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MECANISMOS DE FADIGA DA CONTRAÇÃO MUSCULAR ENTRE CORRENTES DE FREQUÊNCIA QUILOHERTZ E DURAÇÕES DE FASE: UM ENSAIO CRUZADO RANDOMIZADO

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Dissertação apresentada ao Programa de Pós-graduação em Ciências da Reabilitação (PPG-CR) da Universidade de Brasília, como parte dos requisitos necessários à obtenção do título de mestre.

Linha de pesquisa: Processos Biológicos Aplicados à Estrutura, Função e Reabilitação.

Tema: Plasticidade Muscular.

Orientador(a): Prof. Dr. João Luiz Quagliotti Durigan.

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DEDICATÓRIA

Eu, Luis André Oliveira, dedico este trabalho aos meus pais, André e Márcia, que nunca mediram esforços para que eu tivesse a melhor educação possível, o que me permitiu chegar até aqui. Dedico também às minhas irmãs, Amanda e Luana, que sempre me apoiaram em todos os momentos de dificuldade e a todos aqueles que de certa forma contribuíram com esta dissertação.

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RESUMO

Objetivo: A estimulação elétrica neuromuscular (EENM) tem sido aplicada em diversos contextos de reabilitação clínica. No entanto, a eficácia terapêutica da ENM é frequentemente limitada pelo rápido início da fadiga neuromuscular durante a estimulação. O objetivo é examinar os efeitos de quatro protocolos de ENM na fadiga muscular, no desconforto sensorial e na excitabilidade espinhal.

Métodos: Um delineamento cruzado foi usado para avaliar KFACs em 1 kHz (corrente australiana) e 2,5 kHz (corrente russa), e correntes pulsadas (PC) com durações de fase estreitas (200 µs) e amplas (500 µs). Protocolos foram aplicados aleatoriamente ao tríceps sural de participantes saudáveis, com pelo menos sete dias entre as sessões. Cada participante realizou duas MVCs antes das medições de torque evocado máximo (MET), fadiga muscular (integral torque-tempo [TTI], declínio do TTI, índice de fadiga e número de contrações), eficiência de NMES, ativação muscular (RMS), desconforto sensorial e excitabilidade espinhal. Os dados foram analisados usando ANOVA de medidas repetidas de duas ou três vias, seguido pelo teste post hoc de Tukey.

Resultados: Quarenta e quatro participantes (idade 24,4 ± 4,9 anos) foram incluídos. Correntes com durações de fase mais amplas (500 µs) geraram TTI significativamente maior, eficiência de EENM ($p > 0,05$) e um número maior de contrações antes de atingir uma redução de 50% no torque evocado, em comparação com 200 µs. Todos os protocolos de estimulação levaram a reduções significativas ($p > 0,05$) nos valores de torque voluntário, torque evocado e RMS pós-fadiga.

Conclusão: Correntes KFAC e PC, aplicados com a mesma duração de fase, induziram níveis semelhantes de fadiga, eficiência de EENM e desconforto percebido, sem diferenças claras nos mecanismos de fadiga entre eles. No entanto, correntes com largura de pulso estreita induziram fadiga maior e mais rápida, independentemente das correntes KFAC ou PC.

Registro: https://clinicaltrials.gov/study/NCT05894044

Palavras-chave: Estimulação elétrica neuromuscular; Torque; Corrente alternada, Fadiga muscular.

ABSTRACT

Purpose: Neuromuscular electrical stimulation (NMES) has been applied in various clinical rehabilitation settings. However, NMES therapeutic efficacy is often constrained by the rapid onset of neuromuscular fatigue during stimulation. The objective is to examine the effects of four NMES protocols on muscle fatigue, sensory discomfort, and spinal excitability.

Methods: A crossover design was used to evaluate KFACs at 1 kHz (Australian current) and 2.5 kHz (Russian current), and pulsed currents (PC) with narrow (200 µs) and wide (500 µs) phase durations. Protocols were randomly applied to the triceps surae of healthy participants, with at least seven days between sessions. Each participant performed two MVCs before measurements of maximum evoked torque (MET), muscle fatigue (torque-time integral [TTI], TTI decline, fatigue index, and number of contractions), NMES efficiency, muscle activation (RMS), sensory discomfort, and spinal excitability. Data were analyzed using two- or three-way repeated-measures ANOVA, followed by Tukey post hoc test.

Results: Forty-four participants (age 24.45±4.97 years) were included. Currents with wider phase durations (500 µs) generated significantly higher TTI, NMES efficiency (p >0.05), and a greater number of contractions before reaching a 50% decline in evoked torque, compared to 200 µs. All stimulation protocols led to significant reductions (p >0.05) in voluntary torque, evoked torque, and RMS values post-fatigue.

Conclusion: KFAC and PC, applied with the same phase duration, induced similar levels of fatigue, NMES efficiency and perceived discomfort, with no clear differences in the mechanisms of fatigue between them. However, currents with narrow pulse width induced greater and more rapid fatigue, regardless of whether KFAC or PC currents.

Register: https://clinicaltrials.gov/study/NCT05894044

Keywords: Electrical Stimulation, Torque, Alternated Current, Muscle Fatigue.

LISTA DE TABELAS

SUMÁRIO

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INTRODUCTION

Neuromuscular electrical stimulation (NMES) is a rehabilitation tool that is commonly used in clinical practice to reduce muscle atrophy and other disuse-related complications[1,2,3]. Nonetheless, the early onset of muscle fatigue remains a significant limitation of NMES, potentially restricting its effectiveness in certain orthopedic and neurological rehabilitation settings.[4,5,6]. Muscle fatigue, whether caused by maximal voluntary contraction (MVC) or evoked through NMES, consists of progressive loss of muscle force over time. However, during an MVC, motor units (MUs) are recruited in an orderly fashion according to Henneman's size principle[6,7], whereas during a maximal evoked muscle contraction, all MUs in the stimulated area are activated at the same time. As a result, NMES can be more fatiguing than voluntary contractions due to the simultaneous and continuous activation of the same MUs regardless of size and type[6]. Additionally, it is well established that high stimulation intensities can elicit discomfort, which may further compromise the clinical effectiveness of NMES[8,9,10].

