of 2000 m

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group</th>
<th>V (m·s⁻¹)</th>
<th>SR (cycles·min⁻¹)</th>
<th>SL (m)</th>
<th>Propulsive phases E+R (%)</th>
<th>Non-propulsive phases PL+PS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G1</td>
<td>1.37 ± 0.04</td>
<td>33.6 ± 0.06</td>
<td>2.28 ± 0.16</td>
<td>40.3 ± 5.69</td>
<td>59.7 ± 5.69</td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>1.34 ± 0.05</td>
<td>36.8 ± 4.41*</td>
<td>2.11 ± 0.20*</td>
<td>43.4 ± 9.42</td>
<td>56.6 ± 9.42</td>
</tr>
<tr>
<td></td>
<td>G1+G2</td>
<td>1.36 ± 0.06</td>
<td>35.2 ± 4.04</td>
<td>2.20 ± 0.20</td>
<td>41.8 ± 7.81</td>
<td>58.2 ± 7.81</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group</th>
<th>La (mmol·l⁻¹)</th>
<th>IdC (%)</th>
<th>E (%)</th>
<th>PL (%)</th>
<th>PS (%)</th>
<th>R (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G1</td>
<td>7.03 ± 2.09</td>
<td>-9.9 ± 5.13</td>
<td>38.0 ± 7.36</td>
<td>14.9 ± 2.71</td>
<td>25.4 ± 3.81</td>
<td>21.7 ± 2.78</td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>7.36 ± 2.14*</td>
<td>-4.6 ± 7.77*</td>
<td>33.7 ± 12.4</td>
<td>16.2 ± 4.6</td>
<td>27.2 ± 5.8</td>
<td>22.9 ± 3.93</td>
</tr>
<tr>
<td></td>
<td>G1+G2</td>
<td>7.19 ± 2.08</td>
<td>-7.3 ± 7.0</td>
<td>35.8 ± 10.26</td>
<td>15.5 ± 3.79</td>
<td>26.3 ± 4.90</td>
<td>22.4 ± 3.39</td>
</tr>
</tbody>
</table>

*p < 0.05

Table 3. Mean swimming velocity, selected parameters of the front crawl stroke and lactate blood concentration marked after each 500m leg of the 2000 m distance in G1 and G2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group</th>
<th>V (m·s⁻¹)</th>
<th>La (mmol·l⁻¹)</th>
<th>SR (cycles·min⁻¹)</th>
<th>IdC (%)</th>
<th>SL (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I 500 x, SD</td>
<td>G1</td>
<td>1.38 ± 0.05</td>
<td>5.95 ± 2.11</td>
<td>33.1 ± 3.08</td>
<td>-9.9 ± 5.7</td>
<td>2.32 ± 0.21</td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>1.33 ± 0.05*</td>
<td>5.56 ± 2.06</td>
<td>35.7 ± 5.13</td>
<td>-4.8 ± 8.3</td>
<td>2.15 ± 0.25*</td>
</tr>
<tr>
<td>II 500 x, SD</td>
<td>G1</td>
<td>1.38 ± 0.05</td>
<td>6.81 ± 2.15</td>
<td>33.5 ± 3.45</td>
<td>-10.6 ± 5.2</td>
<td>2.29 ± 0.17</td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>1.34 ± 0.05</td>
<td>6.89 ± 2.19</td>
<td>37.7 ± 4.61*</td>
<td>-4.8 ± 7.2*</td>
<td>2.14 ± 0.20*</td>
</tr>
<tr>
<td>III 500 x, SD</td>
<td>G1</td>
<td>1.37 ± 0.05</td>
<td>7.34 ± 2.19</td>
<td>33.6 ± 2.80</td>
<td>-9.2 ± 5.3</td>
<td>2.28 ± 0.18</td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>1.34 ± 0.05</td>
<td>8.15 ± 2.50</td>
<td>37.3 ± 4.36*</td>
<td>-4.3 ± 8.4</td>
<td>2.10 ± 0.21*</td>
</tr>
<tr>
<td>IV 500 x, SD</td>
<td>G1</td>
<td>1.34 ± 0.05</td>
<td>8.01 ± 2.10</td>
<td>34.3 ± 3.22</td>
<td>-10.0 ± 5.4</td>
<td>2.23 ± 0.15</td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>1.34 ± 0.05</td>
<td>8.83 ± 2.54</td>
<td>37.1 ± 4.71</td>
<td>-4.7 ± 7.8*</td>
<td>2.05 ± 0.20*</td>
</tr>
</tbody>
</table>

*p < 0.05

Oblic changes to the energetic expenses of muscle work in this exercise. The SR in G1 was more stable and its increase was statistically non-significant; similarly in G2 after covering the first 500 m.

