UNIVERSIDADE DE BRASÍLIA – UNB

FACULDADE DE EDUCAÇÃO FÍSICA – FEF

PROGRAMA DE PÓS-GRADUAÇÃO EM EDUCAÇÃO FÍSICA

ESTIMULAÇÃO ELÉTRICA NEUROMUSCULAR: COMPARAÇÃO DE FREQUÊNCIAS PORTADORAS, DURAÇÕES DE BURSTS E CICLOS DE TRABALHO NA GERAÇÃO DE TORQUE EVOCADO, DESCONFORTO SENSORIAL E FADIGA MUSCULAR.

Karenina Arrais Guida Modesto Prado

Orientador: Prof. Dr. João Luiz Quagliotti Durigan

Co-orientador: Prof. Dr. Marco Aurélio Vaz

TESE DE DOUTORADO EM EDUCAÇÃO FÍSICA

Brasília – DF

2023

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PROGRAMA DE PÓS-GRADUAÇÃO EM EDUCAÇÃO FÍSICA

Estimulação Elétrica Neuromuscular: Comparação de frequências portadoras, durações de bursts e ciclos de trabalho na geração de torque evocado, desconforto sensorial e fadiga muscular.

Karenina Arrais Guida Modesto Prado

TESE DE DOUTORADO EM EDUCAÇÃO FÍSICA

Aprovada por:

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Prof. Dr. João Luiz Quagliotti Durigan

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Prof. Dr. Martim Francisco Bottaro Marques

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Prof. Dr. Bruno Mafredini Baroni

____

Prof. Dr. Denis César Leite Vieira

Brasília – DF

2023

SUMÁRIO

DEDICATÓRIA

Dedico esta tese de doutorado aos meus pais, irmão e amigos, em especial ao meu marido e filho, cujo apoio e amor foram a bússola que guiou cada passo desta trajetória. À minha orientação e colegas de pesquisa, cujas contribuições e insights enriqueceram este trabalho. Que estas páginas sejam um tributo à busca incessante pelo conhecimento e à paixão pela ciência. Que este trabalho possa inspirar outros a se aventurarem nos horizontes do saber. Dedico estas palavras com gratidão e humildade a todos que compartilharam este caminho comigo.

AGRADECIMENTOS

Queridos familiares, amigos e queridos que estiveram ao meu lado nesta jornada,

Hoje, ao concluir esta fase significativa da minha vida acadêmica, é com profunda gratidão que expresso meus agradecimentos a todos vocês que foram fundamentais para o sucesso desta jornada.

À Deus, a base da minha vida, por todo o amor e por toda graça concedida durante essa caminhada, eu nada seria sem minha fé e a presença de Deus em minha vida.

À minha família, que sempre foi meu porto seguro, agradeço por seu amor incondicional, paciência e apoio contínuo. Vocês foram minha fonte de inspiração e força, e cada conquista alcançada é um reflexo direto do amor e apoio que recebi de vocês.

Aos meus amigos, que compartilharam risos, incentivaram nos momentos difíceis e celebraram as vitórias, agradeço por fazerem parte da trama colorida desta jornada. Suas palavras de encorajamento foram como raios de sol nos dias nublados.

Ao meu orientador e co-orientador, cuja orientação sábia e expertise foram guias essenciais, expresso minha profunda gratidão. Toda dedicação, paciência e crença em meu potencial foram fundamentais para o desenvolvimento deste trabalho. Ao meu grupo de pesquisa GPlast e ao LaPlast que mais do que um grupo se tornou uma família que levarei no coração. Aos participantes da pesquisa que sem eles não seria possível desenvolvê-la.

E, a meu amado marido e filho, palavras não são suficientes para expressar minha gratidão. Vocês foram minha âncora, meu estímulo e a luz que iluminou meu caminho. Compreenderam as ausências, incentivaram minhas paixões e celebraram cada pequeno avanço. Este trabalho não seria possível sem o amor e apoio inabaláveis que recebi de vocês. Obrigada filho por entender quando a mamãe não estava em casa, para poder realizar outro sonho além do sonho de ser mãe.

A todos, meu sincero obrigado. Esta jornada foi feita de desafios, aprendizados e crescimento, e eu sou verdadeiramente abençoada por ter compartilhado cada passo com pessoas tão incríveis. Que esta conquista seja não apenas minha, mas nossa, e que o futuro reserve novos capítulos igualmente emocionantes.

Com profunda gratidão,

EPÍGRAFE

"É justo que muito custe o que muito vale"

Santa Teresa D'Ávila

APRESENTAÇÃO

Comecei minha jornada no ano de 2009 quando ingressei na Universidade de Brasília no curso de graduação em Fisioterapia na Faculdade de Ceilândia. Durante a graduação conheci a iniciação científica que despertou em mim um interesse genuíno pela pesquisa. Nesse período fiz diversas iniciações científicas, tanto voluntárias como bolsista. Logo senti grande interesse em buscar mais conhecimento e desta forma após a graduação no ano de 2016 ingressei no Programa de Pós-Graduação em Ciências da Reabilitação na Universidade de Brasília na Faculdade de Ceilândia.

Durante o Mestrado desenvolvi uma pesquisa com estimulação elétrica para o fortalecimento muscular em atletas jogadores de futebol a qual gerou "frutos" com a publicação de um artigo científico intitulado "Russian and Low-Frequency Currents Induced Similar Neuromuscular Adaptations in Soccer Players: A Randomized Controlled Trial" *(https://pubmed.ncbi.nlm.nih.gov/31141429/)* isso gerou em mim grande alegria e entusiasmo para continuar nessa jornada que é fazer ciência.

Assim continuei minha caminhada e no ano de 2018 ingressei no Doutorado pelo Programa de Pós-Graduação em Educação Física na Universidade de Brasília. Muitas surpresas vieram após. Neste período já tínhamos decidido que iríamos continuar nossa pesquisa de acordo com o meu Mestrado, com a utilização da estimulação elétrica como forma de fortalecimento e assim faríamos um protocolo de treinamento para população com osteoartrite de joelho. Entretanto percebemos que após uma verificação na literatura teríamos que dar um passo atrás para depois darmos um passo à frente, assim escrevemos um outro projeto fortalecer nossa base de conhecimento para no futuro podermos voltar ao nosso trabalho inicial. Desta forma então iríamos fazer um projeto mais fisiológico para depois fazermos um trabalho clínico. O nosso objetivo era avaliar as adaptações neuromusculares após o treinamento com estimulação elétrica neuromuscular no nervo tibial e no ventre do músculo tríceps sural e assim começamos nossa pesquisa.

Nesse período descobri a gravidez do meu primeiro filho o que foi uma das maiores alegrias da minha vida. E para melhorar ainda mais fui aprovada no concurso para professora substituta no curso de Fisioterapia na Faculdade de Ceilândia. Então durante um período de 1 ano vivi a pesquisa, o ensino e a maternidade. Tudo estava indo bem e de repente aconteceu o inesperado, o mundo se viu em meio a uma pandemia que atingiria não apenas nosso trabalho, mas também nossas vidas e as vidas das pessoas que amamos.

Em 2019 então deu-se início à pandemia da COVID-19 e tudo mudou. As universidades fecharam e nossos laboratórios também, assim modificando nossos planos. Durante o período da pandemia em que estivemos em casa não ficamos parados. Não era possível saber o que esperar e assim comecei uma nova etapa dessa minha jornada e escrevi o primeiro artigo que faz parte desta tese de doutorado. O primeiro trabalho trata de uma revisão sistemática intitulada "Effects of kilohertz frequency, burst duty cycle, and burst duration on evoked torque, perceived discomfort and muscle fatigue: a systematic review", publicada no ano de 2022 na forma online. Esse trabalho é de grande importância, visto que foi nos baseando nele que iríamos mudar novamente nosso roteiro. Além de ter sido árduo sua produção durante a pandemia, em que fui acometida duas vezes e muito me atrapalhou, pois, sequelas como perda de memória, dificuldade de apreender tudo que eu lia e todo desgaste emocional devido particularidades familiares, o desenvolvimento deste trabalho muito me alegrou pois me motivou a continuar mesmo tantas vezes querendo desisti, eu consegui.

A pandemia se "estabilizou" com a redução dos casos de covid-19 e então pudemos voltar a retomada das pesquisas em nossos laboratórios. Retornamos no início de 2022. Entretanto, já não possuíamos tanto tempo para desenvolver o primeiro trabalho inicialmente pensado, e assim nos baseando na revisão sistemática escrevemos um novo trabalho para ser desenvolvido em um tempo hábil para as datas predeterminas pelo Programa de Pós-Graduação. Desta forma o novo projeto a ser desenvolvido seria "Estimulação Elétrica Neuromuscular: Comparação de frequências portadoras, durações de bursts e ciclos de trabalho na geração de torque evocado, desconforto sensorial, fadiga muscular e extração periférica de oxigênio". De fato, este é o trabalho que está em vossas mãos e foi desenvolvido com muito carinho e dele tiramos muito aprendizado.

Desta forma o primeiro artigo desta tese é a revisão sistemática "Effects of kilohertz frequency, burst duty cycle, and burst duration on evoked torque, perceived discomfort and muscle fatigue: a systematic review", já publicada no ano de 2022 na forma online. O segundo estudo é o manuscrito "Influence of kilohertz frequency, burts duty cycle and burst duration on evoked torque, discomfort and muscle efficiency: a randomized crossover trial". O terceiro estudo é o manuscrito "Aussie kilohertz frequency alternating current induces less contraction fatigue and high neuromuscular efficiency than Russian current in healthy people: a randomized crossover trial".

Ademais desejo a todos uma boa leitura e que este trabalho desperte em todos toda satisfação e alegria que senti ao realizá-lo.

PRODUÇÃO CIENTÍFICA DURANTE O PERÍODO DO DOUTORADO

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Manuscritos que serão submetidos após parecer da banca de Doutorado

INFLUENCE OF KILOHERTZ FREQUENCY, BURTS DUTY CYCLE AND BURST DURATION ON EVOKED TORQUE, DISCOMFORT AND MUSCLE EFFICIENCY: A RANDOMIZED CROSSOVER TRIAL

AUSSIE KILOHERTZ FREQUENCY ALTERNATING CURRENT INDUCES LESS CONTRACTION FATIGUE AND HIGH NEUROMUSCULAR EFFICIENCY THAN RUSSIAN CURRENT IN HEALTHY PEOPLE: A RANDOMIZED CROSSOVER TRIAL

Trabalhos relativos à linha de pesquisa apresentados em eventos

INFLUÊNCIA DO CICLO DE TRABALHO DAS CORRENTES RUSSA E AUSTRALIANA NO DESCONFORTO SENSORIAL. XVII Fórum Nacional de Pesquisa e Pós-Graduação em Fisioterapia da Associação Brasileira de Pesquisa e Pós-Graduação em Fisioterapia na Universidade Federal de Santa Catarina, Campus Florianópolis. Florianópolis – SC, 18 de novembro de 2022.

RESUMO

ESTIMULAÇÃO ELÉTRICA NEUROMUSCULAR: COMPARAÇÃO DE FREQUÊNCIAS PORTADORAS, DURAÇÕES DE BURSTS E CICLOS DE TRABALHO NA GERAÇÃO DE TORQUE EVOCADO, DESCONFORTO SENSORIAL E FADIGA MUSCULAR.

Autora: Karenina Arrais Guida Modesto Prado

Orientador: João Luiz Quagliotti Durigan

Programa de Pós-Graduação em Educação Física – Tese de Doutorado

Brasília, dezembro de 2023

Introdução:

A Estimulação Elétrica Neuromuscular (EENM) busca gerar contrações musculares para combater a atrofia e melhorar o desempenho. A EENM tem sido usada por mais de 40 anos, mostrando benefícios no fortalecimento muscular em diversas populações. As correntes com frequência em quilohertz são comumente empregadas na prática clínica para esse fim. Contudo, a relação entre seus parâmetros físicos e a eficiência da estimulação, incluindo a geração de torque, o desconforto sensorial e a fadiga muscular não são clara devido à falta de padronização. Estudos apontam que frequências portadoras mais baixas permitem uma maior geração de torque, mas os resultados variam entre diferentes frequências. O ciclo de trabalho abaixo de 50% parece ser mais favorável para o aumento do torque e redução do desconforto. A influência da duração do burst e a relação com o torque, o desconforto e principalmente da fadiga muscular ainda carece de investigação. A falta de padronização dos parâmetros da EENM pode explicar os resultados inconsistentes sobre a geração de torque, desconforto e fadiga muscular. Este estudo buscou entender o efeito da frequência portadora, duração do burst e ciclo de trabalho na geração de torque, desconforto e fadiga muscular. Espera-se que esses resultados auxiliem na otimização dos protocolos de reabilitação com EENM, promovendo benefícios terapêuticos mais eficientes e estimulando a adesão dos pacientes a essa terapia.

Objetivos

Artigo 1: Investigamos os efeitos da frequência portadora, dos ciclos de trabalho e das durações dos bursts no torque evocado, desconforto percebido e fadiga muscular.

Artigo 2: Comparar as correntes Aussie de 1000 Hz e a corrente Russa de 2500 Hz, pressupondo que frequências mais baixas e ciclos de trabalho mais curtos melhoram o torque e a eficiência sem aumento do desconforto.

Artigo 3: Investigamos os efeitos de quatro protocolos diferentes de EENM aplicados ao músculo tríceps sural em relação ao torque evocado máximo, fadiga muscular, eficiência, desconforto sensorial e excitabilidade espinhal.

Métodos:

Artigo 1: Uma busca em oito fontes de dados por dois revisores independentes resultou na seleção de 13 estudos revisados por pares, seguindo as diretrizes dos Itens Preferenciais para Relatórios de Revisões Sistemáticas e Meta-Análises, e foram avaliados utilizando a escala PEDro para avaliar a qualidade metodológica dos estudos.

Artigo 2: Utilizando um desenho cross-over, correntes alternadas com frequência em quilohertz de 1 kHz (ciclo de trabalho de 10% e 20%) e 2,5 kHz (ciclo de trabalho de 10% e 20%) foram aplicadas aleatoriamente no tríceps sural de participantes saudáveis, com um intervalo mínimo de sete dias entre as sessões. O torque evocado, a eficiência, a intensidade e o desconforto da EENM foram medidos em condições máximas e submáximas. As análises estatísticas foram realizadas utilizando ANOVA de modelo misto de duas vias com medidas repetidas [dois níveis: correntes (Aussie e Russa) X ciclo de trabalho (10% e 20%)], seguidas por um teste *post-hoc* de Tukey.

Artigo 3: Com um desenho cross-over, utilizou-se correntes alternadas com frequência em quilohertz de 1 kHz (ciclo de trabalho de 10% e 20%) e 2,5 kHz (ciclo de trabalho de 10% e 20%), aplicadas aleatoriamente no tríceps sural de participantes saudáveis, com um intervalo mínimo de sete dias entre as sessões. O torque evocado máximo, fadiga muscular (TTI total, declínio do TTI, índice de fadiga e número de contrações), eficiência, desconforto sensorial e excitabilidade espinhal foram medidos. As análises estatísticas foram realizadas utilizando ANOVA de modelo misto de duas vias com medidas repetidas [três níveis: correntes (Aussie e Russa) X ciclo de trabalho (10% e 20%) X tempo (pré e pós)], seguidas por um teste *post-hoc* de Tukey.

Resultados

Artigo 1: A maioria dos estudos mostrou que as frequências portadoras de até 1 kHz evocaram um torque mais elevado, enquanto as frequências entre 2,5 e 5 kHz resultaram em menor desconforto percebido. Além disso, a maioria dos estudos indicou que ciclos de trabalho mais curtos (10% a 50%) induziram um torque evocado maior e um desconforto percebido menor. As pontuações de qualidade metodológica variaram de 5 a 8 na escala PEDro.

Artigo 2: Quarenta e quatro participantes (idade de 25,65 ± 6,55 anos) foram incluídos. As correntes Aussie produziram um torque evocado e eficiência mais elevados em condições máximas e submáximas. O ciclo de trabalho de 20% proporcionou uma eficiência mais alta em condições submáximas. As correntes Aussie apresentaram uma menor minimização do uso de intensidade em condições máximas e submáximas. O ciclo de trabalho de 20% mostrou uma menor minimização do uso de intensidade em condições submáximas. As correntes Aussie geraram um desconforto maior em condições máximas; no entanto, não houve diferença em condições submáximas.

Artigo 3: Foram incluídos no estudo quarenta e quatro participantes (idade de 25,65 ± 6,55 anos). A corrente Aussie produziu um torque evocado e valores de TTI mais altos. As correntes Aussie apresentaram uma soma total mais elevada para TTI, com um declínio menor em TTI e índice de fadiga. A corrente Aussie requer mais contrações para uma queda perceptível na geração de torque. Apenas o sóleo mostrou uma redução entre as avaliações pré e pós para RMS e FM. Os gastrocnêmios apresentaram uma redução entre as avaliações pré e pós para RMS e valores mais altos para o ciclo de trabalho de 20% para FM. A corrente Aussie demonstrou uma eficiência mais alta, tanto para a eficiência máxima, como durante a fadiga. A corrente Aussie resultou em um desconforto geral mais alto. O desconforto durante a fadiga é maior no início do protocolo em comparação com o final.

Conclusão

Artigo 1: Concluímos que a corrente alternada de frequência em quilohertz desenvolve um torque evocado maior para frequências portadoras entre 1 e 2,5 kHz e ciclos de trabalho inferiores a 50%. Um menor desconforto percebido foi gerado utilizando correntes alternadas de frequência em quilohertz entre 2,5 e 5 kHz e ciclos de trabalho dos bursts inferiores a 50%.