Different NMES waveforms are employed to induce muscle contractions, with the goal of minimizing muscle fatigue while preserving optimal NMES efficiency. Traditional NMES uses pulsed currents (PC) with phase durations <500 µs at 20–100 Hz[7,11]. Kilohertz-frequency alternating currents (KFAC) operate at 1–10 kHz[11]; the Russian current, developed in the 1970s to enhance muscle strength, delivers 2.5 kHz carrier bursts at 1–200 Hz[7,12]; and the Australian current, another commonly used KFAC, uses a 1.0 kHz carrier with 1–200 Hz bursts and is designed to reduce fatigue and discomfort[13]. While some studies have demonstrated that KFAC leads to greater muscle fatigability compared to PC[14,15,16], other investigations found no significant differences between the two NMES modalities[17,18]. These discrepancies may be attributed to methodological variations, including differences in stimulation frequency, phase duration, and on-off cycles, all of which influence the total duty cycle of NMES.

In fact, KFAC may generate more action potentials per burst, potentially accelerating muscle fatigue[19]. However, when applied with supra-threshold intensities and sufficiently long bursts, it can reduce discomfort and enhance force compared to PC[19]. Despite these proposed advantages, a scoping review found that KFAC is not superior to PC, as it typically yields similar or lower force, equal or greater fatigue, and comparable or higher discomfort[7]. Two systematic reviews with meta-analyses also reported no significant differences in evoked torque or perceived discomfort between KFAC and PC in healthy individuals[11,20]. More recently, evidence suggests that phase duration, rather than waveform type (KFAC or PC), primarily determines the recruitment of sensory and motor axons in the tibial nerve, with narrow durations favoring motor axons and wider durations favoring motor and sensory axons[21]. However, due to the limited research available, the mechanisms underlying NMES-induced fatigue for both KFAC and PC remain to be determined[7]. Thus, in the present study, we primarily investigated the effects of four protocols using two KFACs (2,500 kHz/Russian current and 1,000 kHz/Aussie current, with phase durations of 200 μs and 500 μs, respectively) and two PCs (phase durations of 200 μs and 500 μs, respectively) on muscle fatigue mechanisms in healthy participants. To explore the level of fatigability and mechanisms leading to fatigue when using different types of KFAC compared to PC, we also investigated the potential underlying neuromuscular mechanisms by evaluating the H-reflex/M-wave, torque-time integral (TTI), Root Mean Square (RMS) values, Median Frequency (MDF) values[22,23,24,25], and Central Activation Ratio (CAR)[26].

LITERATURE REVIEW

Neuromuscular Electrical Stimulation

Neuromuscular electrical stimulation (NMES), also known internationally as NMES, is a technique that uses electrical currents applied to muscle tissue via the intact peripheral nervous system to induce controlled muscle contractions[2,3]. Its therapeutic use dates to antiquity, but the first relevant scientific experiments occurred in the 18th century, with Luigi Galvani demonstrating, in 1791, that electrical discharges could induce muscle contractions in frogs[7,12]. The clinical development of NMES intensified throughout the 20th century, becoming established as a physiotherapeutic resource in the 1960s and 1970s, especially after the contributions of Yakov Kots, who introduced Russian current for muscle strengthening in elite athletes[7,12]. NMES is widely used in contemporary physiotherapy to promote muscle strengthening, prevent atrophy in immobilized patients, accelerate postoperative recovery, and aid in the rehabilitation of patients with neuromuscular or orthopedic dysfunctions. The mechanism of action of NMES differs from voluntary contraction: while physiological recruitment follows the Henneman principle (progressive activation of type I to type II fibers), NMES preferentially recruits fast-twitch (type II) fibers due to the external application of electrical stimulation[7]. Due to its versatility, effectiveness, and scientific basis, NMES has become a fundamental resource in physical therapy rehabilitation protocols, being indicated for both critical patients and athletes or healthy individuals undergoing functional recovery[4,5,6].

Pulsed Currents

The most common pulsed currents used in neuromuscular electrical stimulation (NMES) include symmetrical and asymmetrical biphasic forms, notable for their versatility and clinical efficacy. Symmetrical biphasic current, often used for muscle strengthening and rehabilitation, offers advantages such as a lower total load per pulse and less discomfort. It is preferred for stimulating large muscle groups due to its ability to generate visible and tetanic contractions with a lower risk of pain[14,15]. Typical parameters for these currents include frequencies between 35 and 50 Hz, pulse durations between 200 and 400 μs, and duty cycles with adjustable contraction and rest times according to the therapeutic objective[18]. That said, the appropriate choice of pulsed current modulation parameters is essential to maximize the therapeutic benefits of NMES, being widely recommended in muscle rehabilitation protocols[3].

Kilohertz-Frequency Alternating Current

Medium-frequency alternating currents, known as KFAC (kilohertz-frequency alternating current), have been widely studied in neuromuscular electrical stimulation (NMES) due to their potential to generate high muscle torques with discomfort levels comparable to or lower than conventional pulsed currents. Controlled studies demonstrate that KFAC, when applied with phase durations of 500 μs, induces absolute and relative torque at maximum voluntary contraction like those obtained with pulsed currents, with no significant differences in perceived discomfort[9]. Furthermore, the efficiency of NMES (milliampere-evoked torque) is similar between the two modalities, especially at submaximal intensities. KFAC has the advantage of lower skin impedance, facilitating stimulus transmission and allowing the application of more intense currents without a proportional increase in discomfort[9]. However, systematic reviews indicate that, despite its technical advantages, the superiority of KFAC over pulsed currents in terms of evoked torque and comfort remains controversial, reinforcing the need for individualization of stimulation parameters to maximize clinical benefits[3,7].

Russian and Australian Currents

Among the medium-frequency currents used in neuromuscular electrical stimulation (NMES), Russian current and Aussie (or Australian) current stand out, both recognized for their role in muscle strengthening, preventing atrophy, and improving muscle function in therapeutic and aesthetic contexts. Russian current, developed by Yakov Kots in the 1970s, uses a carrier frequency of 2,500 Hz modulated at 50 Hz, providing vigorous and synchronized muscle contractions through stimulation of motor nerves, resulting in significant increases in strength and muscle hypertrophy, including in healthy populations and high-performance athletes. Its waveform can be rectangular or sinusoidal, bipolar, and symmetrical, and the burst modulation allows the current to pass through the skin with less resistance, making application more efficient and comfortable, even at high intensities[12]. Aussie current, developed later in Australia, has a carrier frequency of 1,000 or 4,000 Hz, generally modulated at 50 Hz, and its main characteristic is the provision of shorter and gentler stimuli, which favors greater patient comfort and allows the stimulation of deep muscles and sensitive areas[27]. Aussie current is frequently used in post-injury rehabilitation protocols and muscle strengthening in individuals with low discomfort tolerance[27].

