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# Shoulder tensiomyography and isometric strength in swimmers before and after a fatiguing protocol

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**Shoulder tensiomyography and isometric strength in swimmers before and after a fatiguing protocol**


## ABSTRACT

**Context.** Shoulder muscles are active during front crawl swimming to provide propulsion and stabilize the glenohumeral and scapulothoracic joints. It has been proposed that fatigue might contribute to altered activation of these muscles and represent a risk factor for injuries. Tensiomyography (TMG) might represent a non-invasive tool to detect exercise-induced neuromuscular fatigue changes in contractile parameters of the skeletal muscles, and it has never been used in the shoulder muscles in swimmers. **Objective.** The aim of this study was to assess the effects of a fatiguing swimming protocol on shoulder muscles TMG parameters and isometric strength in competitive swimmers. **Design.** A cross-sectional study. **Setting.** A swimming pool facility. **Patients or Other Participants.** Sixteen young front crawl competitive swimmers were invited to participate in the study, and 14 of them (21 y, range 17-26, 11 males 3 females) completed all the assessments before and after a 30-min high-intensity swimming training. **Main Outcome Measure(s).** The main outcome included the TMG assessment which was performed on seven muscles of the shoulder according to front crawl biomechanics and applicability of the technique, in order to obtain data such as time to contraction and muscle belly radial displacement (Dm), whereas isometric strength was assessed with a digital dynamometer during shoulder flexion, extension, external rotation and internal rotation. **Results.** Fatigue induced a smaller Dm (-0.5 mm, 95% CI: -0.7 - -0.3, $p < 0.001$, $p\eta^2 = 0.692$), mostly observable in latissimus dorsi and pectoralis major muscles. Only shoulder extension showed a significant isometric strength reduction after the fatiguing protocol (-0.03 N/kg, 95% CI: -0.05 - -0.01, $p = 0.045$, $p\eta^2 = 0.275$). **Conclusions.** This study provides preliminary evidence for the usefulness of TMG to detect fatigue-induced changes in contractile properties of the shoulder muscles in swimmers, in particular the latissimus dorsi, pectoralis major and lower trapezius.



**Keywords**: fatigue; swimming; muscle; neuromuscular; contraction.

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**Key points:**

- Tensiomyography is a non-invasive tool to detect skeletal muscle contractile properties and could be used to evaluate the effects of fatigue in swimmers.
- In front crawl swimmers, tensiomyography suggested increased indexes of fatigue in the latissimus dorsi and pectoralis major.
- Extensor muscles showed a decreased maximum isometric strength after a swimming fatiguing protocol.

## 1. Introduction

Competitive swimming is a sport characterized by a large training volume, with an estimated impact on the shoulder muscles and joint between 16'000 and 25'000 rotations during a typical training week [1,2]. Swimming is characterized by the activation of several muscles that might contribute to fatigue after training. In particular, the shoulder is often reported as a body area where fatigue and pain could be commonly present in swimmers. Indeed, the shoulder is commonly referred to as one of the sites where pain is often reported, leading to the development of "shoulder pain" [1]. Fatigue has been suggested to possibly affect the shoulder's strength, proprioception and range of motion, therefore representing possible risk factors for overuse shoulder injury [2]; indeed, decreased muscle endurance or either hypo or hyperactivation of shoulder muscles could lead to abnormal movement of the gleno-humeral and scapulothoracic joints, and consequently, continuous aggravation of susceptible tissues [2–5]. As such, identifying the muscles that might be more influenced by fatigue in swimming might help to recognize subjects at a higher risk of developing shoulder pain and to design training and physiotherapy protocols aimed to strengthen and improve endurance in the specific muscles.