Artigo 2: A corrente Aussie demonstra desempenho superior ao provocar um torque evocado mais elevado, eficiência aprimorada e amplitude de corrente reduzida quando comparada à corrente Russa, independentemente de ser avaliada em condições máximas ou submáximas. Embora a corrente Australiana cause maior desconforto durante condições máximas, nenhuma disparidade significativa é observada em comparação com a corrente Russa em condições submáximas. Além disso, um ciclo de trabalho de 20% apresenta eficiência aprimorada e utiliza intensidade de corrente mais baixa em condições submáximas.

Artigo 3: A corrente Aussie apresentou desempenho superior na geração de torque evocado e eficiência muscular. Em relação à fadiga muscular, a corrente Aussie parece induzir menos fadiga muscular em comparação com a corrente Russa, com ciclos de trabalho de 10% resultando em maior fadiga. Embora a corrente Aussie seja mais desconfortável em termos de desconforto total, não há diferença significativa no desconforto entre as correntes durante o protocolo de fadiga, exceto que o desconforto diminui ao longo do tempo.

Palavras-chaves: Estimulação elétrica, Ciclo de trabalho, Burst.

ABSTRACT

NEUROMUSCULAR ELECTRICAL STIMULATION: COMPARISON OF CARRIER FREQUENCY BURST DURATIONS, AND DUTY CYCLES IN EVOKED TORQUE GENERATION, SENSORY DISCOMFORT, MUSCLE FATIGUE, AND PERIPHERAL OXYGEN EXTRACTION.

Author: Karenina Arrais Guida Modesto Prado

Supervisor: João Luiz Quagliotti Durigan

Programa de Pós-Graduação em Educação Física – Tese de Doutorado

Brasília, dezembro de 2023

Introdution:

Neuromuscular Electrical Stimulation (NMES) aims to generate muscle contractions to counteract atrophy and enhance performance. NMES has been utilized for over 40 years, demonstrating muscle strengthening benefits across diverse populations. Kilohertz-frequency currents are commonly employed in clinical practice for this purpose. However, the relationship between their physical parameters and stimulation efficiency, including torque generation, sensory discomfort, and muscle fatigue, remains unclear due to a lack of standardization. Studies suggest that lower carrier frequencies allow for increased torque generation, yet results vary across different frequencies. Duty cycles below 50% appear more favorable for torque enhancement and discomfort reduction. The impact of burst duration on torque, discomfort, and, particularly, muscle fatigue is still underexplored. The absence of standardization in NMES parameters may account for inconsistent findings regarding torque generation, discomfort, and muscle fatigue. This study aimed to understand the effects of carrier frequency, burst duration, and duty cycle on torque generation, discomfort, and muscle fatigue. It is anticipated that these results will contribute to optimizing NMES rehabilitation protocols, fostering more efficient therapeutic benefits and encouraging patient adherence to this form of therapy.

Objectives

Artigo 1: We investigated the effects of carrier frequency, burst duty cycles, and burst durations on evoked torque, perceived discomfort, and muscle fatigue.

Artigo 2: Compare Aussie currents with 1000 Hz and Russian currents with 2500 Hz, hypothesizing lower frequencies and shorter duty cycles improve torque and efficiency without increased discomfort.

Artigo 3: Investigated the effects of four different NMES protocols applied to the triceps surae muscle on maximum evoked torque, fatigue muscle, efficiency, sensory discomfort and spinal excitability.

Methods:

Artigo 1: A search across eight data sources by two independent reviewers led to the selection of 13 peer-reviewed studies following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, and they were assessed using the PEDro scale to evaluate the methodological quality of the studies.

Artigo 2: Using a cross-over design, kHz frequency alternating currents (KFAC) with 1 kHz (10% and 20% of duty cycle) and 2.5 kHz, (10% and 20% of duty cycle) were randomly applied on triceps surae of healthy participants with a minimum of seven days between sessions. The NMES-evoked torque, NMES-efficiency, NMES-intensity, and NMES-discomfort were measured in maximum and submaximum conditions. Statistics were conducted using a two-way mixed-model ANOVA with repeated measures [two levels: currents (Aussie and Russa) X duty cycle (10% and 20%)], followed by Tukey post-hoc.

Artigo 3: A cross-over design, using a kHz frequency alternating currents (KFAC) with 1 kHz (10% and 20% of duty cycle) and 2.5 kHz, (10% and 20% of duty cycle) were randomly applied on triceps surae of healthy participants with a minimum of seven days between sessions. The maximum evoked torque (MEC), fatigue muscle (total TTI, decline of TTI, fatigue index and number of contraction), efficiency, sensory discomfort and spinal excitability were measured. Statistics were conducted using a two-way mixed-model ANOVA with repeated measures [three levels: currents (aussie and russa) X duty cycle (10% and 20%) X time (pre and post] followed by Tukey post-hoc.

Results:

Artigo 1: Most studies showed that carrier frequencies up to 1 kHz elicited higher torque, while frequencies between 2.5 and 5 kHz resulted in lower perceived discomfort. Additionally, most studies indicated that shorter burst duty cycles (10% to 50%) induced higher evoked torque and lower perceived discomfort. Methodological quality scores ranged from 5 to 8 on the PEDro scale.

Artigo 2: Forty-four participants (age 25.65 ± 6.55 years) were included. Aussie currents produced a higher evoked torque and efficiency in maximum and submaximum conditions. Duty cycle 20% produced a highest efficiency in submaximum conditions. Aussie currents presented a lower minimization of intensity usage in maximum and submaximum conditions. Duty cycle 20% presented lower minimization of intensity usage in submaximum condition. Aussie currents produced a higher discomfort in maximum condition, however, there was no difference in submaximal conditions.

Artigo 3: Were included forty-four participants (age 25.65 ± 6.55 years). The Aussie current produced higher evoked torque and TTI values. Aussie currents showed a higher total sum for TTI with a lower decline in TTI and fatigue index. The Aussie current takes more contractions for a noticeable drop in torque generation. Only the soleus showed a decrease between pre and post assessments for RMS and FM. The gastrocnemius muscles showed a reduction between pre and post assessments for RMS and higher values for the 20% duty cycle for FM. The Aussie current demonstrated higher efficiency, regardless of pre and post assessments, as well as during fatigue. The Aussie current resulted in higher overall discomfort. Discomfort during fatigue is higher at the beginning of the protocol compared to the end.

Conclusion:

Article 1: We concluded that kilohertz-frequency alternating current generates greater evoked torque for carrier frequencies between 1 and 2.5 kHz and burst duty cycles below 50%. Lower perceived discomfort was generated using kilohertz-frequency alternating currents between 2.5 and 5 kHz and burst duty cycles below 50%.

Article 2: The Aussie current demonstrates superior performance in eliciting higher evoked torque, enhanced efficiency, and reduced current amplitude when compared to the Russian current, irrespective of whether assessed under maximal or submaximal conditions. While the Australian current induces greater discomfort during maximal conditions, no significant disparity is observed when compared to the Russian current under submaximal conditions. Furthermore, a 20% duty cycle exhibits enhanced efficiency and utilizes lower current intensity in submaximal conditions.

Article 3: The Aussie current presented superior performance in evoked torque generation and muscular efficiency. Regarding muscle fatigue, the Aussie current appears to induce less muscular fatigue compared to the Russian current, with 10% duty cycles resulting in higher fatigue. Although the Aussie current is more uncomfortable in terms of total discomfort, there is no significant difference in discomfort between the currents during the fatigue protocol, except that discomfort decreases over time.

Key-words: Electrical stimulation, Duty cycle, Burst.

JUSTIFICATIVA

A lacuna existente na literatura científica em relação à falta de padronização dos parâmetros físicos da estimulação elétrica, a diversidade significativa nas abordagens metodológicas utilizadas em estudos relacionados à eletroestimulação neuromuscular (EENM) com correntes de média frequência, especialmente no que diz respeito à frequência portadora, ciclo de trabalho e duração de bursts nos impele ao desenvolvimento de trabalhos sobre este tema. A variabilidade nos protocolos de EENM dificulta a comparação direta dos resultados entre diferentes estudos, comprometendo a consistência e confiabilidade das conclusões alcançadas. A ausência de uma padronização clara dos parâmetros de estimulação pode levar a interpretações contraditórias e dificulta a replicação dos experimentos. Além disso, a compreensão aprofundada do impacto da frequência portadora, ciclo de trabalho e duração de bursts no torque evocado, fadiga, desconforto sensorial e eficiência muscular é crucial para otimizar a aplicação prática da EENM, principalmente dentro das correntes de média frequência. Essa otimização é essencial para maximizar os benefícios terapêuticos, minimizando efeitos adversos e proporcionando diretrizes mais claras para profissionais da área de saúde. Portanto, este trabalho busca preencher essa lacuna, contribuindo para a consolidação de uma base científica mais robusta na área da EENM. A investigação cuidadosa desses parâmetros permitirá avanços significativos na compreensão dos mecanismos fisiológicos subjacentes, melhorando assim a eficácia e segurança dessa modalidade terapêutica.

REFERENCIAL TEÓRICO

Artigo 1. Publicado em American Journal of Physical Medicine & Rehabilitation

EFEITOS DA FREQUÊNCIA EM QUILOHERTZ, CICLO DE TRABALHO DO BURST E DURAÇÃO DE BURST NO TORQUE EVOCADO, PERCEPÇÃO DE DESCONFORTO E FADIGA MUSCULAR: REVISÃO SISTEMÁTICA

Karenina Arrais Guida Modesto[1], Júlia Aguillar Ivo Bastos[2], Marco Aurélio Vaz[3], João Luiz Quagliotti Durigan[4]

1. Doutoranda, Faculdade de Educação Física, Universidade de Brasília, Brasília, Distrito Federal, Brasil.
2. Mestre, Programa de Ciências da Reabilitação, Universidade de Brasília, Brasília, DF, Brasil.
3. Professor Titular, Programa de Ciências do Movimento Humano, ESEFID, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brasil.
4. Professor Associado, Programa de Ciências da Reabilitação, Universidade de Brasília, Brasília, DF, Brasil.

Autor correspondente:
Sra. Karenina Arrais Guida Modesto
Doutoranda, Faculdade de Educação Física, Universidade de Brasília, Brasília, Distrito Federal, Brasil.

Resumo

Introdução: A corrente alternada em frequência de quilohertz é utilizada para minimizar a atrofia e fraqueza muscular e melhorar o desempenho muscular. No entanto, não há revisões sistemáticas que tenham avaliado os melhores parâmetros destas correntes para esse propósito. **Objetivos:** Investigamos os efeitos da frequência portadora, ciclos de trabalho e durações dos bursts no torque evocado, desconforto percebido e fadiga muscular. **Métodos:** Uma busca em oito fontes de dados por dois revisores independentes resultou na seleção de 13 estudos revisados por pares, seguindo as diretrizes do PRISMA, e foram avaliados utilizando a escala PEDro para avaliar a qualidade metodológica dos estudos. **Resultados:** A maioria dos estudos mostrou que frequências portadoras de até 1 kHz evocavam um torque mais elevado, enquanto frequências portadoras entre 2,5 kHz e 5 kHz resultavam em menor desconforto percebido. Além disso, a maioria dos estudos indicou que ciclos de trabalho dos bursts mais curtos (10% a 50%) induziam um torque evocado mais elevado e um desconforto percebido menor. As pontuações de qualidade metodológica variaram de 5 a 8 na escala PEDro. **Conclusão:** A corrente alternada em frequência de quilohertz desenvolve um torque evocado maior para frequências portadoras entre 1 kHz e 2,5 kHz e ciclos de trabalho dos bursts inferiores a 50%. Um menor desconforto percebido foi gerado utilizando KFACs entre 2,5 kHz e 5 kHz e ciclos de trabalho dos bursts inferiores a 50%.

Palavras-chaves: Estimulação elétrica, Torque, Corrente modulada em bursts, Ciclo de trabalho, Corrente alternada.

Introdução

A estimulação elétrica neuromuscular (EENM) provoca contrações musculares que podem minimizar a atrofia e a fraqueza muscular (BALDI, JACKSON, MORAILLE, 1998; CHAE, SHEFFLER, KNUTSON, 2008; DIRKS, 2015; SHEFFLER; CHAE, 2007), e melhorar o desempenho muscular (BILLOT et al., 2010; BROCHERIE et al., 2005). O torque evocado determina a carga mecânica produzida na unidade músculo-tendão (MAFFIULETTI et al., 2018; VAZ, FRASSON, 2018), e está diretamente relacionado às adaptações mencionadas anteriormente. No entanto, o torque evocado depende de vários parâmetros da EENM, como carga de fase, duração do pulso, frequência do pulso e forma de onda (GORGEY et al., 2009; SZECSI, FORNUSEK, 2014; SCOTT, CAUSEY, MARSHALL, 2009; WARD, ROBERTSON, IOANNOU, 2004).

Na prática clínica, a eficiência da EENM é definida como a maior produção de torque enquanto se aplica a menor amplitude de corrente com desconforto percebido razoável (LIEBER, KELLY, 1991; VAZ, FRASSON, 2018). A eficiência da EENM também depende do trabalho total produzido pelo torque evocado. Uma redução no trabalho evocado pela EENM geralmente ocorre devido à fadiga muscular, pois a fadiga reduz a duração e intensidade das sessões de estimulação (RODRIGUEZ-FALCES, PLACE, 2013). Quanto maior a fadiga evocada, menor a carga mecânica da unidade músculo-tendão, e menor a eficiência da EENM e os benefícios dos programas de EENM na prática clínica. Portanto, reduzir a fadigabilidade das contrações evocadas ajudará a maximizar os benefícios da EENM para uso clínico (GORGEY et al., 2006). A definição dos parâmetros mais apropriados da EENM ajudará a diminuir a fadiga evocada e a melhorar a eficiência da EENM.

A corrente alternada em frequência de quilohertz envolve frequências de corrente relativamente altas, variando entre 1 kHz e cerca de 20 kHz. O uso de corrente alternada em frequência de quilohertz na prática clínica se expandiu globalmente após Kots, um cientista russo (KRAMER, MENDRYK, 1982; WARD, SHKURATOVA, 2002), afirmar que o KFAC usado em seu estudo (2,5 kHz, modulado a 50 Hz, bursts/inter-bursts de 10 ms/10 ms, ciclo de trabalho do bursts de 50%) (WARD; SHKURATOVA, 2002) aumentou a contração isométrica voluntária máxima em ~40%. Este torque evocado pela KFAC depende de vários parâmetros da EENM, como carga de fase, duração do pulso, frequência do pulso, frequência portadora, ciclo de trabalho do burst e forma de onda (SZECSI, FORNUSEK, 2014; WARD, ROBERTSON, IOANNOU, 2004).

Teoricamente, a corrente alternada em frequência de quilohertz, com frequências portadora mais altas deveriam diminuir a impedância da pele e permitir que menos energia elétrica seja dissipada, gerando assim contrações evocadas mais intensas (MEDEIROS et al., 2017). No entanto, frequências portadora mais baixas demonstraram evocar maior torque do que outras frequências (DANTAS et al., 2015; WARD, OLIVER, BUCCELLA, 2006; WARD, ROBERTSON, IOANNOU, 2004), enquanto frequências portadora entre 2,5 e 5 kHz apresentaram resultados conflitantes. Por exemplo, enquanto o torque evocado máximo relatado ocorreu com 1 kHz (WARD, ROBERTSON, IOANNOU, 2004), não foram relatadas diferenças significativas no torque evocado entre frequências portadora de 2,5 kHz e 5 kHz (SELKOWITZ; ROSSMAN; FITZPATRICK, 2009). Em contraste, foi demonstrado que 2,5 kHz induz um torque mais alto do que 5 kHz (PARKER, KELLER, EVERSON, 2005). Resultados conflitantes semelhantes foram encontrados em relação ao desconforto, pois foi relatado que corrente alternada em frequência de quilohertz com 4 kHz era mais confortável do que frequências portadora mais baixas (WARD, ROBERTSON, IOANNOU, 2004), enquanto resultados diferentes para a percepção de desconforto foram relatados em diferentes estudos (DANTAS et al., 2015; ROONEY, CURRIER, NITZ, 1992; MEDEIROS et al., 2017; WARD, OLIVER, BUCCELLA, 2006; WARD, ROBERTSON, IOANNOU, 2004).

Embora alguns estudos tenham demonstrado a influência do ciclo de trabalho dos bursts no torque evocado, desconforto percebido e fadiga muscular (SZECSI, FORNUSEK, 2014; MCLODA, CARMACK, 2000; PARKER et al., 2011; WARD; ROBERTSON, IOANNOU, 2004; LAUFER, ELBOIM, 2008), pouco se sabe sobre como o ciclo de trabalho dos bursts influenciam esses resultados ou quais são os melhores parâmetros de ciclo de trabalho dos bursts na prática clínica para evocar o torque mais alto com o menor desconforto e fadiga. Ciclos de trabalho dos bursts inferiores a 50% parecem evocar um torque maior (SZECSI, FORNUSEK, 2014; LIEBANO, WASZCZUK, CORRÊA, 2013; MCLODA, CARMACK, 2000; WARD, ROBERTSON, IOANNOU, 2004) com baixo desconforto percebido (SZECSI, FORNUSEK, 2014; LIEBANO, WASZCZUK, CORRÊA, 2013; MCLODA, CARMACK, 2000; WARD, ROBERTSON, IOANNOU, 2004;LAUFER, ELBOIM, 2008), embora alguns estudos não tenham encontrado diferenças ou não tenham analisado a influência desse parâmetro nesses resultados (DANTAS et al., 2015; ROONEY, CURRIER, NITZ, 1992; LIEBANO, WASZCZUK, CORRÊA, 2013; MEDEIROS et al., 2017).