Muscle Fatigue

Muscle fatigue is defined as the transient inability of the neuromuscular system to maintain force or power production, resulting from physiological processes involving both central (related to the central nervous system) and peripheral (intrinsic to the skeletal muscle itself) factors[14]. From a central perspective, fatigue can be attributed to reduced neural command, failures in synaptic transmission, or decreased motor neuron excitability. At the peripheral level, mechanisms such as metabolite accumulation and dysfunction of contractile mechanisms stand out[10]. The manifestation of fatigue compromises not only functional performance but also the integrity of motor control, increasing the risk of injury and limiting the efficiency of rehabilitation and training processes.

NMES is emerging as a relevant tool for the controlled induction of muscle fatigue in clinical and research settings[38]. The application of NMES allows for repeated stimulation and objective analysis of progressive force reduction, in addition to enabling the investigation of electrophysiological parameters, such as the RMS variation of the electromyographic signal during fatigue protocols[37]. Furthermore, NMES can promote metabolic and structural adaptations that increase muscle resistance to fatigue and is indicated for both clinical populations and athletes[38]. The careful selection of modulation parameters, such as frequency, pulse width, and intensity, is crucial for optimizing the therapeutic effects of NMES and mitigating early fatigue[19]. Therefore, monitoring and studying muscle fatigue through NMES are essential for the development of individualized, evidence-based protocols for rehabilitation and physical performance.

OBJECTIVES AND HYPOTHESES

In the present study, we mainly investigated the effects of four protocols using two KFACs (2,500 kHz/Russian current and 1,000 kHz/Australian current, with phase durations of 200 µs and 500 µs, respectively) and PC (with phase durations of 200 µs and 500 µs, respectively) on contraction fatigue mechanisms in healthy participants. To explore the level of fatigability and the mechanisms that lead to the use of different types of KFAC compared to PC, we also investigated the potential underlying neuromuscular mechanisms by evaluating H reflex/M wave, TTI, Root Mean Square (RMS), Median Frequency (MF) (Neyroud et al., 2014; Bergquist et al., 2014; Neyroud et al., 2019; Cavalcante et al., 2022) and the Central Activation Ratio (CAR) (De Oliveira et al., 2018). We hypothesize that PC currents present better efficiency and less fatigue when compared to KFAC.

MATERIALS AND METHODS

Trial Design

This randomized, crossover, double-blind study was conducted after obtaining written informed consent from all participants prior to enrollment. The study protocol was approved by the Institutional Review Board of the University of Brasília (protocol 67915523100008093) and reported in accordance with the Consolidated Standards of Reporting Trials (CONSORT; see Supplementary Material). The trial was registered at ClinicalTrials.gov (identifier: NCT05894044) on June 08, 2023, prior to the enrollment of the first participant.

Participants

To be included in the study, participants were required to be between 18 and 45 years of age, physically active, with a normal range of motion in the knee joint, and report no previous experience with NMES, and no history of neuromuscular injury or disease[27]. Exclusion criteria included the use of NSAIDs or nutritional supplements, skin lesions or allergies, neuromuscular disorders, external fixation devices, or metal implants in the lower limbs, and intolerance to NMES due to fear or hypersensitivity.

Randomization and allocation concealment

Participants were randomly assigned to four NMES conditions (using computer-generated lists from random.org) (Table 1): (1) PC with a 500 µs phase duration (PC 500), (2) PC with a 200 µs phase duration (PC 200), (3) a 500 µs phase duration and low carrier frequency (KFAC 500: 1 kHz/Aussie current), and (4) a 200 µs phase duration and high carrier frequency (KFAC 200: 2.5 kHz/Russian current). A researcher (LBC) prepared sealed, numbered opaque envelopes to define the order of NMES conditions.

Blinding

The researcher responsible for administering the NMES currents (LAOS) and the participants were blinded to the treatment allocation. A second researcher (LBC), who was aware of the treatment allocation and current intensity, programmed the NMES parameters and covered the device panel with an opaque shield, ensuring that the current intensity was only visible to him, while blinding both LAOS and the participants.

Procedures

Participants completed five 2-h sessions, each separated by at least 7 days. A different NMES type was tested per session. All assessments were conducted at the same time of the day by the same assessor[1]. Participants were asked to avoid stimulants (e.g., alcohol, caffeine, chocolate) and exercise on testing days. The first session served as familiarization, during which participants were informed about the recommendations, study criteria, and testing protocols[1,27]. The height, body mass, and body mass index (BMI) were recorded for all participants. Each of the five experimental sessions began with a warm-up, followed by an NMES-induced fatigue phase consisting of 20 isometric evoked contractions at 20% of MVC. Two MVCs were performed prior to the fatigue protocol. During each randomized NMES session, two maximally tolerated evoked contractions were conducted to determine the participant's maximum tolerable intensity, and the maximal evoked torque (MET) value was recorded. Spinal excitability (via H-reflex and M-wave) and central activation (via CAR) were assessed, with all outcomes measured before and after the fatigue protocol (Figure 1). All NMES protocols were applied to the participants' right side[1,27], with 50 Hz frequency/bursts delivered (Figure 1; Table 1). NMES currents were administered with an "on" time of 6 sec of constant stimulation, followed by a 60-sec "off" time for recovery, and the visual-analogue scale (VAS) was used to measure discomfort after the MET and during the fatigue protocol (1^{st}, 10^{th}, and 20^{th} contractions)[9].

Table 1. Overview of the physical parameters for the four types of neuromuscular electrical stimulation currents.

Current Type	Current frequency (Hz)	Phase duration (µs)	Burst duration (ms)	Interburst duration (ms)	Burst frequency (Hz)
PC500	50	500			
PC200	50	200			
KFAC500	1000	500	2	18	50
KFAC200	2500	200	10	10	50

Legend. PC, Pulsed Current; KFAC, kHz frequency alternating current. All electrical currents had an on-time of 6s and 60 s off-time.

Outcomes

The primary outcomes included muscle fatigue assessed by MVCs, MET, total TTI, TTI reduction, fatigue index, number of contractions, and NMES efficiency. Secondary outcomes were NMES-induced discomfort, spinal excitability (H-reflex and M-wave), mechanical properties (central activation ratio), and electromyographic measures (RMS and MDF values).

Warm-up and maximal voluntary isometric contraction

Participants sat in the chair of an isometric dynamometer (Cefise, Nova Odessa, SP) with their right foot secured to the footplate. Procedures were performed on the right leg, with the hip, knee, and ankle at ~90°[28]. The warm-up consisted of six submaximal isometric plantar flexions (6-sec each) with a 10-sec rest between them. After a 1-min rest, two 6-sec MVCs were performed with a 1-min interval, and the highest torque was recorded. The MVC torque was calculated over a 6-sec window[27] and reassessed post-fatigue using the same procedure.

