Physiological and biomechanical analyses of a 200 m all-out front crawl

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ABSTRACT. This study aimed to analyze the effort effects of laps on general stroke kinematics and associate the peak oxygen uptake (VO2peak) with all-out 200-m front crawl time. Fourteen regional-level swimmers (age 16.14 ± 2.68 years; height 1.65 ± 0.08 m; body mass 58.17 ± 7.76 kg) performed an all-out 200 m front crawl. Oxygen consumption (VO2) was measured post-all-out 200 m trial to assess physiological variables and stroke mechanics was assessed based on the time to perform 10 m and to perform three complete arm stroke cycles. The 1st lap had a higher stroke rate (SR) than the 3rd lap (44.73 vs. 40.82 cycles min-1; p = 0.04). The 1st lap showed a higher mean swimming speed (SS) than the following laps (1.45 ± 0.10 vs. 1.35 ± 0.11 vs. 1.30 ± 0.11 vs. 1.28 ± 0.13 m s-1; p < 0.01) and the 2nd was greater than the 4th lap (p < 0.05). The swimming index (SI) was smaller and greater in the 3rd lap compared to the 1st and 4th laps (2.60 ± 0.65 vs. 2.97 ± 0.71 vs. 2.43 ± 0.50 m2 s-1 cycles-1), respectively. There was moderate and inverse coefficient of correlation between the VO2peak and 200-m time (rho = -0.653; p < 0.05). Our findings suggest that VO2peak values should be assessed in post 200-m all-out effort due to the strong shared variance with performance and a pacing strategy should be adopted during the race to avoid detrimental effects of fatigue.

Keywords: aerobic power; post-exercise VO2; swimming; middle-distance.

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Introduction

Swimming performance depends on anthropometric, psychological, environmental, biomechanical, and physiological factors (Barbosa et al., 2010a; Figueiredo, Zamparo, Sousa, Vilas-Boas, & Fernandes, 2011), among which the physiological and biomechanical aspects are the most investigated and controlled (Figueiredo et al., 2003; Monteiro et al., 2020). Competitive swimming performance depends on the swimmer’s maximal metabolic power (aerobic energy sources; Rodríguez, Chaverri, Iglesias, Schuller, & Hoffmann, 2017). Hence, the maximal oxygen uptake (VO2max) is considered an important performance factor that expresses maximal aerobic power. Assessing cardiopulmonary gas exchange and oxygen uptake (VO2) in swimming is a complex and cumbersome procedure that involves limitations imposed by the water environment and the equipment (Fernandes et al., 2012; Chaverri, Schuller, Iglesias, Hoffman, & Rodríguez, 2016). From a technical standpoint, the following two main indirect calorimetry approaches have been used to collect and analyze inspiratory gases in swimming: (I) measurements during exercise using snorkels with built-in valves connected to Douglas bags (Holmer, 1972), open-circuit metabolic carts (Fernandes et al., 2003) or breath-by-breath portable gas analyzers (Fernandes et al., 2012; de Jesus et al., 2015) and (II) post-exercise measurements with gas collection via face mask or mouthpiece connected to Douglas bags or open-circuit metabolic carts (Rodríguez et al., 2017).

The VO2post-exercise measurements (i.e. gas collection after swimming only) by estimating the peak oxygen uptake (VO2peak) and the oxygen uptake efficiency slope (OUES) has been pointed out as a good surrogate replacing the role of VO2peak to assess cardiorespiratory fitness in samples that cannot attain maximal effort (Han et al., 2021). Therefore, VO2post-exercise measurement can be applied to maximal tests in field conditions where the annoying valve system could affect the performance and improve the estimation error (Leger, Seliger, & Brassard, 1980; Chaverri et al., 2016; Rodriguez et al., 2017). The post-exercise VO2 measurements during a 200-m all-out swim allowed us to estimate exercise VO2peak in elite competitive swimmers with good accuracy (Chaverri et al., 2016). Estimating post-exercise VO2peak allows swimmers to perform completely unrestricted (i.e., without a mouthpiece, snorkel, or tubing), which is a clear
advantage for pool testing and research provided that VO₂ can be estimated with sufficient accuracy (Rodríguez et al., 2017). The VO₂peak proved to be very closely related to short- (100-m; r² = 0.62) and middle-distance events performance (400-m; r²=0.56; Rodríguez, Keskiner, Keskiner, & Malvela, 2003); however, it has not been tested for regional-level swimmers.

