Pressure on the Electrode to Reduce Discomfort During Neuromuscular Electrical Stimulation in Individuals With Different Subcutaneous-Fat Thickness: Is the Procedure Effective and Reliable?

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***Abstract*—The addition of manual pressure on the electrode during neuromuscular electrical stimulation (NMES) has been used to reduce current intensity and perceived discomfort. In this study we aimed to test i) whether this approach affect the reliability of commonly made torque output measurements and ii) whether subcutaneous-fat thickness influence the efficacy of this approach in reducing current intensity and perceived discomfort. Twenty-one men (24 ± 3.1 years) performed knee extension maximal voluntary isometric contractions with and without manual pressure on the NMES femoral nerve electrode (superimposed and resting doublets, 2 pulses at 100 Hz) during two separate sessions. Torque output was measured in an isokinetic dynamometer and thigh subcutaneous-fat thickness assessed with ultrasonography. A scale of perceived discomfort was presented after contractions. Reductions in current intensity ($p < 0.001$) and discomfort during superimposed doublet ($p = 0.002$) and resting doublet ($p = 0.002$) were confirmed for the condition in which pressure was applied to the electrode. Fat thickness was correlated to changes in current intensity (r = 0.63; $p = 0.002$) and changes in discomfort (r = 0.45; $p = 0.04$) and no differences between pressure conditions and testing sessions were observed for torque output ($p > 0.05$; ICC 0.95). Adding manual pressure during NMES on femoral nerve reduces discomfort and the maximal NMES intensity required to reach maximum torque without affecting torque output magnitude and reliability. Greater reduction in intensity and discomfort were observed in participants with higher subcutaneous-fat thickness levels after adding pressure on the electrode.**

***Index Terms*—Electrical nerve stimulation, fat thickness, discomfort, knee extension, reliability.**

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I. Introduction

NEUROMUSCULAR electrical stimulation (NMES) is widely used to investigate muscular and neurophysiological mechanisms associated with resting states or responses to acute and chronic interventions [1]. It can provide information about the contractile properties of the muscle [2]–[4], such as peak force, rate of force development, and half relaxation time without major interference from the central nervous system [1], [3], [5]. Despite the importance of using NMES for neuromuscular assessments, delivering an electrical stimulus may cause great discomfort (in some cases, described as unbearably painful) [6], [7].

Strategies to reduce the NMES-induced pain/discomfort have been investigated in the past years [6], [8]. For example, stimulating the nerve induces a lower discomfort compared to stimulating the muscle belly [9]. Also, the use of a subject-specific identification of motor points instead of a standardized reference chart for electrode positioning has been recommended [8]. Recently, another strategy has been show useful: the application of pressure on the electrode. Cattagni *et al.* [6] have shown that the discomfort induced by single pulses reduced significantly when applying pressure on the electrode compared with no pressure. Moreover, the manual pressure can help to stabilize the electrode during prolonged experimental sessions, especially at the femoral nerve area, since the quadriceps muscle can present different movements that could dislocate the electrode from its original location. Authors confirmed that this effect was not accompanied by significant changes on neurophysiological parameters such as the M-wave and H-reflex amplitudes but no information regarding torque output parameters were obtained. Additionally, only single pulses were tested. Although a single pulse is useful in estimating voluntary activation level, more than two stimuli were shown to result in less force variability and, consequently, better sensitivity in assessing torque changes [10]. Some studies have applied pressure on the electrode with manual pressure, adhesive tape or straps [6], [11]–[13], however the reliability of this technique was never tested.