Nenhum estudo relatou a influência da duração dos bursts no torque evocado, desconforto e fadiga muscular. Parece que o grau de fadiga é determinado pelo número total de ciclos por segundo (ou seja, frequência de estimulação) e não pelo número de bursts por segundo (LAUFER, ELBOIM, 2008). Frequências mais altas aumentam a fadiga muscular causando uma falha na geração de potencial de ação nas fibras musculares (JONES, 1981; LAUFER, ELBOIM, 2008). No entanto, apenas um estudo comparou protocolos com corrente alternada em frequência de quilohertz para determinar a fadiga evocada (LAUFER, ELBOIM, 2008). Não está claro se a fadiga da contração é reduzida ou se os resultados da EENM são melhorados quando os parâmetros da corrente alternada em frequência de quilohertz são manipulados. Os resultados inconsistentes sobre os efeitos da corrente alternada em frequência de quilohertz no torque evocado, desconforto e fadiga neuromuscular podem ser devidos à falta de padronização dos parâmetros da EENM. Estudos anteriores não descreveram e/ou padronizaram o uso dos três principais parâmetros físicos da corrente alternada em frequência de quilohertz: a frequência portadora (número de pulsos por segundo), a duração do burst (tempos ON e OFF do burst) e o ciclo de trabalho do burst (relação entre a duração do burst e a soma do burst e os tempos de interburst). Embora a corrente alternada em frequência de quilohertz seja amplamente utilizada na prática clínica, não há consenso sobre os melhores parâmetros da EENM para orientar os profissionais de saúde a incluírem a corrente alternada em frequência de quilohertz em protocolos de reabilitação. Assim, a presente revisão sistemática investiga os efeitos da frequência portadora da corrente alternada em frequência de quilohertz, do ciclo de trabalho do burst e da duração do burst no torque evocado, desconforto percebido e fadiga muscular em pacientes com lesões neurológicas ou musculoesqueléticas e em participantes saudáveis. Os resultados desta revisão podem fornecer orientações aos profissionais que utilizam a EENM na prática clínica para realizar protocolos mais eficientes na reabilitação de pacientes que podem se beneficiar desse recurso terapêutico.

MÉTODOS

Pesquisa Bibliográfica

O protocolo desta revisão sistemática foi registrado no Registro Internacional Prospectivo de Revisões Sistemáticas - PROSPERO (número de registro

CRD42020197371). A aprovação do Comitê de Ética em Pesquisa e o formulário de consentimento não foram aplicados.

Realizamos buscas nas seguintes bases de dados eletrônicas até novembro de 2020: PubMed, Medline (BVS), Web of Science (todas as bases de dados), Scientific Electronic Library Online (SciELO), EBSCO (Academic Search Premier, CINAHL e SPORT Discus), LILACS (BVS), Physiotherapy Evidence Database (PEDro), Cochrane Central Register of Controlled Trials (CENTRAL) e Embase (via Ovid). Os descritores utilizados em nossa estratégia de busca estavam relacionados a "neurological injuries", "musculoskeletal injuries", "healthy individuals", "neuromuscular electrical stimulation", "burst duty cycle", "burst-modulated", “burst duration", "muscle strength", "muscle fatigue", and "perceived discomfort". As buscas foram adaptadas para cada base de dados a fim de identificar todos os artigos relevantes. Também procuramos nas listas de referências dos estudos relevantes, mas não foram realizadas buscas adicionais na literatura cinzenta ou em estudos não publicados. A literatura cinzenta não foi incluída devido à falta de revisão por pares ou revisão científica independente rigorosa, o que pode gerar viés e fatores de confusão que não são adequadamente abordados, enquanto a falta de rigor científico pode reduzir significativamente a validade dos resultados.

Seleção de Estudos

Dois revisores avaliaram de forma independente os títulos e resumos de todos os estudos recuperados pela estratégia de busca quanto à elegibilidade e avaliaram se os relatos preenchiam os critérios de inclusão. Se nenhuma informação relevante fosse encontrada no título e resumo, o artigo era recuperado para uma busca mais aprofundada no texto completo. Ambos os autores aprovaram a inclusão dos ensaios na revisão e, em caso de discrepâncias de elegibilidade, um terceiro autor arbitrou essas discrepâncias por meio de discussão com os revisores. Incluímos ensaios clínicos randomizados publicados e ensaios cruzados randomizados que recrutaram sujeitos saudáveis e pacientes com distúrbios neurológicos ou musculoesqueléticos ($\geq$ 18 anos de idade). Os títulos, resumos e textos completos de manuscritos potencialmente relevantes foram avaliados sem restrições quanto ao idioma e à data de publicação. Os desfechos primários foram torque evocado e desconforto percebido, enquanto o desfecho secundário foi fadiga muscular.

Avaliação da Qualidade Metodológica

A avaliação da qualidade metodológica dos estudos selecionados foi realizada por dois revisores independentes, utilizando a escala PEDro de 11 itens (YAMATO et al., 2017): 1) critérios de elegibilidade (não utilizado no cálculo da pontuação); 2) alocação aleatória; 3) alocação mascarada; 4) comparabilidade inicial; 5) participantes mascarados; 6) terapeutas mascarados; 7) avaliadores mascarados; 8) acompanhamento adequado; 9) análise por intenção de tratar; 10) comparações estatísticas entre grupos; 11) estimativa pontual e variabilidade. Cada item foi marcado como "sim (1/0)" ou "não (0/0)" e totalizado em uma escala de 0 a 10, sendo que pontuações mais altas refletem estudos de maior qualidade.

Intervenção

Foram incluídos estudos que utilizaram diferentes frequências portadora da corrente alternada em frequência de quilohertz, ciclos de bursts ou durações de bursts aplicados sobre um músculo ou ponto motor. Como o objetivo do estudo era investigar os efeitos desses três parâmetros de Estimulação Elétrica Neuromuscular (EENM), não avaliamos comparadores passivos, como placebo ou terapia simulada, ou comparadores ativos, como outra intervenção.

Extração de Dados

Dois revisores extraíram de forma independente e simultânea os seguintes dados dos artigos selecionados: características dos participantes (número total, idade, sexo), descrição das intervenções (parâmetros de EENM), ferramentas utilizadas para avaliar os desfechos e os resultados do estudo. Quando necessário, foi feito contato com os autores para obter informações adicionais sobre a metodologia e/ou resultados do estudo.

RESULTADOS

Descrição dos Estudos

Resultados da busca

A busca inicial recuperou 4032 registros. Após a remoção de 1071 duplicatas, avaliamos 2961 estudos pelo título e excluímos 2912. Dos 49 estudos restantes, 30 foram excluídos após análise dos resumos. Os 19 estudos restantes foram revisados na íntegra, e seis ensaios foram excluídos, resultando assim em 13 estudos (BELLEW ET AL., 2012; DANTAS et al., 2015; ROONEY, CURRIER, NITZ, 1992; SZECSI, FORNUSEK, 2014; LIEBANO, WASZCZUK, CORRÊA, 2013; MCLODA, CARMACK, 2000;

MEDEIROS et al., 2017; PARKER, KELLER, EVERSON, 2005; PARKER et al., 2011; SELKOWITZ, ROSSMAN, FITZPATRICK, 2009; WARD, OLIVER, BUCCELLA, 2006; WARD, ROBERTSON, IOANNOU, 2004; LAUFER, ELBOIM, 2008) incluídos na revisão. Este estudo está em conformidade com todas as diretrizes PRISMA e relata as informações necessárias.

Estudos Incluídos

As características dos estudos incluídos são apresentadas na Tabela 1. Todos os estudos eram ensaios multicêntricos, realizados em cinco países diferentes, no período de 1992 a 2017, e todos os manuscritos foram redigidos em inglês. Os estudos incluídos eram ensaios clínicos (PARKER, KELLER, EVERSON, 2005; PARKER et al., 2011; WARD, OLIVER, BUCCELLA, 2006; LAUFER, ELBOIM, 2008) e ensaios cruzados (BELLEW ET AL., 2012; DANTAS et al., 2015; ROONEY, CURRIER, NITZ, 1992; SZECSI, FORNUSEK, 2014; LIEBANO, WASZCZUK, CORRÊA, 2013; MCLODA, CARMACK, 2000; MEDEIROS et al., 2017; SELKOWITZ; ROSSMAN; FITZPATRICK, 2009; WARD, ROBERTSON, IOANNOU, 2004). Um total de 321 participantes, com idades médias variando de 18,8 (LIEBANO, WASZCZUK, CORRÊA, 2013) a 55 anos (WARD, OLIVER, BUCCELLA, 2006), foram avaliados nos treze ensaios incluídos. Dentre esses participantes, um total de 321 eram saudáveis (BELLEW et al., 2012; DANTAS et al., 2015; ROONEY, CURRIER, NITZ, 1992; SZECSI, FORNUSEK, 2014; LIEBANO, WASZCZUK, CORRÊA, 2013; MCLODA, CARMACK, 2000; MEDEIROS et al., 2017; PARKER, KELLER, EVERSON, 2005; PARKER et al., 2011; SELKOWITZ, ROSSMAN, FITZPATRICK, 2009; WARD, OLIVER, BUCCELLA, 2006; WARD, ROBERTSON, IOANNOU, 2004; LAUFER, ELBOIM, 2008), e nenhum estudo incluiu pacientes com distúrbios neurológicos ou musculoesqueléticos. Doze estudos relataram torque evocado (BELLEW et al., 2012; DANTAS et al., 2015; SZECSI, FORNUSEK, 2014; LIEBANO, WASZCZUK, CORRÊA, 2013; MCLODA, CARMACK, 2000; MEDEIROS et al., 2017; PARKER, KELLER, EVERSON, 2005; PARKER et al., 2011; SELKOWITZ, ROSSMAN, FITZPATRICK, 2009; WARD, OLIVER; BUCCELLA, 2006; WARD, ROBERTSON, IOANNOU, 2004; LAUFER, ELBOIM, 2008), nove estudos relataram desconforto percebido (DANTAS et al., 2015; ROONEY, CURRIER, NITZ, 1992; SZECSI, FORNUSEK, 2014; LIEBANO, WASZCZUK, CORRÊA, 2013; MCLODA, CARMACK, 2000; MEDEIROS et al., 2017; WARD, OLIVER, BUCCELLA, 2006;

WARD, ROBERTSON, IOANNOU, 2004; LAUFER, ELBOIM, 2008), e um estudo relatou fadiga muscular (LAUFER, ELBOIM, 2008) durante a intervenção de EENM.

Intervenções

Todos os parâmetros utilizados nas intervenções estão apresentados nas Tabelas 2 e 3. Os ensaios incluídos utilizaram os seguintes parâmetros: frequência portadora, duração do pulso, frequência do bursts, ciclo do bursts e duração do bursts. Quatro estudos utilizaram apenas 2,5 kHz (LIEBANO, WASZCZUK, CORRÊA, 2013; MCLODA, CARMACK, 2000; PARKER et al., 2011; LAUFER, ELBOIM, 2008), e nove estudos compararam diferentes frequências portadora (500 Hz, 1 kHz, 1,76 kHz, 2,5 kHz, 3,75 kHz, 4 kHz, 5 kHz, 10 kHz e 20 kHz) (BELLEW el al., 2012; DANTAS et al., 2015; ROONEY, CURRIER, NITZ, 1992; SZECSI, FORNUSEK, 2014; MEDEIROS et al., 2017; PARKER, KELLER, EVERSON, 2005; SELKOWITZ, ROSSMAN, FITZPATRICK, 2009; WARD, OLIVER, BUCCELLA, 2006; WARD, ROBERTSON, IOANNOU, 2004). Um estudo não descreveu a duração do pulso (WARD, ROBERTSON, IOANNOU, 2004). Seis estudos utilizaram apenas 200 µs (BELLEW et al., 2012; ROONEY, CURRIER, NITZ, 1992; LIEBANO, WASZCZUK, CORRÊA, 2013; MCLODA, CARMACK, 2000; PARKER et al., 2011; LAUFER, ELBOIM, 2008), e seis estudos utilizaram mais de uma duração de pulso (100 µs, 133 µs, 200 µs, 500 µs, 125000 µs, 250000 µs) (DANTAS et al., 2015; SZECSI, FORNUSEK, 2014; MEDEIROS et al., 2017; PARKER, KELLER, EVERSON, 2005; SELKOWITZ, ROSSMAN, FITZPATRICK, 2009; WARD, OLIVER, BUCCELLA, 2006). Quanto à frequência do bursts, um estudo utilizou 50 Hz, 70 Hz e 90 Hz (ROONEY, CURRIER, NITZ, 1992), um estudo utilizou 50 Hz e 100 Hz (PARKER et al., 2011), um estudo utilizou 50 Hz e 20 Hz (LAUFER, ELBOIM, 2008), um estudo utilizou 71 Hz (SZECSI, FORNUSEK, 2014) e nove estudos utilizaram apenas 50 Hz (BELLEW et al., 2012; DANTAS et al., 2015; LIEBANO, WASZCZUK, CORRÊA, 2013; MCLODA, CARMACK, 2000; MEDEIROS et al., 2017; PARKER, KELLER, EVERSON, 2005; SELKOWITZ, ROSSMAN, FITZPATRICK, 2009; WARD, OLIVER, BUCCELLA, 2006; WARD, ROBERTSON, IOANNOU, 2004). Para o ciclo do bursts, um estudo utilizou 23% (ROONEY, CURRIER, NITZ, 1992), dois estudos utilizaram 50% (PARKER, KELLER, EVERSON, 2005; SELKOWITZ ROSSMAN, FITZPATRICK, 2009), um estudo utilizou 10% e 20% (MEDEIROS et al., 2017), três estudos utilizaram 20% e 50% (DANTAS et al., 2015; WARD, OLIVER, BUCCELLA, 2006; YOCHEVED

LAUFER, ELBOIM, 2008), três estudos utilizaram três ciclos de bursts diferentes (35%, 90% e 9%) (BELLEW et al., 2012; LIEBANO, WASZCZUK, CORRÊA, 2013; PARKER et al., 2011), e três estudos utilizaram mais de três ciclos de bursts (entre 2% e 100%) (SZECSI, FORNUSEK, 2014; MCLODA, CARMACK, 2000; WARD, ROBERTSON, IOANNOU, 2004). Quanto à duração do bursts e duração entre bursts, dois estudos utilizaram apenas 10 ms/10 ms (PARKER, KELLER, EVERSON, 2005; SELKOWITZ, ROSSMAN, FITZPATRICK, 2009), dez estudos utilizaram diferentes durações de bursts/duração entre bursts (entre 0,28 ms e 13,72 ms) (BELLEW et al., 2012; DANTAS et al., 2015; SZECSI, FORNUSEK, 2014; LIEBANO, WASZCZUK, CORRÊA, 2013; MCLODA, CARMACK, 2000; MEDEIROS et al., 2017; PARKER et al., 2011; WARD, OLIVER, BUCCELLA, 2006; WARD, ROBERTSON, IOANNOU, 2004; LAUFER, ELBOIM, 2008), e um estudo descreveu apenas uma das três durações de bursts (10 ms/10 ms) utilizadas no estudo (ROONEY, CURRIER, NITZ, 1992).

Todos os ensaios incluídos descreveram o Tempo ON e Tempo OFF. Apenas dois estudos utilizaram um Tempo ON e Tempo OFF semelhantes (10 segundos/3 minutos) (DANTAS et al., 2015; MEDEIROS et al., 2017), enquanto os outros onze estudos utilizaram tempos ON/OFF diferentes (entre 3 segundos - 30 segundos/3 segundos – 300 segundos) (BELLEW et al., 2012; ROONEY, CURRIER, NITZ, 1992; SZECSI, FORNUSEK, 2014; LIEBANO, WASZCZUK, CORRÊA, 2013; MCLODA, CARMACK, 2000; PARKER, KELLER, EVRESON, 2005; PARKER et al., 2011; SELKOWITZ, ROSSMAN, FITZPATRICK, 2009; WARD, OLIVER, BUCCELLA, 2006; WARD, ROBERTSON, IOANNOU, 2004; LAUFER, ELBOIM, 2008). Quanto ao número de contrações, dois estudos utilizaram duas contrações (WARD, OLIVER, BUCCELLA, 2006; WARD, ROBERTSON, IOANNOU, 2004), cinco estudos utilizaram três contrações (BELLEW et al., 2012; DANTAS et al., 2015; LIEBANO, WASZCZUK, CORRÊA, 2013; SELKOWITZ, ROSSMAN, FITZPATRICK, 2009; LAUFER, ELBOIM, 2008), dois estudos utilizaram dez contrações (ROONEY, CURRIER, NITZ, 1992; MEDEIROS et al., 2017), e os outros estudos utilizaram diferentes métodos e/ou técnicas para determinar o número de contrações (SZECSI, FORNUSEK, 2014; MCLODA, CARMACK, 2000; PARKER, KELLER, EVERSON, 2005; PARKER et al., 2011). Quatro dos estudos incluídos compararam outros protocolos de estimulação elétrica e tipos de corrente; no entanto, apenas as comparações entre corrente alternada em frequência de quilohertz estão incluídas nesta revisão (DANTAS et al., 2015; MEDEIROS et al., 2017; WARD, OLIVER, BUCCELLA, 2006; LAUFER, ELBOIM, 2008).

A avaliação da qualidade metodológica - escala PEDro

A avaliação da qualidade metodológica dos estudos está apresentada na Tabela 5. As pontuações totais variaram de 5 a 8 pontos, com uma pontuação média de 6. Todos os estudos utilizaram alocação aleatória, e apenas um estudo utilizou alocação mascarada. Apenas dois estudos relataram semelhança entre os participantes no início do estudo. Todos os estudos mascararam os participantes para a intervenção, e cinco estudos relataram que o mascaramento da intervenção foi realizado pelo terapeuta. Apenas dois estudos relataram um acompanhamento adequado. Apenas um estudo não descreveu a intenção de tratar na análise. Todos os estudos relataram diferenças entre os grupos. Os relatórios de monitoramento e variabilidade dos participantes foram utilizados em todos os estudos.

