Volto à parte deste parágrafo que mais prendeu a minha atenção: **o ofício de pensar o mundo existe graças aos livros e à leitura, ou seja, quando podemos ver as palavras, e refletir devagar sobre elas, em vez de nos limitarmos a ouvi-las pronunciar no veloz rio do discurso**. Assim deve ser, em meu entender, a atitude leitora dos textos que compreendem este número – a lentidão de quem saboreia as palavras que expressam o cuidado e rigor que as e os autores colocaram nos seus artigos. Mais, deve ser também a atitude de quem dedica um tempo, sem pressas, para mergulhar verdadeiramente no conteúdo e no alcance de cada um. Tal como refere, eloquentemente, o poeta José Tolentino de Mendonça,

> Perguntas quanto tempo deves rezar?
> A papoila na montanha é vermelha.
> Sempre.

Num tempo em que a "fast science" impera em muitos lados e tem uma "taxa de penetração" elevada em muitas mentes, pouco dadas à reflexão, espero que o leitor dê um espaço e um tempo à "slow science" e a uma leitura cuidada exatamente no mesmo sentido da sugestão do comentário sobre "Retire statistical significance" do dia 21 de março de 2019, volume 567, página 307, da Revista Nature (autores - Valentin Amrhein, Sander Greenland, Blake McShane):

> "Decisions to interpret or to publish results will not be based on statistical thresholds. People should spend less time with statistical software, and more time thinking".

Entremos devagar na revista, e boa leitura.

A semi-tethered swimming test better predicts maximal swimming velocity if drag force is considered.

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ABSTRACT

Semi-tethered swimming is a method used to evaluate the propulsive forces generated by swimmers and could be performed using a load cell while the participant swims at a constant and controlled velocity. Usually, the correlation between semi-tethered force and swimming maximal velocity is lower than the value observed for fully tethered swimming, probably due to the propulsive force necessary to overcome the drag during the test usually disregarded on the models. The aim of the current study was to examine the relation between semi-tethered swimming force and swimming mean velocity while considering the necessary force for swimmers to overcome the hydrodynamic drag. Twelve experienced front crawl swimmers performed five maximal 25m swim trials and five trials of semi-tethered swimming. Data correlation was evaluated by a non-linear model based on both the mean propulsive force and the mean velocity during the semi-tethered test. The linear regression between the mean swimming velocity and the mean semi-tethered force showed an r^2= .597 and a higher value (r^2= .900) when the force to overcome the drag was considered. The high correlation coefficient found between the mean semi-tethered force (considering the force to overcome the drag) and the mean swimming velocity suggests that this force could be more suitable for practical purposes.

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Força de nado semi-atado prediz melhor a velocidade se a força de arrasto é considerada.

RESUMO

O nado semi-atado é um método utilizado para avaliar a força propulsiva do nadador, podendo ser realizado usando uma célula de carga enquanto o participante nada a uma velocidade constante e controlada. Normalmente, a correlação entre a força semi-atada e a velocidade máxima de nado é menor do que a apresentada para o nado totalmente atado, provavelmente devido ao facto da força propulsiva necessária para superar o arrasto durante o teste usualmente não considerada nos modelos. O objetivo deste estudo foi examinar a relação entre a força média de nado semi-atado e a velocidade média de nado considerando a força necessária para superar o arrasto hidrodinâmico. Doze nadadores experientes realizaram cinco repetições de nado semi-atado e cinco repetições máximas de 25m na técnica de crol. A correlação entre os dados foi verificada por um modelo de regressão não linear baseado na força propulsiva media e na velocidade média do teste semi-atado. A regressão linear entre a velocidade media de nado livre e a força media de nado semi-atado apresentou um r^2 = .597 e um valor maior (r^2 = .900) foi observado quando a força para superar o arrasto foi considerada. O alto coeficiente de correlação encontrado entre a força média de nado semi-atado (calculada considerando a força de arrasto) e a velocidade média de nado sugere que esta força pode ser mais indicada para aplicações práticas.

PALAVRAS-CHAVE:

Força propulsiva. Força de arrasto.
Dinamometria. Performance.