The reason for this reduction in discomfort when pressure is applied to the electrode is thought to be related to the compression of fat tissue, which would reduce the distance between the electrode and the nerve [14], [15]. The fat thickness is it is a measurement that can be estimated easily with ultrasound and also with simple instruments as a skinfold caliper in the clinical practice, as an example in the study of Medeiros *et al.* [15] that used a skinfold caliper, it was found that women with thicker skinfold thickness needed higher current intensity to evoke a muscle response. Also, fat tissue has a high resistance, and with thicker fat tissue, the greater the resistance lesser the energy/intensity of electric stimulus will transfer to the nerve [14]. Indeed, this leads to a higher intensity required to evoke a response. As a result, the discomfort/pain perception is increased since it is related to the intensity of the electrical stimulation. One may expect that the effect of adding pressure on the electrode during NMES offer greater benefits to volunteers with thicker subcutaneous-fat layer than to lean participants. This might be expected because this method reduces the distance between the electrode and the nerve reducing the stimulation intensity, and consequently attenuating the perceived discomfort.

In this study we aimed to investigate the effect of adding manual pressure to the electrode during NMES on the current intensity required to reach maximum torque, on perceived NMES-related discomfort, and on maximal torque output across individuals with different subcutaneous-fat thickness. The dependence current intensity and discomfort reduction on subcutaneous-fat thickness and the reliability between protocols and between sessions for each protocol were assessed. We hypothesized that i) applying pressure on the electrode results in a reduction current intensity and perceived discomfort that is dependent on subcutaneous-fat thickness and ii) that the application of pressure will reduce the test-retest reliability of torque output measurements.

II. Methods

A. Subjects

To participate in this study, volunteers should: 1) be males aged between 18 and 35; 2) report no previous record of neural and musculoskeletal disease or injury in the tested limbs that could interfere in the test output; 3) withstand the electrical stimulation. The participants received a detailed explanation about the experimental procedure of the study and gave their written consent. The local Ethics Committee (protocol number: 86710718.0.0000.0121) approved all the experimental procedures, which followed the code of ethics of the world medical association (Declaration of Helsinki). Sample size calculation was based on the study of Cattagni *et al.* [6] that have ten participants. And the sample size calculation of reliability was based on Bonett [16] and was made on an online sample calculator [17] with a minimum acceptable reliability of 0.4, expected reliability of 0.8, significance level 0.05, power level of 80%, with two days and an expected dropout rate of 10%. A sample size of 19 volunteers was obtained, therefore twenty-three healthy adult men were recruited, two participants were excluded due to unbearable discomfort to the NMES in the familiarization session, and twenty-one healthy adult men (24 $\pm$ 3.1 years, 1.75 $\pm$ 0.05 m, and 85.9 $\pm$ 9.4 kg) have completed all the sessions. All participants reported having previous experience (i.e. in at least two different protocols that used supramaximal stimulation) with NMES.

B. Procedures

The participants visited the laboratory in three different sessions 48 hours apart. They were asked to avoid exercise training in the last 48 hours before tests and to avoid caffeine consumption on the testing sessions. On the first sessions, the subcutaneous-fat thickness over the rectus femoris muscle was assessed with ultrasonography. After that, participants were familiarized to the protocol involving maximal voluntary isometric contractions (MVIC) and NMES procedures. On the second day, participants performed the neuromuscular tests in the following order: i) determination of the maximal NMES current intensity, ii) voluntary warm-up, and iii) MVIC with superimposed doublet and resting doublet in two different protocols (with the evaluator pressing the electrode on the femoral nerve or not pressing) assigned in a random order (10 participants started with pressure and 11 started without pressure). In the third day, the same procedures were followed, including the order of protocols.

A computerized ultrasound system (LOGIC S7 Expert, General Electric, USA) with a 50 mm linear transducer (6-15 MHz linear array) was used to evaluate the subcutaneous thigh fat thickness of the participants. The measurement on the front thigh (rectus femoris muscle) is a standardized site to measure subcutaneous-fat thickness for the thigh and have a high reliability and accuracy [18]. The transducer was positioned over the rectus femoris muscle at 50% of the total thigh-length using a water-based conductive gel to perform the acoustic coupling of the transducer to the participant's skin. A single, experienced evaluator performed this evaluation. Three cross-sectional images were recorded. The subcutaneous-fat thickness evaluations were performed by identifying in the middle of the image, the upper and lower aponeuroses and passing a perpendicular line between them; this procedure was performed using the software ImageJ 1.8.0 (National Institute of Health, USA). After that, an averaged of thickness values on the three images was calculated.

