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Research Articles

Tethered force at lower limbs and swimming during a 30 s exercise bout and its association with 50 m front crawl performance

KARLA DE JESUS[1] | VITÓRIA DE MIRANDA[1] | MARCOS FRANKEN[2] | KELLY DE JESUS[1]

[1] Human Performance Studies Laboratory, Faculty of Physical Education and Physiotherapy, Federal University of Amazonas, Manaus, AM, Brazil.
[2] Health Sciences Department, Regional Integrated University of Alto Uruguay and the Missions, Santiago, RS, Brazil.

Correspondence to: Kelly de Jesus. Orcid -https://orcid.org/0000-0001-5516-4756
email: kellydejesus@ufam.edu.br
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HIGHLIGHTS

• Propulsive forces at lower limbs actions and swimming conditions was examined.
* Mean swimming is affected during 30 s maximal tethered swimming test.
* The importance of front crawl lower limbs actions was revealed , mainly at intermediate part of the test.
* Variations on horizontal force during swimming could depreciate the performance at intermediate and final effort.
* Future studies could explore these findings on elite swimmers.

ABBREVIATIONS

CNPq	National Council for Scientific and Technological Development
CV	Coefficient of force variation
Maxforce	Maximum force
N	Force

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BACKGROUND: The capacity to produce force should be promoted especially for the fastest swimming events.
AIM: This study aimed to analyze the effects of different test periods in mean, maximal and coefficient of force variation and to correlate the coefficient of force variation and 50 m front crawl time.
METHOD: Twelve well trained swimmers (age: 22.33 ± 8.08 years, 1.69 ± 0.48 m height, body mass 56.08 ± 7.86 kg) randomly performed three maximal 30 s repetitions of full swimming and lower limbs actions in front crawl swimming technique with ~15 min resting period. A load cell system permitted the continuous measurement of exerted tethered forces, and 50 m time was registered as the best time obtained at the 12 months before the test.
RESULTS: Mean swimming force was greater at 10 s compared to 20 and 30 s period (26.40 [20.66-54.20], 25.33 [21.70-52.35] and 21.39 [17.91-43.98] respectively, $p < 0.05$). Mean, maximal and force coefficient variation at tethered test with full swimming were higher than lower limbs (24.37 vs. 12.71, 77.97 vs. 39.78 and 0.77 vs. 0.49 respectively, $p < 0.05$). Strong and inverse correlations were noticed between coefficient of force variation at 10 s during full swimming, at 20 s during kicking and performance (28.75 s [26.20 - 30.68 s]; $r = -0.75$; $p < 0.01$). Very strong correlation was noticed between coefficient of force variation during swimming at 20 s, 30 s and performance ($r = -0.91$ and -0.92; $p < 0.0001$).
CONCLUSION: Mean swimming force at full swim and lower limbs is affected by the period of the 30 s maximal tethered swimming test and is associated with performance. Data reported may be used as reference for setting training strategies at short distance events.

KEYWORDS: Dynamometry | Horizontal force | Performance | Front crawl technique

INTRODUCTION

The ability of swimmers to produce large amounts of propulsive forces while minimizing opposite hydrodynamic drag can determine their successes in competition, as the propulsive forces increments leads to an enhancement in the performance outcome mostly at a sprinting race [1,2,3]. The assessment of such parameters is essential to plan, re (plan) and monitor training load and progress [4,5], because they are associated with other parameters that evolves during a swimming training plan (e.g. technique and physical conditioning [3]). Analyzing swimmers' force production should be a priority in their training control and research, as the capability to produce high propulsive force, while reducing the apposite drag is decisive to achieve a certain velocity determining the competitive success [4,6]. Tethered swimming has been used to evaluate the force contribution in swimming due to the low cost, specificity and ability to monitor the propulsive forces throughout the swimmers' actions [7,8], which consists of swimming with a cable attached to the swimmer's waist, while propulsive forces are measured by a strain gauge [5,8].