Tensiomyography (TMG) represents a non-invasive technique that has been suggested to measure several skeletal muscle mechanical contractile properties [6,7]. The effects of exercise-induced fatigue have been suggested to be detectable by TMG on the different muscles of the lower limbs [8–11], and in particular by reporting a decreased radial displacement (Dm) [8,12,13]. In the upper limb, TMG has been reported to be highly sensitive in detecting fatigue-induced changes in biceps brachii after high-volume and high-load resistance exercises [14]. Despite isometric strength assessment and TMG-derived parameters might reflect different aspects of fatigue-induced muscle contraction alterations, it might be hypothesized that those muscles presenting altered TMG parameters (e.g., decreased Dm) after a fatiguing protocol, could be the same muscles that are primarily active during specific shoulder movements characterized by fatigue-induced isometric strength reduction. Indeed, exercise-induced muscle damage of the elbow flexors induced a significant reduction of maximum voluntary contraction (MVC), rate of torque development, and TMG Dm [15]. As such, TMG could provide additional information about muscle contractile properties in swimming, and might be associated with isometric strength before and after fatigue in specific shoulder movements.

The aim of the present study was to concomitantly measure isometric strength and TMG parameters in healthy shoulders of young competitive swimmers before and after performing high-intensity swimming training.

## 2. Methods

### *2.1 Participants*

A cross-sectional study was conducted on young swimmers of both sexes recruited from local swimming clubs and who volunteered to participate in the study, between January and April 2023. To be included, participants aged between 16 and 35 were asked to: train in swimming for at least 3 years and with a training volume of not less than 4.5 h per week. Front crawl had to be their main swimming style. Participants were excluded if they had a history of chronic or acute muscular or joint diseases at the tested shoulder or upper limb. All the participants and their legal guardians read and signed informed consent and were instructed about the study procedures. The study was approved by the local university ethics committee (122/2022) and was conducted according to the Declaration of Helsinki principles.

*2.2 Study protocol*

All the participants were invited to a first visit to the university lab, where their demographics and anthropometrics were collected, including information about training habits; inclusion and exclusion criteria were then confirmed. During the first introductory visit, participants familiarized themselves with the assessments' procedures, i.e., shoulder tensiomyography (TMG) and isometric strength evaluation. The training was repeated until the participant felt confident with the assessment techniques. Participants received a copy of the fatiguing protocol that was previously designed by the research team together with an expert swimming trainer, and they were recommended to try it in the following days. Then, participants were invited to the experimental session between 7 and 14 days after the first visit. The experimental session was conducted in a local swimming pool (25 m, depth, water temperature between 26 and 29 °C). Measurements were conducted in the morning, at least after 2 h after participants woke up. Participants were asked to avoid strenuous training in the previous 48 h, and they were asked to refrain from smoking or alcohol consumption in the morning. After arriving at the swimming facility, they were asked to wear their swimwear. TMG and strength assessments were performed (pre). Hence, the fatiguing protocol was performed, consisting of 30-min front crawl swimming at different incremental intensities (**Figure 1**) (**Supplementary Material 1**); the overall exercise intensity was monitored with a waterproof heart rate monitor, resulting in the heart rate being > 70% its maximum for more than 90% of the training time, and > 80% for more than 30% of the training time. Participants were also asked to rate their perceived exertion (RPE) during the different phases of the fatiguing protocol trying to respect the training protocol. The assessments were then repeated with the same measurements protocol within 20 minutes from the completion of the fatiguing protocol. To reduce the influence of arm dominance, the participants were randomly tested on their dominant or non-dominant shoulder and according to the absence of any shoulder pain symptom.