Resultados primários

Os resultados dos estudos incluídos estão resumidos na tabela 4.

Torque evocado

Torque evocado, um dos nossos resultados principais, foi quantificado como o torque elétrico induzido máximo (LIEBANO, WASZCZUK, CORRÊA, 2013; WARD, OLIVER, BUCCELLA, 2006; WARD, ROBERTSON, IOANNOU, 2004), contração elétrica induzida máxima (DANTAS et al., 2015; MEDEIROS et al., 2017; LAUFER, ELBOIM, 2008), torque elétrico induzido normalizado médio (PARKER, KELLER, EVERSON, 2005), torque isométrico elétrico induzido absoluto (SZECSI, FORNUSEK, 2014), média % da contração isométrica voluntária máxima (SELKOWITZ, ROSSMAN, FITZPATRICK, 2009), média das contrações induzidas eletricamente (PARKER et al., 2011), ou % da força extensora máxima voluntária isométrica do joelho (BELLEW et al., 2012; MCLODA, CARMACK, 2000). Doze estudos avaliaram o torque evocado (BELLEW et al., 2012; DANTAS et al., 2015; SZECSI, FORNUSEK, 2014; LIEBANO, WASZCZUK, CORRÊA, 2013; MCLODA, CARMACK, 2000; MEDEIROS et al., 2017; PARKER, KELLER, EVERSON, 2005; PARKER et al., 2011; SELKOWITZ, ROSSMAN, FITZPATRICK, 2009; WARD, OLIVER, BUCCELLA, 2006; WARD, ROBERTSON, IOANNOU, 2004; LAUFER, ELBOIM, 2008); quatro estudos utilizaram apenas a frequência portadora de 2,5 kHz (LIEBANO, WASZCZUK, CORRÊA, 2013; MCLODA, CARMACK, 2000; PARKER et al., 2011; LAUFER, ELBOIM, 2008), um estudo utilizando apenas 4 kHz (SZECSI, FORNUSEK, 2014), dois estudos utilizando 1 kHz e 2,5 kHz (DANTAS et al., 2015; WARD, OLIVER, BUCCELLA, 2006), um estudo utilizando 2,5 kHz e 5 kHz (SELKOWITZ, ROSSMAN, FITZPATRICK, 2009), um estudo utilizando 1 kHz e 4 kHz (MEDEIROS et al., 2017), um estudo utilizando 1,7 kHz e 2,5 kHz (BELLEW et al., 2012), e dois estudos utilizando diferentes frequências portadora, incluindo 2,5 kHz (PARKER, KELLER, EVERSON, 2005; WARD, ROBERTSON, IOANNOU, 2004).

Três estudos (DANTAS et al., 2015; WARD, OLIVER, BUCCELLA, 2006; WARD, ROBERTSON, IOANNOU, 2004) constataram que a frequência portadora de 1 kHz provocou um torque maior do que as outras frequências portadoras utilizadas para comparação. Ao comparar 2,5 kHz e 5 kHz, um estudo não encontrou diferenças entre as duas frequências portadora. No entanto, 5 kHz exigiu uma carga de energia mais elevada para atingir um torque evocado semelhante ao obtido com a frequência portadora de 2,5 kHz, sendo menos eficiente (SELKOWITZ, ROSSMAN, FITZPATRICK, 2009). Um torque menor também foi evocado pela frequência portadora de 2,5 kHz (2,5 kHz, modulado a 50 Hz, 200 µs de duração de pulso, durações de bursts de 10 ms/10 ms) quando comparado com outras duas frequências portadora (2,5 kHz interferindo com 2,55 kHz, modulado a 50 Hz, 200 µs de duração de pulso, duração de bursts de 20 ms; 1,76 kHz, modulado a 50 Hz, 200 µs/100 µs de duração de pulso, durações de bursts de 1,7 ms/18,3 ms) (BELLEW et al., 2012). Quando a frequência portadora de 4 kHz foram comparadas com 1 kHz, a última frequência portadora provocou um torque mais elevado (MEDEIROS et al., 2017).

Ao comparar o torque evocado entre corrente alternada em frequência de quilohertz com formas de pulso senoidais e retangulares, com uma frequência portadora de 4 kHz, a forma de onda retangular provocou um torque mais elevado (SZECSI, FORNUSEK, 2014). Apenas cinco estudos discutiram diretamente a influência do ciclo de bursts no torque evocado (SZECSI, FORNUSEK, 2014; LIEBANO, WASZCZUK, CORRÊA, 2013; MCLODA, CARMACK, 2000; PARKER et al., 2011; WARD, ROBERTSON, IOANNOU, 2004). Esses estudos mostraram que ciclos de bursts abaixo de 50% (0,25% – 50%) provocaram torques mais elevados, sendo que ciclos de bursts de 10%, 20% e 30% apresentaram os melhores resultados. Nenhum dos estudos avaliou a influência da duração do bursts no torque evocado.

Desconforto percebido

Desconforto percebido, outro resultado primário, foi avaliado usando a escala visual analógica, escala numérica e relato do participante. Dos oito estudos que avaliaram o desconforto percebido (DANTAS et al., 2015; ROONEY, CURRIER, NITZ, 1992; SZECSI, FORNUSEK, 2014; LIEBANO, WASZCZUK, CORRÊA, 2013; MEDEIROS et al., 2017; WARD, OLIVER, BUCCELLA, 2006; WARD, ROBERTSON, IOANNOU, 2004; LAUFER, ELBOIM, 2008), cinco utilizaram a pontuação da escala visual analógica (DANTAS et al., 2015; ROONEY, CURRIER, NITZ, 1992; LIEBANO, WASZCZUK, CORRÊA, 2013; MEDEIROS et al., 2017; LAUFER, ELBOIM, 2008), dois estudos utilizaram o relato do participante (auto-relato) (WARD, OLIVER, BUCCELLA, 2006; WARD, ROBERTSON, IOANNOU, 2004), e um estudo utilizou a escala numérica (SZECSI, FORNUSEK, 2014). Dessas oito pesquisas, cinco avaliaram a influência da frequência portadora na percepção do desconforto (DANTAS et al., 2015; ROONEY, CURRIER, NITZ, 1992; MEDEIROS et al., 2017; WARD, OLIVER, BUCCELLA, 2006; WARD, ROBERTSON, IOANNOU, 2004), e apenas um estudo (WARD, ROBERTSON, IOANNOU, 2004) mostrou que a frequência portadora de 4 kHz provocou menos desconforto percebido em comparação com as outras frequências portadora (0,5 kHz – 20 kHz). Um dos estudos apresentou os resultados de desconforto entre 1 kHz e 2,5 kHz, mas não foi possível determinar uma diferença significativa no desconforto entre as frequências portadora (WARD, OLIVER, BUCCELLA, 2006).

Apenas quatro estudos relataram a influência do ciclo de bursts no desconforto percebido (SZECSI, FORNUSEK, 2014; LIEBANO, WASZCZUK, CORRÊA, 2013; WARD, ROBERTSON, IOANNOU, 2004; LAUFER, ELBOIM, 2008). Destes estudos, enquanto nenhuma diferença no desconforto percebido foi observada entre três ciclos de bursts (20%, 35% e 50%)27, em um estudo, o ciclo de bursts de 20% provocou menos desconforto percebido ao comparar 20% e 50% (LAUFER, ELBOIM, 2008). Outro estudo mostrou que quanto maior o ciclo de bursts, maior o desconforto percebido, sendo que o ciclo de bursts de 50% provocou um desconforto percebido mais elevado (2% - 50%) (SZECSI, FORNUSEK, 2014). Um estudo utilizou um intervalo de diferentes ciclos de bursts (intervalo = 0,25% - 100%) e demonstrou que ciclos de bursts de 20% e 25% provocaram menos desconforto percebido (WARD, ROBERTSON, IOANNOU, 2004).

Resultado secundário – Fadiga muscular

O resultado secundário, fadiga muscular, foi avaliado pela área sob a curva de 21 contrações provocadas (LAUFER, ELBOIM, 2008). Embora nenhum dos estudos tenha avaliado a fadiga exclusivamente com corrente alternada em frequência de quilohertz, um estudo comparou os efeitos de diferentes parâmetros (frequência de bursts, ciclo do bursts e duração do bursts) de três corrente alternada em frequência de quilohertz (2,5 kHz, modulado a 50 Hz, 200 µs de duração de pulso, ciclo de bursts de 50%, duração de bursts de 10 ms/10 ms; 2,5 kHz, modulado a 50 Hz, 200 µs de duração de pulso, ciclo de bursts de 20%, duração do bursts de 4 ms/16 ms; e 2,5 kHz, modulado a 20 Hz, 200 µs de duração de pulso, ciclo de bursts de 20%, duração de bursts de 10 ms/40 ms). A corrente alternada em frequência de quilohertz com 2,5 kHz, modulado a 50 Hz, 200 µs de duração de pulso, ciclo de bursts de 50% e duração de bursts de 10 ms/10 ms gerou maior fadiga muscular do que as outras duas correntes alternadas em frequência de quilohertz utilizadas (LAUFER, ELBOIM, 2008).

Discussão

Nossos principais achados contribuem para a prática clínica ao estabelecerem como os diferentes parâmetros da EENM influenciam a força/torque evocado, o desconforto e a fadiga. Até onde sabemos, esta é a primeira revisão sistemática a avaliar alguns dos benefícios propostos da Corrente Alternada de Frequência de Quilohertz para programas de reabilitação e treinamento. Mais especificamente, descobrimos que a corrente alternada em frequência de quilohertz provocou um torque maior quando as frequências portadoras foram ajustadas entre 1 kHz e 2,5 kHz, com torque evocado mais alto em 1 kHz (DANTAS et al., 2015; MEDEIROS et al., 2017; WARD, OLIVER, BUCCELLA, 2006; WARD, ROBERTSON, IOANNOU, 2004). Um ciclo de trabalho de bursts abaixo de 50% produziu um torque maior, com os valores mais altos em 10%, 20% e 30% (LIEBANO, WASZCZUK, CORRÊA, 2013; MCLODA, CARMACK, 2000; WARD, ROBERTSON, IOANNOU, 2004). Frequências portadoras entre 2,5 kHz e 5 kHz provocaram menos desconforto percebido (DANTAS et al., 2015; ROONEY, CURRIER, NITZ, 1992; MEDEIROS et al., 2017; WARD, OLIVER, BUCCELLA, 2006; WARD ROBERTSON, IOANNOU, 2004), e ciclos de trabalho de bursts abaixo de 50% provocaram menos desconforto percebido (SZECSI, FORNUSEK, 2014; LIEBANO, WASZCZUK, CORRÊA, 2013; WARD, ROBERTSON, IOANNOU, 2004; LAUFER, ELBOIM, 2008). Nenhum dos estudos avaliou a fadiga muscular considerando exclusivamente os protocolos de corrente alternada em frequência de quilohertz. No entanto, de acordo com a avaliação da escala PEDro, esses resultados devem ser analisados com cautela, pois a classificação média foi moderada tanto para o torque evocado quanto para os resultados de desconforto percebido. Portanto, novos ensaios podem ser necessários para confirmar esses resultados.

Do ponto de vista clínico, dispositivos de EENM geralmente fornecem Corrente Alternada de Frequência em Quilohertz com frequências portadora de 2 e 4 kHz. Sugeriu-se que a frequência portadora de 2,5 kHz pode ser subótima para fins de EENM (LIEBANO, WASZCZUK, CORRÊA, 2013; MCLODA, CARMACK, 2000; PARKER, KELLER, EVERSON, 2005; PARKER et al., 2011). Bellew et al. (2012) (BELLEW et al., 2012) mostraram que a frequência portadora de 2,5 kHz provocava menos torque do que outras duas corrente alternada em frequência de quilohertz (2,5 kHz interferindo 2,55 kHz, modulado a 50 Hz, 200 µs de duração de pulso, duração de bursts de 20 ms; 1,76 kHz, modulado a 50 Hz, 200 µs/100 µs de duração de pulso, duração de bursts de 1,7 ms/18,3 ms) (BELLEW et al., 2012). Além disso, frequências portadora abaixo de 2,5 kHz provocaram maior torque em comparação com frequências portadora de 2,5 kHz ou maiores (4 kHz, 10 kHz e 20 kHz), sendo que uma frequência portadora de 1 kHz provocou o maior torque (BANKOV, DASKALOV, 1981; DANTAS et al., 2015; MEDEIROS et al., 2017; WARD, OLIVER, BUCCELLA, 2006; WARD, ROBERTSON, IOANNOU, 2004; WARD, ROBERTSON, 1998). Esses estudos sugerem que quanto menor a frequência portadora, maior o torque evocado. Isso pode estar relacionado à relação inversa entre frequências portadora e duração de pulso, pois quanto menor a frequência portadora, maior a duração de pulso (WARD, ROBERTSON, IOANNOU, 2004). Os motoneurônios que inervam as fibras musculares esqueléticas têm diferentes diâmetros de axônio. Essa variação de tamanho influencia o gráfico de resistência-duração das fibras nervosas. As correntes alternadas em frequência de quilohertz com durações de pulso menores podem não atingir o limiar do potencial de ação de grandes axônios motores, enquanto durações de pulso mais longas podem atingir esse limiar, recrutando assim um número mais significativo de unidades motoras do músculo estimulado (LI, BAK, 1976; WARD, ROBERTSON, IOANNOU, 2004).

A evidência que apoia essa ideia foi fornecida por um estudo elegante, que demonstrou que uma duração de pulso mais longa resultou em torque evocado e normalizado maiores do que uma duração de pulso curta (GORGEY, DUDLEY, 2008). Além disso, Medeiros et al. (MEDEIROS et al., 2017) mostraram uma dependência da corrente alternada em frequência de quilohertz em relação às frequências portadora e à duração do pulso, uma vez que uma frequência mais baixa (1 kHz) e uma duração de pulso mais longa (500 us) provocaram um torque maior. Os autores concluíram que a carga total estimada desempenha um papel crucial no torque evocado pela EENM, ou seja, há uma dependência de carga de corrente do grau de recrutamento de unidade motora explicado pelos efeitos da duração do pulso no torque evocado (MEDEIROS et al., 2017). Assim, quanto maior a duração do pulso, maior o pulso/trem de estimulação (LAUFER et al., 2001; STARKEY, 1999). Outro fator que pode explicar essa relação entre duração do pulso e torque evocado é que durações de pulso mais longas também podem ativar um maior número de neurônios sensoriais, que, por sua vez, via vias reflexas, ativam os neurônios motores (BARSS et al., 2018). Nesse caso, os motoneurônios são recrutados de acordo com o princípio do tamanho de Henneman, aumentando o número de unidades motoras recrutadas e aumentando a área transversal estimulada do músculo.

Não foi encontrada padronização para os parâmetros de ciclo de trabalho ou duração do bursts entre os diferentes estudos de corrente alternada em frequência de quilohertz, tornando as comparações entre estudos difíceis para as variáveis de resultado de torque evocado, fadiga e desconforto percebido. No entanto, a frequência portadora da corrente alternada em frequência de quilohertz, a duração do bursts e o ciclo de trabalho do bursts induziram maior contração muscular ao usar durações de bursts de 2-4 ms e ciclos de trabalho inferiores a 20% (SZECSI, FORNUSEK, 2014; LIEBANO, WASZCZUK, CORRÊA, 2013; MCLODA, CARMACK, 2000; PARKER et al., 2011; WARD, CHUEN, 2009; WARD, ROBERTSON, IOANNOU, 2004). Por exemplo, Ward et al. (WARD, ROBERTSON, IOANNOU, 2004) testaram diferentes faixas de ciclo de trabalho de bursts (0-100%) e mostraram que ciclos de trabalho de bursts abaixo de 20% atingiram o maior torque evocado, independentemente das frequências portadora (WARD; ROBERTSON; IOANNOU, 2004). Szecsi e Fornusek (2014) (SZECSI, FORNUSEK, 2014) também testaram diferentes ciclos de trabalho de bursts (2-50%) e mostraram que ciclos de trabalho de bursts entre 7% e 14% atingiram o maior torque evocado, independentemente da forma de onda usada (SZECSI, FORNUSEK, 2014). Moreno-Aranda e Seireg (1981) (MORENO-ARANDA, SEIREG, 1981) sugerem que um ciclo de trabalho de bursts de 20% é o ideal para evocar torque (MORENO-ARANDA, SEIREG, 1981). Parker et al. (PARKER et al., 2011) também demonstraram que o ciclo de trabalho de explosão de 10% provocou torque mais elevado do que os outros ciclos de trabalho de bursts (90%), independentemente das frequências de bursts utilizadas (PARKER et al., 2011).

O maior torque evocado com ciclos de trabalho de bursts mais curtos pode ser porque ciclos de trabalho de bursts maiores (com durações de bursts superiores a 4 ms) podem produzir um maior número de potenciais de ação, diminuindo a resposta da fibra nervosa devido ao esgotamento de neurotransmissores, falha na propagação ou até mesmo bloqueio da condução nervosa, causando fadiga sináptica (SZECSI, FORNUSEK, 2014; LIEBANO, WASZCZUK, CORRÊA, 2013). Portanto, parece que ciclos de trabalho de bursts curtos podem evitar a despolarização excessiva das fibras nervosas e evocar mais torque (LIEBANO, WASZCZUK, CORRÊA, 2013). Valores de torque evocado mais altos produzidos por ciclos de trabalho de bursts curtos também podem ser explicados pelos intervalos entre bursts que causam uma redução geral no valor médio quadrático da raiz da corrente, permitindo que um pico mais alto de torque seja alcançado e, consequentemente, uma contração muscular mais forte. Esses intervalos são maiores em ciclos de trabalho de bursts mais curtos, permitindo que uma amplitude de corrente mais alta seja entregue (LIEBANO, WASZCZUK, CORRÊA, 2013). Portanto, o ciclo de trabalho de bursts e a duração de bursts desempenham um papel crucial no torque evocado, ou seja, uma maior contração muscular é relatada ao usar durações de bursts de 2-4 ms e ciclos de trabalho de bursts inferiores a 20% (BANKOV, DASKALOV, 1981; SZECSI, FORNUSEK, 2014; LIEBANO, WASZCZUK, CORRÊA, 2013; MCLODA, CARMACK, 2000; PARKER et al., 2011; WARD, CHUEN, 2009; WARD, ROBERTSON, IOANNOU, 2004).