The required force that each swimmer has to apply may be exerted by upper and lower limbs, and its assessment is of great interest for training prescription [2,8,9]. Within these segments, their contribution seems to differ, with the lower limbs' actions being commonly considered a factor of secondary importance for front crawl propulsion in swimmers [8]. The lower limb contribution has been found at ~31% to whole body mean forces, evidencing the need of not discarding the kicking contribution to the propulsion [2,8,10]. Those changes were observed for the overall maximal effort, without discriminating each part of the 30 s maximal test. Despite some interesting findings in the tethered swimming literature, there is still few data (i.e. discriminating each part of the tethered swimming test and analyzing only lower limbs) and there are some drawbacks that should be considered in forthcoming studies. For instance, the maximal 30 s maximal tethered swimming test is commonly used to analyze mean and maximal force profiles, but the variations of lower limbs and full swimming force profile during the test is not clear, as well as their associations with sprint event performance. Moreover, to minimize force variations along training efforts, tethered swimming has been pointed out as a useful method to be introduced during different periods of periodization [11].

The assessment of propulsive forces in competitive swimming is a key - aspect for training control and diagnosis [2], however, there are still discrepancies about the tethered swimming force variables. In fact, most studies have analyzed overall mean and maximal force along the effort (e.g. [8]). The quantification of the force output at each part of a maximal test may help to define singular aspects of the stroke cycle (i.e. the most propulsive phases) and possible fatigue effects on the force-time curve [12]. The increment of those forces leads to an enhancement in performance outcome mostly at a sprinting pace [2,4] (e.g. dry-land strength gains to get improvements in maximal and mean force [2]). The variation of the tethered force exerted along with the test, as the coefficient of variation of the force during the effort can highlight the swimmer's movement variability (e.g.[8]), revealing the swimmers' ability to effectively apply force in the water, and thus, can be used to evaluate swimmers' performance [13,14,15].

It is well established that front crawl is the fastest and most economical swimming technique covering a wide range of distances in official events [2] and the propulsive forces applied by a swimmer affect performance, being, therefore, among the key variables of interest in swimming research [14]. The aim of the present study was: (i) to compare the mean, maximal and the coefficient of horizontal force variation among the 10, 20 and 30 s of the tethered swimming under full swimming and lower limbs conditions and (ii) to verify associations between force coefficient variation and 50 m time. We hypothesize that in swimming and lower limbs actions a decrease of mean force will be noticed and variations on force generation in both test conditions will be directly associated with the 50 m time. Thus, from a practical point of view this study can highlight tethered force variations along with the common 30 s maximal test, helping coaches to gain information concerning the force application profile at maximal efforts, reducing/eliminating force fluctuations that will compromise performance.

METHODS

Participants

Twelve well-trained swimmers competing regularly at regional level swimmers (mean ± standard deviation, minimum and maximum; age: 22.33 ± 8.08, 12 and 38 years, 1.69 ± 0.48, 1.65 and 1.76 m height, body mass 56.08 ± 7.86, 45 and 67 kg) volunteered to contribute and were informed of the potential benefits and risks associated with participation. The study was approved by a local ethics committee under number (CAAE 795227917.5.0000.5020). Participants and their legal guardians (if under 18 years of age) signed an informed consent form prior to the study.

All participants were sprint or middle-distance specialists, participating in national level competitions on a regular basis. Participants were informed about the purpose of the study and any known risks and parents and coaches gave their consent for inclusion. All procedures followed the 1975 Declaration of Helsinki concerning human research and were approved by the Ethics Committee of the hosting research center. None of the swimmers suffered from illness of from restrictions that hindered their performances during the experiments. Tests were performed during the competitive period of the spring training cycle to ensure that participants were in prime training period.

Experimental protocol

Experiments were conducted during a competitive training period to ensure that participants were in a prime training period. All tests occurred in a 25 m open swimming pool (26 - 27º C of water temperature).

Apparatus

The testing apparatus consisted of a load cell system (CEFISE Ltda, nova Odessa, São Paulo, Brazil) recording at a 100 Hz, composed by four extensometers with a measurement capacity of 2000 N. The load-cell was connected by a cable to a Ergometer data acquisition system N200 Pro (CEFISE Ltda, Nova Odessa, São Paulo, Brazil; cf., [4]) that exported the data in .xlsx format to a PC. The load cell was attached to the starting block (Figure 1) through a chain locked with a certified aluminum carabiner. It was proofed and tested prior to testing and between tests. Prior to the testing, the load cell was calibrated with the use of 5, 10 and 20 kg standard weights (cf. [9]). Participants were wearing a nylon belt attached to a steel cable with a certified aluminum carabiner with 3.5 m length (0.5 cm diameter). The attachment load-cell to the starting block creates a 5º angle in relation to water surface.

