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NOVEL INSIGHTS INTO AN OLD METHODOLOGY: UPGRADING THE USE OF TETHERED SWIMMING

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More than 40 years ago, Magel (1970) used tracings with a compensating polar planimeter to measure propelling forces in swimming. By that time, average height of the curves was calculated in millimetres and converted to average force measures. Advances in technology, permitted picking up old methodologies and give them new features. In fact, the use of a force transducer to assess the forces exerted by a swimmer in his/her real environment turned out to be a useful methodology for training prescription. Nowadays, a load-cell can continuously record the force-time curves and to straightaway provide the calculation of several variables. Thus, swimmers can perform a tethered test with immediate feedback, enhancing the effects for performance improvement. This paper aims to identify and describe procedures that fits the purpose of biomechanical evaluation, i.e., to provide the necessary tools for training prescription, rapidly after the evaluations.

KEY WORDS: biomechanics, swimming, force, performance.

INTRODUCTION: It is undeniable that swimming performance is dependent on the ability of the swimmer to apply force (effectively and efficiently) in a fluid environment (Vilas-Boas, Fernandes & Barbosa, 2010). Furthermore, sport biomechanics has been demonstrating that the movements used in training should be mechanically similar to those used in competition (Barbosa et al., 2010). Thus, it can (and should) be used as a primordial resource for the correct evaluation and prescription of swimmers training.

More than 40 years ago, Magel (1970) used a planimeter to estimate the propulsive forces for each of the swimming techniques. By that time, the mean height (in millimeters) of the curves for each stroke was measured and, later, converted to mean force values. Recognizing the validity of the measurement being performed in the water, several studies were done examining the relationship of this test and swimming performance. However, the technological limitations of that time inhibited rapid achievement of results and conclusions about other factors that affect swimming performance. Advances in technology turned possible to give it new functionalities. Nowadays, the use of a force transducer to evaluate the forces exerted by a swimmer, maintaining ecology (measuring the forces applied in the water), has become a useful method for the evaluation and prescription of training, in several variants of aerobic (Kalva-Filho et al., 2016), or anaerobic (Loturco et al., 2016) domains.

This methodology, commonly referred to as tethered swimming, has already been described as one of the most specific ergometers for swimming (Pessôa-Filho & Denadai, 2008), since it presents high similarities with free swimming for maximum oxygen consumption (Lavoie & Montpetit, 1986) and muscular electrical activity (Bollens et al., 1988).

The objective of the present study was to examine the potential of biomechanics, by measuring the propulsive forces exerted in water, for the evaluation and training prescription of high-level swimmers.

METHODS: The study included 22 high-level male swimmers (18.6±2.4 years old, 1.79±0.09 m of stature, 70.1±9.0 kg of body mass, 56.2±2.8 s PB at 100-m front crawl in long course), who voluntarily agreed to participate in the study. They had a minimum of 6 years of competitive practice, participation in territorial and national representations, and previous experience with the tethered swimming test. Participants' informed consent was obtained and all procedures complied with the Declaration of Human Rights of Helsinki 1975. In 48-hours, swimmers randomly performed in a 50-m pool, after 1000-m warm-up (400-m free at low intensity, 100-m only upper limbs, 100-m only lower limbs, 4x50-m with progressive velocity increase and 200-m free at low intensity) (Neiva et al., 2014), and at maximum intensity: (i) 50-m front crawl; and 30-s tethered swimming (ii) with all-body; (iii) only with the upper limbs; and (iv) only with the lower limbs (for more details Morouço et al., 2015a).

A load-cell (Globus, Codognè, Italy) was attached to the starting block and measured with an acquisition frequency of 100-Hz; was attached to the swimmer through a 3.5-m iron cable with insignificant extensibility. Using signal processing analysis software (AcqKnowledge v.4.0, Biopac Systems, Santa Barbara, USA), the data were filtered according to the cut-off value of the residual analysis. After rectifying the angular force (Morouço et al., 2011), the force-time curves were obtained and visualized for each of the tests performed, and calculated for each test (when applicable), of each participant: (i) the maximum force value as the maximum value recorded in the test; (ii) the mean test force, as the arithmetic mean of the force values in the 30-s; the mechanical impulse, as the integral of the force-time curve by stroke, (iii) maximum and (iv) mean. The time obtained in free swimming was considered as the reference value for performance.

