Evaluation of Adolescent Swimmers Through a 30-s Tethered Test

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Our purpose was to demonstrate that 30-s tethered swimming test can be a useful tool to estimate swimming performance in short distance freestyle events. Thirteen high level adolescent swimmers (7 male and 6 female of 16.6 ± 1.0 and 15.8 ± 0.8 years old) performed a 30-s maximum effort in front crawl tethered swimming. Afterward, subjects completed 50-m and 100-m freestyle events at the National Championships. Both maximum and mean force values obtained in the tethered test related directly with 50-m ($r = .78$ and $r = .72$, $p < .01$, respectively) and 100-m freestyle velocities ($r = .63$ and $r = .61$, $p < .05$, respectively). Fatigue index did not present a significant relationship with any of the studied performance variables. However, a proposed parameter—fatigue slope—correlated with 50-m ($r = -.75$, $p < .01$), 100-m performances ($r = -.57$, $p < .05$) and with $[\text{La}]$ ($r = -.90$, $p < .01$). It is concluded that, for adolescent swimmers, values obtained from 30-s tethered test are well related with swimming performance in sprint events. In addition, fatigue slope seems to be more associated with swimming performance in short distance events than fatigue index.

Swimmer’s performance evaluation has been mainly conducted through biomechanical or physiological approaches. However, it is advisable to link biomechanical and physiological knowledge to enhance swimmer’s performance (2). For instance, the tests of critical velocity (30) or the 30 min continuous test (T30; 23), are frequently applied methods. In these approaches, relevant information about the aerobic capacity training pace of each swimmer is estimated, but technical parameters are not assessed.

In this context, in the area of swimmer’s bioenergetical evaluation (and corresponding training advice), some issues are not yet completely clear. Anaerobic testing methodologies have been controversial for many years, being the anaerobic capacity and power assessment less studied comparing to the aerobic conditioning
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Evaluation of adolescent swimmers through a 30-s tethered test has been carried out using different methodologies, namely: (i) the maximal accumulated oxygen deficit (6,34); (ii) the anaerobic critical velocity (7,18); (iii) the Wingate arm or leg ergometer test (10,11,27,31); (iv) the force-velocity test (29) and; (v) the tethered swimming test (3,8,19,33). Tethered swimming is an easy, operative and inexpensive way to assess the anaerobic capacity, particularly in children and young swimmers once the methodologies used on regular basis with adult swimmers are not suitable to be implemented in younger populations.

Evaluation of athletes, including swimmers, has to be specific to the nature of the sport. Thus, it is essential the appropriate selection of the testing ergometer to be used during the protocols as it should closely replicate the movement patterns employed in real training and competition conditions (3,4). Thus, tethered swimming testing has been used for a long time, particularly since the pioneer study of Magel (19), aiming to characterize the force production during a short swimming effort. Some years later, relationships between maximum forces obtained through tethered swimming and sprint swimming velocity were noticed for the front crawl technique (14,33). Accordingly, Keskinen (16) stated that tethered swimming allows accurate evaluations of the force production performed by a swimmer in specific exercise conditions, being considered a valid and reliable method (4,17).

In the firstly conducted tethered swimming studies, 10–15-s efforts were implemented. These evaluations assessed the individual maximal force value that was representative of ATP-CP catabolism rate (3,33). Later on, studies used the 30-s Wingate anaerobic arm test to determine the peak power, mean power and fatigue index of athletes (11), being these two last parameters considered good estimators of anaerobic power and anaerobic capacity, respectively (21). These parameters related with anaerobic metabolism prevail in the 50 and 100-m swimming events, presenting high relationships with performance in short swimming events (18).

However, research has not focused yet in testing the probable direct relationship between force production decrease and swimming performance in short maximum intensity efforts, especially concerning adolescent swimmers. The purpose of the current study was to assess the relationship between 30-s tethered force and blood lactate with performance in short swimming freestyle events in adolescent swimmers. It was hypothesized that, as in adult swimmers, subjects that present higher values in the 30-s tethered force present a higher velocity in the swimming events.