*2.3 Tensiomyography (TMG)*

TMG is a mechanomyographic method that has been used in several studies and represents a promising tool to assess in vivo skeletal muscle mechanical contractile properties; compared to other methods such as myotonometry or shear-wave elastography, it is based on radial muscle belly displacement after electrical stimulation, therefore presenting an "active" response of the muscle [7,16,17]**.** A sensitive digital displacement sensor (TMG-BMC Ltd., Ljubljana, Slovenia) placed on the skin's surface at the measuring site of the muscle of interest, was used to record muscle belly oscillations induced by a single 1 ms maximal monophasic electrical impulse. The stimulation amplitude was gradually increased from the minimum intensity to induce a recordable oscillation, until the measured radial twitch Dm (mm) did not increase further, with electrical pulses ranging between 85 and 110 mA at constant 30 V. To provide sufficient resting, 10-15 s inter-stimulation time interval was chosen. The analyzed parameters were recorded from two maximal responses and were averaged and then included in the final analysis. The standardized TMG-derived parameters included the maximal radial displacement (Dm, mm), the time from electrical pulse to 10% of Dm (Td, delay time, ms), the time to contraction between 10% and 90% of Dm (Tc, contraction time, ms], the time when the response was above 50% of Dm (Ts, sustain time, ms), and the time between 90% and 50% of Dm during the muscle relaxation phase (Tr, half-relaxation time, ms). All these parameters were extracted by the TMG software (Version 3.6.16) and used for offline analysis [17]. Reduced Dm has been suggested as an index of increased muscle stiffness, whereas larger Dm implies lower muscle stiffness; Td represents a measure of muscle responsiveness; Tc represents the speed of twitch force generation, and it has been suggested to reflect muscle fiber type or tendon stiffness; Ts and Tr are the least studied parameters, with Ts suggesting possible implication in the assessment of muscle fiber fatigue status, although these last two parameters require further investigation [18]. In particular, TMG reliability was considered high for Tc, Td and Dm, whereas Tr demonstrated poor reliability [18]. Substantial evidence for its reliability has been also suggested for exercise-induced muscle fatigue, whereas more studies are required to determine its accuracy/validity[9]. The following muscles were investigated according to their role during front crawl swimming biomechanics [19] and their validation with TMG according to the manufacturer's guidelines: anterior deltoid (m.AD), medial deltoid (m.MD), latissimus dorsi (m.LD), pectoralis major (m.PM), upper trapezius (m.UT), middle trapezius (m.MT), lower trapezius (m.LT). The participants were tested while sitting (m.AD, m.MD, m.UT), laying supine (m.PM) or prone (m.LD, m.MT, m.LT). The electrodes and sensor were placed by the same researcher with expertise in the use of TMG (ABS) on the muscle area, and positions were marked with waterproof drawing ink to assure the constant location of the electrodes on the skin over the repetitions.

*2.4 Shoulder strength*

Isometric shoulder strength assessments were performed in the suping position on a treatment bed, with a digital handheld dynamometer (Kinvent, Italy). Shoulder flexion and extension were performed with the shoulder abducted at 140° in the scapular plane (30° anterior to the frontal plane) with the elbow extended and the forearm pronated. To assess external rotation and internal rotation, the arm was positioned at 90° shoulder abduction with the forearm vertical and the elbow flexed to 90°. All starting positions were checked with a goniometer and the dynamometer was aligned to be perpendicular to the forearm. These positions were chosen according to previous literature, suggesting being similar to the shoulder position during the relevant phases of the crawl swim stroke [20]. Swimmers were instructed to keep the trunk from moving during testing and without any external stabilization; such protocol and shoulder positions have been previously suggested to provide excellent intra-rater reliability. An experienced sport physiotherapist performed the strength measurements and instructed the participants about the assessment protocol. Before the measurements, all the participants were allowed to perform a short warm-up and familiarize themselves with the positions and movement at submaximal effort. The different movements were assessed following a randomized order and two repetitions of each strength test were performed with a rest period of five seconds between each repetition and thirty seconds between each test. The swimmer was asked to gradually build up to a maximum force and maintain the effort, then relax when instructed after a total of five seconds. Verbal encouragement was provided during testing to produce a maximum effort matched by the tester (make test) according to previous literature [20]. The maximum value (Newton, N) was chosen, and it was normalized according to participants body mass.

*2.5 Statistics and data analyses*

All statistical analyses were performed with SPSS version 23 (IBM). This is the primary analysis of these data. Outcomes are reported as the means, standard deviation, counts and proportions (%) as appropriate. Two-tailed testing was performed. Normality testing using the Shapiro–Wilk test was performed for all datasets, and TMG Tr and Ts were not normally distributed in all the assessed muscles. Therefore, a log transformation was applied for these variables. A repeated measures analysis of variance (ANOVA) was performed. Since the different muscles assessed by TMG, a within-within ANOVA was performed considering the time effect (pre and post) and muscle effect (the 7 assessed muscles). Greenhouse–Geisser correction was applied in case of lack of sphericity, and Sidak's correction was applied for post-hoc analyses. Effect size was determined by $p\eta^2$. In the event of a statistically significant main group effect, simple main effects were performed to compare each muscle independently. Finally, a Pearson's coefficient correlation analysis was performed between the changes in isometric strength and TMG parameters before and after the fatiguing protocol. Significance was set for $p < 0.05$.