After testing the reliability (with 8 swimmers who repeated the tests within 48-hours), normality and homogeneity were verified and parametric statistics were adopted for: (i) comparison of means (repeated measures and independent measurements); (ii) correlation between variables; and (iii) linear and nonlinear multiple regression. It was adopted a significance level of $p<0.05$.

RESULTS: The ICC values ranged from 0.94 (0.90-0.97) to 0.97 (0.95-0.98) for the parameters evaluated (n=8). Of the 22 swimmers tested, 17 had a (a)symmetry index (Robinson, Herzog & Nigg, 1987) greater than 10%. Figure 1 shows the asymmetric force application behaviour over the 30-s. Differences were detected between the dominant vs. non-dominant upper limb in the first 21 swimming cycles ($p<0.05$). Additionally, it was verified that the dominant upper limb started decreasing its force application from the 10th swimming cycle, while in the non-dominant this occurred from the 14th cycle. The descriptive values for the swimming tests are presented in table 1. Swimmers presented higher means ($p<0.01$) when they were allowed to use the upper limbs, compared to the exclusive use of the lower limbs. However, they failed to achieve significant improvements when they were allowed to use the lower limbs in the all-body trial ($p>0.05$).

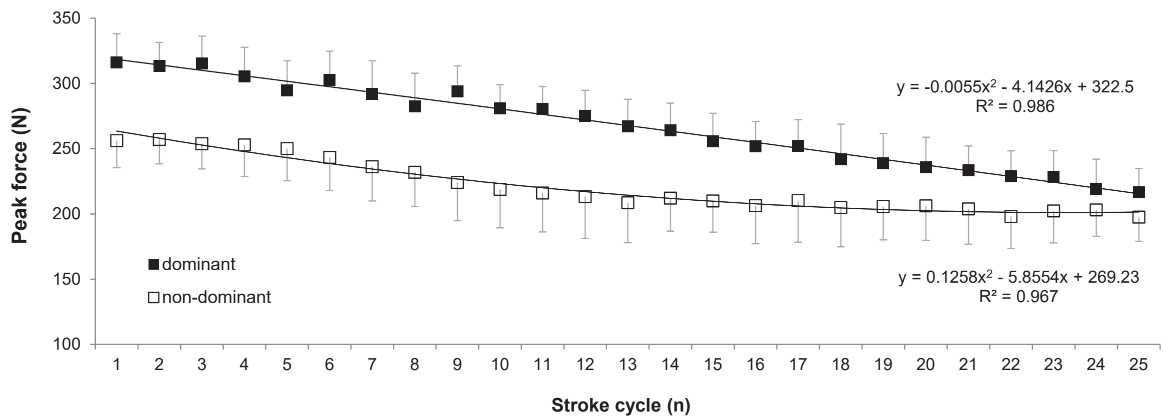

Figure 1. Mean values ± sd of peak force and polynomial regression (2nd order) for the dominant (■) and non-dominant (□) upper limbs.

There were moderate to very strong relationships between the test parameters evaluated and the performance in free swimming (28.1±1.02s). The parameter with the highest correlation was the mean mechanical impulse of the all-body test (r=0.91, $p<0.001$).

DISCUSSION: The present work aimed to analyse the potentialities of measuring the propulsive forces exerted in water, for the evaluation and training prescription of high-level swimmers. The main results showed that the methodology adopted allowed: (i) to identify bilateral kinetic asymmetries at the upper limbs level, as well as to obtain the pattern of force decreased production per upper limb (Morouço et al., 2015b); (ii) to evaluate the effectiveness of force application for swimmers velocity through the linear relationship of mechanical impulse with swimming speed (Morouço et al., 2014); (iii) examine a potential predisposition for competitive events, according to short or long distances (Morouço et al., 2011); (iv) evaluate the contribution of upper limb and lower limb actions, inferring the (mis)balance between strength and coordination (Morouço et al., 2015a).