INTRODUCTION

Swimming performance is often analyzed considering the swimmers propulsive forces and the corresponding hydrodynamic drag force (e.g. Costill, Rayfield, Kirwan, & Thomas, 1986; Morouço, Keskinen, Vilas-Boas, & Fernandes, 2011; Yeater, Martin, White, & Gilson, 1981). A fully-tethered test is a reliable, valid and specific method used to evaluate propulsive forces, showing a significant correlation with swimming velocity (Amaro, Morouço, Marques, Fernandes, & Marinho, 2017; Kjendlie & Thorsvald, 2006; Morouço et al., 2011; Yeater et al., 1981) and with the power to overcome drag during swimming (Gatta, Cortesi, & Zamparo, 2016). Nevertheless, in this test, swimmers are not affected by drag force due to the no displacement condition, since the drag force is dependent of the swimming velocity (Sharp & Costill, 1989). Semi-tethered swimming is other possible method to evaluate propulsive force, differing of the previous by allowing swimmers displacement.

The correlation coefficient between semi-tethered test results and swimming performance (Costill et al., 1986; Klentrou & Montpetit, 1991) is lower than those found in fully-tethered tests (Morouço et al., 2011; Yeater et al., 1981) although this latter is a more specific procedure. A possible explanation may be the non-consideration of the part of the propulsive force used to overcome drag since it is known that the tethered force is related to the power to overcome drag in swimming (Gatta et al., 2016). So, the propulsive force in semi-tethered swimming should be the result of the difference in the force to overcome drag in freely and semi-tethered swimming. By motion laws, propulsive force and swimming velocity are related each other, meaning that, if those values were measured and a correlation coefficient between them was calculated, a high and significant result will be expected. However, since the amount of force used to overcome drag is not registered by the load cell in semi-tethered swimming, the measured force will be lower than the actual propulsive force and, consequently, the correlation coefficient between semi-tethered force and swimming performance will be underestimated.

Based on the above-referred problematic, the current study aims to examine the relationship between the semi-tethered mean force and mean swimming velocity considering the force necessary to overcome the hydrodynamic drag. It was hypothesized that using the parameter that takes into account the force to overcome the drag will improve the relationship between this parameter and swimming performance.

METHODS

The experimental protocol consisted in five maximal swimming trials, both freely and semi-tethered, with 10 min rest in-between.

PARTICIPANTS

Twelve male front crawl swimmers (21.6 ± 4.7 years old, 1.77 ± 0.09 m and 71.6 ± 5.3 kg) with at least five years of competitive swimming experience (26.18 ± 1.70 s of best performance in 50m freestyle in a 50m pool) participated in the study. The study was approved by the local university's ethics committee (code number 395/08).

INSTRUMENTS

Swimming and semi-tethered tests were conducted in a 25m pool with 27ºC of water temperature, with tests being recorded by a video camera (A602fc, Basler, Germany) operating at 100Hz sampling frequency. In the semi-tethered test swimmers wore a waist belt attached to a steel cable and a load cell (JBA, Zb Staniak, Poland) connected to the cable was used to measure the exerted force at 1000Hz rate. The load cell was attached to another steel cable passing through a pulley, which worked controlled by a geared motor (RX-400, Ringcone, Brazil), allowing to control the test velocity (FIGURE 1). The total errors affecting the forces recorded (Psycharakis, Paradisis, & Zacharogiannis, 2011) were 0.65% using masses ranging from 0-35kg (covering the range of propulsive forces that were applied during semi-tethered swimming).