## 3. Results

From sixteen participants initially recruited, only fourteen swimmers (21 y, range 17-26, 11 males 3 females) were included in the study as they completed all the assessments. Participants' demographics, anthropometrics and training habits are reported in **Table 1**.

### *3.1 Tensiomyography*

A significant interaction effect between time and the tested muscle was found for Dm ($F_{6,78}$= 2.504, p= 0.029, $p\eta^2$= 0.161). In particular, after the fatiguing protocol, a significant reduction of Dm was found in the m.LD (-1.0 mm, 95% CI: -1.7 - -0.3, p= 0.007) and m.PM (-1.4 mm, 95% CI: -2.4 - -0.4, p= 0.007). No significant differences were found for the other TMG-derived parameters (**Figure 2**) (**Table 2**).



### *3.2 Shoulder strength*

Shoulder strength was affected by the fatiguing protocol, as a significant time effect was found during the extension task ($F_{1,13}$= 4.936, p= 0.045, $p\eta^2$= 0.275). In particular, maximum isometric strength during extension was reduced by 0.03 N/kg (95% CI: 0.01 - 0.05) (**Figure 3**). No significant effects were reported during flexion, external rotation, and internal rotation (**Table 3**).

### *3.3 Correlation analysis*

A significant correlation was found between the change in isometric strength during extension and m.LD Tc (r= -0.544, p= 0.044), m.LD Dm (r= 0.549, p= 0.042) and m.UT Dm Tc (0.645, p= 0.013), and between isometric strength during flexion and m.UT Tc (r= 0.683, p= 0.007).

## 4. Discussion

This study provides preliminary evidence that tensiomyography (TMG) could help to detect skeletal muscle contractile changes after a fatiguing protocol in swimmers, and provides an evaluation map of the most affected muscles. In particular, significantly reduced radial displacement was reported in the overall assessed muscles, where the latissimus dorsi and pectoralis major were the mostly affected muscles.

Although a reduction in Tc has been previously observed after a lower limb fatiguing protocol [21], it is not clear what the physiological mechanism underlying such alteration in the time needed to reach the peak radial displacement could be. However, it might be speculated that such reduced time could be associated with a significant reduction in muscle belly radial displacement [17], as also reported in this study. Indeed, it has been suggested that lower Dm, which is an indirect measure of muscle stiffness to the electrical stimulation [7,17], could be observed after fatiguing tasks [15,22], and this might be due to the swelling response and increased intracellular water content after exercise-induced muscle fatigue, resulting in increased muscle stiffness [21]. More in detail, local fatigue has been previously suggested to reduce Dm in the skeletal muscles impairing the propagation of the electrical stimulus along the sarcolemma as pH-driven alteration of the Na+ and K+ gradient might be influenced by the pH-associated alterations across the muscle membrane [23], therefore influencing the excitation-contraction coupling. Finally, accumulation of inorganic phosphate within the muscle cells might further impair the radial displacement of the muscle. resulting in reduced Ca2+ and subsequent excitation–contraction coupling [13], or through accumulation of inorganic phosphate within muscle cells [17]. In general, the findings from the present study seem to be in line with some previous studies suggesting that Dm could be reduced after exercise induced muscle fatigue, whereas Tc presents conflicting results which needs additional research [8,9].