Dada a natureza subjetiva e multidimensional do desconforto, determinar o desconforto percebido associado à EENM é um desafio. Diferentes tipos de corrente alternada em frequência de quilohertz nos estudos incluídos geraram níveis diferentes de desconforto percebido (DANTAS et al., 2015; ROONEY, CURRIER, NITZ, 1992; SZECSI, FORNUSEK, 2014; LIEBANO, WASZCZUK, CORRÊA, 2013; MEDEIROS et al., 2017; WARD, OLIVER, BUCCELLA, 2006; WARD, ROBERTSON, IOANNOU, 2004; LAUFER, ELBOIM, 2008). Rooney et al. (1992) (ROONEY, CURRIER, NITZ, 1992) testaram várias combinações de frequências portadora e frequências de bursts e mostraram que as combinações de 50, 70 e 90 Hz de frequências de bursts com frequências portadora de 2,5 kHz e 5 kHz geraram desconforto semelhante, sendo que 10 kHz gerou o maior desconforto (ROONEY, CURRIER, NITZ, 1992). Ward et al. (2004) (WARD, ROBERTSON, IOANNOU, 2004) demonstraram que a frequência portadora de 4 kHz provocou desconforto percebido mínimo em comparação com as outras frequências portadora, variando de 0,5 a 20 kHz (WARD, ROBERTSON, IOANNOU, 2004). Em contraste, Medeiros et al. (MEDEIROS et al., 2017) relataram que não houve diferença no desconforto percebido ao usar frequências portadora de 1 kHz e 4 kHz (MEDEIROS et al., 2017). As diferenças entre os resultados desses estudos podem ser explicadas pelo método usado para avaliar o desconforto, já que o primeiro estudo realizou uma avaliação de acordo com o relato do próprio sujeito (avaliação qualitativa) (WARD, ROBERTSON, IOANNOU, 2004), e o segundo utilizou a escala visual analógica (avaliação quantitativa) (MEDEIROS et al., 2017). O desconforto sensorial possui uma natureza subjetiva e multidimensional. Estudos sobre o desconforto associado à EENM concluíram que a dimensão emocional pode interferir na resposta ao desconforto percebido, resultando em grande variabilidade individual. Experiências negativas anteriores com EENM, medo, apreensão e nível de ansiedade podem influenciar o desconforto percebido associado à EENM (DELITTO et al., 1992; MEDEIROS et al., 2017).

Szecsi e Fornusek (2014) (SZECSI, FORNUSEK, 2014) utilizaram uma frequência portadora de 4 kHz, mostrando que quanto maior o ciclo de trabalho do bursts, maior o desconforto percebido, sendo observado desconforto significativo com um ciclo de trabalho do bursts de 50% em comparação com ciclos de trabalho de bursts inferiores a 50%. Esses resultados demonstraram que os ciclos de trabalho de bursts também influenciam o desconforto percebido (SZECSI, FORNUSEK, 2014). Ward et al. (2004) (WARD, ROBERTSON, IOANNOU, 2004) demonstraram que o menor desconforto foi relatado com ciclos de trabalho de bursts de 20–25% (WARD, ROBERTSON, IOANNOU, 2004). Da mesma forma, Laufer e Elboim (2008) (LAUFER, ELBOIM, 2008) mostraram desconforto mínimo com um ciclo de trabalho de bursts de 20%, independente das frequências de bursts (LAUFER, ELBOIM, 2008). No entanto, Liebano et al. (2013) (LIEBANO, WASZCZUK, CORRÊA, 2013) não encontraram diferença no desconforto percebido entre ciclos de trabalho de bursts de 20%, 35% e 50% (LIEBANO, WASZCZUK, CORRÊA, 2013). Bursts de corrente alternada em frequência de quilohertz usando um ciclo de trabalho de bursts de 50% determinam uma taxa de disparo máxima de menos de 500 Hz, enquanto um ciclo de trabalho de bursts de 20% determina uma taxa de disparo de menos de 200 Hz. Taxas de disparo próximas a 500 Hz podem resultar em rápida inativação das fibras devido à depleção de neurotransmissores, falha na propagação (JONES, 1996; JONES, 1981), e/ou um bloqueio nervoso (BOWMAN, McNEAL, 1986; WARD, ROBERTSON, 2001). Portanto, é possível que o bloqueio da atividade da fibra nervosa para a dor seja ideal quando as fibras sensoriais são estimuladas em taxas de 100 Hz a 200 Hz (JOHNSON et al., 1989; LOW, 2000; NELSON, HAYES, 1999; SELKOWITZ, 1999). Uma possível explicação para a diferença nos resultados de desconforto percebido é a diferente frequência de estimulação gerada pelos diferentes ciclos de trabalho de bursts, e taxas de disparo acima de 200 Hz aparentemente são menos eficientes do que taxas de disparo mais baixas para modular a sensação de dor (WARD, ROBERTSON, IOANNOU, 2004).

Nenhum dos estudos comparou os efeitos dos parâmetros da corrente alternada em frequência de quilohertz (frequência portadora, ciclo de trabalho de bursts e duração de bursts) na fadiga muscular. Em teoria, mantendo a frequência do bursts constante, as frequências portadoras e o ciclo de trabalho de bursts podem potencialmente influenciar o estado de fadiga muscular (por exemplo, em uma frequência constante de bursts, frequências portadora mais altas e/ou ciclo de trabalho de bursts mais alto), pois podem aumentar o número de ciclos por segundo administrados ao músculo, induzindo assim a fadiga muscular (LAUFER, ELBOIM, 2008). Laufer e Elboim (2014) (LAUFER, ELBOIM, 2008) compararam 3 correntes alternada em frequência de quilohertz, e a corrente alternada em frequência de quilohertz com 2,5 kHz e 200 µs de duração do pulso determinou maior fadiga muscular em comparação com as outras duas correntes (2,5 kHz, modulado a 50 Hz, ciclo de trabalho de bursts de 20%, duração de bursts de 4 ms/16 ms; 2,5 kHz, modulado a 20 Hz, ciclo de trabalho de bursts de 20%, duração de bursts de 10 ms/40 ms) (LAUFER, ELBOIM, 2008). A taxa de fadiga estava relacionada ao número total de pulsos e não ao número de bursts. A corrente alternada em frequência de quilohertz com 2,5 kHz e 200 µs também gerou mais fadiga do que correntes monofásicas e bifásicas com a mesma duração de fase e frequência de estimulação (bursts/pulso) (LAUFER et al., 2001), enfatizando ainda mais a relação entre o número de pulsos entregues e a fadiga neuromuscular. Starkey (STARKEY, 1999) também afirmou que um ciclo de trabalho de bursts alto poderia causar fadiga muscular prematura devido ao aumento do uso do sistema de energia de fosfocreatina no músculo (STARKEY, 1999). Parker et al. (PARKER et al., 2011) esperavam que um alto ciclo de trabalho de bursts fornecesse carga aumentada por bursts e, portanto, evocasse uma contração mais forte e, consequentemente, fadigasse o músculo mais rapidamente do que um ciclo de trabalho de bursts baixo (PARKER et al., 2011). Mais estudos são necessários para definir os parâmetros ideais da corrente alternada em frequência de quilohertz (frequência portadora, ciclo de trabalho de bursts e duração de bursts) para evitar a fadiga muscular.

Limitações

Embora tenhamos realizado uma pesquisa abrangente na literatura eletrônica em várias bases de dados, a busca resultou em ensaios publicados principalmente em inglês. Portanto, é possível que alguns ensaios publicados em bancos de dados locais não tenham sido incluídos nesta revisão. Devido à grande variedade e heterogeneidade dos parâmetros usados para frequência da portadora, ciclo de trabalho da explosão e duração da explosão, não foi possível utilizar a Grade de Recomendações, Avaliação, Desenvolvimento e Avaliação (GRADE) nesta revisão sistemática para analisar a qualidade geral das evidências (SCHÜNEMANN et al., 2019). Além disso, a variabilidade entre dados e a heterogeneidade entre estudos nos impediram de realizar meta-análises. Finalmente, os parâmetros de EENM usados nos estudos eram eminentemente diferentes para frequência da portadora, ciclo de trabalho da explosão e duração da explosão, assim como os métodos usados para avaliar o desconforto percebido, tornando difícil a comparação de resultados entre estudos.

Conclusões

Em conclusão, as evidências atuais sugerem que a corrente alternada em frequência de quilohertz evoca maior torque quando as frequências portadoras são ajustadas entre 1 kHz e 2,5 kHz, com um torque mais alto em frequências portadora de 1 kHz. Ciclos de trabalho de bursts inferiores a 50% evocaram maior torque, com o torque mais alto sendo evocado com um ciclo de trabalho de bursts de 20%. Frequências portadoras entre 2,5 kHz e 5 kHz, e um ciclo de trabalho de bursts inferior a 20%, induziram menos desconforto percebido. Não foram observados efeitos aparentes da duração do bursts nos resultados avaliados. Em relação à fadiga muscular, não há evidências suficientes para indicar parâmetros adequados da corrente alternada em frequência de quilohertz. Futuros ensaios clínicos randomizados projetados devem ser realizados para estabelecer os melhores parâmetros da corrente alternada em frequência de quilohertz para aumentar a força muscular, reduzir a fadiga da contração e o desconforto percebido, além de testar se essas descobertas são semelhantes quando usadas com participantes clínicos.

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Tabela 1. Características dos estudos

Ano	Autores	Desenho do estudo	Participantes	Idade	Sexo	Resultados principais
2012	Bellew et al.	Cross-over	23	23.2 ± 1.8	7 homens; 16 mulheres	Força evocada (%Força Isométrica Máxima Voluntária dos Extensores do Joelho)
2015	Dantas et al.	Cross-over	21	21.6 ± 2.5	21 mulheres	Torque evocado (% Máxima contração voluntária – Newton metro) e Desconforto
2008	Laufer & Elboim	Ensaio clínico	26	27.4 ± 5.0	15 mulheres; 11 homens	Máxima contração induzida eletricamente - % Contração isométrica voluntária máxima; Fadiga; Disconforto

2013	Liebano et al.	Cross-over	30	18.8	30 homens	Torque evocado (%Contração isométrica voluntária máxima – Newton metros) e Desconforto percebido
2000	McLoda & Carmack	Cross-over	48	26.4 ± 8.5	27 homens; 21mulheres	Força (Newton) and Eficiência (Newton/ Milicoulomb)
2017	Medeiros et al.	Cross-over	25	21.0 ± 3.0	25 mulheres	Pico de torque (% Contração voluntária máxima – Newton metros) e Disconforto
2005	Parker et al.	Ensaio clínico	23	22.7 ± 1.7	11 homens; 12 mulheres	Torque evocado (Newton metros)
2011	Parker et al.	Ensaio clínico	18	24.9 ± 3.4	18 homens	Contração induzida eletricamente (Newton)
1992	Rooney et al.	Cross-over	27	22.0 ± 2.2	22 homens;	Percepão de dor

					5 mulheres	
2009	Selkowitz et al.	Cross-over	10	32.0 ± 2.7	8 homens; 2 mulheres	Torque máximo tolerado (% Contração isométrica voluntária máxima - [Torque máximo tolerado por corrente / Contração isométrica voluntária máxima] x 100)
2014	Szecsi & Fornusek	Cross-over	22	33.0 ± 8.0	22 homens	Torque evocado isométrico e Disconforto
2004	Ward et al.	Cross-over	16	26.0 ± 10.4	8 homens; 8 mulheres	Torque evocado (Newton metros) – ciclo de trabalho e Disconforto(Auto relatado)
2006	Ward et al	Ensaio clínico	32	30.0 ± 14.5	Não especificado	Torque máximo induzido eletricamente (Newton metros) e Disconforto (Auto relatado)

Tabela 2. Resumo dos parâmetros das correntes alternadas com frequências em quiloherts.

Autores (Ano)	Frequência (Hz)	Duração de fase (µs)	Frequência do bursts (Hz)	Ciclo de trabalho do bursts (%)	Duração do burst/interburst (ms)	Tempo ligado/Tempo desligado	Número de contrações
Bellew et al., 2012	2.5 kHz	200 µs	50 Hz	50%	10 ms/10 ms	10 sec	3
	2.5 kHz/ 2.55 kHz	200 µs			20 ms		
	1.76 kHz	200 µs /100 µs		9%	1.7 ms/18.3 ms	90 sec	
Dantas et al., 2015	2.5 kHz	200 µs	50 Hz	50%	10 ms/10 ms	10 sec	3
	1 kHz	500 µs		20%	4 ms/16 ms	3 min	
Laufer & Elboim, 2008	2.5 kHz	200 µs	50 Hz	50%	10 ms/ 10 ms	6 sec	3
			50 Hz	20%	4 ms/16 ms	90 sec	
			20 Hz	20%	10 ms/40 ms		

Liebano et al., 2013	2.5 kHz	200 µs	50 Hz	20% 35% 50%	4 ms/16 ms 7 ms/13 ms 10 ms/10 ms	9 sec 5 min rest	3
McLoda & Carmack, 2000	2.5 kHz	200 µs	50 Hz	10% - 90% [1]	2 ms/18 ms 6 ms/14 ms 10 ms/10 ms 14 ms/6 ms 18 ms/2 ms	5 ciclo de trabalho de bursts 10 sec	2 ciclos de trabalho de bursts
Medeiros et al., 2017	1 kHz 4 kHz	500 µs 250 µs	50 Hz	10% 20%	2 ms/18 ms 4 ms/16 ms	10 sec 3 min	10
Parker et al., 2005	2.5 kHz	200 µs	50 Hz	50%	10 ms/10 ms	10 sec	5 min

	3.75 kHz	133 µs				50 sec	
	5 kHz	100 µs					
Parker et al., 2011	2.5 kHz	200 µs	50 Hz	10%	2 ms/18 ms	15-30 sec	3 at 4
			50 Hz	90%	18 ms/2 ms	3 min	12
			100 Hz	10%	1 ms/9 ms		

Legenda: Valores apresentados e/ou inferidos a partir do artigo: [1] 10 %, 30%, 50%, 70% and 90%; [2] 10%, 20%, 50%, 70% and 100%; [3] 5 %, 10%, 25%, 50%, 75% and 100%; [4] 2%, 4%, 10%, 20%, 40%, 60% and 100%; [5] 1.25%, 2.5%, 6.25%, 12.5%, 25%, 50%, 75% and 100%; [6] 0.5%, 1%, 2.5%, 5%, 10%, 25% and 50%; [7] 0.25%, 0.5%, 1.25%, 2.5%, 5%, 12.5%, 25% and 50%; [8] 2%, 4%, 5%, 7%, 9%, 11%, 12.5%, 14%, 16%, and 18%; [9] 7%, 14%, 21%, 29%, 36%, 43%, and 50%; [10] 0.28 ms/13.72ms; 0.50ms/13.44ms; 0.70ms/13.3ms; 0.98ms/13.02ms; 1.26ms/12.74ms; 1.54ms/12.46ms; 1.75ms/12.25ms; 1.96ms/12.04ms; 2.24ms/11.76ms; 2.52ms/11.48ms; [11] 0.98ms/13.02ms; 1.96ms/12.04ms; 2.94ms/11.06ms; 4.06ms/9.94ms; 5.04ms/8.96ms; 6.02ms/7.98ms; 7ms/7ms.

Tabela 3. Resumo dos parâmetros das correntes alternadas com frequências em quilohertz.

Autores (Ano)	Frequência (Hz)	Duração da fase (µs)	Frequência do bursts (Hz)	Ciclo de trabalho do bursts (%)	Duração burst/interburst (ms)	Tempo ligado/Tempo desligado	Número de contrações
Rooney et al., 1992	2.5 kHz 5 kHz 10 kHz	200 µs Não mencionado Não mencionado	50 Hz 70 Hz 90 Hz	23%	10 ms/10ms	15 seg 50-seg descanso	10
Selkowits et al., 2009	2.5 kHz 5 kHz	200 µs 100 µs	50 Hz	50%	10 ms/10 ms	6 seg 2 min	3
Szecsi & Fornusek, 2014	4 kHz	125000 µs	71 Hz	2% - 18% [8]	0.28ms/13.72ms - 2.52ms/11.48ms [10]	20 seg (com uma modulação de	8 estimulos 8 bloqueios (=

		250000 µs		7% - 50% [9]	0.98ms/13.02ms - 7ms/7ms [11]	interrupção de 5 seg ligado/15 seg desligado)	64 períodos de estimulação)
Ward et al., 2004	0.5 kHz 1 kHz 2.5 kHz 4 kHz 10 kHz 20 kHz	Não mencionado	50 Hz	10% - 100% [2] 5% - 100% [3] 2% - 100% [4] 1.25% - 100% [5] 0.5% - 50% [6] 0.25% - 50% [7]	Não mencionado	3 seg 3seg	2
Ward et al., 2006	2.5 kHz 1 kHz	200 µs 500 µs	50 Hz	50% 20%	10 ms/10 ms 4 ms/16 ms	3 seg 3 sec	2

Legenda: Valores apresentados e/ou inferidos a partir do artigo : [1] 10 %, 30%, 50%, 70% and 90%; [2] 10%, 20%, 50%, 70% and 100%; [3] 5 %, 10%, 25%, 50%, 75% and 100%; [4] 2%, 4%, 10%, 20%, 40%, 60% and 100%; [5] 1.25%, 2.5%, 6.25%, 12.5%, 25%, 50%, 75% and 100%; [6] 0.5%, 1%, 2.5%, 5%, 10%, 25% and 50%; [7] 0.25%, 0.5%, 1.25%, 2.5%, 5%, 12.5%, 25% and 50%; [8] 2%, 4%, 5%, 7%, 9%, 11%, 12.5%, 14%, 16%, and 18%; [9] 7%, 14%, 21%, 29%, 36%, 43%, and 50%; [10] 0.28 ms/13.72ms; 0.50ms/13.44ms; 0.70ms/13.3ms; 0.98ms/13.02ms; 1.26ms/12.74ms; 1.54ms/12.46ms; 1.75ms/12.25ms; 1.96ms/12.04ms; 2.24ms/11.76ms; 2.52ms/11.48ms; [11] 0.98ms/13.02ms; 1.96ms/12.04ms; 2.94ms/11.06ms; 4.06ms/9.94ms; 5.04ms/8.96ms; 6.02ms/7.98ms; 7ms/7ms.