Maximum Evoked Torque - MET

Participants were instructed to relax while seated upright on the isometric dynamometer. NMES was delivered using a stimulator (DIGITIMER DS8R, London, UK) connected to two pairs of 25 cm^2 self-adhesive electrodes (Valutrode, São Paulo, Brazil). After shaving and cleaning the skin, two electrodes were placed below the knee near the proximal insertion of the medial and lateral gastrocnemius, and two approximately 5 cm above the Achilles tendon[27,29]. Evoked torque was calculated over a 6-sec window and normalized to maximal voluntary torque using the formula: [(NMES-evoked torque ÷ maximal voluntary torque) × 100][1]. Two minutes after MVC testing, two METs were recorded at the highest tolerated NMES intensity, as determined during familiarization. This procedure was repeated after the fatigue protocol. Participants were instructed to inform the researcher if their pain threshold was reached and, in this case, the current intensity was decreased to remain within the motor level[27,30,31].

Assessment of Muscle Fatigue

Total decline in Torque-Time Integral (TTI)

The torque-time integral (TTI), representing the isometric work, was defined as the area under the torque-time curve. Total TTI was calculated by summing the TTIs of all NMES-evoked contractions during the fatigue protocol[24]. The TTI reduction was expressed as the percentage decrease in work, calculated as the ratio between the average TTI of the first five and the last five evoked contractions[16,22].

Muscle Fatigue Index

The muscle fatigue index was calculated as the ratio of the average torque from the first to the last evoked contraction, across the 20 NMES-elicited contractions, with each torque value expressed as a percentage of MVC for each protocol[16]

Number of Contractions until a 50% Drop in Initial Torque

To identify fatigue onset, evoked torque values from the first to the twentieth contraction were normalized to the initial contraction. The contraction at which torque dropped to 50% of the initial value marked the point of significant fatigue during the NMES protocol[16].

NMES Efficiency Assessment

NMES efficiency was assessed by calculating the ratio of NMES-evoked torque to current intensity (Nm/mA), using the evoked torque values recorded during the 20th contraction of the fatigue protocol[16]..

Discomfort

VAS was used to evaluate sensory discomfort on a scale from 0 (no discomfort) to 10 (maximum discomfort), being administered after NMES-evoked contractions during the familiarization session and at the 1st, 10th, and 20th contractions of the fatigue protocol[1].

Central Nervous System Outcomes

The Supplementary Material includes a detailed description of the methodology and results for Spinal Excitability (H Reflex and M Wave), central activation ratio (CAR), and Electromyographic (EMG) activity.

NMES Fatigue protocol

Immediately following the assessment of the H-reflex and M-wave, the stimulation intensity was gradually increased from 1 mA[1], until reaching 20% MVC[16].

The current intensity remained constant from the first contraction of the fatigue protocol, thus avoiding progressive recruitment of MUs during fatigue[1]. The fatigue protocol involved 20 evoked contractions at 20% MVC. Each contraction had a 20-second duration with a 20-second interval between them. The submaximal evoked torque (SET) was expressed as a percentage of the torque values obtained during the MVC, normalized using the equation [SET x voluntary torque (-1)) x 100][1].

Statistical analysis

The sample size was determined a priori using G*Power (version 3.1.3; University of Trier, Trier, Germany), with a significance level of $p=0.05$ and power $(1-\beta) = 0.80$ to detect a large effect size (0.52), based on differences in NMES-induced fatigue using the TTI over time. Based on these criteria[35], 36 participants were required per condition. Allowing for a 20% dropout rate, 44 participants were allocated to each condition.

Outcome measures are reported as mean values with confidence intervals. Data normality (Shapiro-Wilk) and homogeneity of variance (Levene's test) were confirmed. Two-way and three-way mixed-model ANOVAs with repeated measures were used to compare currents (PC vs. KFAC), pulse duration (500 vs. 200 µs), and time (pre- vs. post-fatigue), followed by Tukey post-hoc tests. Analyses were performed with STATISTICA (version 12.5.192.0, StatSoft Inc) with a significance value of $p<0.05$, and the figures were created with GraphPad Prism 6.0 (San Diego, CA, USA).

RESULTS

General Observation

The baseline characteristics (mean ± SD) of the 44 participants were as follows: age, 24.45 ± 4.97 years; body mass, 67.72 ± 14.08 kg; height, 169.68 ± 0.08 cm; and body mass index, 23.4 ± 3.97 kg/m². There were no adverse effects during the application of the four NMES protocols and all the participants completed the 5 sessions of the protocol.

MVC and MET

No interaction was found between time and current for MVC ($F = 1.201$, $p=0.311$, $\eta p^2 = 0.020$; Table 2), but there was a main effect of time ($F = 42.446$, $p<0.001$, $\eta p^2 =$

0.197), indicating reduced voluntary torque across all four currents after the fatigue protocol. No main effect of current was observed ($F = 0.096$, $p=0.962$, $\eta p^2 = 0.001$). Similarly, for MET, no time × current interaction was found ($F = 2.635$, $p=0.051$, $\eta p^2 = 0.043$), but a main effect of time was observed ($F = 13.124$, $p<0.001$, $\eta p^2 = 0.070$), showing reduced MET after fatigue across all currents. No main effect of current was observed ($F = 0.835$, $p=0.476$, $\eta p^2 = 0.014$).

Table 2. Results of different NMES currents and phase durations before (PRE) and after (POST) the fatigue protocol.

	PC 500		**PC 200**		**KFAC 500**		**KFAC 200**	
	PRE	POST	PRE	POST	PRE	POST	PRE	POST
MVC*	87.82	79.85	90.77	82.27	89.98	83.73	87.28	83.7
(Nm)	(77.64-98)	(70.42-89.28)	(81.11-100.43)	(73.69-90.86)	(81.04-98.92)	(74.68-92.78)	(79.53-95.04)	(74.85-92.55)
MET*	64.59	58.37	58.55	58.30	64.59	59.65	59.28	54.19
(Nm)	(57.78-71.4)	(52.23-64.51)	(51.58-62.72)	(51.45-65.13)	(57.78-71.4)	(53.2-66.11)	(51.41-67.16)	(48.70-59.68)
Discomfort	2.50	2.57	2.50	2.91	3.43	3.14	3.09	3.16
(VAS: 0–10)	(1.92-3.07)	(1.92-3.21)	(1.82-3.17)	(2.17-3.64)	(2.73-4.12)	(2.34-3.93)	(2.39-3.78)	(2.32-3.99)

Legend: Data are reported as mean (95% CI). ***** = Time effect condition ($p < 0.001$). KFAC, kilohertz-frequency alternated current; MET, maximal evoked torque; MVC, maximal voluntary contraction; PC, pulsed current; VAS, visual analogue scale.