Methods

Subjects

Thirteen high level young swimmers (7 male and 6 female) from the Youth National Swimming Team volunteered to take part in this study. Parents gave written informed consent for the swimmers to participate in this study. All procedures were in accordance to the Declaration of Helsinki in respect to Human research. The local Ethics Committee approved all the experimental procedures. Individual and mean ± SD values for the main physical and performance characteristics of the participants are described in Table 1. Body mass, fat, and lean body mass were assessed through a bioelectric impedance analysis method (Tanita BC 420S MA, Japan). Body mass index was calculated with the traditionally used formula. The surface area was estimated using the equation of Du Bois & Du Bois (5):
Table 1  Individual and Mean ± SD Values for the Main Physical and Performance Characteristics of the Participants

<table>
<thead>
<tr>
<th>Swimmer</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Body mass (kg)</th>
<th>BMI (kg.m⁻²)</th>
<th>Fat (kg)</th>
<th>Lean body mass (kg)</th>
<th>Surface area (m²)</th>
<th>100 freestyle (Final points)</th>
</tr>
</thead>
<tbody>
<tr>
<td>females</td>
<td>15.8 ± 0.8</td>
<td>166.7 ± 1.0</td>
<td>54.5 ± 2.8</td>
<td>19.6 ± 0.9</td>
<td>10.6 ± 1.8</td>
<td>43.9 ± 1.2</td>
<td>1.58 ± 0.0</td>
<td>597.5 ± 84.4</td>
</tr>
<tr>
<td>males</td>
<td>16.6 ± 1.0</td>
<td>174.9 ± 6.9*</td>
<td>68.1 ± 7.8*</td>
<td>22.2 ± 1.1*</td>
<td>9.0 ± 1.5</td>
<td>59.1 ± 7.1*</td>
<td>1.80 ± 0.1*</td>
<td>589.7 ± 66.0</td>
</tr>
</tbody>
</table>

Note. BMI = body mass index.

*Significantly different from female swimmers, p < .05
Surface Area = Stature^{0.655} \cdot \text{Body Mass}^{0.441} \cdot 94.9 \quad \text{(Eq. 1)}

The best performance in 100-m freestyle refers to the highest FINA2008 points classification obtained by each swimmer in a short course competition event temporary close to the implementation of the experimental protocol. As there was no difference between genders in the above-referred variable, data were pooled. All the subjects were proficient freestyle swimmers with at least four years of competitive experience, engaging in six to eight training units per week (2 hr per training session).

**Testing Protocol**

Testing took place in a 25-m indoor swimming-pool (27 °C of water temperature) during the competitive period of the spring training macrocycle, in a taper micro-cycle that occurred 10 days before the National Championships. After a 1000-m low intensity warm-up, following the proposals of Mitchell and Huston (20), each participant performed a 30-s maximum intensity front crawl tethered swimming test. The subjects wore a belt attached to a steel cable (sufficiently stiff that its elasticity could be neglected) with 5-m length, and with a 5.7° angle in relation to the water surface, as proposed before (22). A load-cell system connected to the cable was used as a measuring device, recording at 100 Hz, with a measure capacity of 5000 N. The load-cell was connected to a Globus Ergometer data acquisition system (GlobusTM, Italy) that exported the data to a PC. 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. This procedure was used to avoid the inertial effect of the cable extension usually observed immediately before or during the first arm action. The test ending was set through an acoustic signal. Swimmers were told to choose the breathing patterns that normally apply in the 50-m freestyle event.

Capillary blood samples for lactate concentrations ([La−]) analysis (Lactate Pro, Arkay, Inc) were collected from the earlobe in the final of the warm-up and after the test. These data allowed the assessment of the net increase of blood lactate (Δ [La−]), i.e., the difference between the maximal values measured after the test and those obtained after the warm-up.

Individual force to time—F(t)—curves were assessed and registered to obtain the following parameters: (i) maximum force (Fmax); (ii) mean force (Fmean); (iii) fatigue index (Fat\text{index}), expressed as the relative decrease of force from its maximum peak registered in the first 10-s to its minimum peak obtained in the last 5-s of the test:

\[
\text{Fat index} = \frac{[(\text{maximum peak} - \text{minimum peak}) / \text{maximum peak}]}{100}
\quad \text{(Eq. 2)}
\]

(iv) fatigue slope (Fat\text{slope}), assessed through a linear regression equation:

\[
y = ax + b
\quad \text{(Eq. 3)}
\]

computed between the x and y coordinates of the its maximum peak and minimum peak, and (v) the y-interception in the origin of the xx axis (y\text{intercept}).
Performance Data Collection

Swimming performance was assessed one week after the testing protocol at the long course National Championships. Swimming velocity was calculated through the official electronic chronometric times of 50 and 100-m freestyle events.