Tabela 4.Resultados dos estudos revisados .

Ano	**Autores**	**Resultados**
2012	Bellew et al.	Os dados mostraram que uma porcentagem significativamente maior da contração isométrica voluntária máxima dos extensores do joelho foi obtida utilizando corrente interferencial ou corrente modulada em burst em comparação com a corrente convencional do tipo usada por Kots (KRAMER; MENDRYK, 1982; WARD; SHKURATOVA, 2002).
2015	Dantas et al.	Tipo de corrente utilizada por Kots et al. (KRAMER; MENDRYK, 1982; WARD; SHKURATOVA, 2002) desenvolveu menos torque evocado, mas não houve diferença estatisticamente significativa no desconforto.

2008	Laufer & Elboim	A força evocada não foi afetada pelo tipo de corrente. A corrente alternada com frequência em quilohertz (2,5 kHz e 200 µs) foi a mais fadigante, enquanto as outras duas corrente alternada com frequência em quilohertz tiveram um efeito intermediário. O grau de desconforto foi maior com a corrente alternada com frequência em quilohertz modulada a 20 Hz.
2013	Liebano et al.	O ciclo de trabalho de burst de 20% produziu um torque induzido eletricamente maior do que os ciclos de trabalho de burst de 35% e 50%, sem diferença entre os ciclos de trabalho de burst de 35% e 50%. Não houve diferença na quantidade de desconforto sensorial produzido pelas três durações de ciclos de trabalho de burst.
2000	McLoda & Carmack	A força média gerada em um ciclo de trabalho de burst de 10% foi de 132,9 N, 30%: 104,2 N, 50%: 93,1 N, 70%: 52,9 N e 90%: 41,3 N. A eficiência média (em - Nm/C) no ciclo de trabalho de burst de 10% foi a mais alta, com 6,49 N/mC, e a de 90% foi a mais baixa, com 1,05 N/mC.
2017	Medeiros et al.	Correntes com longas durações de pulso induziram um torque evocado maior do que as correntes com durações de pulso curtas. Todas as correntes apresentaram desconforto semelhante.
2005	Parker et al.	O torque induzido eletricamente (% Contração isométrica voluntária máxima [Torque induzido eletricamente / Contração isométrica voluntária máxima] × 100) produzido em amplitudes de corrente equivalentes foi

		significativamente maior ao utilizar a frequência portadora de 2,5 kHz em comparação com as frequências de 3,75 kHz e 5,0 kHz, respectivamente.
2011	Parker et al.	Os ciclos de trabalho de 10% produziram 42,9% e 32,1% mais força muscular do que o ciclo de trabalho de 90%. Não houve efeito de interação significativo entre os padrões de estimulação elétrica e a fadiga nos níveis de contração induzida eletricamente.
1992	Rooney et al.	As combinações de frequências de burst (50, 70 e 90 bps) e frequências portadoras (2,5 e 5,0 kHz) não diferiram na intensidade percebida da dor. A dor percebida diferiu significativamente das combinações de frequências de burst na frequência portadora de 10,0 kHz.
2009	Selkowitz et al.	A média do torque máximo tolerado foi de 37,6% para 2,5 kHz e 37,2% para 5,0 kHz, não significativamente diferente. No entanto, a média da amplitude de corrente necessária para produzir torque de contração isométrica maximamente tolerado com 2,5 kHz foi de 91,9 miliampères, e com 5,0 kHz, foi de 167,4 miliampères.
2014	Szecsi & Fornusek	Ambos os tipos de corrente provocaram um pico de torque isométrico elétrico induzido em 14%. Significativamente mais torque isométrico elétrico foi produzido pela corrente alternada retangular do que pela

		estimulação de corrente alternada senoidal. O desconforto aumentou com o ciclo de trabalho do burst e foi semelhante para ambos os tipos de corrente.
2004	Ward et al.	O torque induzido foi semelhante em baixas frequências, mas diminuiu em 2.5 kHz. Também diminuiu acima de um ciclo de trabalho de 20%. Relatos subjetivos de desconforto foram menores em 4.0 kHz e em ciclos de trabalho na faixa de 20-25%.
2006	Ward et al	Corrente alternada com frequência em quilohertz (2.5 kHz e 200 μs) produziu um torque médio menor do que aquele produzido pela corrente alternada com frequência em quilohertz (1 kHz e 500 μs). A corrente alternada com frequência em quilohertz (2.5 kHz e 200 μs) e corrente alternada com frequência em quilohertz (1 kHz e 500 μs) provocaram significativamente menos desconforto do que as duas outras condições (correntes pulsadas).

Tabela 5. Qualidade metodológica dos estudos incluídos (escala PEDro).

Autores (Ano)	**Alocação aleatória**	**Alocação oculta**	**Grupos semelhantes no início**	**Sujeitos (cegos)**	**Terapeuta (cego)**	**Avaliador (cego)**	**Follow- up adequado**	**Análise por intenção de tratar**	**Comparação entre grupos**	**Estimativa pontual e variabilidade**	**Total**

Bellew et al., 2012	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	6
Dantas et al., 2015	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	8
Laufer et al., 2008	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	7
Liebano et al., 2013	Yes	No	Yes	Yes	No	No	Yes	No	Yes	Yes	6
Mcloda et al., 2000	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	6
Medeiros et al., 2017	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	8
Parker et al., 2005	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	7
Parker et al., 2011	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	6
Rooney et al., 1992	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	5
Selkowitz et al., 2009	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	6

Szecsi et al., 2014	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	6
Ward et al., 2004	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	6
Ward et al., 2006	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	6

Artigo 2. Será submetido após avaliação da banca de Doutorado

INFLUENCE OF KILOHERTZ FREQUENCY, BURTS DUTY CYCLE AND BURST DURATION ON EVOKED TORQUE, DISCOMFORT AND MUSCLE EFFICIENCY: A RANDOMIZED CROSSOVER TRIAL

Authors:

Karenina Arrais Guida Modesto[1], Priscila Karen Silva Raposo[2], Isabella da Silva Almeida[3], Marco Aurélio Vaz[4], João Luiz Quagliotti Durigan[5]

Affiliations:

1. Ph.D. Candidate, University of Brasilia, Physical Education College, Program, Laboratory of Muscle and Tendon Plasticity, Brasília, DF, Brazil

2. Undergraduate student, University of Brasilia, Faculty of Ceilândia, Laboratory of Muscle and Tendon Plasticity, Brasília, DF, Brazil

3. Ph.D. Candidate, University of Brasilia, Physical Education College, Program, Laboratory of Muscle and Tendon Plasticity, Brasília, DF, Brazil

4. Full Professor, Human Movement Sciences Program, ESEFID, Federal University of Rio Grande do Sul, Porto Alegre, RS, Brazil

5. Associate Professor, University of Brasilia, Faculty of Ceilândia, Rehabilitation Sciences Program, Laboratory of Muscle and Tendon Plasticity, Brasília, DF, Brazil

*** Correspondence:**

João Luiz Quaglioti Durigan

Associate professor

University of Brasilia, Faculty of Ceilândia, Rehabilitation Sciences Program, Laboratory of Muscle and Tendon Plasticity, Brasília, DF, Brazil

ABSTRACT

Background: Kilohertz frequency alternating currents (KFACs) gained attention in the 1970s for muscle strength gains. KFACs, like the Aussie and Russian currents, have high carrier frequencies (1 kHz and 2.5 kHz, respectively), claiming to reduce skin impedance and enhance contractions. However, despite some studies suggest advantages of the Aussie over the Russian current, different protocols and inconsistent findings limit our conclusion. In addition, physical parameters like carrier frequency and burst duty cycle influence torque and discomfort and should be evaluated. **Objective**: To compare the effects of the Aussie and Russian currents, while hypothesizing that lower carrier frequencies and shorter duty cycles will evoke higher torque with higher efficiency without increasing discomfort. **Methods**: Using a cross-over design, KFACs with 1 kHz and 2.5 kHz and two duty cycles (10% and 20%) were randomly applied on the triceps surae muscle of healthy participants with a minimum of seven days between sessions. NMES-intensity, NMES-evoked torque, NMES-efficiency, and NMES-discomfort were measured in maximum tolerated and submaximum conditions. Statistics were conducted using a two-way mixed-model ANOVA with repeated measures [two levels: currents (Aussie and Russian) X duty cycle (10% and 20%)], followed by Tukey post-hoc test. **Results**: Forty-four participants (age 25.65 ± 6.55 years) were included. Aussie currents produced higher evoked torque and efficiency in maximum and submaximum conditions, with higher discomfort in maximum but not in submaximal conditions. The 20% duty cycle produced the highest efficiency in submaximum conditions. **Conclusion**: The Aussie current: (1) demonstrated superior NMES-efficiency, yielding higher torque with lower amplitude than the Russian current in both maximal and submaximal conditions; (2) induced greater discomfort compared to the Russian current during maximal conditions, with similar discomfort under submaximal conditions; (3) the 20% duty cycle enhanced efficiency while requiring the application of less intense currents, particularly in submaximal conditions.

Keywords: Electrical Stimulation, Torque, Burst-Modulated Current, Duty Cycle, Alternated Current

INTRODUCTION

Kilohertz frequency alternating currents (KFACs) are a type of Neuromuscular Electrical Stimulation (NMES) that gained attention in the 1970s after a Russian study demonstrated that such currents allowed a gain in muscle strength (WARD; SHKURATOVA, 2002). KFACs involve relatively high carrier frequencies, ranging from 1 kHz to less than 10 kHz (DA SILVA et al., 2015). It has been claimed that higher carrier frequencies in KFACs reduce skin impedance and allow less electrical energy dissipation, potentially generating greater evoked contractions (DA SILVA et al., 2015; MEDEIROS et al., 2017). A specific KFAC current with parameters of 2.5 kHz, modulated in bursts of 50 Hz with intervals of 10/10 ms burt/interburst and a burst cycle of 50%, became known as the Russian current (WARD; SHKURATOVA, 2002). Over time, other alternating currents such as the Aussie and the Interferential currents have emerged, and their effects on evoked torque and muscle strengthening were investigated (BELLEW et al., 2012; MEDEIROS et al., 2017; PARKER; KELLER; EVERSON, , 2005). A series of studies conducted by Ward and colleagues (WARD; LUCAS-TOUMBOUROU, 2007; WARD; OLIVER; BUCCELLA, 2006; WARD; ROBERTSON, 1998) have demonstrated that modifying the carrier frequency to 1 kHz and utilizing narrow burst durations, such as 2 and 4 ms (Aussie current), may provide specific advantages in comparison to the Russian current, both in terms of evoking higher torque and reducing perceived discomfort.

KFACs have specific physical parameters such as carrier frequency, pulse duration, burst duty cycle, and burst duration (LIEBANO; WASZCZUK; CORRÊA, 2013; DAMO et al., 2021; MEDEIROS et al., 2017; MODESTO et al., 2022; WARD; OLIVER; BUCCELLA, 2006; WARD; ROBERTSON; IOANNOU, 2004) that are closely linked to the evoked torque and the perception of discomfort (DAMO et al., 2021; MODESTO et al., 2019; MODESTO et al., 2022). A recent systematic review investigated the relationship between KFACs' physical parameters and the evoked torque, sensory discomfort, and muscle fatigue. Carrier frequencies up to 1 kHz were associated with higher discomfort, whereas carrier frequencies within the range of 2.5 to 5 kHz were associated with reduced discomfort, with one study indicating that a carrier frequency of 4 kHz induced lower discomfort when compared to lower carrier frequencies (WARD; ROBERTSON; IOANNOU, 2004). However, distinct findings concerning discomfort perception were documented in the literature (DANTAS et al., 2015; DAMO et al., 2021; MEDEIROS et al., 2017; ROONEY; CURRIER; NITZ, 1992; WARD; OLIVER; BUCCELLA, 2006), with the current literature on KFAC protocols yielding inconsistent findings related to evoked torque and perceived discomfort (DANTAS et al., 2015; PARKER; KELLER; EVERSON, 2005; SELKOWITZ; ROSSMAN; FITZPATRICK, 2009; WARD; OLIVER; BUCCELLA, 2006; WARD; ROBERTSON; IOANNOU, 2004; MODESTO et al., 2022).

Currently, there is a lack of studies exploring the effects of burst duration on evoked torque and discomfort (MODESTO et al., 2022). The burst duty cycle is defined as the ratio of the burst's duration on-time to the sum of the burst on-time and the interburst interval, while the time that current flows is the burst duration (WARD; OLIVER; BUCCELLA, 2006). Most studies have shown that shorter burst duty cycles (10% to 50%) induced higher evoked torque and lower perceived discomfort (MODESTO et al., 2022). It has been claimed that shorter duty cycles allow for a greater evoked torque generation by accommodating a higher frequency of action potentials. This, in turn, may mitigate the potential for diminished nerve response attributable to factors such as neurotransmitter depletion, propagation failure, or even nerve conduction block (SZECSI; FORNUSEK, 2014; LIEBANO; WASZCZUK; CORRÊA, 2013; MODESTO et al., 2022).

The evoked torque is significantly constrained by the magnitude of current intensity, primarily due to the increased sensory discomfort levels with increasing current intensity (DAMO et al., 2021), which have the potential to limit the NMES' effectiveness (LAUFER; ELBOIM, 2008). A fundamental aspect to take into account is the NMES' efficiency, which reflects the goal of maximizing the evoked torque output while minimizing the intensity of the applied NMES (LIEBER; KELLY, 1991; DAMO et al., 2021). Controlling the current intensity has been recommended within clinical contexts to enhance the achievement of maximal evoked torque and adaptations in muscular strength facilitated by NMES (MAFFIULETTI, 2010). In addition to assessing maximum NMES-evoked torque, submaximal evoked torque levels dosage (5% to 50%) have been found to be effective in strength training for different clinical populations. These findings underline the potential benefits of monitoring the NMES efficiency at various submaximal intensity levels for muscle strengthening purposes in clinical settings (BELLEW et al., 2012; DIRKS et al., 2015; LAUFER; SNYDER-MACKLER, 2010; MAFFIULETTI et al., 2011; WARD; SHKURATOVA, 2002). While the dosage of evoked torque is of great importance, no studies have concurrently investigated the submaximal and maximal levels in relation to both torque generation and perceived discomfort when utilizing different KFAC currents.

The inconsistent findings regarding the impact of KFAC on evoked torque, discomfort and efficiency may result from the lack of standardized NMES parameters, particularly carrier frequency, burst duration, and burst duty cycle. Given the potential clinical differences between KFAC currents, our study was designed to ensure a fair comparison of carrier frequency, burst duration, and burst duty cycle parameters by standardizing the stimulation parameters across different KFACs widely used in clinical practice. Therefore, the primary aim of this study was to compare the effects of two carrier frequencies in KFAC (2.5 kHz/Russian current and 1 kHz/Aussie current, with phase durations of 200 µs and 500 µs, respectively), applied at submaximal and maximal tolerated current intensity levels, on NMES-evoked torque, NMES efficiency, and discomfort at the triceps surae muscle of healthy participants. We also aimed to investigate the impact of altering the carrier frequencies (2.5 kHz for Russian current and 1 kHz for Aussie current) and manipulating the burst duty cycle (10% or 20%) with corresponding burst durations (2 ms or 4 ms). Our hypothesis was that using lower carrier frequencies and shorter burst duty cycle would lead to increased evoked torque and improved current efficiency, both at maximum and submaximal levels, without significant differences in sensory discomfort.

METHODS

Trial design

This study was a randomized, cross-over, and double-blind study, comparing submaximal and maximal protocols with four different NMES conditions. Participants were informed about the purposes, benefits, and risks before enrollment, and all agreed to participate by signing the consent form. Approval was obtained (protocol number 47989121.6.0000.8093) from the Research Ethics Committee of the University of Brasilia (Faculty of Ceilândia) in accordance with the Helsinki Declaration of 1975. Participants were recruited between January 2022 and March 2023. The primary outcome assessed in this study was evoked torque, while sensory discomfort and muscle efficiency were considered secondary outcomes. This study and its outcomes are part of a larger study registered at http://clinicaltrials.gov (NCT05061056). Consort was used as a form of evaluation for the preparation of this article (Supplementary Material I).

Participants

To be included in the study, participants needed to be aged between 18 and 40 years, and physically active. They also needed to present a full knee joint range of motion and should not have previous experience with NMES. Participants who were using non-steroidal anti-inflammatory drugs and nutritional supplements, who presented skin lesions or skin allergies, had been previously diagnosed with neuromuscular diseases, or presented external fixation or metal implants in the lower limbs were excluded from the study. In addition, participants who presented intolerance to NMES (due to fear or hypersensitivity to the stimulus), or did not achieve a minimum evoked torque of 20% of the maximal voluntary isometric contraction (MVIC) during NMES, were also excluded.