The skeletal muscles acting on the shoulder joint during swimming which presented the largest changes after exercise were the latissimus dorsi, the pectoralis major and lower trapezius, despite only the first two reaching statistical significance. The latissimus dorsi is primarily activated during the Mid Pull Through and Late Pull Through, whereas the pectoralis major is mainly active during the Early Pull Through and Mid Pull Through [24]. Electromyographic assessment of muscle fatigue during 100-m front crawl showed decreased mean power frequency of these muscles [25]. The lower trapezius is a muscle that plays an important role in scapula movement and positioning, and also dynamic scapula stability and might be important during swimming [26], and might be impaired after a 3-min maximal effort in swimmers [27]. If the impact of the fatiguing exercise protocol proposed in this study expectably affected all the tested muscles and, in particular, latissimus dorsi and pectoralis major since their important role in front crawl, the notable effect on upper and lower trapezius compared to other muscles, if confirmed in other studies on larger samples, could inform about its contribution in swimming.



Shoulder strength was assessed during isometric tasks aimed to test the effects of fatigue on flexion, extension, external rotation and internal rotation, providing values in line with previous literature [20]. Shoulder extension contributes to assisting pulling the body over the arm through the water in the front crawl stroke [20]. In contrast, shoulder flexors might have a minor role in front crawl, as no differences in flexion have been previously found between swimmers and healthy young adults [20]. In previous swimming research, maximum strength during internal and external rotation has been suggested as not being affected by fatigue [2]. In the present study, only extension was found to be significantly reduced after the fatiguing swimming protocol. During shoulder extension, subscapularis and latissimus dorsi muscles were found to be more active than during flexion, whereas during flexion, supraspinatus, infraspinatus, deltoid, trapezius, and serratus anterior were more highly activated than during extension [28]; in addition, the pectoralis muscles are part of the shoulder stabilizing structures and are active in shoulder extension [29]. In particular regarding trapezius, also lower trapezius is mainly activated during flexion, although it might be active during extension [30]. Interestingly, the larger fatigue-induced TMG-related changes were found in those muscles that might have a major role during shoulder extension, which showed a significant isometric strength reduction. Indeed, the correlation analysis suggested that there was a significant association between the decrease in extension strength and decreased latissimus dorsi radial displacement (i.e., index of fatigue). Curiously longer time to contraction of the latissimus dorsi and shorter time to contraction of the upper trapezius were significantly correlated with decreased extension strength, and shorter time to contraction of the upper trapezius was correlated with flexion strength, confirming the above-mentioned conflicting results about this parameter, and fatigue.

Taken together, the results from the present study are in line with previous literature suggesting tensiomyography might be helpful to detect some hallmarks of muscle fatigue, and, reduced radial displacement might reflect increased stiffness due to exercise-induced alterations of muscle contractile properties. Although such findings have been previously suggested in other studies, to the best of the authors' knowledge this is the first study attempting to report TMG alterations in shoulder muscles after a fatiguing swimming exercise protocol. In addition, isometric strength was assessed during different shoulder movements, suggesting some potential associations between the muscles which presented the most impaired TMG parameters and the reduced isometric strength task. Despite such promising results, it should be noted that this study was performed on a relatively small sample size and that other individual factors might have affected the outcomes; therefore, further studies are needed to confirm the proposed findings. Since the role of the tested muscles to stabilize and prevent pain and injuries, future studies should evaluate the role of fatigue in the development of such conditions and to assess if "shoulder pain" could influence the reported outcomes in competitive swimmers.

Exercise induced muscle fatigue in swimming could be detected by TMG parameters in the shoulder's muscles, and in particular as a reduced radial displacement. Latissimus dorsi and pectoralis major were found to be the most affected muscles, although a significant fatigue-effect was reported for the overall tested muscles. According to the isometric strength assessment, only shoulder extension was significantly reduced after the fatiguing swimming protocol. These findings encourage the use of TMG as a non-invasive assessment tool to detect peripheral fatigue, also in shoulder muscles, and could assist trainers and physiotherapists to design training and rehabilitation protocols based on the most affected muscles, suggesting specific exercises that might focus on the most affected muscles (such as pectoralis and latissimus dorsi), combining swimming and strength training [31].



**Conflict of Interest Statement**

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. The figures are original and not previously published.