Two adhesive electrodes (ValuTrode, Axelgaard, Fallbrook, CA, USA) were used for the NMES protocols. The circular cathode (3.2 cm of diameter and 5 cm^2) was positioned on the femoral triangle and the rectangular anode (13 $\times$ 7.5 cm and 97.5 cm^2) below the gluteal fold. Then, participants were seated on the isokinetic dynamometer (Biodex Medical Systems 4, Shirley, NY, EUA) and the dominant knee positioned at 70° of flexion (0° = total extension). Inelastic bands were used on the trunk, waist and evaluated thigh, to reduce unnecessary body movement. The lateral epicondyle of the knee was aligned with the axis of rotation of the dynamometer.

The electrical stimulation rectangular pulses (0.2 ms duration) were generated using a constant current stimulator (Digitimer DS7AH, Hertfordshire, UK) and doublets (paired pulse with 10 ms interpulse timing) were delivered using LabView software (Labview 11.0, National Instruments, Austin, TX, USA). The NMES current intensity was determined separately and randomly for each condition (i.e., pressure or no pressure). It was initiated with single pulses with step increases of 10 – 20 mA in the intensity until the first torque output was identified. This current intensity was used to start the determination of the intensity for the doublets. The maximal NMES current intensity was reached when torque values were unchanged in three consecutive doublet stimulations. Thereafter, intensities were increased by 50% to guarantee that the stimulations were supra-maximal during the protocols. This intensity (150%) was used in all stimulation (doublets) for each condition (i.e., pressure or no pressure).

The isometric warm-up for knee extensors consisted of 15 submaximal repetitions of 3 to 5-s with 10-s intervals between them. After that, two knee extensor MVIC of 3 to 5-s duration was performed with doublet stimulus being delivered at the plateau of the isometric contraction and at 3 s after relaxation. Between each contraction, there was a 2-min rest period. The described testing procedures were performed twice and randomly, once for the pressure on the electrode condition and once for no pressure condition. The same experienced researcher applied the manual pressure aiming to bring the cathode electrode as close as possible to the femoral nerve using the index and middle finger, also this researcher has no previous knowledge of thigh subcutaneous-fat thickness of the participant.

Immediately after each protocol, a visual analogue scale of perceived discomfort was presented to the participants. It consisted of a straight line with 10 cm having the words "no discomfort" and "the worst discomfort you can imagine" at the beginning and end respectively, and participants had to indicate with a pen their perceived discomfort in regards to the doublet stimulus delivered at the plateau of the MVIC and the one at rest. The values of perceived discomfort were subsequently measured with a ruler (100 mm) and placed in a spreadsheet for further analysis.

The torque signal was recorded by the Miotool 400 system (Miotec Equipamentos Biomédicos Ltda., Porto Alegre, Brasil) with a sampling frequency of 2000 Hz. All torque data of interest were analyzed offline using mathematic routines on MATLAB® (MathWorks Inc., Natick, MA, USA). After a set-order frequency to minimize signal residues as described by Winter [19] torque signals were filtered using a Butterworth low-order recursive third-order filter with a cut-off frequency of 10 Hz. From the torque–time curve, it was obtained the peak torque values produced before the stimulus (plateau), at the superimposed doublet amplitude, and at the resting doublet amplitude.

C. Statistical Analyses

A 2×2 repeated measures ANOVA (protocols vs. testing session) was conducted for peak torque values during the plateau (before stimulation), during superimposed doublet, and during resting doublet, perceived discomfort, and NMES current intensity. Data normality was assessed using Shapiro Wilk test, and the equality of variance and sphericity using Levene's test and Mauchly's W respectively. The eta squared for the ANOVAs were presented as a measure of effect size. The influence of subcutaneous-fat thickness on the efficacy of the pressure protocol to reduce current intensity and discomfort was tested with Pearson correlations between subcutaneous-fat thickness and the variation (delta) in NMES current intensity and discomfort between protocols. Correlation coefficient was interpreted as recommended by Cohen [20], as >0.1 = small, >0.3 = moderate, and >0.5 = large. Reliability between sessions and protocols was tested using Intraclass correlation coefficient (ICC) and percent coefficient of variation (%CV) from an Excel spreadsheet developed by Hopkins [21]. Agreement between protocols was explored using Bland-Altman plots. All data are presented as mean and 95% confidence interval (95%CI) lower and upper limits. P-values were considered statistically significant when <0.05.