Managing the stroking parameters is a key performance aspect that coaches should consider when designing training (Cortesi, Di Michele, Fantozzi, Bartolomei, & Gatta, 2021). Recent studies have widely adopted 200-m maximal swims for competitive swimmers (Figueiredo et al., 2011) due to its average duration (~2 min to 2.5 min on average), sufficient to elicit VO₂max in most cases (Rossiter, Kowalchuk & Whipp, 2006). In a 200-m front crawl race, the inter-lap stroke rate (SR) develops a U-shaped manner with a smooth increase at the end of the effort to compensate for the decrease in stroke length (SL) because of the augmented effort when attempting to maintain a constant speed (Figueiredo, Sanders, Gorski, Vilas-Boas, & Fernandes, 2013; Koga et al., 2024). Thus, swimmers adjust their speed by adapting their SR and SL since an almost even pace is optimal for 200-m swimming performance across all strokes (Figueiredo et al., 2011; Figueiredo et al., 2013; Franken, Ludwing, Cardoso, Silveira, & Castro, 2016). Biomechanical and physiological factors have strongly influenced the middle-distance event performance and should be analyzed in conditions like those of free swimming in a pool (Jürimäe et al., 2007).

Therefore, different parameters that might affect swimming performance should be further studied considering both physiological and biomechanical aspects (Jürimäe et al., 2007). This study aimed to assess the VO₂peak through the post-exercise method and general stroke kinematics during a 200-m performance by comparing the swimmers’ mechanics comparing the laps and correlating the VO₂peak and OUES with 200-m time. We hypothesized that swimmers would change their stroke frequency, length, stroke index, and velocity, showing fatigue effects; in addition, a strong association among the VO₂peak OUES, and 200-m front crawl performance would be observed. Our study might contribute to highlighting evidence for regional-level swimmers concerning training adjustments and performance improvement.

**Material and methods**

Fourteen regional-level front crawl swimmers volunteered to participate in this study. The participants had the following individual and mean (±SD) values for the subjects’ main physical and performance features: age 16.14 ± 2.68 years, height 1.65 ± 0.08 m, and body mass 58.17 ± 7.76 kg. The swimmers had at least 4 years of competitive experience and trained normally during the data collection (5 ± 1 day) period with 4,000 ± 300 m of volume per session. This study was conducted in the first macrocycle (6 weeks) of the training season. All swimmers were in the base training period during the protocol. All the procedures described following were approved by the institutional ethics committee, according to the Helsinki Declaration for human experiments. All participants were fully informed on the procedures and demands of the study and signed a written informed consent form approved by the institutional ethics committee, according to the Brazilian Council of Ethics in research with human subjects.

The test sessions took place in a 25-m indoor swimming pool with a water temperature of 27.5°C. After a standard competition warm-up (Chaverri et al., 2016), all subjects rested outside the water while the equipment was set up and calibrated for the experiments. The swimmers performed an all-out 200-m front crawl with a block start and with no companions in the same lane or either one next to it to determine VO₂peak. Time was manually recorded to the nearest 0.01 s by three experienced timers, and the median values were used for analysis. The swimmers were encouraged to swim with their best effort.

The swimmers performed the 200-m effort without the respiratory equipment (i.e. completely unrestricted swimming; cf. Rodríguez et al., 2017). The VO₂ was collected using a portable metabolic system (VO2000, The Med Graphics, Minnesota, USA), with a patented flowmeter and a proportional sampling valve and a 3-breath average to measure VO₂, carbonic gas volume (VCO₂), ventilatory expiration (VE), and VO₂ efficiency slope (OUES). For a more detailed, see Crouter, Antezak, Hudak, DellaValle, & Haas, 2006; Jürimäe et al., 2007; Han et al., 2021.

The VO2000 was calibrated according to the manufacturer’s instructions before testing, by performing an auto-calibration routine on a software using a proprietary room air calibration of the oxygen and carbon dioxide analyzers, as well as an auto-calibration procedure for the pneumotach. The software program used for the VO2000 does not allow for a two-point calibration using known gas volumes or manual calibration of the pneumotach with a calibration syringe.
The oronasal mask (VO2000, The Med Graphics, Minnesota, USA) was firmly applied immediately after the swim with care to avoid leakage and to minimize the time before the first respiratory data with the subject resting in the water in an upright position immersed to the mid-sternum (Wahrlich, Anjos, Going, & Lohman, 2006; Chaverri et al., 2016). The swimmers were instructed about the proper technique before the test or repeated measures and a Mauchly test verified the data sphericity. The main effects were checked by a posthoc Bonferroni to compare values of SR, SL, SS, and SI among laps L1, L2, L3, and L4, respectively. ANOVA was applied for repeated measures and a Mauchly test verified the data sphericity. The main effects were checked by a posthoc Bonferroni to compare values of SR, SL, SS, and SI among laps L1, L2, L3, and L4 of 200 m. The effect size (eta squared) was also calculated. The level of significance was set at p < 0.05 and all statistical analyses were performed on SPSS 23.0 for Windows.