Statistical Analysis

The normality assumption was checked with the Shapiro-Wilk test for all the variables before the descriptive analysis. To obtain the descriptive statistics (mean ± SD) standard statistical methods were used. Independent sample t test was used to verify eventual differences among group characteristics. Pearson correlation coefficients were computed to observe eventual relationships between variables. In addition, linear regression analysis allowed assessing determination coefficient (r²) together with the Passing-Pablok parameters (intercept, slope). The level of statistical significance was set at p < .05.

Results

Mean ± SD values for the tethered swimming test related variables were, respectively, 243.6 ± 60.15 N for Fmax, 89.8 ± 22.13 N for Fmean, 39.49 ± 6.97% for Fatindex and 7.73 ± 1.87 mmol/L for Δ[La−]. Swimming velocities for the 50 and 100-m freestyle events were 1.75 ± 0.15 m.s⁻¹ and 1.61 ± 0.11 m.s⁻¹, respectively.

The values of the relationships obtained between the variables representative of muscular force production obtained in the tethered swimming test and Δ[La−], as well as with the swimming velocities for the 50 and 100-m freestyle competitive events are presented in Table 2.

Table 2 Correlation Coefficient Values Obtained Between Tethered Force Parameters, Net Blood Lactate Production and Short Distances Swimming Competitive Performances

<table>
<thead>
<tr>
<th></th>
<th>Δ [La−] (mmol/L)</th>
<th>v50 (m.s⁻¹)</th>
<th>v100 (m.s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fmax (N)</td>
<td>0.83**</td>
<td>0.78**</td>
<td>0.63*</td>
</tr>
<tr>
<td>Fmean (N)</td>
<td>0.83**</td>
<td>0.72**</td>
<td>0.61*</td>
</tr>
<tr>
<td>Fatindex (%)</td>
<td>0.44</td>
<td>0.27</td>
<td>0.03</td>
</tr>
<tr>
<td>Fat_slope</td>
<td>-0.90**</td>
<td>-0.75**</td>
<td>-0.57*</td>
</tr>
<tr>
<td>y_intercept</td>
<td>0.85**</td>
<td>0.82**</td>
<td>0.69**</td>
</tr>
</tbody>
</table>

Note. Fmax = maximum force; Fmean = mean force; Fatindex = fatigue index; Fat_slope = fatigue slope; y_intercept = Y-intercept value of the linear regression equation; Δ[La−] = net increase of blood lactate; v50 = velocity for the 50 m freestyle event; v100 = velocity for the 100 m freestyle event.

*p < .05; **p < .01; n.s. = non significant.
Analysis revealed high correlations between $F_{\text{max}}$ and $F_{\text{mean}}$ with $\Delta[\text{La}^-]$, and moderate to high relationships between $F_{\text{max}}^2$ and $F_{\text{mean}}$ with $v_{50}$ and $v_{100}$. Fat_index did not present any significant correlation with $\Delta[\text{La}^-]$ and swimming performances. The proposed parameter—Fat_slope—presented a very high inverse relationship between Fat_slope and $\Delta[\text{La}^-]$ (see also Figure 1), as well as high and a moderate correlation values with $v_{50}$ and $v_{100}$, respectively (cf. Figure 2). The $y_{\text{intercept}}$ value showed high correlations with $\Delta[\text{La}^-]$ and $v_{50}$, and a moderate relationship with $v_{100}$. Moreover, a moderate correlation value was obtained between $\Delta[\text{La}^-]$ and $v_{50}$ ($r = .68, p < .05$), but no significant relationship was observed between $\Delta[\text{La}^-]$ and $v_{100}$ ($r = .41, p > .05$).

**Figure 1** — Relationship between Fat_slope values and net blood lactate production, in 30-s tethered test.

**Figure 2** — Relationships between Fat_slope values and swimming velocity in 50-m (panel a) and 100-m (panel b) events
Discussion

The major finding of this study is that the decrease in force production in a maximal 30-s tethered swimming can be used as a reliable estimator of adolescent swimmers performance on short distance events. These data were obtained in well trained adolescent swimmers with body size values similar to those previously reported for elite adolescent competitive swimmers (31). Traditionally, tethered swimming is considered to be a valid procedure to evaluate the swimmer’s force production, allowing a higher propulsion output (16). Even though tethered swimming does not evaluate the hydrodynamic drag that the swimmer must overcome, it allows assessing the swimmer’s capacity to use energy to force production. In addition, tethered swimming may be a useful methodology to understand the onset mechanisms (and the way to delay) of fatigue, as it is one of the main restrictions to higher performances (9,18).