III. Results

No significant interaction was observed between protocol and sessions for peak torque during MVIC ($p = 0.99$). In addition, no significant differences between protocols ($p = 0.77$) or sessions ($p = 0.12$) were observed (Fig. 1a). There was also no significant interaction between protocols and sessions for peak torque during resting doublet ($p = 0.75$) and no differences between protocols ($p = 0.26$) or sessions ($p = 0.26$) (Fig. 1b).

There was no significant interaction between protocols and sessions for peak torque during resting doublet ($p = 0.17$), and no differences between protocols ($p = 0.06$) or sessions ($p = 0.91$) (Fig. 1c). Reliability between protocols and sessions for these variables is presented in Table I.

Given the excellent reliability and the lack of interaction or significant effects involving the factor "sessions," further analyses were based on pooled data between sessions. In the Bland-Altman plots we show low bias (residual value of average of percent difference) and moderate random errors that were found for peak torque during MVIC, peak torque during superimposed doublet, and peak torque during resting doublet (Fig. 2) between protocols showing a good agreement for torque output variables.

No significant interaction was observed between protocol and sessions for NMES current intensity ($p = 0.43$) and discomfort during ($p = 0.07$) and after the protocol ($p = 0.26$). In contrast to torque variables, significant differences between protocols were observed for NMES current intensity and discomfort during superimposed doublet and during resting doublet (Table II). In table II, we present