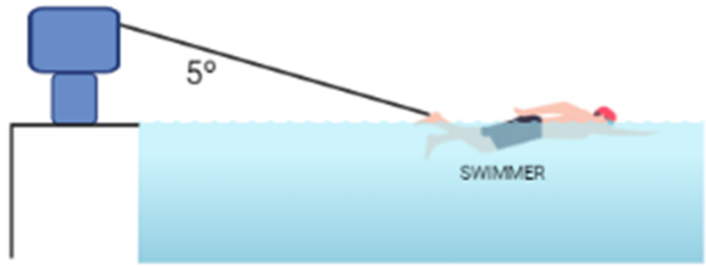


Figure 1. Schematic representation of the experimental apparatus of the tethered swimming test.

Procedures

Before tests and aiming to familiarize participants with the methodology, some specific training sections had been conducted during which the participants engaged in different tethered swimming exercises using only upper and lower limbs with various intensities and durations (cf. [9]).

After a moderate intensity warm-up (800 m swim, including 100 m pull and 100 m kick, 2 x 4 x 25 at increasing speed (1- swim and 2 - kick), each participant randomly executed three maximal front crawl tethered swimming tests and three maximal lower limb tethered tests with ~15 min resting interval (cf. [8]) and the median values of the three trials of each participant were used for statistical analysis. For both conditions, preceding the starting signal, swimmers adopted a horizontal position with the cable fully extended starting the data collection only after the first stroke cycle was completed to avoid the inertial effect of the cable extension usually produced immediately before or during the first arm action (cf. [1]).

For all trials, the duration of exercise was 40 s with an initial phase of 10 s with moderate intensity followed by 30 s at maximum intensity. For swim conditions, the participants were told to follow the breathing pattern they would normally apply during a 50 m front crawl event, and were verbally encouraged throughout the testing trials to maintain maximal effort during the entire test. The end of the test was marked through an acoustic signal.

Data analysis

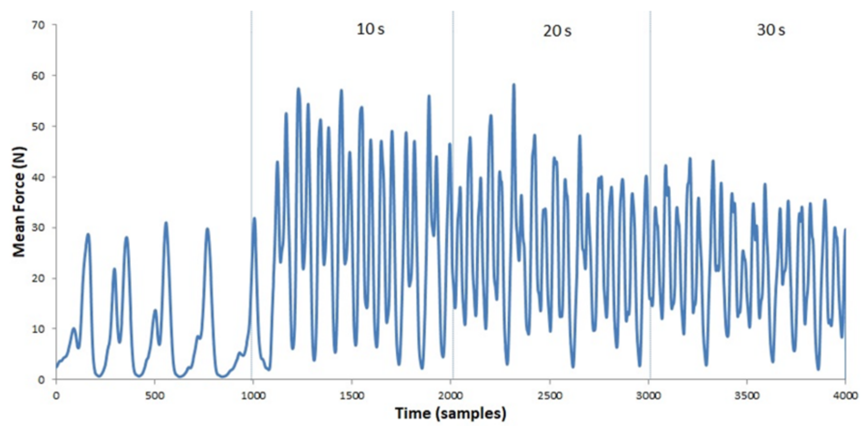
Tethered swimming data were exported to a signal processing software (Matlab R2007a, MathWorks Inc., Natick, MA, USA), to assess the individual curves of force along the time (*x* and *y* axis). Data were filtered with a 4.5 Hz cut-off low pass fourth-order Butterworth filter. The cut-off value was chosen according to residual analysis (residual error versus cut-off frequency) [8]. As the force vector in the tethered system presented a 5º angle in relation to the water surface, data were corrected computing the horizontal force component (cf. [8]). The following measures were estimated for each participant at each 10 s period of test: mean force (Meanforce) as the sum of the set by the number of values, maximum force (Maxforce) as the higher value obtained in the individual force-time curve, and coefficient of force variation (CV) as the value of the standard deviation of the tethered force divided by the mean force. The 50 m front crawl swimming time was assumed as the best time obtained at the 12 months before the test [14].

Statistical procedures

Normality and homoscedasticity assumptions were checked by Shapiro-Wilk and Levene tests, respectively. Data was presented as median and interquartile range. The significance of differences among the three test periods and between the two test conditions at each period was evaluated with a Friedman and Wilcoxon test with exact p-value ($p < 0.05$). Spearman correlation coefficient was used between coefficient of force variation of full swimming and lower limbs at 10, 20 and 30 s of test, and 50 m front crawl. Friedman's test was used for inter-trial repeatability. Level of significance was defined as $p < 0.05$.