Randomization and allocation concealment

Four NMES conditions were randomly presented: 1) 500 µs of phase duration, low carrier frequency and low burst duty cycle (1 kHz – AC 10% or Aussie current at 10% of burst duty cycle); 2) 500 µs of phase duration, low carrier frequency and high burst duty cycle (1 kHz – AC 20% or Aussie current at 20% of burst duty cycle); 3) 200 µs of phase duration, high carrier frequency and low burst duty cycle (2.5 kHz – RC 10% or Russian current at 10% of burst duty cycle); 4) 200 µs of phase duration, high carrier frequency and high burst duty cycle (2.5 kHz – RC 20% or Russian current at 20% of burst duty cycle; see Table 1 for further details). Computer-generated randomization sequences were created using the website www.random.org, which assigned the stimulation protocols to each participant in a sequential manner. The order of NMES conditions for each participant was prepared by a single researcher (PKR).

Table 1. Description of the physical parameters for the 4 types of electrical stimulation

Current type	Carrier Frequency (Hz)	Phase duration (µs)	Burst duration (ms)	Interburst duration (ms)	Burst duty cycle (%)	Burst Frequency (Hz)
AC10%	1000	500	2	18	10	50
AC20%	1000	500	4	16	20	50
RC10%	2.500	200	2	18	10	50
RC20%	2.500	200	4	16	20	50

Legend. AC: Australian current. RC: Russian current. All electrical currents had an on-time of 6 seconds (1 sec rise and 1 sec of decline) and 60 seconds off-time.

Blinding

The researcher (KAGMP) that applied the currents and the participants were blinded to treatment allocation. For this blinding, a second researcher (PKR) performed the programming of each NMES, and placed a black cover on the NMES device panel to blind the parameters for the researcher (KAGMP) and participants, except for the current intensity.

Procedures

Participants were involved in five sessions, each of which lasted ~2 hrs and were at least 7 days apart (DAMO et al., 2021). A different type of NMES was tested in each session. Each participant was assessed in the same period of the day (at 2:00 or 7:00 pm) in the Musculotendinous Plasticity Laboratory by the same assessor. They were asked to avoid stimulants (e.g., alcohol, caffeine, chocolate), and practicing exercise on testing days. The first session served as a familiarization period, during which subjects were asked about previous recommendations and criteria for participation in the study. They were also introduced to the testing procedures and protocols. Height, body mass, and BMI measurements were recorded for each participant. The sequence of stimulation protocols was then randomized for each individual using the website www.randomizer.org. The maximum supported intensity for all NMES protocols was evaluated.

All five experimental sessions were preceded by a warm-up phase, during which two MVICs were performed to measure the highest ankle joint torque. Following the MVICs, a randomized NMES protocol was performed for that particular session, aiming to reach the maximum intensity tolerated by the participant (with the maximum evoked contraction, MET, recorded) and the intensity that generated a submaximal MET with the NMES protocol (equivalent to 20% of MVIC). All procedures were conducted on the participants' right side. All NMES protocols were delivered with 50 Hz bursts (Table 1). All currents were delivered with an “on” time of 8s (1s of ramp-up, 6 s of constant time, and 1s of decay) and “off” time of 60s for recovery (MODESTO et al., 2019).

Outcomes

Primary outcome was NMES-maximum evoked torque. Secondary outcomes were NMES efficiency and NMES discomfort.

Warm up and Maximal Voluntary Isometric Contraction (MVIC)

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 ~90º (GROSPRÊTRE et al., 2018). Subsequently, six submaximal isometric plantar flexion contractions were performed, each lasting six seconds, with ten seconds of rest between contractions. After the warm-up phase, maintaining the same position, a 1-minute rest period was given. Following this rest period, two MVICs were performed for six seconds each, with 1-minute interval between them. The highest torque achieved during these MVICs was recorded.

NMES-maximum evoked torque (MET)

Participants were instructed to relax the leg to avoid any voluntary contraction and were seated up right on the isokinetic dynamometer. Stimulation was produced using a neuromuscular electrical stimulator (version 2.0; Neurodyn, Ibramed, Amparo, SP, Brazil), connected to two pairs of 25 cm^2 self-adhesive electrodes (Valutrode, São Paulo, Brazil). The skin was trichotomized and cleansed with alcohol, and four electrodes were positioned on the triceps surae muscle group, two electrodes positioned below the knee line (which forms the popliteal fossa) close to the proximal insertion of the medial and lateral gastrocnemius muscles, and two electrodes positioned approximately 5 cm from the Achilles tendon, as previously described (BOTTER et al., 2011). Two minutes after completing the MVIC evaluation, the stimulation intensity was gradually increased from 10 mA, with 10 mA increments (DAMO et al., 2021), until 20% of the MVIC was reached (submaximal evoked torque). Then, the intensity was increased until the participant reported having reached the maximum tolerated intensity (MET) for that stimulus determined in the familiarization session. Evoked-torque was normalized (NMES-evoked relative torque) using the following formula [(NMES-evoked torque x voluntary $torque^{-1}$) x 100] (DAMO et al., 2021).

NMES-efficiency assessment

NMES-efficiency was calculated as NMES-evoked torque/current intensity (Nm/mA) (DAMO et al., 2021; MEDEIROS et al., 2017; PETROFSKY et al., 2008).

Visual Analogue Scale (VAS)

The Visual Analog Scale (VAS) was used to assess sensory discomfort. This scale consists of a 10 cm line, where 0 cm represents no discomfort and 10 cm corresponds to the maximum discomfort perceived by the participant. The VAS was presented to the participants after the NMES-induced contractions, during the familiarization sessions and during all NMES-evoked contractions.

Statistical analysis

The sample size was determined a priori using G*Power (version 3.1.9.4) with the significance level set at $p < .05$, power $(1 - \beta)$ 0.95, and an effect size of $f = 0.42$. Evoked torque values from a previous study, following a similar NMES protocol to that used in the present study, were used (71.7 N.m, 76.9 N.m, 50.8 N.m, and 70.1 N.m ± 12.4) to calculate the effect size (DANTAS et al., 2015). Thus, a sample of 44 individuals was defined as the appropriate number of subjects, based on the calculation with the highest value among the primary outcomes (for the larger project that was developed) (BELLEW et al., 2019; DANTAS et al., 2015; PAZ et al., 2021), taking into account a sample loss of 20% (BELLEW et al., 2019; PAZ et al., 2021).

Values for MVIC, MET, muscle efficiency, and VAS were reported as mean and confidence intervals (95%). We used parametric tests based on normal distribution (Shapiro-Wilk test) and homogenous variance (Levene's test) of the data. A two-way mixed-model ANOVA with repeated measures [two levels: currents (Aussie and Russian) X duty cycle (10% and 20%)] was used to compare the different groups for the above mentioned variables. In case of a significant interaction effect, a Tukey post-hoc test was used. All statistics were performed using the STATISTIC program version 16. All graphs were designed with GraphPad Prism 6.0 software (San Diego, CA, USA). In addition, the effect size was calculated using Cohen's equation (COHEN, 1988). Effect sizes (d) were categorized as trivial (<0.20), small (0.20–0.49), moderate (0.50–0.79), large (0.80–1.29), and very large (>1.30) effect (ROSENTHAL, 1996). In addition, we calculated the Cohen f effect size using G*Power software through the conversion of partial eta-squared values provided by STATISTIC to Cohen f values. Cohen f values were interpreted as follows: small (0.10–0.24), medium (0.25–0.39), and large ($f \geq 0.40$) effect (COHEN, 1988).

RESULTS

General evaluation

Baseline characteristics (mean ± SD) of the 44 participants were: men: 13, woman: 31, age 25.65 ± 6.55 years, body mass 64.11 ± 11.95 kg, height 167.67 ± 0.09 cm, and body mass index 22.72 ± 3.30 kg·m^{-2}. Three participants withdrew after the familiarization session for personal reasons. There were no adverse effects during the application of NMES protocols. All protocols presented a similar MVIC value ($p = 0.225$, $F = 1.511$, η_ρ^2: 0.033, power: 0.225; Table 2). There was no difference for the maximum NMES-evoked relative torque ($p = 0.893$, $F = 0.018$, η_ρ^2: 0.000, power: 0.051) (Figure 1.A). For submaximal NMES-evoked relative torque, a main effect was found for currents ($p = 0.011$, $F = 6.930$, η_ρ^2: 0.138; power: 0.730), where the the Aussie currents presented a higher NMES-evoked relative torque when compared to the Russian current protocols ($p < 0.011$) (Figure 1. B).

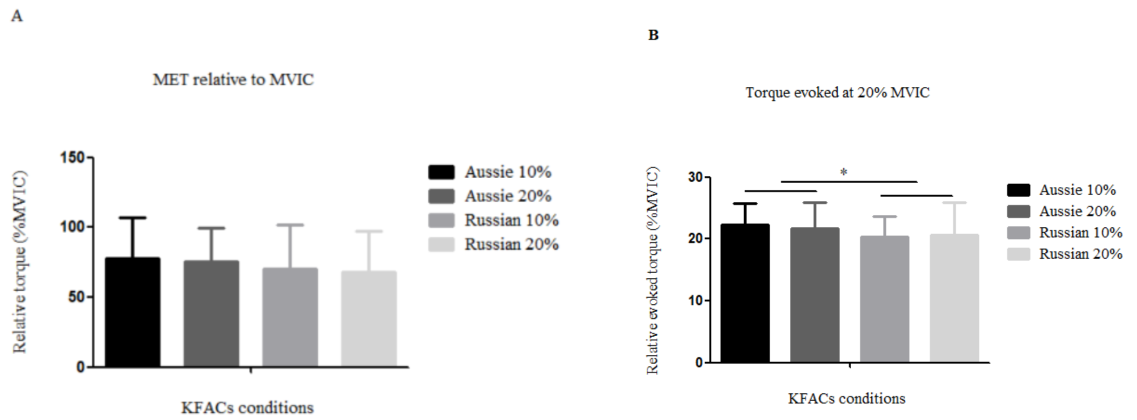

Figure 1.A: There was no difference between NMES protocols for maximal evoked torque (MET) normalized by the maximal voluntary isometric contraction (MVIC). Aussie currents evoked higher relative evoked torques when compared to the Russian current at submaximum conditions ($p < 0.011$).

Intensity

No interaction was found for current and duty cycle in relation to maximum and submaximal KAFCs' intensities ($p = 0.875$, $F = 0,025$, $\eta_\rho^2 < 0.001$, power: 0.052; $p = 0.055$, $F = 0.356$, η_ρ^2: 0.008, power: 0.089, respectively). A main effect was found for current both for maximum and submaximal intensities ($p < 0.001$, $F = 85.681$, η_ρ^2: 0.665, power: 1.000; $p < 0.001$, $F = 109.735$, η_ρ^2: 0.718, power: 1.000, respectively). Russian conditions presented a higher NMES-intensity compared to the Aussie current conditions ($p < 0.001$) (Figure 2.A and B) with large effect sizes (Table 3). In terms of submaximal torque, there was a significant effect for duty cycle (p = 0.011, F = 6.911, ηρ2: 0.138, power: 0.729), with the 20% duty cycle resulting in lower NMES-intensity compared to the 10% duty cycle (p < 0.011) (Figure 2.C). This difference between duty cycles showed large effect sizes (Table 3).

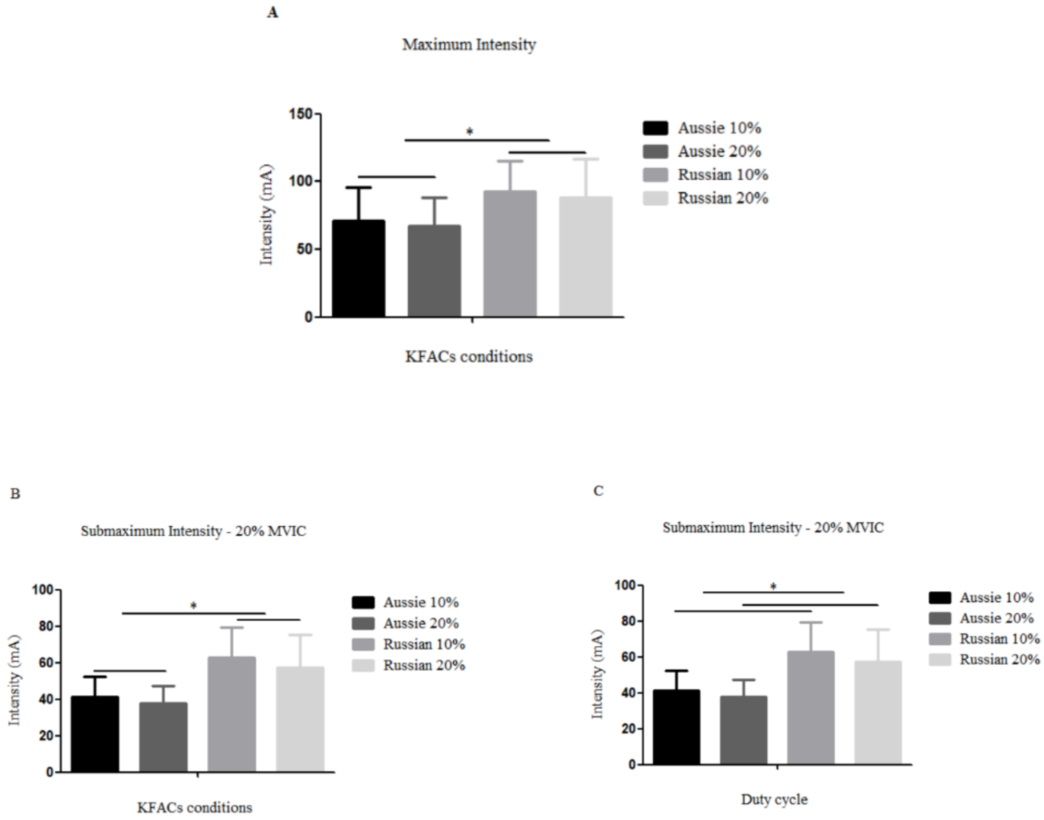

Figure 2.A: Aussie currents presented a lower generation NMES-intensity when compared to the Russian current in maximum conditions (p < 0.001). **B:** Aussie currents presented a lower generation NMES-intensity when compared to the Russian current in submaximum conditions (p < 0.001). C: Duty cycle 20% presented lower NMES-intensity than duty cycle 10% (p = 0.011).

NMES-maximum evoked torque (MET)

Regarding absolute NMES-MET, interaction was found between current and duty cycle (p = 0.564, F = 0.336, η_ρ^2 : 0.007, power = 0.087). However, a main effect was found for the current (p = 0.006, F = 8.101, η_ρ^2: 0.158, power: 0.794), with the Aussie current conditions (AC 10% and AC 20%) presenting a higher NMES-evoked torque compared to the Russian current protocols (RC 10% and RC 20%) (p = 0.006) (Figure 3.A), with large effect sizes (Table 3). In addition, no interaction was found between current and duty cycle for submaximal absolute evoked torque (p = 0.262, F = 1.29, η_ρ^2 : 0.029, power = 0.199). However, a main effect was found for currents (p = 0.002, F = 10.699, η_ρ^2: 0.199, power: 0.891), where Aussie currents presented higher NMES-evoked torques compared to the Russian current protocols ($p = 0.002$) (Figure 3.B), with large effect sizes (Table 3).

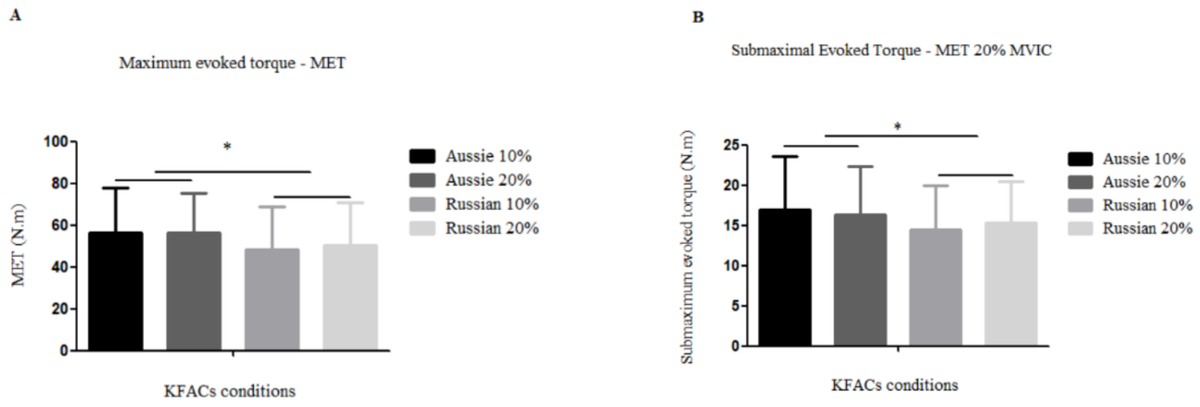

Figure 3.A: Aussie currents evoked higher absolute torques when compared to the Russian current at maximum conditions ($p = 0.006$). **B:** Aussie currents presented a higher NMES-evoked torque when compared to the Russian current in submaximum conditions ($p = 0.002$).

NMES-efficiency

No interaction was observed in terms of efficiency between current and duty cycle for both maximum and submaximal evoked torques ($p = 0.497$, $F = 0.468$, η_ρ^2: 0.010, power: 0.102; $p = 0.458$, $F = 0.559$, η_ρ^2: 0.012, power: 0.113, respectively). However, a main effect was found for both current conditions ($p < 0.001$, $F = 35.175$, η_ρ^2: 0.449, power: 0.999; $p < 0.001$, $F = 63.115$, η_ρ^2: 0.594, power: 1,000, respectively). Aussie currents presented a higher NMES-efficiency compared to the Russian currents ($p < 0.001$; $p < 0.001$) (Figura 4.A and B), with large effect sizes (Table 3). For submaximal NMES-efficiency, a main effect for duty cycle was found ($p = 0.017$, $F = 6.155$, η_ρ^2: 0.125, power: 0.679). The 20% duty cycle showed greater NMES efficiency compared to the 10% duty cycle ($p = 0.017$) (Figure 4.C), with a medium effect size (Table 3).