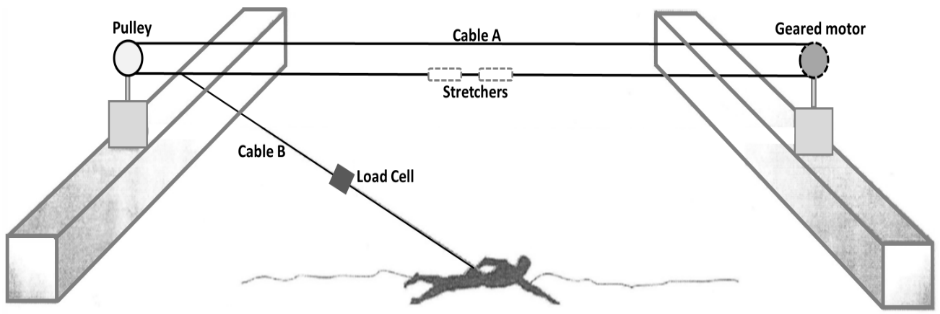

FIGURA 1. Plataforma de forças

PROCEDURES

Firstly, swimmers warmed-up for 15min and, then, performed three submaximal repetitions of the semi-tethered swimming test for familiarization. All swimmers had previous experience with fully tethered swimming and were used to swim with parachutes and elastic resistance in their training routines. The experimental protocol consisted of five maximal swimming trials (without breathing) performed freely and semi-tethered (Gatta et al., 2016; Yeater et al., 1981), with 10min rest interval in-between. Tests were performed alternately, with half of the swimmers begging with the swimming test and half with the semi-tethered swimming test. Swimming test consisted in maximal 25m front crawl, starting in-water with an initial impulse but without an underwater phase. The camera was positioned out of the water, on the side of the pool, 14m far from the starting wall. Markers were added in the swimming lines at 8 and 20m from the starting wall to calculate the mean swimming velocity, with the time to cover this distance being measured by the number of frames required for the swimmers' head to cross both markers.

In the semi-tethered test, each swimmer began swimming at a sub-maximal intensity and, when the cable was fully extended, the geared motor started and an acoustic signal was given to start swimming with maximal effort for 12 complete upper limbs cycles. The geared motor was set to allow a constant swimming velocity of 0.60 m · s-1 and the displacement of the steel cable joint was recorded by the camera to verify the swimming velocity (determined before by video analysis to ensure that it was lower than the lowest intra-cycle velocity for all swimmers in the current study). This procedure was vital to the force measurement because if velocity became < 0.60 m · s-1, swimmers were not able to generate enough force to overcome the drag force matching this velocity, not existing a net force to be registered by the load cell.

DATA ANALYSIS

The first five cycles force data were waived to prevent inertial effects to the testing setup, with the following five cycles being selected for further processing (the last two cycles were also rejected to avoid testing end and eventual fatigue effects since swimmer knew the moment when the test would be interrupted). Footage treatment was performed using SIMI motion 7.0 (SIMI Reality Motion Systems, Germany) and force data analysis was performed in Matlab 2009b (MathWorks, USA) and low-pass filtered (eighth-order Butterworth, 16Hz). The angle between the cable and the swimming direction was assumed constant, only the force component in the swimming direction was considered (Xin-Feng, Lian-Ze, Wei-Xing, De-Jian, & Xiong, 2007) and the mean force of each valid cycle was calculated. The mean velocity was the variable from the swimming test used in the analysis, with the mean velocity and the mean force being the variables selected from the semi--tethered test.

FORCE PARAMETERS DEFINITION

At a constant swimming velocity, the mean active drag force is equal to the mean propulsive force (de Groot & van Ingen Schenau, 1988; Hollander et al., 1986). The regression equation used to relate the mean swimming velocity and the propulsive force considering the necessary force to overcome the drag and guarantee the swimmers displacement was derived from drag equation assuming a quadratic relationship between drag force and velocity:

$$D = \frac{1}{2}\rho S C_x v^2 \qquad (1)$$

- where D is the drag force, ρ is the water specific mass, S is the maximal cross-sectional area of the swimmer exposed to the flow, C_x is the drag coefficient and v is the swimming velocity. Assuming that ρ is constant and that the drag force is linearly affected by C_x and S (Di Prampero, Pendergast, Wilson, & Rennie, 1974) the product $1/2\,\rho S C_x$ was replaced by a constant k called "drag factor" (Kjendlie, Per Ludvik, & Stallman, 2008), yielding the following equation:

$$F_T = k\bar{v}^2 \qquad (2)$$

- where F_T is the total propulsive force and $\bar{v}$ is the mean velocity. In the semi-tethered test, it is necessary to consider that F_T is equal to the sum of the net force measured by the load cell (F_m) and the force necessary for the swimmer displacement, which is the force required to overcome the active drag and maintain the preset velocity during the test (F_{pt}), giving this equation:

$$F_T = F_m + F_{pt} \qquad (3)$$

If the F_T in the semi-tethered test, when it is performed with maximal effort, equals the F_T generated by the swimmer during maximal swimming and substituting equation 2 into equation 3, it is possible to find another equation 4:

$$F_m = k\bar{v}^2 - k v_{st}^2 \qquad (4)$$

- where v_{st} is the semi-tethered swimming velocity. Reordering the equation, the following equation is obtained:

$$\bar{v} \approx \sqrt{\frac{\overline{F_m}}{k} + v_{st}^2} \qquad (5)$$

- where the coefficient k is unknown. The right-side parameter was determined by disregarding the effect of force variation around the mean and includes the squared terms of the equation, yielding the following regression model:

$$\bar{v} \approx a + b\left(\sqrt{\frac{\overline{F_m}}{k} + v_{st}^2}\right) \qquad (6)$$

- where coefficient a represents any factor not considered by the parameters described in equation 5 and coefficient b is a proportionality constant that also includes any embedded errors in equation 5. Equation 6 essentially states that a swimmer's maximal velocity is a function of their semi-tethered force at maximum effort and their drag factor (k).

STATISTICAL ANALYSIS

The Kolmogorov-Smirnov test was used to evaluate force and velocity data normality, and regression analysis residuals. A one-way repeated measures ANOVA was performed to evaluate any possible effects of fatigue and familiarization (considering each trial as a factor). The coefficients a, b and k defined above (model R2, equation 6) were calculated using a non--linear least squares method using the software Matlab 2009b (Moré, 1978). To evaluate the effect of disregarding the force necessary to overcome the drag in the semi-tethered test, the linear regression between the semi-tethered test mean force and the swimming velocity (R1) was also calculated (Costill et al., 1986; Klentrou & Montpetit, 1991), with models R1 and R2 being summarized in table 1. To evaluate the quality of the adjustment, the sum of the squared errors, the correlation coefficient (r) and the coefficient of determination (r) of the models were calculated (adopting a value of p < .05 as significant).

TABLE 1. Regression models for the semi-tethered swimming test.

MODELS	MODEL VARIABLES	REGRESSION EQUATIONS
R1	$\overline{F}_m \times \bar{v}$	$\bar{v} \approx a + b\overline{F}_m$
R2	$[\overline{F}_m \; v_{st}] \times \bar{v}$	$\bar{v} \approx a + b\left(\sqrt{\frac{\overline{F_m}}{k} + v_{st}^2}\right)$

Semi-tethered test mean force ($\overline{F}_m$), mean swimming velocity ($\bar{v}$), semi-tethered velocity, product 1/2 $\rho S C_x$ (k), water specific mass (ρ), swimmer maximal cross-sectional area exposed to the flow (S) and drag coefficient (C_x).

RESULTS

There were no differences between the five repetitions in each test condition regarding swimming velocity (swimming test: $F_{(4.44)}$ = 0.452, p = .77; semi-tethered: $F_{(4,44)}$ = 0.154, p = .96) and mean propulsive force ($F_{(4.44)}$ = 0.368, p = .83), suggesting that familiarization, fatigue or any other factor did not affected results across the attempts. The mean velocities during swimming and semi-tethered tests were 1.83 ± 0.18 and 0.59 ± 0.05 m ·s-1 (respectively) and the semi-tethered mean propulsive force was 9.63 ± 1.75 kgf (both equations residuals showed normal distribution). The regression analysis of both models showed significant relationships between the propulsive force parameters and the mean swimming velocity. The sum of the squared errors values of models R1 and R2 were 0.159 and 0.039 (respectively) and the values of r, r^2, a, b and k are presented on table 2.

TABLE 2. Coefficients a, b, k, correlation coefficient (r), coefficient of determination (r^2) and confidence interval (CI 95%) for the regression equation.

