CAN INTRA-CYCLIC FORCE VARIATION BE A VALUABLE PARAMETER TO EVALUATE THE FORCES EXERTED BY SWIMMERS?

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The purpose of this study was to examine the force pattern produced during the front crawl swimming cycle, plus to analyze possible relationships of intra-cyclic force variation (*d*F) with swimming performance. Thirty four competitive swimmers, representing various levels of competitive performance (17.2 ± 2.72 yrs; 1.76 ± 0.09 m; 67.4 ± 9.94 kg; personal best 100 m long course freestyle swimming: 58.39 ± 2.19 s), randomly performed the tethered and free swimming tests. The free swimming velocity was found to be negatively correlated with *d*F ($r = -0.85$; $p < 0.001$). Adding *d*F with maximum impulse per cycle into a multiple regression model, it was possible to explain 87.6% of the 50 m performance variation. This novel parameter (*d*F) showed to be a valuable variable to evaluate the swimmers ability to effectively apply force in the water.

KEY WORDS: tethered swimming, force, front crawl, training and testing.

INTRODUCTION: Swimming is considered a cyclic exercise, with swimmers aiming to accomplish a certain distance in the lowest time possible and with exercise economy being considered one of the major factors that influence performance. One of the cited procedures to infer about the more or less economic swimming technique is through the intra-cyclic velocity variations (*d*v). These velocity variations and swimming performance are related, with most studies stating that a higher *d*v leads to a lower swimming velocity (Vilas-Boas et al., 2011), regardless of the swimming technique. However, the nature (linear vs. non-linear) of this relationship can diverge, according to age, level or swimming technique. Recently, it was examined the relationships between *d*v and the swimming velocity of the 4 conventional swimming techniques in young swimmers being observed that *d*v and velocity are related, but through a non-linear relationship (Barbosa et al., 2013). Given that *d*v depend on the action of the propulsive and drag forces resultant (Vilas-Boas et al., 2011), theoretically, the higher *d*v is imposed by a higher variation of these forces.
However, the assessment of exerted forces in free swimming is challenging, being one of the major concerns over the past years. One available methodology is the use of a load-cell to register the forces exerted while swimming tethered to the starting block (Morouço et al., 2014). This methodology presented a similar muscular activity (Bollens et al., 1988) and oxygen consumption (Lavoie & Montpetit, 1986) to those obtained in free swimming and is highly reliable (Kjendlie & Thorsvald, 2006). Indeed, it has been extensively used to evidence that force exerted in water is a major factor for success. Furthermore, the contribution of force exertion for swimming performance over short distances has been examined through a wide spectrum of swimming performances (Morouço et al., 2014) and revealed that maximum force exerted in the water, as *d*v, presents a non-linear relationship with swimming performance. These results suggest that both *d*v and force have a major role in the performance enhancement till a certain level, but it may be questionable if these parameters can explain variability in very high swimming velocities. Furthermore, this breakdown may lead to a new point of view: swimming velocity is dependent on velocity variations, which are

dependent of the forces exerted. Thus, is it possible to calculate the force variations and, if so, would it add any valuable information regarding the swimmers evaluation?
The purpose of the present study was to examine the force pattern produced during the front crawl swimming cycle, in a population of male swimmers representing various levels of competitive performance to assure more reasonable generalizability. Additionally, the association of intra-cyclic force variations with swimming performance was analysed.