RESULTS

An individual force-time curve example is depicted in Figure 2 for each test condition (full swimming – a and lower limbs – b).



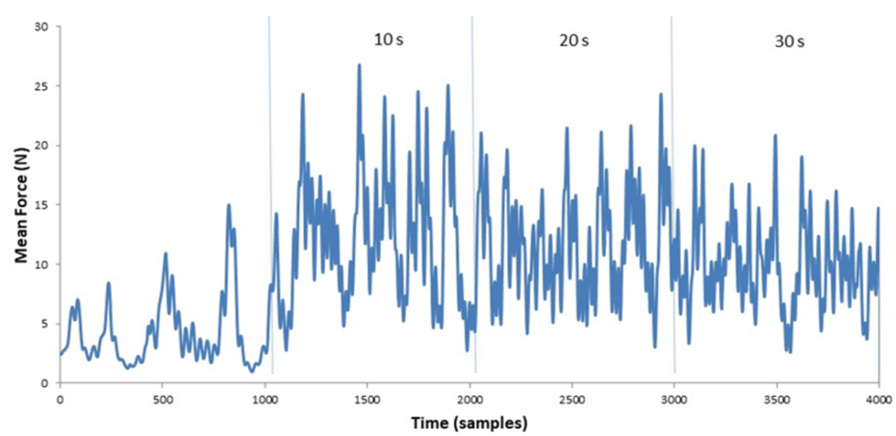


Figure 2. An individual force-time curve for each test condition (full swimming – a and lower limbs – b).

Table 1 shows the median and interquartile range of the mean, maximal and coefficient of force variation values during full swimming and lower limbs test conditions during the 10 s, 20 s and 30 s of a maximal tethered swimming test. Friedman's test revealed no difference among trials ($p > 0.05$).

Considering the swimming condition, mean force was greater at 10 s compared to 20 s and 30 s ($p < 0.0001$). No difference was observed among the three testing periods for maximal force and coefficient of force variation ($p > 0.05$). Regarding the lower limb's contribution, no differences were noticed among the three periods for mean, maximal and coefficient of force variation ($p > 0.05$). Greater horizontal mean and maximal force values and coefficient of variation for the swimming than lower limbs were noticed along with the test ($p < 0.05$).

Table 1. Median and interquartile range of mean, maximal and coefficient of variation of horizontal force (N) applied during swimming and lower limbs actions.

Variables	Full swim	Lower limbs
Meanforce 10 s	26.40 (20.66-54.20)	14.14 (11.34 – 16.69)
Meanforce 20 s	25.33 (21.70 – 52.33)	11.90 (11.32 – 14.35)
MeanForce 30 s	21.39 (17.91 – 43.98)	12.09 (9.82 – 13.33)
MaxForce 10 s	87.97 (47.32 – 172.82)	41.58 (28.23 – 89.27)
Maxforce 20 s	76.91 (44.43 – 175.71)	39.90 (29.48 – 91.73)
Maxforce 30 s	69.03 (42.65 – 177.71)	37.87 (29.48 – 91.73)
CV 10 s	0.73 (0.53 – 1.20)	0.45 (0.37 – 0.51)
CV 20 s	0.77 (0.54 – 1.13)	0.56 (0.35 – 0.68)
CV 30 s	0.81 (0.62 – 1.02)	0.47 (0.40 – 0.56)

Strong and inverse correlations were noticed between coefficient of force variation at 10 s during full swimming, at 20 s during kicking and performance (28.75 s [26.20 - 30.68 s]; $r = -0.75$; $p < 0.01$). Very strong correlation was noticed between coefficient of force variation during swimming at 20 s, 30 s and performance ($r = -0.91$ and -0.92; $p < 0.0001$). No significant correlations were noticed between coefficient of force variation at 10 s and 30 s ($r = -0.37$ and -0.50; $p < 0.05$). When age and body mass were controlled the coefficients of correlations followed similar profile.

DISCUSSION

This study examined the effects of test period (i.e., 10 s, 20 s and 30 s) and tethered swimming test condition (i.e., full swimming and lower limbs propulsion) on the force-time curve profile and the associations between the force variation coefficient and 50 m front crawl time. Findings revealed that mean swimming force was greater at 10 s compared to 20 s and 30 s and greater horizontal mean and maximal force values and coefficient of force variation for the swimming compared to lower limbs condition were noticed along with the test, partially corroborating our hypothesis. Strong and very strong inverse correlations were noticed between coefficient of force variation and full swimming at 10, 20 and 30 s and kicking at 20 s and 50 m front crawl time, partially corroborating our hypothesis.