MODELS	a (CI 95%)	b (CI 95%)	k CI 95%)	r - (r^2)
R1	1.003 (0.530 - 1.477)	0.084 (0.035 - 0.132)	--	.773* - (.598)
R2	-0.607 (-1.217 - 0.002)	3.176 (2.225 - 4.127)	41.210 (5.557 - 76.850)	.949* - (.900)

* $p < .05$, y intercept (a), slope (b), product 1/2 ρSC_x (k), water specific mass (ρ), swimmer maximal cross-sectional area exposed to the flow (S) and drag coefficient (C_x)

DISCUSSION

The linear relationship between the semi-tethered mean force and the mean swimming velocity (R1) resulted in an r^2 of .598, lower than the .706 reported by Costill et al. (1986) and higher than the reported by Klentrou and Monpetit (1991) whose values were not reported but expected to be lower than .157 (due to its degrees of freedom). These previously mentioned r^2 values are all lower than those found for the same regression model for the fully-tethered test (between .640 and .887; Marinho, 2002; Morouço et al., 2011; Yeater et al., 1981). Semi-tethered swimming, allowing swimmers displacement in still water, should provide a more ecological force generation mechanism, with a higher correlation coefficient with velocity being expected when compared to fully-tethered swimming conditions. Since this was not the case for the model R1 (Costill et al., 1986; Klentrou & Montpetit, 1991; Morouço et al., 2011; Yeater et al., 1981), it seems further recommended to explore the relationship of swimming velocity with the corrected propulsive force parameter.

The model R2 presents a higher determination coefficient comparing to model R1 (r^2 = .900) and to values reported previously for both semi-tethered and fully-tethered tests (Costill et al., 1986; Klentrou & Montpetit, 1991; Morouço et al., 2011; Yeater et al., 1981). This likely occurred because swimming during the semi-tethered test is affected by drag force and model R2 takes into account the force necessary for swimmers' displacement during the semi-tethered test. Thus, R2 allows a more accurate assessment of the propulsive force effect on swimming velocity. This hypothesis is also supported by the a coefficient value that does not differ from zero in model R2, indicating that a non-significant fraction of the mean swimming velocity is independent of the proposed force parameters. In model R1, this coefficient is 1.003, significantly different from zero and lower than the value of 1.575 reported by Costill et al. (1986). This difference suggests that a velocity significant fraction is independent of the mean propulsive force in the semi-tethered test. The coefficient k was significantly higher than zero, which is consistent with the physical nature of this coefficient that represents $1/2\,\rho SC_x$.

To make this analysis model possible, it was assumed that the relationship between swimming velocity and drag force is quadratic, and that the total propulsive force in a maximal semi-tethered test is equal to the force to overcome the drag during maximal swimming (Gatta et al., 2016). These assumptions are similar to those proposed by Kolmogorov and Duplishcheva (1992) and the effects of the force variation around the mean in the relationship between force and velocity are disregarded. Complementarily, it is probable that there is different swimmers' ability to produce propulsive force in both tests (due to the flow conditions), but the same limitation is assumed in the classic analysis (R1) when the force or power is used as an output parameter. The errors due to the violation of this assumption are quantified in the regression coefficients, showing that the proposed model has a better quality of fit. When analyzing the a coefficient, it is possible to note a lower value in model R2 and only in this model this value was not significantly different from zero (meaning that a non-significant part of the swimming velocity is independent of the force parameter and obviously in agreement with the motion laws).

Although the semi-tethered test requires more hardware than the fully-tethered test (the geared motor and the pulley), it can be set up in any pool, only requiring fixations points for the motor and the pulley. Theoretically, the semi-tethered test is a more specific test for practical purposes than the fully tethered test due to the drag influence. Data support this rationale, although to prove it a comparison of both tests performed by the same swimmer is needed. In this way, the semi-tethered test could provide coaches a force parameter related to the swimming performance and it is a parameter influenced by swimmers drag characteristics. Two prominent follow-ups for the current study are the above mentioned direct comparison between the semi-tethered and the fully-tethered, and to obtain an individual coefficient k and compare it with values obtained using other methods designed to evaluate the active drag (e.g., the active drag system or the velocity perturbation method; Hollander et al., 1986; Kolmogorov & Duplishcheva, 1992). Both perspectives could clarify the hypothesis about the higher specificity of the semi-tethered test due to the drag influence.

In conclusion, the semi-tethered test using the model R2 is an alternative to the fully tethered test to evaluate the swimmers propulsive force, with the improved correlation found with the model R2 suggesting that the semi-tethered swimming test is closely related to the swimming performance. Therefore, the force parameter measured by the semi-tethered swimming test is valid and specific for evaluating the swimming propulsive force and more suitable for practical purposes.

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