METHODS: *Subjects:* Thirty-four competitive swimmers, with different competitive levels (age: 17.2 ± 2.72 yrs; height: 1.76 ± 0.09 m; mass: 67.4 ± 9.94 kg; personal best 100 m long course freestyle swimming: 58.39 ± 2.19 s), were selected for the study. The swimmers were recruited from national swimming teams and had at least 5 years of experience in competitive swimming. All subjects were male and have not reported any injury or restriction that hindered their performance, within the last 6 months prior to testing. The study protocol was fully approved by the Human Research Ethics Committee and informed consent was obtained prior to testing. All procedures were in accordance with the Declaration of Helsinki in respect to human research. *Apparatus:* An uni-axial calibrated strain-gauge load cell (Model ABA Ergo Meter, Globus, Codogne, Italy) was fixed to the starting block with a chain locked, which was proofed and tested prior to data collection. The calibration was verified with the use of 5, 10 and 20 kg standard weights. On the other end, the load cell was connected to a steel cable fixed on the swimmers' hip. Data was recorded at 100 Hz (maximum measurement capacity of 4905 N) and exported to a laptop by an ergometer data acquisition system (Globus, Codogne, Italy). *Procedures:* Swimmers randomly performed the tethered and free swimming tests 24 h apart, ensuring that both conditions were assessed at the same time of day. Preceding each test, a 1000 m moderate intensity warm-up (400 m swim, 100 m pull, 100 m kick, 4 x 50 m at increasing speed and 200 m easy swim) was completed in a 50 m indoor swimming pool (water temperature of 26–27° C). The tethered swimming test consisted of a 30 s front crawl maximal trial. Reliability and validity studies were conducted prior to the actual testing (n = 8). The participants underwent familiarization trials to the tethered apparatus before data collection. The free swimming condition was evaluated with a 50 m front crawl maximal bout, following an underwater start. Swimmers were verbally encouraged throughout the tests to maintain maximal effort during the bouts. *Measurements:* Tethered swimming data was exported to signal processing software (AcqKnowledge v.3.7, Biopac Systems, USA) and filtered through a 4.5-Hz cut-off low-pass filter. The cut-off value was chosen according to residual analysis (residual error versus cut-off frequency). As the force vector in the tethered system presented a small angle to the horizontal, data was corrected by computing the horizontal component of the force, assessing the individual force-time curves. Following, maximum and mean force and maximum and mean impulse of force were estimated for each participant. The intra-cyclic variation of the horizontal force exerted (dF) was calculated as:

$$dF = \frac{\sqrt{\frac{\sum_i (F_i - F)^{-2} \cdot f_i}{n}}}{\frac{\sum_i F_i \cdot f_i}{n}} \cdot 100 \qquad (1)$$

where F represents the mean force of the cycle, Fi represents the instantaneous force, fi represents the acquisition frequency and n is the number of observations. For further analysis, the dF mean value of 8 consecutive cycles was considered. Swimming velocity was calculated from the time for the 50 m (v50) free swim. *Statistical Analyses:* For the validity and reliability studies, 8 swimmers completed 2 tethered swimming tests in consecutive days. The normality of all distributions was verified using Kolmogorov-Smirnov tests and parametric statistical analysis was adopted. Pearson correlation coefficients (r) were determined to assess the relationships among selected variables and linear and non-linear regression analyses were applied to evaluate the potential associations. Multiple regression analysis was used to verify the combination of significant variables that could explain performance variability in the free swimming. Intraclass correlation coefficients were used to assess the validity of procedures. All statistical procedures were performed using SPSS 20.0 (Chicago, IL, USA). The level of statistical significance was set at $p < 0.05$.

RESULTS: Using the proposed equation 1, *d*F was assessed ranging between 83.9 and 51.3%, with a mean of 68.12 ± 10.20%. The *d*F was found to be negatively correlated with both the maximum and average force (r = -0.77 and r = -0.87; $p < 0.001$, respectively) and the maximum and average impulse (r = -0.78 and r = -0.65; $p < 0.001$, respectively). Intraclass test-retest correlation coefficients were between 0.95 (0.92 to 0.98) and 0.98 (0.96 to 0.99) for the force measurements (n = 8). The free swimming velocity was found to be negatively correlated with *d*F (r = -0.85; $p < 0.001$), as exposed in Figure 1 (panel A). Adding the *d*F with maximum impulse (maxI) into a multiple regression model (cf. Figure 2, panel B), it was possible to explain 87.6% of the 50 m performance variation (v50 ($m.s^{-1}$) = $1.497 + 5.5 \cdot 10^{-3}maxI - 3.5 \cdot 10^{-3}dF$; $R^2 = 0.876$; $R^2_a = 0.868$; SEM = 0.037; $p < 0.002$). The model obtained a standard error of predicted value ranging between 0.006 and 0.019.