Few studies aimed to analyze the importance of lower limbs force profile in front crawl swimming [8], which is understandable due to the higher contribution of the upper limbs in comparison to the lower limbs to generate the total propulsive thrust in the front crawl swimming technique [8,10,16]. It has been reported that the lower limbs should focus stabilization of the body rather than propulsion, being the use of them as a primary source of propulsion uneconomical [16]. In short distance events the addition of leg kicking may make a useful albeit small contribution to power output [17]. The present study has reinforced the need for maintaining propelling force profile magnitude stable. The mean force has not been stable along with the 30 s effort and swimmers showed greater value at 10 s of the test compared to the two following periods, which underpins the need for coaches and athletes to monitor such instabilities for better performance (e.g. [5]). The decrease in force production in a maximal 30 s tethered swimming can be used as a reliable estimator of young swimmers performance on short distance events [12].For all swimmers tested, force variables were greater during swimming than lower limbs action, corroborating previous findings [8,10,16]. Deschodt and colleagues [10] indirectly reported a 10% higher speed was achieved when using lower limbs propulsion. Biomechanical characteristics are fundamental in understanding propulsion mechanics in the highly specific hydrodynamic environment [2,3,6] and the study of the effect of different periods of the maximal tethered swimming test on lower limbs and full swimming conditions are still scarce. Moreover, a recent review revealed that despite there is some understanding in the field of segmental actions contribution, deeper research is needed with the possibility to clarify the real contribution for the propulsion by each segmental action within each competitive stroke [2].

Relationships between front crawl tethered swimming and performance have been previously studied (e.g. [1]). However, the analysis of one swimming cycle or coupling results of the overall test hampers a better characterization of the swimming action [2]. The analysis per period of test in both conditions (i.e. swimming and lower limbs) might clarify changes due to different physiological responses to high intensity demands. As related by Zera et al. [18], during the tethered swimming test progression it is possible to see the trainability of the anaerobic power and capacity of the swimmers. Strong association between lower limb coefficient of force variation and 50 m time evidenced that the lower limbs actions should not be neglected in sprint swimmers training [1,16]. The ability to keep low swimming coefficient of force variation, mainly from the intermediate to the end of the maximal efforts, shares a very strong variance with performance (c.f. [15]). Different parameters of a force-time curve are used to evaluate the technique (e.g. time to peak and minimum forces; [13]). The intra-cycle force fluctuation was already calculated to describe technique changes and can be used as a valuable parameter to monitor the forces exerted by swimmers [15]. In fact, the tethered swimming performance depends on the force applied to the water, which is influenced by the both technique and the neuromuscular ability to produce strength [4] and analyzing swimmers' force production should be a priority for their training control and research.

The present findings allowed identifying the changes in propulsive force along with 30 s maximal tethered swimming test during full swimming and lower limbs action, which may be a useful procedure to identify lack of strength and/or coordination [5,8] and reveal singular aspects of the front crawl swimming technique [2]. Moreover, it reinforced the need to increase the use of tethered swimming to monitor training effects and transferability of strength [11] as the tethered swimming test allows accurate evaluations of the force production performed by a swimmer in specific exercise conditions [12]. In the present study, the maximal 30 s tethered swimming test was analyzed along the three 10 s periods for a detailed understanding of technical variations along a front crawl swimming and kicking efforts. Despite the overall contributions of the present study, limitations should be presented considering the small sample size and the absence of considering technical and performance analysis using a wide biomechanical approach for a clear understanding of changes along with the test. Future studies are suggested to consider in detail propulsive force changes beyond the peak and mean force assessment (e.g. rate of force development) at different swimming techniques and swimmers' performance level in a short and long-term training period perspective.

CONCLUSION

Mean swimming force is affected by the period of the 30 s maximal tethered swimming test. Despite lower limbs propulsion force is smaller than swimming, the importance of front crawl lower limbs movements was revealed through force coefficient variation, mainly at the intermediate part of the test. Moreover, variations on horizontal force during swimming are highly depreciate factors to performance, mainly considering the intermediate and final effort. These data are based on data on regional level swimmers and, thus, it should be explored in further research if they also apply on elite national and international level swimmers.

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