**Results and discussion**

Table 1 presents the anthropometric characteristics (age, body mass, and height), performance in the 200-m front crawl, and VO₂peak of the group of swimmers.

<table>
<thead>
<tr>
<th>Sample characterization of the group of swimmers evaluated; n = 14.</th>
<th>VO₂peak (mL kg⁻¹ min⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>16.14</td>
</tr>
<tr>
<td>Minimum</td>
<td>13.08</td>
</tr>
<tr>
<td>Maximum</td>
<td>23.14</td>
</tr>
</tbody>
</table>

The group of swimmers (n = 14) reached a mean velocity of 1.42 ± 0.12 m·s⁻¹ in the 200-m front crawl performance. Table 2 presents the values of SR, SL, SS, and SI obtained from 25-m sections before laps of 50, 100, 150, and 200-m (L1, L2, L3, and L4, respectively). A decrease in SR values was found only between L1 and L3 (F₁₃₉ = 4.089; p < 0.05; η² = 0.259). The laps of the 200-m performance had similar SL values (F₃₁₁ = 2.076; p = 0.162; η² = 0.362). Furthermore, lower SS values were found only between L1 and L2, L3 and L4, and L2 and L4 (F₃₁₉ = 22.279; p < 0.001; η² = 0.632). Lower SI values were found only between L1 and L3 and L4 of 200 m. The effect size (eta squared) was also calculated. The level of significance was set at p < 0.05 and all statistical analyses were performed on SPSS 23.0 for Windows.

Table 3 shows the correlation matrix between the time values in the 200-m swimming front crawl performance and the VO₂peak respiratory quotient (RQ), and OUES for the group of swimmers (n = 14).

According to Table 3, a negative and significant correlation was found only between VO₂peak and time in the performance of the 200-m front crawl (rho = -0.653; p = 0.011), thus indicating that the higher the VO₂peak values, the lower the values of the time variable in the performance of 200-m front crawl swimming.

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metabolic power (aerobic energy sources; Rodríguez et al., 2017). Prepubertal swimmers (e.g. reducing body rolling) and breathing patterns, thus unabling to perform diving starts or flip turns (Barbosa et al., 2007). The moderate association between VO\textsubscript{2peak} and 200-m front crawl performance was expected since competitive swimming performance depends on the swimmer’s maximal metabolic power (aerobic energy sources; Rodriguez et al., 2017).

Table 2. Stroke rate (SR), stroke length (SL), mean swimming speed (SS), and stroke index (SI) in laps L1 (25-50 m), L2 (75-100 m), L3 (125-150 m), and L4 (175-200 m) of 200 m front crawl; n = 14.

<table>
<thead>
<tr>
<th>Variables</th>
<th>L1</th>
<th>L2</th>
<th>L3</th>
<th>L4</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR (cicles·min\textsuperscript{-1})</td>
<td>44.72 ± 9.98</td>
<td>43.15 ± 9.38</td>
<td>40.82 ± 8.61a</td>
<td>42.54 ± 8.88</td>
</tr>
<tr>
<td>SL (m)</td>
<td>2.06 ± 0.59</td>
<td>2.00 ± 0.63</td>
<td>2.00 ± 0.53</td>
<td>1.90 ± 0.43</td>
</tr>
<tr>
<td>SS (m·s\textsuperscript{-1})</td>
<td>1.45 ± 0.10</td>
<td>1.35 ± 0.11a</td>
<td>1.30 ± 0.11</td>
<td>1.28 ± 0.15a</td>
</tr>
<tr>
<td>SI (m·s\textsuperscript{-1}·cycles\textsuperscript{-1})</td>
<td>2.97 ± 0.71</td>
<td>2.71 ± 0.84</td>
<td>2.60 ± 0.65a</td>
<td>2.43 ± 0.50a</td>
</tr>
</tbody>
</table>

*a indicates difference from L1 to L3 (p<0.05); L indicates differences from L1 to L2, L3 and L4 (p<0.05); II indicates difference between L2 and L4 sections (p=0.05).