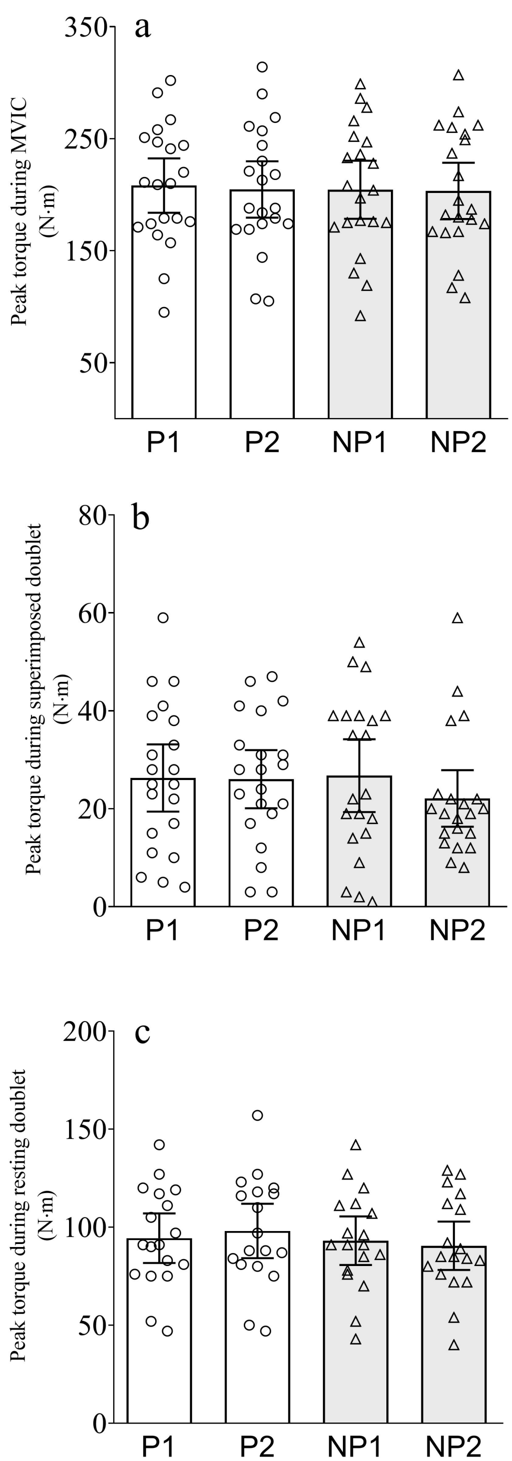

Fig. 1. Mean and 95% confidence interval lower and upper limits for peak torque during MVIC (a); peak torque during superimposed doublet (b); peak torque during resting doublet (c) for pressure and no pressure conditions. The NMES supramaximal current intensities varied from 92-220 mA depending on each condition. P, pressure; NP, no pressure; and 1 and 2 refer to consecutive sessions.

the mean and 95%CI between protocols for NMES current intensity, discomfort during superimposed doublet and discomfort during resting doublet.

TABLE I
TEST VS. RETEST AND PRESSURE VS. NO PRESSURE RELIABILITY

	Test vs. retest				Pressure vs. no pressure			
	Pressure		No pressure		Test		Retest	
	ICC	CV%	ICC	CV%	ICC	CV%	ICC	CV%
Peak torque during maximal voluntary isometric contraction	0.95	7.4	0.96	6.3	0.97	5.7	0.97	5.6
Peak torque during superimposed doublet	0.97	5.3	0.96	5.8	0.97	5.3	0.97	5.0
Peak torque during resting doublet	0.92	12.0	0.91	12.3	0.88	11.0	0.97	6.8

ICC, Intraclass correlation coefficient; CV, coefficient of variation.

TABLE II
COMPARISON BETWEEN THE NEUROMUSCULAR ELECTRICAL STIMULATION (NMES) CURRENT INTENSITY AND PERCEIVED DISCOMFORT DURING SUPERIMPOSED AND RESTING DOUBLETS FOR PRESSURE AND NO PRESSURE ON THE ELECTRODE

	Pressure	No pressure	p-value	F	η^2
NMES current intensity (mA)	134 (95 – 172)	169 (118 - 220)	<0.001	25.661	0.575
Discomfort during superimposed doublet (cm)	1.8 (1.3 – 2.2)	2.4 (1.7 – 3.0)	0.002	19.067	0.501
Discomfort during resting doublet (cm)	2.6 (1.7 – 3.4)	3.3 (2.4 – 4.3)	0.002	20.241	0.516

Data are presented as mean and 95% confidence interval lower and upper limits.

Participants presented 0.41 cm (95%CI: 0.28 – 0.52 cm) of thigh subcutaneous-fat thickness. We observed a positive large correlation between thigh subcutaneous-fat thickness and changes in current intensity between protocols (ΔINTENSITY) ($r = 0.63$, and $p = 0.002$) (Fig. 3a) and a positive moderate correlation between thigh subcutaneous-fat thickness and changes in discomfort (ΔDISCOMFORT) ($r = 0.45$, $p = 0.04$) (Fig. 3b).

IV. DISCUSSION

The main findings of this study suggest that applying manual pressure on the cathode electrode during the plateau