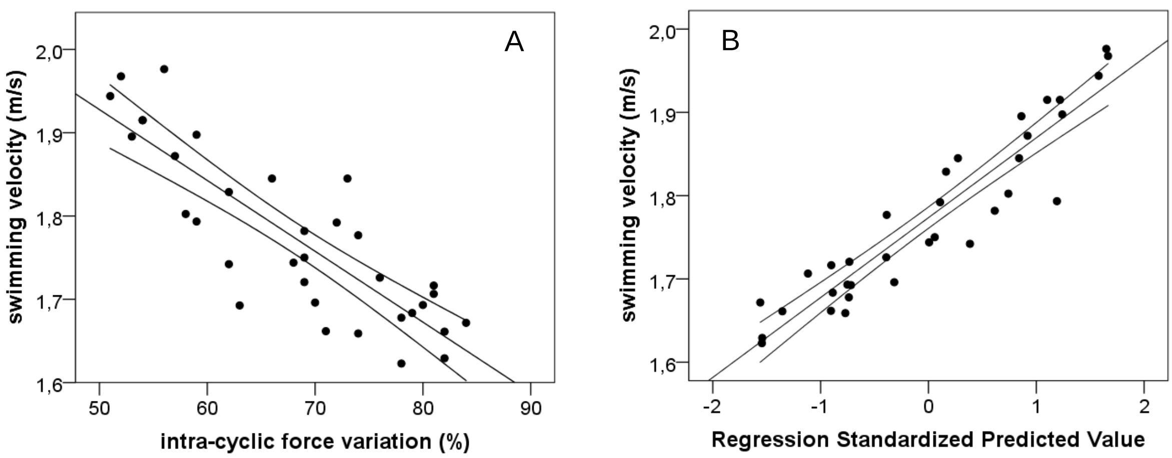

Figure 1: The scatter plots of the relationships between the swimming velocity and the intra-cyclic force variation (panel A) and with the multiple regression model standardized predicted value (panel B).

DISCUSSION: The aim of the present study was to examine the force pattern produced during the front crawl swimming cycle and to analyse possible associations between intra-cyclic force variation and swimming performance. The main finding was that *d*F can be used as a valuable parameter to monitor the forces exerted by swimmers. Its use enables a more accurate evaluation for very high swimming velocities, as the relationship when it is considered tend to be linear.

Recently, the free swimming velocity was found to be highly correlated with maximum impulse (cf. Morouço et al., 2014). In fact, it was proposed that maximum impulse per cycle should be used to evaluate the balance between force and the ability to effectively apply force during sprint swimming. This was based on the assumption that propulsion occurs during the entire propulsive phase of the cycle (Marinho et al., 2011), thus, the effect of force with respect to time should be considered. Keeping this in mind, the variation of force along the cycle may also be valuable. In the present study, this was confirmed by the very high negative relationship between *d*F and swimming velocity (cf. Figure 1, panel A). However, more studies need to be conducted so that values of *d*F can be compared (e.g. age or gender effect) and give a clearer interpretation of its magnitude.

Coaches have the perception that the evaluation of their swimmers should be specific and try to mimic the nature of the sport. Hence, it is not only essential to choose an adequate methodology to be applied, but also to calculate the appropriate parameters. Previously, intra-cyclic variations of velocity (Vilas-Boas et al., 2011; Barbosa et al., 2013) or acceleration (Tella et al., 2008) were studied. It is well known that swimming velocity is the result of: (i) a circumstantial prevalence of total propulsive forces or the drag force, or; (ii) a consequence of an increased (or decreased) added mass effect during a given swim cycle (Vilas-Boas, et al. 2011). Therefore, the estimation of propulsive forces is important to identify determinant factors for swimming performance enhancement (Marinho et al., 2011). Accordingly, tethered swimming allows the measurement of exerted forces assessing individual force-time curves during the exercise. Consequently, its use improves the possibility of analysis and comparison of swimming technique profiles and allows to accurately knowing the sequence of propulsive forces during swimming (Keskinen, 1997). This is a pioneer study demonstrating that the variation of force exertion during a cycle is a valuable parameter to evaluate swimmers. The proposed model explained more than 85% of performance variability, proofing of concept to the interpretation of high swimming velocities.

CONCLUSION: Tethered swimming allows the evaluation of forces exertion during swimming, enabling the assessment of the force variation within a cycle. Thus, this novel parameter – intra-cyclic force variation – showed to be a valuable variable to evaluate the swimmers ability to effectively apply force in the water.

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