Fatigue Protocol

- *TOTAL TTI:* For total TTI, a pulse × current interaction was found ($F = 12.268$, $p=0.001$), with 500 μs producing values greater than 200 μs ($p=0.001$; Figure 3A).

- *NMES Efficiency during fatigue:* A main effect was found for the 20th contraction in the fatigue protocol ($F = 16.893$, $p<0.001$, $\eta p^2 = 0.227$), with 500 μs phase currents showing higher efficiency than 200 μs ($p=0.0001$; Figure 3B).

- *Number of contractions for a 50% drop in evoked torque:* No interaction was found between current and pulse duration for the number of contractions until a 50% drop in evoked torque ($F = 0.2191$, $p=0.6421$, $\eta p^2 = 0.0051$). However, KFAC200 showed a steeper qualitative decline to 50% of initial evoked torque compared to the other protocols (Figure 3C). On average, a 50% TTI decline occurred by the 4th contraction with KFAC200, 9th with PC200, and 16th with PC500, while KFAC500 did not reach a 50% drop during the fatigue protocol. Similar results were observed for the TTI decline%, with KFAC200 showing the fastest reduction and KFAC500 maintaining torque above 50% throughout the NMES-fatigue protocol.

- *TTI Decline:* The TTI decline curve showed no interaction between current and time ($F = 1.083$, $p=0.357$, $\eta p^2 = 0.018$). However, a main effect of time was found ($F = 76.520$, $p<0.001$, $\eta p^2 = 0.029$; Figure 3D), while no main effect of current was observed ($F = 0.885$, $p=0.449$, $\eta p^2 = 0.015$).

- *Fatigue Index:* No interaction was observed between currents for torque ($F = 0.013$, $p=0.051$) or TTI ($F = 0.057$, $p=0.056$). The torque reductions were: PC200 = 58.83% [–1.72, 0.97], KFAC200 = 77.91% [–1.72, 0.98], PC500 = 31.99% [–1.25, 0.93], and KFAC500 = 41.86% [–1.24, 0.89], and the TTI reductions were: PC200 = 93.22% [–2.18, 0.99], KFAC200 = 79.63% [–6.45, 0.98], PC500 = 46.02% [–2.08, 0.95], and KFAC500 = 47.96% [–2.67, 0.92]. Data are presented as mean [95% CI].

Figure 3

Legend. A: Currents with 500μs pulse phase duration showing higher torque-time integral (TTI) sum when compared to the 200μs pulse phase currents ($p = 0.0001$). **B:**

Currents with 500μs of phase duration showing higher NMES efficiency compared to the 200μs phase duration currents ($p = 0.0001$). **C:** TTI decay during the fatigue protocol ($p = 0.0001$). **D:** TTI decay during the fatigue protocol normalized by the maximal voluntary contraction ($p = 0.0001$). Arrows pointing down indicate a 50% drop in TTI in KFAC 200, PC 200 and PC 500 currents.

Discomfort

No interaction was found between time and current for discomfort during the fatigue protocol ($F = 1.405$, $p=0.211$, $\eta p^2 = 0.023$; Table 2). There were no main effects of time ($F = 0.311$, $p=0.732$, $\eta p^2 = 0.001$) or current ($F = 0.918$, $p=0.433$, $\eta p^2 = 0.015$).

DISCUSSION

The present study aimed to compare the fatigue-related responses, torque output, NMES efficiency, and discomfort induced by PC and KFAC using two phase durations (200 μs and 500 μs). Our findings demonstrate that pulse duration, rather than current type, is the primary determinant of NMES efficiency and fatigue resistance. The 500 μs pulse duration protocols (both PC500 and KFAC500) consistently outperformed their 200 μs counterparts in terms of TTI, fatigue resistance, and NMES efficiency, regardless of current type. Based on these results, physical therapists should carefully consider pulse duration, as it may exert a greater influence than current type on optimizing muscle work, mitigating fatigue, and maintaining comfort during NMES.

Regarding the fatigue index, KFAC200 demonstrated the most severe fatigue (77.91% reduction), followed by PC200 (58.83%), while the wide-pulse protocols (KFAC500: 41.86%; PC500: 31.99%) led to less fatigue. Our results partially align with those of Aldayel et al.[17], who reported no differences between PC and KFAC for acute muscle torque production, hormonal/metabolic markers, or perceived exertion during bilateral knee extensor NMES using 400 μs pulses at 75 Hz. Similarly, our findings showed no differences between KFAC and PC, at the same phase durations, in fatigue or NMES efficiency, reinforcing the conclusion that waveform type alone may not significantly influence acute mechanical outcomes when phase duration and frequency are matched. However, our findings contrast with Laufer et al.[14,15] and Paz et al.[35], who observed greater fatigue and/or lower torque with KFAC compared to PC. Laufer and colleagues[14,15] showed that monophasic and biphasic PC waveforms induced greater torque and less fatigue than polyphasic KFAC, and Paz et al.[35] confirmed higher fatigability and lower TTI for KFAC in a submaximal fatigue protocol. These discrepancies can be attributed to several methodological differences.

Paz et al.[35] observed higher fatigability and torque decline, and a TTI of 2.5 kHz AC compared to PC during a submaximal NMES protocol using constant current intensity over 80 contractions (time on:off = 5:10 sec). In contrast, our study employed only 20 contractions (20:20-sec on:off time), resulting in a shorter protocol, which may explain the differing results relative to the prior investigation. Laufer and Elboim[15] also reported that the Russian current (2.5 kHz KFAC with 25 cycles per burst at 50 Hz) was more fatiguing than low-frequency PC, particularly due to its higher number of cycles per second. However, that study compared KFAC with varying burst durations (10 vs. 25 cycles), introducing differences in total charge delivery that could account for the greater fatigue observed with KFAC. In contrast, our study controlled for phase duration (200 vs. 500 μs) across all current types, minimizing variability in delivered charge per pulse. Discrepancies may arise from differences in the muscle groups studied. Previous research primarily assessed the quadriceps (vastus lateralis and medialis)[18], whereas we evaluated the triceps surae (soleus and lateral gastrocnemius), which differ in architecture, fiber composition, and activation patterns, likely influencing NMES-induced fatigue. Additionally, our protocol used 20 contractions with a 20:20-second duty cycle, shorter than the 30 contractions applied by Aldayel et al.[17,18], who observed similar or slightly lower fatigue with KFAC depending on waveform and intensity.