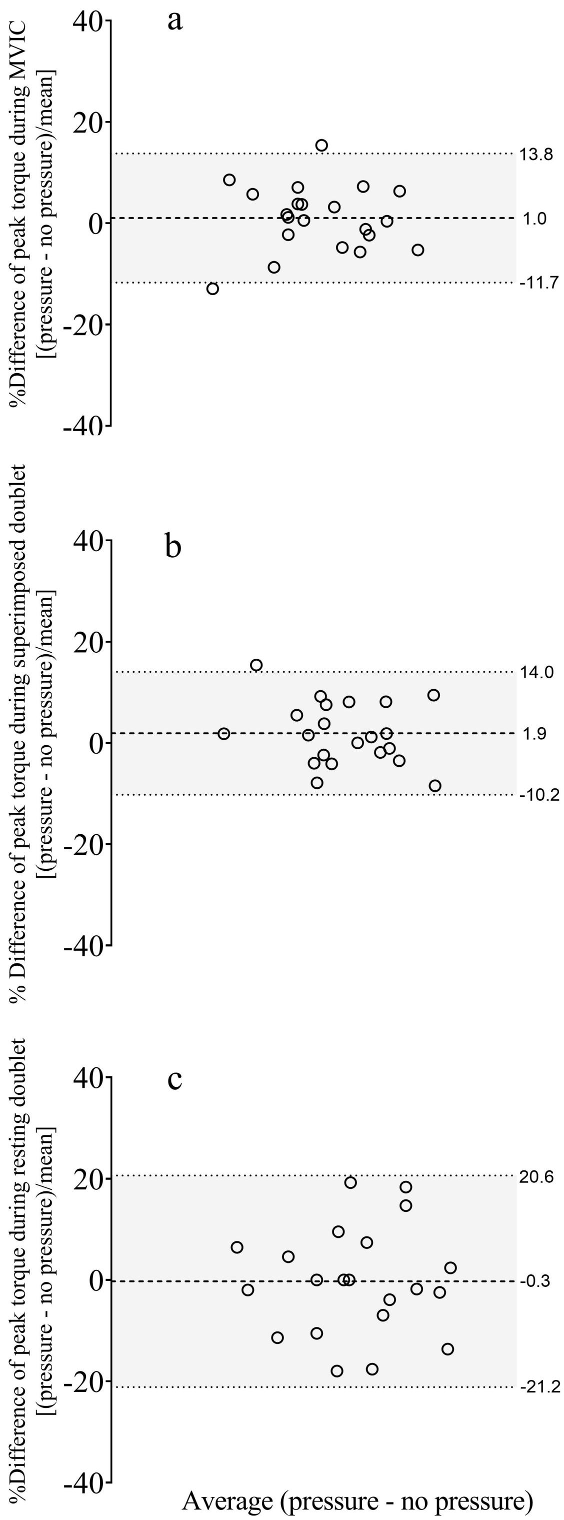

Fig. 2. Bland-Altman plots for peak torque during MVIC (a), peak torque during superimposed doublet (b), and peak torque during resting doublet (c).

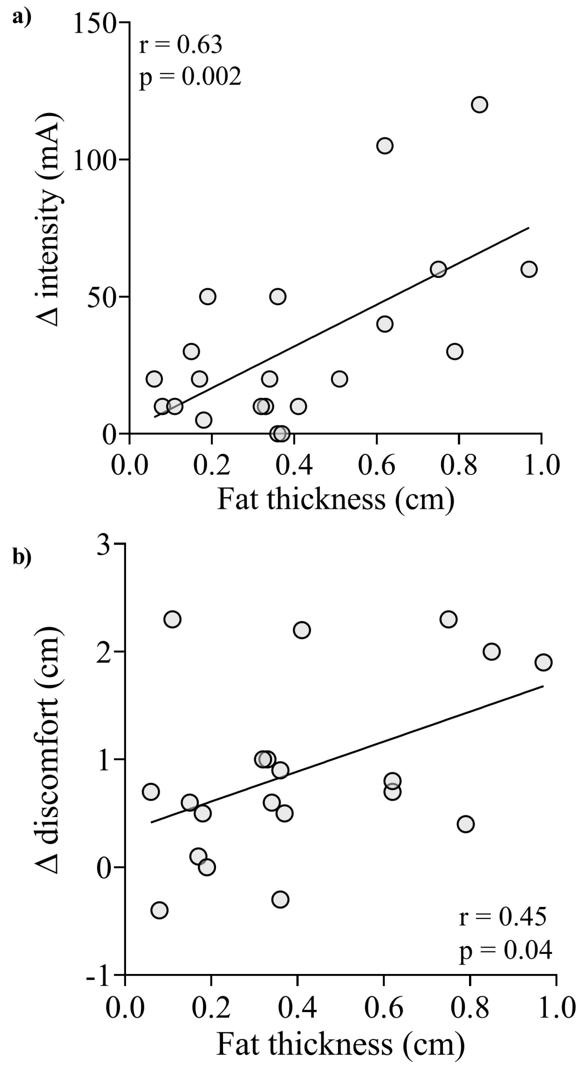

Fig. 3. Pearson correlation between thigh subcutaneous-fat thickness (cm) with stimulation ΔINTENSITY (a); and ΔDISCOMFORT (b).