**Data availability**

The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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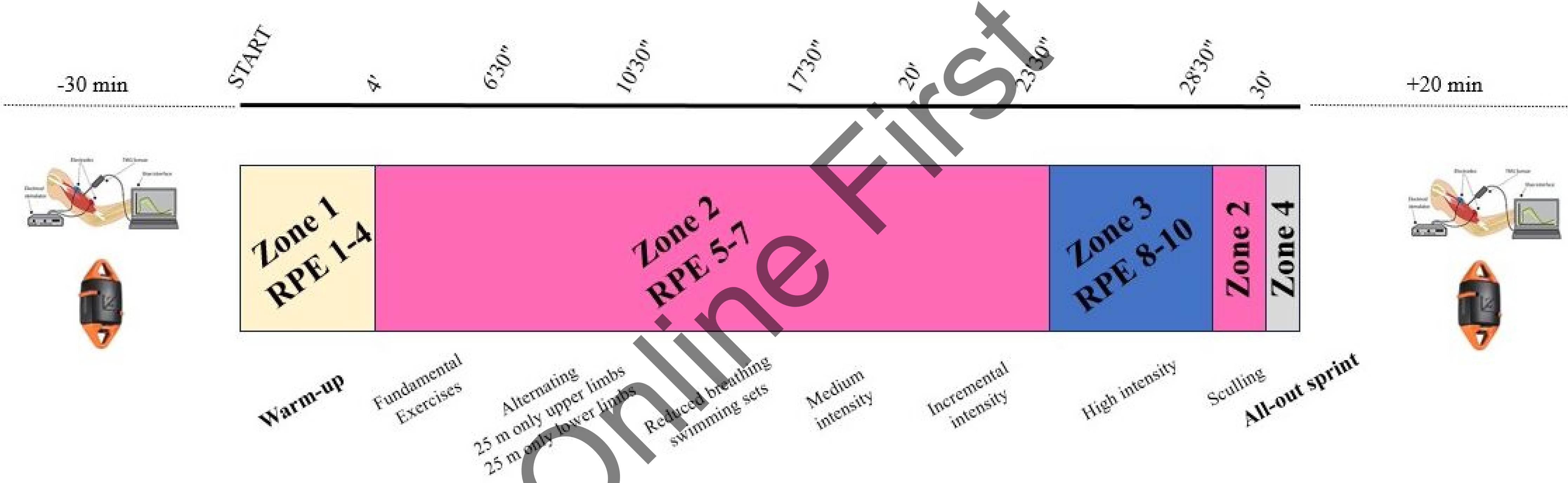
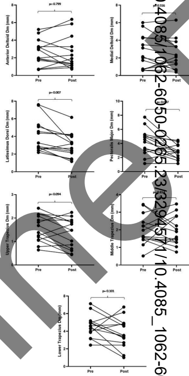
## Figure captions

**Figure 1**. Representation of the swimming training protocol to induce fatigue. Outcomes assessment performed before and after the training protocol, total 30 min. Intensity zones from 1 to 4, and corresponding rate of perceived exertion (RPE).

**Figure 2**. Radial displacement (Dm, mm) of the selected shoulder muscles before (pre) and after (post) a fatiguing swimming protocol in the included sample (n= 14). Within-within analysis of variance (ANOVA) showed a time x muscle interaction $F_{6,78}$= 2.504, p= 0.029, $p\eta^2$= 0.161.

**Figure 3**. Isometric strength during shoulder extension before (pre) and after (post) a fatiguing swimming protocol in the included sample (n= 14). Repeated measures analysis of variance (ANOVA) time effect $F_{1,13}$= 4.936, p= 0.045, $p\eta^2$= 0.275.