The obtained F max and F mean values are in agreement with the literature (1,13,14). However, Hooper et al. (13) obtained lower values of F max in a 20-s test, which could be explained by the lower swimming level of the participants. In addition, F mean is slightly lower than other studies conducted in shorter efforts (mainly supported by phosphagenic energy source) and without breathing (1,3,14). Differences can be explained by age and gender differences between subjects studied.

Former studies have proved that, to remain stationary, the swimmer relies mostly on fast glycolytic muscle fibers increasing the production and diffusion of lactic acid into the blood (32). However, this phenomenon was not verified in the current study, since blood lactate concentration values obtained were lower than those obtained by elite swimmers in free swimming for similar effort duration (15). This fact can be explained by the fact that adolescent swimmers are changing from the basic training phase, in which they develop their basic conditional capacities (particularly their aerobic capacity), to the specialization phase (23); thus, their anaerobic metabolism is not yet fully developed. Nevertheless, the correlation obtained between Δ[La−] and v50 seems to point out the contribution of glycolytic power in short competitive distances, in accordance with Hill et al. (12). In addition, high correlations between F max and F mean with Δ[La−] were observed, indicating that the capacity to obtain higher values of force production is related with an enhanced production of energy through the glycolytic system.

The association between the studied force variables and short distance performances, particularly between both F max and F mean and v50 and v100 supports the data obtained in previous studies (8,22,33). Since those relationships are higher with v50 than with v100, it supports previous statements that force exerted in water is a major important factor for success in swimming performance, being its importance increased as the competitive distance diminishes (22).

By means of the individual F(t) curves, it was also possible to obtain fatigue related parameters. Fat index has been used in the Wingate test as an estimator of individual anaerobic capacity (21). Through the analysis of the acquired curves, it was possible to identify swimmers with different declines in force production, presenting similar Fat index. This inaccuracy is due to, traditionally, not taking into account the time gap between the two points analyzed; so, to overcome this gap, Fatslope was calculated using the same points that were used for the Fat index measurement. These statements are corroborated by the fact that Fat index did not present any
significant relation with metabolic or performance variables. Conversely, \( F_{\text{slope}} \) presented a very high correlation with \( r[La^-] \), expressing that swimmers with a higher slope attain superior \( \Delta[La^-] \) values. This formulation also can be applied to the association between \( y_{\text{intercept}} \) and \( \Delta[La^-] \). Therefore, as the relative contribution of the anaerobic energy system in a 30-s maximal exercise is considered to be about 73 ± 10% (9), it was expected that swimmers who presented a higher decrease in force production also attained higher values of \( \Delta[La^-] \) (12). In addition, tethered swimming may be an easy operative methodology, to predict performance in short distance events (cf. Figure 2). In that sense, it can be useful to monitor and evaluate anaerobic training.

When evaluating force production in short maximal exercises, the \( F(t) \) curve decrease, being referred that short distance swimmers commonly present higher decreases than long distance counterparts (28). We have hypothesized that knowing the individual curve characteristics it is possible to estimate the swimmer’s anaerobic performance. Mean velocity in the 50-m swimming event was 46.1% higher than in the 100-m front crawl, suggesting that swimmers presenting higher decreases in force production had better performances in the shorter event. This data suggests that this methodology is indeed specific to evaluate and/or predict anaerobic performance.

Training with the scope to achieve higher anaerobic power usually relies on increasing the production of ATP, the use of CP, or the rate and magnitude of anaerobic glycosis (23). With the ability to evaluate the individual decrease in force production, the swimming coach can better understand the effects of his specific training for swimming distances lower than 200-m, more specifically for 50-m. Both \( F_{\text{slope}} \) and \( y_{\text{intercept}} \) showed a high correlation with \( v_{50} \) and net increase of blood lactate indicating that, for the present sample, this indicator may be a good estimator for anaerobic performances.

It can be considered as main limitations of this research: (i) there is some bias pooling the data of males and females swimmers; (ii) the small number of subjects evaluating according to gender does not allow to identify the eventual differences induced by gender; (iii) in a near future may be useful to understand the contribution of other biomechanical (e.g., limbs kinematics’) and motor control (e.g., neuromuscular and interlimb coordination) variables in relationships between force exerted in water and swimming performance in short distance events.

References