Regarding the number of contractions required to reach a 50% decline in evoked torque, our results showed that KFAC200 reached this threshold first (4 contractions), followed by PC200 (9 contractions) and PC500 (16 contractions), while KFAC500 did not reach this threshold during the protocol. Despite being a qualitative analysis, these results suggest that wide-pulse durations may enhance fatigue resistance, contrary to previous reports that KFAC generally induces greater fatigue than PC[14,15,16]. The superior performance of wide pulses for mitigating fatigue induced by NMES may be attributed to their ability to activate a larger proportion of sensory afferents[21], potentially facilitating central recruitment mechanisms that follow the size principle (smaller, fatigue-resistant MUs recruited first)[4,6]. In fact, previous studies demonstrated that NMES-evoked torque is directly related to the pulse duration. Damo et al.[1] and Medeiros et al.[36] reported that increasing the pulse duration from 200 μs to 500 μs resulted in ~30% and 23% greater torque output, respectively. Although no interaction between current type and time was observed for MVC, RMS, or spinal excitability (see Supplementary Material), the consistent advantage of 500 μs over 200 μs pulses suggests that longer durations deliver a greater NMES charge, enhancing MU recruitment and delaying fatigue. Taken together, the increase in torque generation and mitigation of fatigue induced by NMES are supported by research demonstrating that wider pulse durations preferentially activate sensory axons compared to narrow pulse durations, due to their lower rheobase and longer strength-duration time constants compared to motor axons[1,4,6].

Perceived discomfort, a critical factor that can affect NMES therapeutic efficacy, did not differ during our fatigue protocol. Although few studies have evaluated discomfort during or after submaximal fatigue protocols comparing PC and KFAC, our results are consistent with prior research involving 15 to 30 contractions, which similarly found no differences[16,40,41]. However, these results contrast with those of Vaz et al.[10], who reported differences in discomfort, potentially attributable to the different waveforms (rectangular for PC and sinusoidal for KFAC). This distinction is relevant, as sinusoidal currents are generally perceived as more uncomfortable than rectangular currents[42], whereas we utilized only rectangular waveforms for all four currents tested, possibly accounting for the observed similarity in discomfort levels.

The current study presents some limitations. First, our assessment focused on plantar flexor muscles, and the results cannot be generalized to muscles with different fiber compositions[1,22,39]. Second, submaximal NMES intensities were used, and the findings might differ at higher intensities that recruit more high-threshold MUs[22,37]. Although phase duration was key for fatigue, other parameters such as the current amplitude, electrode size, and duty cycle were held constant, limiting analysis of their combined effects on NMES-fatigue and efficiency. In addition, the study was limited to young, healthy adults, restricting generalizability to older or clinical populations. Future research should examine long-term NMES adaptations across pulse durations and current types (KFAC vs. PC)[4,9,26] and investigate effects in clinical populations to optimize rehabilitation protocols[3,43].

CONCLUSION

KFAC and PC, applied with the same phase duration, induced similar levels of fatigue, NMES efficiency, and perceived discomfort, with no clear differences in the mechanisms of fatigue between them. However, currents with smaller phase durations induced greater and more rapid fatigue, with lower NMES efficiency compared to wide pulses, regardless of current type (KFAC or PC). Clinically, currents with wider phase durations (500 µs) resulted in improved NMES efficiency and greater resistance to fatigue, making them more suitable for applications where endurance is required or early-onset fatigue is present during rehabilitation, such as in post-injury training, neuromuscular re-education, or in populations with limited exercise tolerance.

PERSPECTIVES

Based on the presented findings, it is evident that in clinical practice, a meticulous selection of pulse phase duration during neuromuscular electrical stimulation (NMES) is a critical factor to enhance therapeutic outcomes. Currents with longer phase durations (approximately 500 µs) should be prioritized in interventions aimed at promoting greater fatigue resistance and improved muscle efficiency, such as in post-injury rehabilitation, neuromuscular re-education, or in patient populations with low exercise tolerance. This approach allows for longer and more effective stimulation sessions, facilitating muscle engagement in a tolerable manner even in populations susceptible to early fatigue, which can positively influence functional recovery in these patient profiles.

Furthermore, understanding that modulation of pulse phase duration directly impacts levels of discomfort and fatigue enables the clinician to tailor stimulation protocols according to individual patient demands and limitations. In scenarios where the goal is brief muscle activation or shorter sessions, shorter pulse durations may be indicated, acknowledging that fatigue will develop more rapidly and stimulation efficiency may be compromised. Thus, clinical practice benefits from evidence-based protocols that balance tolerance, NMES efficiency, and muscle fatigue resistance, making interventions safer, more precise, and customized to the individual patient's functional profile.

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APÊNDICES

APÊNDICE 1 – Material Suplementar

SUPPLEMENTARY MATERIAL

METHODS

Spinal Excitability: H Reflex and M Wave

Spinal excitability was assessed via H-reflex and M-wave measurements immediately after the MET assessment. Recruitment curves were generated using 1.0 ms monophasic pulses from a high-voltage stimulator (DIGITIMER DS8R, London, UK). Forty stimuli were delivered at intensities ranging from below motor threshold to ~1.4 × Mmax, with inter-stimulus intervals of 8–12 seconds. Key outcomes included the Hmax:Mmax ratio (mean value of the three largest H-reflex amplitudes divided by the maximal M-wave) and the M-wave amplitude corresponding to the maximal H-reflexes (mean of the three M-waves at peak H-reflex).

Mechanical properties and central activation ratio (CAR)

Mechanical properties (torque and force-time integral) of the plantar flexors and the central activation ratio (CAR) were assessed using the twitch interpolation technique[1]. Stimulation electrodes were placed on the tibial nerve in the popliteal fossa (cathode, 8 mm self-adhesive) and below the patella (anode, 5 × 10 cm self-adhesive), positioned to elicit the strongest visible contraction of the triceps surae. For each subject, the best representative H-reflex, M-wave, and maximal stimulation curves were identified. Single-square-wave stimuli (1 ms duration, max 100 V) were delivered with increasing current until the evoked isometric contraction plateaued. Peak contractions (average of two) and corresponding maximal stimulation intensity were recorded. Paired stimuli (two 1 ms pulses separated by 10 ms) were applied at three time points: at rest, superimposed on the MVC, and during relaxation[2]. CAR was calculated as: CAR (%) = [maximum voluntary torque / (maximum voluntary torque + superimposed torque – maximum voluntary torque)] × 100[3].