-30 min
START
4'
6'30"
10'30"
17'30"
20'
23'30"
28'30"
30'
+20 min
Zone 1
RPE 1-4
Zone 2
RPE 5-7
Zone 3
RPE 8-10
Zone 2
Zone 4
Warm-up
Fundamental
Exercises
Alternating
25 m only upper limbs
25 m only lower limbs
Reduced breathing
swimming sets
Medium
intensity
Incremental
intensity
High intensity
Sculling
All-out sprint


p= 0.799
Anterior Deltoid Dm (mm)
Pre
Post
p= 0.316
Medial Deltoid Dm (mm)
Pre
Post
p= 0.007
Latissimus Dorsi Dm (mm)
Pre
Post
Pectoralis Major Dm (mm)
Pre
Post
p= 0.094
Upper Trapezius Dm (mm)
Pre
Post
Middle Trapezius Dm (mm)
Pre
Post
p= 0.301
Lower Trapezius Dm (mm)
Pre
Post

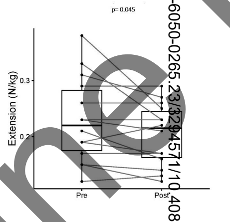

p= 0.045
Extension (N/kg)
0.3
0.2
Pre
Post

**Table 1:** *Demographics and training characteristics of the included sample. Means ± standard deviations and proportions, as appropriate.*

| | **Participants (n= 14)** |
|---|---|
| ***Demographics*** | |
| Age, y | 21±3 |
| Females, n (%) | 3 (21) |
| Body mass, kg | 73.1±9.2 |
| Body height, m | 1.78±6.5 |
| BMI, kg/m$^2$ | 23.0±1.6 |
| ***Training characteristics*** | |
| Years of training in swimming, y | 13±4 |
| Competition level, n (%) | |
| Regional | 6 (43) |
| National/International | 8 (56) |
| Training frequency, training/wk | 6±1 |
| Training volume, h/wk | 13±2 |

**Notes:** BMI: body mass index.

**Table 2:** *Muscle tensiomyography parameters before (Pre) and after (Post) the fatiguing swimming protocol. Means ± standard deviations.*

| | Pre (n= 14) | Post (n= 14) | Significance |
|---|---|---|---|
| ***m.AD*** | | | |
| Tc (ms) | 16.4±4.4 | 15.1±2.2 | 0.232 |
| Td (ms) | 17.8±1.7 | 17.9±1.5 | 0.818 |
| Tr (ms) | 34.3±66.6 | 18.9±16.7 | 0.807 |
| Dm (mm) | 2.6±1.5 | 2.5±1.8 | 0.799 |
| Ts (ms) | 140.4±255.1 | 171.6±304.2 | 0.917 |
| ***m.MD*** | | | |
| Tc (ms) | 14.8±3.2 | 14.5±2.5 | 0.686 |
| Td (ms) | 17.8±1.9 | 17.4±1.7 | 0.211 |
| Tr (ms) | 65.9±150.1 | 15.3±18.3 | 0.193 |
| Dm (mm) | 2.6±1.9 | 2.3±1.7 | 0.316 |
| Ts (ms) | 140.3±259.3 | 58.0±111.7 | 0.279 |
| ***m.LD*** | | | |
| Tc (ms) | 42.1±4.4 | 38.4±6.0 | **0.039** |
| Td (ms) | 23.6±3.5 | 22.8±3.9 | 0.601 |
| Tr (ms) | 39.9±15.6 | 31.3±10.0 | **0.013** |
| Dm (mm) | 4.0±1.8 | 3.0±1.4 | **0.007** |
| Ts (ms) | 105.2±27.3 | 93.7±15.4 | 0.080 |
| ***m.PM*** | | | |
| Tc (ms) | 24.9±4.9 | 25.1±5.6 | 0.852 |
| Td (ms) | 25.2±4.1 | 24.6±5.7 | 0.538 |
| Tr (ms) | 35.4±41.5 | 44.3±56.8 | 0.715 |
| Dm (mm) | 4.2±1.8 | 2.8±1.0 | **0.007** |
| Ts (ms) | 67.6±49.0 | 117.3±195.2 | 0.459 |
| ***m.UT*** | | | |
| Tc (ms) | 20.5±6.6 | 18.7±3.0 | 0.400 |
| Td (ms) | 19.6±2.8 | 19.9±3.7 | 0.669 |
| Tr (ms) | 69.3±63.6 | 103.4±199.6 | 0.896 |
| Dm (mm) | 1.5±0.5 | 1.3±0.6 | 0.094 |
| Ts (ms) | 116.4±74.4 | 162.4±238.2 | 0.787 |
| ***m.MT*** | | | |
| Tc (ms) | 18.1±3.5 | 18.2±3.1 | 0.852 |
| Td (ms) | 20.1±2.7 | 20.1±1.8 | 0.958 |
| Tr (ms) | 60.3±44.7 | 77.1±74.5 | 0.976 |
| Dm (mm) | 2.0±0.8 | 1.9±0.8 | 0.814 |
| Ts (ms) | 111.2±66.3 | 110.6±84.7 | 0.692 |
| ***m.LT*** | | | |
| Tc (ms) | 41.2±23.5 | 30.8±12.7 | 0.202 |
| Td (ms) | 22.8±2.9 | 21.9±1.5 | 0.246 |
| Tr (ms) | 101.6±117.7 | 134.1±228.7 | 0.593 |
| Dm (mm) | 4.6±1.3 | 3.8±1.7 | 0.101 |
| Ts (ms) | 291.2±192.9 | 318.4±244.5 | 0.834 |