Table 3. Spearman’s test correlation matrix values (rho) between time in 200 m swimming front crawl performance (200 m performance) and the peak oxygen uptake (VO\textsubscript{2peak}), the respiratory quotient (RQ), and the oxygen uptake efficiency slope (OUES) for the group of swimmers; n = 14.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Means and Standard Deviations</th>
<th>200 m performance (rho; p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO\textsubscript{2peak} (ml·kg\textsuperscript{-1}·min\textsuperscript{-1})</td>
<td>35.21 ± 5.54</td>
<td>rho = -0.655*; p = 0.011</td>
</tr>
<tr>
<td>RQ</td>
<td>1.44 ± 0.11</td>
<td>rho = -0.272; p = 0.546</td>
</tr>
<tr>
<td>OUES</td>
<td>35.21 ± 5.54</td>
<td>rho = -0.175; p = 0.549</td>
</tr>
<tr>
<td>200 m performance (s)</td>
<td>141.58 ± 12.39</td>
<td>-</td>
</tr>
</tbody>
</table>

The VO\textsubscript{2peak} during a 200-m unrestricted front crawl effort allows testing swimmers under conditions very similar to the competitive situation without altering in any way the swimming mechanics(Chaverri et al., 2016; Rodríguez et al., 2017). This study aimed to analyze the effects of the 200 m all-out front crawl effort laps in the general stroke mechanics and verify the association among VO\textsubscript{2peak}, OUES, and 200-m time. Our main findings partially confirm our hypothesis, as follows: (i) the 1st lap had a higher SR than the the 3rd lap; the 1st lap had a higher SS than the subsequent laps; the 2nd lap was greater than the 4th lap (p < 0.05); the 3rd lap had a higher SI than the subsequent laps, and (ii) moderate and inverse coefficient of correlation appeared between the VO\textsubscript{2peak} and 200-m time and the OUES does not seem to relate to performance.

As expected, the stroke mechanics management changed along the 200-m effort (Figueiredo et al., 2013; Cortesi et al., 2021). The SR behavior corroborated previous results indicating a U-shape, although an increase in the last lap was not significant (Figueiredo et al., 2013). Despite SS and SI decreasing during the effort, the SL did not change. The most commonly used pacing strategies for elite swimmers’ 200-m front crawl are parabolic shaped, with a fast followed by an evenly paced midsection and a fast end sprint(Figueiredo et al., 2011; Cortesi et al., 2021).

Based on our results, swimmers can maintain certain SR along a swimming test but are usually unable to maintain SL values due to potential fatigue. Similar SS behavior was found for the 200 m front crawl among the 16 finalists of the 200 m freestyle race at the French National Championship, including four high-competitive level and six competitive Portuguese swimmers (Figueiredo, Vilas-Boas, Seifert, Chollet, & Fernandes, 2010). The study indicated that the SS decreased between the L1 and the L4 of the race. Such lower SL would be related to the inability to maintain the swimming technique, which would allow a larger distance traveled in each stroke cycle. In contrast, an attempt to eliminate the effect of the reduced SL on the SS values would be to increase SR. These results might be explained by the development of localized muscle fatigue(Zamparo, Turri, Peterson, & Poli, 2014), resulting in a lesser ability to generate power (Toussaint & Truijens, 2005).

Since Montpetit, Léger, Lavoie, and Cazorla (1981), the validity of VO\textsubscript{2max} conventional test assessment has been questioned due to several reasons (e.g. mechanical changes), including regarding the measurements of VO\textsubscript{2peak} during maximal free crawl swimming using post-exercise VO\textsubscript{2} assessment. Previous studies indicated a higher mean speed at which the VO\textsubscript{2peak} was reached in swimming without equipment (~13 to 16% and 5 to 6% in 100 m and 400-m front crawl) than during the conventional test with mouthpiece and tubing(Rodríguez et al., 2017; Montpetit et al., 1981). The use of swimming snorkels might alter swimming technique mechanics (e.g. reducing body rolling) and breathing patterns, thus unabling to perform diving starts or flip turns (Barbosa et al., 2010b). Herein, swimmers obtained absolute VO\textsubscript{2peak} values below those found in the literature involving elite swimmers (absolute values ~3.5 assessed post-exercise; e.g.Chaverri et al., 2016), however close to the prepubertal swimmers (Jürimäe et al., 2007).
Post-exercise VO₂ measurements allow swimmers to exercise without being hindered by the respiratory equipment and exploit their maximal potential (Montpetit et al., 1981; Chaverri et al., 2016; Rodríguez et al., 2017). Despite our important findings, some limitations might be pointed out, such as the absence of a wider range of metabolic variables assessed and a more detailed kinematic analysis.

Conclusion

Assessing cardiorespiratory fitness in cases where the swimming technique has to be maintained and race speed is to be reached requires carrying out all-out, fully unrestricted swimming for the swimmers to perform without being hindered by the respiratory equipment. Our results allow us to conclude that (I) SR changed between the 1st and 5th laps and SS and the 1st lap had a higher SI than the subsequent laps; in addition, (II) a moderate and inverse coefficient of correlation was found between the absolute VO₂peak and 200-m time. Understanding the physiological and biomechanical changes in 200-m all-out front crawl in regional-level swimmers based on the post-effort VO₂ assessment method might improve the application of appropriate training stimuli.

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