of a maximal voluntary contraction (superimposed doublet) and during the subsequent resting period (resting doublet) reduces the stimulation current intensity required to evoke maximal torque and reduces the associated perceived discomfort. Contrary to our hypothesis, the application of pressure on the electrode did not result in significant changes in torque output magnitude and/or reliability. With regards to the influence of subcutaneous-fat thickness on the efficacy of the pressure protocol, we observed a strong positive correlation between the subcutaneous-fat thickness and the difference between protocols for the current intensity required to evoke a maximal torque and for discomfort. This result indicates that participants with higher body fat benefit from the pressure condition in a greater extent than individuals with a thinner subcutaneous-fat layer. For lean participants, the application of pressure does not necessarily lead to a reduction in current intensity (Fig 3a) and may lead to an increase in discomfort (Fig 3b).

The technique of adding pressure during NMES is usually performed with manual pressure and the magnitude of the pressure applied is based on the investigator best judgement. In this study, constant pressure was applied to the electrode using the index and middle fingers. The assessor applied pressure to decrease the electrode-femoral nerve distance, but avoiding any pressure-related discomfort. The assessor adjusted the pressure intensity according to each participant's subcutaneous-fat thickness, with more pressure being applied in individuals with more subcutaneous-fat. This is a common procedure and we are not aware of previous studies have evaluated the reliability of this technique. Our results show that adding manual pressure to the electrode does not affect the torque output during a MVIC, superimposed doublets, or resting doublets, and does not compromise the between-sessions reliability. The good reliability observed in our study is an important factor for the NMES measurement methods [3], [22]. Clark *et al.* [22] showed very high reliability of NMES between two nonconsecutive sessions without pressure on the electrode, and Place *et al.* [3] demonstrated very high reliability even in fatigued conditions. In addition to the benefits of reducing stimulation current intensity and perceived discomfort, we show that the condition with pressure also presents good reliability. The agreement between the protocols suggests that despite their differences in terms of comfort to the subject being evaluated, torque measures are comparable with biases under 4% of the average estimate, this demonstrated that both protocols can be used without interference in maximal torque production.

In addition, errors seem to be independent of the torque produced during the test. The lower electrical stimulation intensity and perceived discomfort observed in our study for the condition with manual pressure added to the electrode compared to the condition with no pressure agrees with a previous study on single pulses conducted by Cattagni *et al.* [6]. The authors focused their investigation on the effect of adding pressure to the electrode on neurophysiological signals (e.g., M-wave). In our study, we show that a significant reduction in discomfort and current intensity can also be reliably achieved for doublet stimulus and that this effect is highly dependent on subcutaneous-fat thickness (Fig. 3a and 3b).

The influence of subcutaneous-fat thickness on stimulation intensity was reported by Maffiuletti *et al.* [23], Medeiros *et al.* [15], and Gorgey *et al.* [24], who demonstrated a positive relationship between subcutaneous-fat thickness and current intensity needed to evoke an electrophysiological response. This is thought to occur because the fat tissue has high resistance [15], and the thicker the layer the longer the distance between the skin and the motor units [14]. In this study, we show that the higher value of current intensity required during NMES in participants with a thick subcutaneous-fat layer might be avoided by adding pressure to the electrode. Individuals with thicker subcutaneous-fat have a lower discomfort threshold [23], and it has been suggested that the discomfort from NMES could activate the afferent nociceptive fibers (Aδ and C nociceptors) [6] to unbearable discomfort. The use of simple methods aiming to diminish the discomfort from NMES, such as the one proposed in our study, could increase the usage of NMES in clinical and research settings. However, we are aware that other tissues (i.e., skin, muscle, and connective tissues) also have nociceptive fibers that could have been compressed; and thus, contributed to the reduction in discomfort.