Table 1
Mean values ± sd for the tethered swiimng tests (n=22)

	all-body	only upper-limbs	only lower-limbs
Peak Force (N)	340.4±40.4	257.6±28.6	114.7±30.1
Mean Force (N)	116.7±14.7	97.3±11.6	46.6±8.5
Max Mechanical Impulse (N.s)	113.3±12.5	84.3±13.6	não aplicável
Mean Mechanical Impulse (N.s)	79.8±12.5	69.9±11.3	não aplicável

In high-level swimming, there are several determining factors for high sport performance (Barbosa et al., 2010). Thus, training of high-level swimmers requires the control of multiple variables (e.g. biomechanical, physiological, psychological), concluding about the appropriate form of loads prescription. Therefore, by measuring separately the parameters of the sports performance, we will be able to draw the profile of the swimmer, in the perspective of increasing his/her performance. However, several questions are commonly asked by the coach: what, how, when and how often those parameters should be evaluated? In addition, how should the results be interpreted in order to provide concrete information for the training prescription? Although the answers are complex, their clarification allows to increase the efficiency of the training process, aiming for greater sport success.

Theoretically, and considering that the upper limbs are the main responsible segments for propulsion in the front crawl technique (Deschodt, Arsac & Rouard, 1999), symmetry between upper limbs may affect the average speed of the swimmer, contributing to postures more associated with a lower resistive drag (Sanders, Thow & Fairweather, 2011). Nevertheless, various investigations report kinematic and kinetic asymmetries in high level swimmers (e.g. Formosa, Sayers & Mason, 2013), corroborating the results of the present study. It is imperative to question how to know if the diagnosed asymmetries can alter the optimal function, or if they are simply within the normal limits of variation. Although studies that analyse this asymmetry along a temporal spectrum are scarce, the methodology used, once it makes a constant measurement of the forces exerted, may allow new inferences about this theme (Morouço et al., 2015b). The fact that most high-level swimmers present asymmetric patterns, suggests that, for short swimming distances, this asymmetry allows a greater impulse to be gained by the dominant upper limb.

The influence of force on swimming performance is a longstanding topic of discussion, and it is suggested by the literature that the force that a swimmer is able to exert in the water is one of the crucial factors for success (Barbosa et al., 2010). For this reason, examining the magnitude of these forces has been a subject of current research, despite the difficulties induced by the complexity that the aquatic environment entails for its measurement. The tethered swimming has emerged as a methodology that, although it induces some kinematic changes by the absence of displacement (Maglischo et al., 1984), allows in a fast way to provide valid indicators for the training prescription. Yet, there are several studies that do not take into account the mechanical impulse produced by the swimming cycle, but rather the peak force obtained. Considering that the force exertion in the water occurs during the entire propulsive phase of the swimming cycle (Marinho et al., 2011), the effect of force with respect to time should be considered (Morouço et al., 2014). In the present study, the mechanical impulse in the all-body tethered test was the indicator that higher correlation obtained with the performance in free swimming, suggesting that investigations that relapsed on the force peak underestimated the association between the forces exerted and the swimming speed. In addition, the observation of the force-time curve behaviour allowed to identify curves with: (i) rapid

increase at the initial moments and abrupt decrease after peak or (ii) progressive increase with reduced decrease over the 30-s. In swimmers' specialization stages, this pattern may suggest a greater predisposition for longer or shorter distances, as suggested by Costill, Maglischo and Richardson (2005).
The relative contribution of the lower limbs to the swimmer's propulsion in the front crawl technique remains inconclusive. Most of the studies, which show a 10% lower limb contribution to swim speed, adopted an indirect measurement; calculated the contribution of lower limbs action by subtracting it to overall performance (Deschodt, Arsac & Rouard, 1999). However, Swaine et al. (2010), using a novel ergometer presented contributions for the upper limbs of 62.7±5.1% and 37.3±4.1% for the lower limbs. These values are similar to those obtained in the present study, and are associated with coordination indicators. By calculating the difference between the full swim and the sum of the upper and lower limbs, it becomes feasible to diagnose levels of effectiveness of force application in the water by the different body segments, inducing different constraints. Considering that a (small) additional amount of force can be obtained through correct synchronization between segments (Seifert, Chollet & Allard, 2005), the used methodology allowed to identify either coordination deficiencies or insufficient force indices (Morouço et al., 2015a).

CONCLUSION: Swimming coaches are aware that their swimmers' evaluation should be specific and matched to the nature of the sport. Thus, it is essential to choose the methodology to be used, objectifying the answers that are sought. In this perspective, the method of tethered swimming can be useful and valid, besides having a simple application.

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