Electromyographic activity (EMG)

H-reflex and M-wave electromyographic (EMG) activity were recorded using a portable surface EMG system (MP160, Biopac, Aero Camino, Goleta, CA, USA; Octopus AMT-8, Bortec Biomedical Ltd, Calgary, AB, Canada) with 14-bit resolution, <2 LSB noise, and 110 dB common-mode rejection. Electrodes were positioned according to SENIAM guidelines for the medial gastrocnemius (GM), lateral gastrocnemius (GL), and soleus (SL) muscles[4]. EMG signals were analyzed over a 500 ms window centered on the maximum torque (250 ms before and after the peak) by calculating the root mean square (RMS) (bandpass 10–500 Hz) and the median frequency (mFREQ) of the power spectrum (low-pass 50 Hz) obtained via Fast Fourier Transformation from each MVC.

RESULTS

Spinal Excitability

In the soleus, M-wave showed no interaction between current and time ($F = 0.215$, $p=0.885$) but a main effect of time ($F = 4.007$, $p=0.046$); current type had no effect. H-reflex and Hmax:Mmax ratio showed no interactions or main effects. In the lateral gastrocnemius, M-wave showed no interaction, but a time effect ($F = 11.791$, $p<0.001$); current type had no effect. H-reflex had no interaction but a time effect ($F = 7.763$, $p<0.001$); current type had no effect. Hmax:Mmax ratio showed no interactions or main effects (Table 1 for further details).

Mechanical properties and central activation ratio (CAR)

No interaction between current and time was found for CAR ($F = 1.240$, $p=0.296$, $\eta p^2 = 0.021$), nor were there main effects for time ($F = 0.260$, $p=0.609$) or current ($F = 1.530$, $p=0.209$; Table 1).

Root mean square (RMS) and Median frequency (MDF)

For RMS, no interaction between current and time was found for the soleus ($F = 2.302$, $p=0.078$, $\eta p^2 = 0.038$), but an interaction was observed for the lateral gastrocnemius ($F = 8.880$, $p<0.001$, $\eta p^2 = 0.134$). A main effect of time was found for both the soleus ($F = 43.791$, $p<0.001$, $\eta p^2 = 0.202$) and lateral gastrocnemius ($F = 12.648$, $p<0.001$, $\eta p^2 = 0.068$), indicating a post-fatigue reduction in RMS ($p<0.001$ for both; Figures 3A and 3B).

A main effect of current type was observed for the soleus ($F = 2.797$, $p=0.041$, $\eta p^2 = 0.046$), but not for the lateral gastrocnemius ($F = 0.709$, $p=0.549$, $\eta p^2 = 0.012$). For MDF, the soleus showed an interaction between current and time ($F = 3.327$, $p=0.020$, $\eta p^2 = 0.054$), though post-hoc analysis revealed no differences ($p>0.05$). No interaction was found for the lateral gastrocnemius ($F = 1.330$, $p=0.266$, $\eta p^2 = 0.022$; Table 2). No main effect of time was found for either the soleus ($F = 3.377$, $p=0.067$, $\eta p^2 = 0.019$) or lateral gastrocnemius ($F = 0.757$, $p=0.385$, $\eta p^2 = 0.022$). Similarly, no main effect of current type was observed for either muscle (soleus: $F = 0.436$, $p=0.727$, $\eta p^2 = 0.007$; lateral gastrocnemius: $F = 0.597$, $p=0.617$, $\eta p^2 = 0.010$)

Table 1. Results of different NMES currents and phase durations on central outcomes.

	PC 500		PC 200		KFAC 500		KFAC 200	
	PRE	POST	PRE	POST	PRE	POST	PRE	POST
RMS-GL* (W)	0.05 (0.03-0.06)	0.02 (0.02-0.03)	0.03 (0.02-0.03)	0.03 (0.02-0.05)	0.05 (0.03-0.07)	0.03 (0.02-0.4	0.03 (0.02-0.04)	0.03 (0.02-0.4)
RMS-SOL* (W)	0.04 (0.03-0.05)	0.02 (0.02-0.03)	0.03 (0.02-0.03)	0.02 (0.02-0.02)	0.04 (0.03-0.05)	0.02 (0.02-0.03)	0.03 (0.02-0.04)	0.03 (0.02-0.03)
MDF-GL (Hz)	162.74 (143.59-181.89)	164.46 (144.10-184.82)	165.12 (149.55-180.7)	173.65 (159.23-188.06)	159.3 (142.6-176)	152.26 (136.12-168.41)	164.57 (147.44-181.70)	172.16 (153.60-190.73)
MDF-SOL* (Hz)	176.10 (166.60-185.60)	166.62 (151.90- 181.34)	149.55 (165.19-183.80)	172.50 (161.85- 183.14)	174.99 (165.59-184.39)	181.25 (173.16- 189.35)	174.49 (165.19-183.80)	167.17 (158.11-176.24)
H-reflex-GL (mA)	0.94 (0.77-1.12)	0.88 (0.72-1.05)	0.95 (0.75-1.14)	0.85 (0.68-1.02)	0.92 (0.76-1.08)	0.86 (0.72-0.99)	0.84 (0.71-0.96)	0.81 (0.69-0.93)
M wave-GL (mA)	3.54 (3.01-4.08)	3.12 (2.56-3.68)	3.92 (3.43-4.41)	3.42 (3.01-3.82)	3.84 (3.28-4.40)	3.72 (3.15-4.29)	3.90 (3.34-4.45)	3.71 (3.20-4.22)
Hmax/Mmax-GL (mA)	0.32 (0.25-0.39)	0.35 (0.27-0.42)	0.26 (0.21-0.32)	0.27 (0.21-0.32)	0.29 (0.22-0.37)	0.28 (0.22-0.34)	0.26 (0.20-0.32)	0.25 (0.20-0.29)
H-reflex-SOL (mA)	3.14 (2.64-3.64)	3.07 (2.60-3.54)	3.11 (2.68-3.53)	3.11 (2.69-3.52)	3.15 (2.66-3.64)	3.19 (2.71-3.67)	2.79 (2.41-3.18)	2.98 (2.59-3.37)
M wave-SOL (mA)	5.32 (4.63-6.02)	5.45 (4.75-6.15)	5.34 (4.77-5.90)	5.38 (4.78-5.97)	5.53 (4.85-6.21)	5.68 (5.01-6.34)	5.23 (4.58-5.88)	5.39 (4.80-5.99)
Hmax/Mmax-SOL (mA)	0.61 (0.53-0.68)	0.59 (0.51-0.67)	0.58 (0.52-0.64)	0.58 (0.52-0.64)	0.58 (0.52-0.65)	0.58 (0.51-0.65)	0.57 (0.50-0.64)	0.57 (0.50-0.64)
CAR (%)	94.64 (91.64-97.65)	93.41 (90.03-96.80)	95.94 (93.60-98.27)	96.02 (94.56-97.47)	97.00 (94.98-99.02)	96.48 (95.31-97.65)	96.20 (94.30-98.10)	97.05 (95.77-98.34)

Legend: Legend: Data are reported as mean (95% CI). * = Time effect condition (p<0.001). PC: Pulsed currents. KFAC: Kilohertz-frequency alternated currents. RMS: Root mean square. MDF: Median Frequency. CAR: Central Activation Ratio. SOL: Soleus muscle.GL: Lateral gastrocnemius.