Two participants were excluded from the study due to unbearable discomfort during the NMES protocol in the familiarization session. The participants presented a rectus femoris fat thickness of 0.62 and 0.69 cm, respectively, and started the protocol with no pressure. Both participants quit the study voluntarily (last NMES intensity 200 and 240 mA, respectively) and reported that current intensity $\approx$100 mA were a bearable discomfort, and above 150 mA the discomfort was higher than expected and they could not keep the quadriceps muscle relaxed before the stimulation.

Future studies controlling the change in subcutaneous-fat thickness over the nerve during pressure application may help understand the interactions between pressure effect and subcutaneous-fat thickness observed in our study. Changes in the pressure applied across individuals may be necessary since those with higher fat tissue required higher pressure than those with lower fat tissue. In our experiment a good reliability of the protocol was confirmed. But it is unknown if this reliability depends on the investigator. Future studies should also address the inter-rater reliability of our findings. Also, our results are not necessarily applicable in other settings (i.e., muscle stimulation) or patients with neurological disorders. Future studies could investigate the benefit of manual pressure on muscle stimulation in other populations.

This study has some limitations. Although the same experienced assessor applied the pressure on the electrodes for all measurements and for all participants, the pressure on the electrodes was not quantified. The assessor subjectively changed the pressure intensity according to each participant's subcutaneous-fat thickness. This flexibility may be necessary since the ones with higher fat tissue required higher pressure compared to the ones with lower fat tissue. Despite the lack of control, the good reliability of the protocol suggests that the assessor is able to produce pressure in a consistent manner. Moreover, the fat thickness was performed in a different location than the stimulus site. The location of ultrasound measurement was selected because it is a standardized site for lean to obese participants, this reduces the error of measurement [18]. We only investigated the doublet pulses and the manual pressure appears to be useful in this type of stimulation, therefore the benefits of manual pressure cannot be extrapolated to other types of stimulation other than doublet pulses. Another limitation of our study is that we did not tested females for two main reasons: 1) It has been demonstrated that the menstrual cycle can influence pain tolerance [23], [25] demonstrated that women have more difficulty activating muscle with electrical current than men; 2) Additionally, the femoral nerve is located in the vicinity of the genital area, and the pressure on the electrode was applied by a male researcher (main investigator). In pilot testing, we often found that women were not comfortable with the procedure and therefore we chose not to include females in the final project. In fact, an important characteristic of the female body composition is the higher fat accumulation in the tested region. Speculatively, our findings could indicate that the benefits of adding pressure to the stimulation electrode would be intensified in this population. However, this hypothesis remains to be tested in future studies. Also, our participants were healthy males with intact sensation and the stimulation was made on femoral nerve, and our results cannot be extrapolated to other populations and different muscles.

The findings of our study may help in the clinical practice since it is a simple technique, with no cost, and is reliable allowing to use in clinical settings. This technique could increase the acceptability of individuals with no previous experience with NMES since the discomfort will decrease over time. Also, the relation of fat thickness with the benefits from manual pressure could help practitioners to choose the use of the technique only on individuals with higher fat thickness. We recommend that practitioners take into account: 1) Manual pressure is a reliable technique between days; 2) Individuals with thick subcutaneous-fat tissue may benefit more from manual pressure than individuals with thinner subcutaneous-fat tissue.

In conclusion, adding manual pressure to the NMES electrode on the femoral nerve results a stimulation current intensity and perceived discomfort that are lower than the ones associated with the protocol with no pressure. Importantly, these findings are accompanied by no changes in torque output during a MVIC, superimposed and resting doublets, and by a good reliability between sessions. The strong relationship between stimulation current intensity and subcutaneous-fat thickness suggests that this protocol can be especially beneficial to individuals with higher body fat, lowering the required intensity during NMES tests.

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