In G1 swimming velocity (V) decreased significantly over the entire distance of 2000 m (F = 4.743, df = 1.14, p = 0.046); in G2 it was more stable (Tab. 3). In both groups the IdC altered more visibly over the entire swimming distance.

In both groups of swimmers the indices of swimming technique and biomechanical and physiological parameters (Tab. 1 and 2) were statistically non-significantly correlated with swimming velocity (V). It should be noticed that the anaerobic threshold in G2 (WL1+AR with V2000) was close to statistical significance (0.48, p = 0.07).

The leg movement quantity (LQ) in G1 was negatively correlated with the arms stroke rate (–0.50, p = 0.057). In the same group of subjects SL was positively correlated with LQ (0.46, p = 0.086).

The analysis of regression (Tab. 4 A and B) made it possible to examine correlations between selected parameters that affected swimming velocity in all subjects (n = 30), with the exception of the subjects' calendar age. Swimming velocity depended on the swimmers' age. Swimming velocity increased to 57.7%.

Discussion

Swimmers' circulatory and respiratory capacity as well as aerobic capacity expressed by the V˙O₂max level and the anaerobic threshold are considered by some authors [5, 7, 23–25] to be decisive in attainment of high sports results in front crawl swimming over long distances. The results of this study correspond partially to the data obtained by other authors. The swimming velocity reached by our swimmers over the distance of 2000 m was related, among the examined physiological...
parameters, to the anaerobic threshold (WLLTAR). The results of the analysis of regression point to parameters of the front crawl technique – the index of correlation, in particular – and arms stroke rate as having the greatest impact on swimming velocity. The IdC was shown to be highly correlated with the arm stroke, which was also observed in swimmers by Chollet et al. [13]. The IdC which was correlated with SR (over 0.6) was not used in the analysis. However, the calculation involving this index in a parallel model of regression showed a statistically significant correlation with swimming velocity (Beta = 0.725, t = 2.621, p = 0.015). As can be seen from the results of our study and other authors’ the so-called “opposition” coordination of arms movements revealing delay minimization between the propulsive phases of arms [13–15] was conducive to attaining a higher swimming velocity over a long distance. No significant effect of the arms stroke length (SL) on swimming velocity was observed.

Some authors suggest that performing longer arm movements engages the swimmer’s anaerobic metabolism to a greater extent [10, 11, 26, 27]. Such claims are also confirmed by Dekerle et al. [9], who noted a decrease in SL by 6.5% in front crawl swimmers during a 30min exercise with the maximal lactate steady speed. On the other hand, in swimmers who did not finish the race due to extreme fatigue the decrease in SL amounted to 11.4%. Pelayo et al. [4] noticed the significance of reduction of power in a motor cycle of arms in front crawl swimming over the distances of 1500 m, 800 m and 400 m. This allows maintaining a higher stroke rate (SR) for the entire race duration. These observations are confirmed by the results of our study, where the SL decreased significantly every consecutive 500 m of the distance, whereas the SR was more stable.

The above observations show that the decrease in the length of arms movement cycles during an exercise of intensity above the anaerobic threshold leads to muscle fatigue demonstrated by a higher lactate concentration in blood. That is why a swimmer’s high anaerobic threshold makes it possible to maintain his or her swimming velocity with the use of an optimal movement technique. On the other hand, it should be noticed that persistent maintenance of long SL by the swimmer may lead to increased fatigue and decline in SR and V. In this context the results achieved by Chollet et al. [28] who studied energetic effects of velocity and stroke rate control in swimmers over three 400m distances seem particularly interesting. They observed that post-exercise lactate concentration and the number of cardiac contractions was lower when the swimmers maintained a predetermined arm stroke rate than when the stroke rate was performed intuitively.

Our study showed that among the swimmers from GI the arms stroke rate was negatively correlated with leg movement quantity (LQ). On the other hand, in the same group the LQ was positively correlated with SL. These results show that some long-distance swimmers mostly focus on maintaining a convenient arms stroke rate while inhibiting the legs stroke rate.

In conclusion, it can be stated that the front crawl swimming velocity of young swimmers over a distance of 2000 m is mainly determined by the stroke rate and index of coordination. It also depends on the anaerobic threshold measured in an incremental test of arms movement (WLLTAR).

### References


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