DISCUSSION

Our analysis of M-wave and H-reflex responses revealed time effects but no interactions between current type and time, suggesting that fatigue-induced changes in spinal excitability were similar across all NMES protocols[5]. The observed time effect on M-wave amplitude in both the soleus and lateral gastrocnemius muscles indicates a decrease in muscle fiber excitability following fatigue, consistent with previous research on NMES-induced peripheral fatigue mechanisms[5,6]. Moreover, the lack of changes in the Hmax/Mmax ratio indicates that spinal excitability was largely maintained across all protocols, contrasting with previous reports of reduced motoneuron excitability following NMES-induced fatigue[7]. The discrepancy from previous studies is likely attributable to the specific features of our protocol rather than motor unit recruitment patterns. Since NMES recruits motor units based on the proximity of motoneuron axons to the electrodes, the type and number of units activated cannot be determined. A more plausible explanation is that the number of evoked contractions at 20% MVC was insufficient to elicit central or neural fatigue but sufficient to induce peripheral fatigue[8]. Finally, the absence of significant changes in the CAR following our NMES protocols indicates that central fatigue mechanisms were not substantially involved in the observed performance decrements[9]. This finding contrasts with some previous studies that reported central contributions to NMES-induced fatigue, particularly at higher stimulation intensities[10]. The discrepancy may be explained by our use of submaximal stimulation intensities and longer rest periods, which may have minimized central fatigue development[11].

Interestingly, although no interaction between current type and time was observed for MVC, RMS, or spinal excitability, the consistent superiority of 500 μs over 200 μs pulse durations suggests that longer pulses deliver greater NMES charge, enhancing motor unit recruitment and delaying fatigue. This was evidenced by the higher number of contractions until a 50% drop in torque and a reduced decline in TTI. These findings are consistent with previous literature[12,13], which demonstrated that increased phase duration augments force output and may facilitate the recruitment of deeper motor units due to improved current penetration. While waveform differences are frequently emphasized in the literature[1,9], our findings suggest that phase duration is a primary determinant of NMES-induced fatigue and efficiency when stimulation frequency and amplitude are matched and tolerable. This is further supported by the absence of differences in discomfort scores, indicating that longer pulse duration can be used without compromising participant tolerance.

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ANEXOS

ANEXO 1 – Aprovação no Comitê de Ética

FACULDADE DE CIÊNCIAS E TECNOLOGIA EM SAÚDE/FCTS - UNB

COMPROVANTE DE ENVIO DO PROJETO

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Efeitos de diferentes modalidades de estimulação elétrica de média e baixa frequência na geração de torque evocado, desconforto sensorial, fadiga muscular e extração periférica de oxigênio no músculo tríceps sural.

Pesquisador: Luis André Oliveira Soares

Versão: 2

CAAE: 67915523.1.0000.8093

Instituição Proponente: Faculdade de Ceilândia

DADOS DO COMPROVANTE

Número do Comprovante: 022417/2023

Patrocionador Principal: FUNDACAO UNIVERSIDADE DE BRASILIA

Informamos que o projeto Efeitos de diferentes modalidades de estimulação elétrica de média e baixa frequência na geração de torque evocado, desconforto sensorial, fadiga muscular e extração periférica de oxigênio no músculo tríceps sural. que tem como pesquisador responsável Luis André Oliveira Soares, foi recebido para análise ética no CEP Faculdade de Ciências e Tecnologia em Saúde/FCTS - UnB em 14/03/2023 às 10:15.

ANEXO 2 – Registro do Ensaio Clínico

Effects of Kilohertz-frequency and Low-frequency Current on Triceps Surae

ClinicalTrials.gov ID **NCT05894044**

Sponsor University of Brasilia

Information provided by University of Brasilia (Responsible Party)

PRODUTOS DESENVOLVIDOS DURANTE PERÍODO DE MESTRADO

PRODUTO 1 – Apresentação de Resumo

COBRAFITO2025
V CONGRESSO BRASILEIRO E INTERNACIONAL DA ABRAFITO

CERTIFICADO

Certificamos que o trabalho intitulado,

ACUTE EFFECTS OF DIFFERENT ELECTRICAL STIMULATION CURRENTS AND PHASE DURATIONS ON MUSCLE: A RANDOMIZED CROSSOVER TRIAL

os autores **VITÓRIA DOS SANTOS NOGUEIRA; LUIS ANDRÉ OLIVEIRA SOARES; JOAO LUIZ QUAGLIOTI DURIGAN** foi aprovado no **V Congresso Brasileiro e Internacional da ABRAFITO - COBRAFITO**, realizado no período de 20 a 23 de agosto de 2025, na cidade de Florianópolis/SC, na forma de apresentação **E-PÔSTER,** tendo como autor(a) apresentador(a) **VITÓRIA DOS SANTOS NOGUEIRA**.

Florianópolis/SC, 23/08/2025

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PRODUTO 2 – Produto de Impacto Social

CERTIFICADO DE EXTENSÃO

Universidade de Brasília
Decanato de Extensão
Secretaria de Administração Acadêmica

Certificamos que, O(A) DISCENTE LUIS ANDRÉ OLIVEIRA SOARES, MATRÍCULA 242101450, participou do evento de extensão 4º SIMPÓSIO INTERNACIONAL DO GRUPO DE PESQUISA PLASTICIDADE MÚSCULO-TENDÍNEA O PASSADO E O FUTURO DA COVID-19: A EVOLUÇÃO CIENTÍFICA., promovido pelo(a) CAMPUS UNB CEILÂNDIA: FACULDADE DE CIENCIAS E TECNOLOGIAS EM SAÚDE, na função de MEMBRO DA COMISSÃO ORGANIZADORA, com 8 hora(s) de atividades desenvolvidas. A atividade foi realizada no período de 11 de Março de 2025 a 11 de Março de 2025.

Brasília, 14 de Março de 2025

JANAINA SOARES DE OLIVEIRA ALVES
Decana de Extensão

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Link para vídeo resumo:

https://drive.google.com/file/d/1eGkEzsdfBtKQ63Uph5NWb8TlTxJ5zToR/view?usp=drive_link