**Notes:** anterior deltoid (m.AD), medial deltoid (m.MD), latissimus dorsi (m.LD), pectoralis major (m.PM), upper trapezius (m.UT), middle trapezius (m.MT), lower trapezius (m.LT); Tc: time of contraction; Td: time of delay; Tr: time of relaxation; Dm: displacement; Ts: time of sustain. Significance for repeated measures analysis of variance, simple main effect. Bold values for $p < 0.05$.

**Table 3:** *Shoulder isometric strength before (Pre) and after (Post) the fatiguing swimming protocol. Means ± standard deviations.*

| | Pre (n= 14) | Post (n= 14) | Significance |
|---|---|---|---|
| ***Isometric strength (N/kg)*** | | | |
| Flexion | 0.22±0.08 | 0.21±0.08 | 0.336 |
| Extension | 0.23±0.08 | 0.20±0.05 | **0.045** |
| External rotation | 0.28±0.07 | 0.26±0.06 | 0.079 |
| Internal rotation | 0.32±0.06 | 0.30±0.07 | 0.444 |

**Notes:** Isometric strength in Newtons per kilogram of body mass (N/kg). Significance for repeated measures analysis of variance, bold values for $p < 0.05$.

**Swimming training – Fatiguing protocol:**

The fatiguing protocol was based on the Italian Swimming Federation (FIN) paces and intensities classification, and was designed and adapted by a certified swimming trainer to meet the common classification of training zones in swimming (https://www.phlexswim.com/blog/the-importance-of-training-zones-and-how-to-individualize-training), and based in rare of physical exertion (RPE) and heart rate HR), indicated as follows:

- *Zone 1 (RPE 1-4, HR< 70% max)*: swimming at these intensities does not cause any major changes in blood lactate/VO2 markers; this zone is mainly used for developing the "aerobic base" fitness and for things such as technical skills, warm-up/cool-down, and for recovery sessions.
- *Zone 2 (RPE 5-7, HR 70-90% max)*: In this zone, blood lactate can be between 2 and 6 mmol/L.
- *Zones 3 (RPE 8-10, HR 90% max)*: Blood lactate can usually be 6 and 20 mmol/L. This zone is used for various forms of interval training aiming to improve both aerobic and anaerobic parameters.
- *Zone 4 (RPE 10)*: This zone includes maximum sprinting speed that represents a ceiling on a swimmer's speed. This zone is used mostly for race pace training, skills, and the development of anaerobic systems.

The proposed training consisted of 4 min of warm up exercises (Zone 1), 2.5 min of fundamental exercises (Zone 2), 4 min alternating 25 m only upper limbs / lower limbs swimming (Zone 2), 13 min at different and progressing intensities(Zone 2), 5 min high intensity swimming (Zone 3), 1.5 min sculling exercises (Zone 2), and a final 100 m maximum intensity swimming (Zone 4) (**Figure 1**).