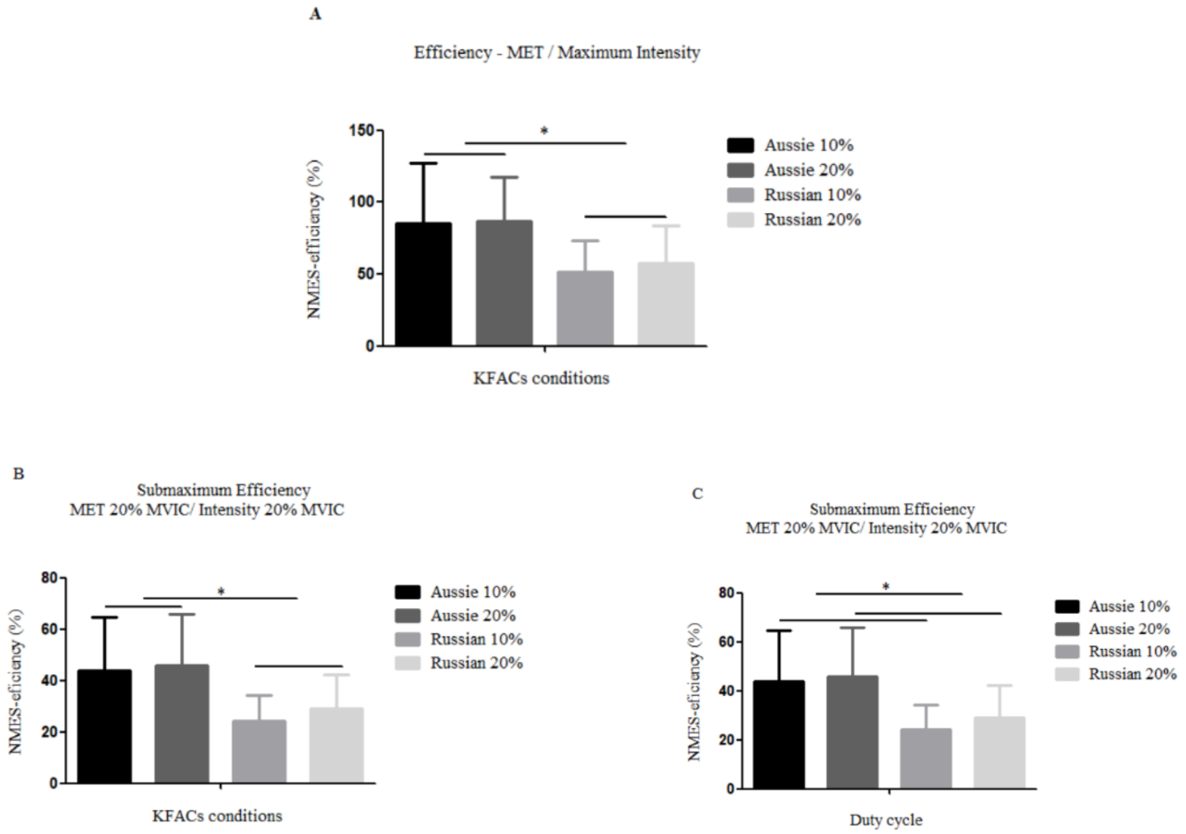

Figure 4.A: Aussie currents presented a higher NMES-efficiency when compared to the Russian currents in maximum conditions ($p < 0.001$). **B:** Aussie currents presented a higher NMES-efficiency when compared to the Russian currents in submaximum conditions ($p < 0.001$). **C:** The 20% duty cycle presented a higher NMES-efficiency than the 10% duty cycle ($p = 0.017$).

NMES-discomfort

For discomfort obtained at both maximum and submaximal levels, no interaction was found between current and duty cycle ($p = 0.187$, $F = 1.794$, η_ρ^2: 0.040, power: 0.258; $p = 0.858$, $F = 0.032$, η_ρ^2: 0.000, power: 0.053, respectively). For maximum evoked discomfort, a main effect was found for current ($p = 0.014$, $F = 6.496$, η_ρ^2: 0.131, power: 0.702). Russian currents presented a lower NMES-evoked discomfort compared to the Aussian current ($p = 0.014$) (Figure 5.A) with medium effect sizes (Table 3). There was no difference between NMES protocols for submaximal discomfort ($p = 0.858$, $F = 0.032$, η_ρ^2: 0.000, power: 0.053) (Figure 5.B).

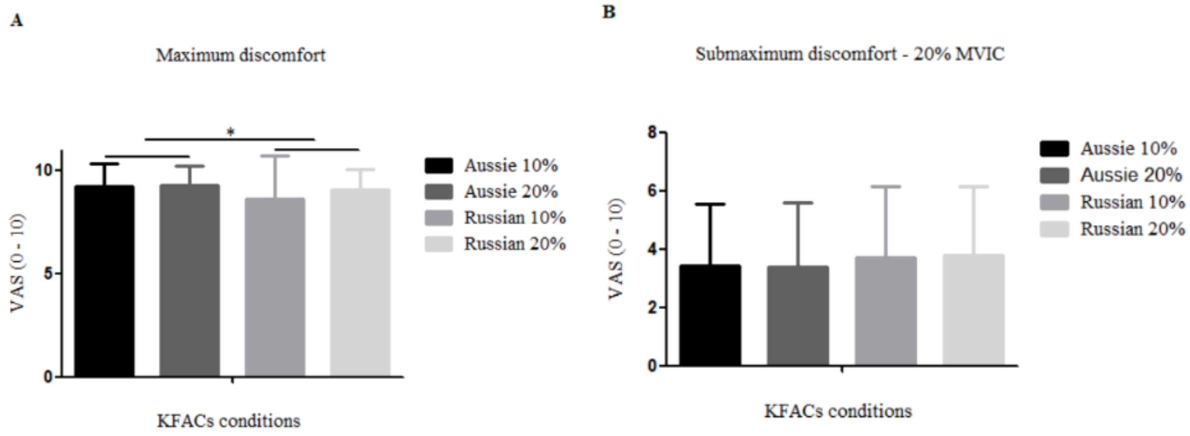

Figure 5.A: Aussie currents presented a higher NMES-discomfort when compared to the Russian current in maximum conditions (p = 0,014). **B:** There was no difference between NMES protocols for submaximal discomfort.

DISCUSSION

This was the first study to perform a rational comparison of carrier frequency, burst duration, and burst duty cycle parameters by standardizing the stimulation parameters across different KFAC modalities widely used in clinical practice. Our results suggest that the Aussie current can lead to higher levels of torque production compared to the Russian current, both in maximal and submaximal settings, regardless of the chosen duty cycle. Nevertheless, it is important to highlight that applying the Aussie current at maximum tolerated levels may lead to higher discomfort, in contrast to submaximum settings where no significant between-currents difference in discomfort was observed. Furthermore, our data indicates that the duty cycle does not appear to affect sensory discomfort across different KFACs. In clinical settings, the Aussie current emerges as a more efficient choice for both maximal and submaximal evoked-torque production, while a 20% duty cycle demonstrates superior NMES-efficiency specifically for submaximum applications. This information is crucial for making evidence-based decisions regarding NMES protocols in clinical settings.

The carrier frequency and burst duty cycle can have an effect on both torque production and perception of discomfort during NMES, and choosing the right parameters may lead to a higher NMES effectiveness (MODESTO et al., 2022). Our resuts showed that the use of Aussie current, with a lower carrier frequency of 1 kHz, led to greater evoked torque compared to Russian current with a higher carrier frequency of 2.5 kHz. These results are consistent with previous studies, where higher torques were evoked with lower carrier frequencies (i.e., 1 kHz), but these torques decreased significantly when frequencies exceed 2.5 kHz (WARD; ROBERTSON; IOANNOU, 2004; 2006). It appears that the 1 kHz carrier frequency is the best one among the KFACs in terms of evoking the highest torque, as it also produced a higher evoked torque compared to KFAC at 4 kHz (MEDEIROS et al., 2017). However, above 2.5 kHz it appears that the evoked torque is similar among KFACs with higher carrier frequencies, as shown when 2.5 kHz was compared to 5 kHz (SELKOWITZ; ROSSMAN; FITZPATRICK, 2009). However, these authors noted that the higher frequency of 5 kHz required a higher current intensity to achieve similar torque as the lower frequency of 2.5 kHz, indicating lower NMES-efficiency (SELKOWITZ; ROSSMAN; FITZPATRICKet al., 2009). Indeed, we observed that the Aussie current with 1 kHz resulted in greater torque with less current intensity applied to the muscle tissue compared to Russian current with 2.5 kHz. This suggests that lower carrier frequencies may enhance NMES-efficiency by producing greater torque with reduced NMES current intensity.

In our study, we compared the Aussie current, with a lower carrier frequency (1 kHz) and longer pulse duration (500 µs), to the Russian current, with higher carrier frequency (2.5 kHz) and shorter pulse duration (200 µs). One of the reasons for this choice was that pulse duration appears to have a significant effect in the neuromuscular system response (MEDEIROS et al., 2017). According to the intensity/duration curve (I/T curve) (ROBERTOSN; WARD; LOW, 2006), with long-duration pulses, the thresholds for large and small-diameter fibers are closer together, which could mean that with supra-threshold stimulation, fibers with a wide range of diameters will be stimulated. In this case, the motoneurons innervating skeletal muscles have a variety of fiber diameters, so it would be expected that a larger population of muscle fibers would be recruited with long-duration pulses (LI; BAK, 1976; WARD; ROBERTSON; IOANNOU, 2004). The activation threshold of larger-diameter motor axons may not be reached by pulses with narrow durations, while wide pulses have the capability to reach this threshold and recruit a higher number of motor units in the stimulated muscle (LI; BAK, 1976; WARD; ROBERTSON; IOUANNOU, 2004). Research has indicated that wide pulses generate greater torque, which aligns with the idea that total electrical charge (i.e., the product from current intensity times pulse duration) plays an important role in NMES-induced torque production (MEDEIROS et al., 2017). Moreover, wide pulses can activate a larger population of sensory neurons, which then stimulate motor neurons through reflex pathways leading to the recruitment of more motor units (BARSS et al., 2018;

BASTOS et al., 2021). These findings suggest that the variations in torque production associated with KFAC carrier frequencies may not be solely attributed to the carrier frequencies. It appears that pulse duration also plays a significant role, as there is an inverse relationship between pulse duration and carrier frequency. Furthermore, an increase in pulse duration reduces the current intensity required to attain the motor threshold (MODESTO et al., 2022). Hence, our findings demonstrate that opting for a lower KFAC carrier frequency leads to a wider pulse duration, consequently promoting higher torque generation while reducing the current intensity thereby maximizing the NMES' effectiveness.

In clinical practice, the amount of evoked torque plays a crucial role for inducing strength gains and preventing muscle wasting among different patient populations. The recommended NMES-evoked torque has been suggested to range between 5% and 50% of MVIC (GIBSON et al., 1988; LAUFER; SNYDER-MACKLER, 2010; SNYDER-MACKLER et al., 1994). In this study, the maximum current intensity tolerated by participants evoked a relative torque of ~66% MVIC across all NMES conditions. However, our data showed that the Aussie current applied at the maximum tolerated current intensity may lead to increased discomfort compared to submaximal torque settings where no significant between-currents difference in discomfort was observed. Interstingly, to prioritize NMES comfort, our data suggest that physical therapists should utilize the Aussie current at a submaximal evoked effort level of 20% MVIC. This threshold is within the range considered effective for strengthening in various patient populations (DIRKS et al., 2015; GIBSON; SMITH; RENNIE, 1988; LAUFER; SNYDER-MACKLER, 2010; MADDOCKS et al., 2016; SNYDER-MACKLER et al., 1994).

The duty cycle is another factor that has been suggested to influence torque production evoked by KFAC along with the carrier frequency (MODESTO et al., 2022). However, this study did not find any significant differences in the evoked torque between different duty cycles when using two types of KFAC. This finding is in agreement with previous studies that showed a greater evoked torque when using burst durations of 2 to 4 milliseconds and shorter duty cycles (SZECSI; FORNUSEK, 2014; LIEBANO; WASZCZUK; CORRÊA , 2013; MCLODA; CARMACK, 2000; PARKER et al., 2011; WARD; ROBERTSON; IOANNOU, 2004), which were also applied in the present study (Aussie: bursts of 2 ms and an interval of 18 ms between bursts; Russian: bursts of 4 ms and an interval of 16 ms between bursts). McLoda and Carmack (2000) compared duty cycles ranging from 10% to 90% and observed that the average evoked force decreased as the duty cycle increased, with the 10% duty cycle producing greater force than the 90% duty cycle. Furthermore, the average efficiency (mean stimulus intensity values were divided by their corresponding evoked torque) was higher with a 10% duty cycle compared to a 90% duty cycle. Ward et al. (2004) tested different duty cycles ranging from 0% to 100%, using different carrier frequencies, and found that duty cycles lower than 20% resulted in greater evoked torque, regardless of the carrier frequency. Similar results were found by Liebano et al. (2013), where three different duty cycles (20%, 35%, and 50%) were compared with the same carrier frequency, revealing that the 20% duty cycle produced greater torque than the 35% and 50% duty cycles, with no significant difference between the 35% and 50% duty cycles. The similarity in the duty cycles used in this study (10% and 20%) might explain the absence of significant differences when comparing our data to the studies conducted by McLoda and Carmack (2000) as well as Ward and colleagues (2004).

The reason shorter duty cycles produce higher torque can be explained by two factors. Firstly, when pulse durations exceed 4 ms, a larger number of action potentials are generated, which may lead to neurotransmitter depletion, signal propagation failure, or even nerve conduction blockage, resulting in synaptic fatigue (SZECSI; FORNUSEK, 2014; LIEBANO; WASZCZUK; CORRÊA , 2013). On the other hand, shorter duty cycles help prevent excessive depolarization of nerve fibers, allowing for increased torque production (LIEBANO; WASZCZUK; CORRÊA, 2013). Secondly, the intervals (interburst intervals) between bursts play a significant role in affecting the root mean square (RMS) of the current (MCLODA; CARMACK, 2000; MODESTO et al., 2022). By increasing these interburst intervals, a higher peak torque and more intense muscle contraction can be achieved, where duty cycles with shorter burst durations are associated with longer interburst intervals, allowing the delivery of a greater magnitude of current. McLoda and Carmack (2000) compared different duty cycles and observed that smaller duty cycles (10%) exhibited higher force and efficiency compared to larger duty cycles (90%). A previous study by Moreno-Aranda and Seireg suggested that 20% duty cycles might be optimal for generating higher torque levels (MORENO-ARANDA; SEIREG, 1981); however, this study did not compare the 20% duty cycle with other duty cycles. In our study, no significant differences were observed in evoked torque and NMES-efficiency across duty cycles when measuring MET, possibly because the duty cycles were small (10% and 20%) and we used the maximum intensity supported by the participant. Nevertheless, our results indicate that using a 20% duty cycle for submaximal evoked torques provides greater NMES efficiency, allowing for higher evoked torque at a given intensity, probably because the intensity used was not the maximum intensity, only the intensity needed to reach 20% of MVIC.

The discomfort perceived by a patient can be a limiting factor in the efficiency of NMES application (BAX; STAES; VERHAGEN, 2005; MAFFIULETTI et al., 2011; VAZ; FRASSON, 2018). Previous studies have shown that carrier frequencies of 2.5 kHz, 5 kHz, and 10 kHz resulted in less perceived discomfort (ROONEY; CURRIER; NITZ, 1992). In our study, no between-currents (1 kHz vs 2.5 kHz) difference was observed when generating submaximal torques, possibly due to their carrier frequency values proximity. In contrast, the 1 kHz carrier frequency generated greater discomfort during the maximum tolerated current intensity. Lower carrier frequencies result in an increased pulse duration, which leads NMES to achieve the motor and pain thresholds more easily thereby increasing discomfort (WARD; CHUEN, 2009). In contrast, a study conducted by Medeiros et al. (2017) reported no difference in perceived discomfort between carrier frequencies of 1 kHz and 4 kHz when producing maximal torques. However, individual variability, influenced by past negative experiences with NMES, fear, apprehension, and anxiety levels, can also contribute to the emotional dimension of discomfort perception (DELITTO; STRUB; SHULMAN, 1992; MEDEIROS et al., 2017). Another factor may be related to the menstrual cycle of the female participants, as this condition was not controlled in the present study and may be directly related to discomfort perception (DANTAS et al., 2015).

In addition, factors such as the duty cycle and neural firing rate can have a significant impact on discomfort perception. For instance, when the duty cycle of neuromuscular stimulation is set at 50%, resulting in a firing rate of less than 500 Hz, it can lead to rapid fiber inactivation due to neurotransmitter depletion or nerve block (BOWMAN; MCNEAL, 1986; JONES, 1996; ROONEY; CURRIER; NITZ, 1992; WARD; ROBERTSON, 2001). On the other hand, lower duty cycles around 20%, with a firing rate under 200 Hz, may mitigate some of these problems by avoiding excessive rates that cause propagation failure or sensory overload within the nerves (MODESTO et al., 2022). Szecsi and Fornusek (2014) found that a 50% duty cycle was more uncomfortable compared to duty cycles below 50% (2% - 50%). However, in the present study, differences were observed between duty cycles of 10% and 20% only in maximum conditions. It has been suggested that optimal blocking of pain fiber activity occurs when sensory fibers are stimulated at firing rates around 100 Hz (JOHNSON et al., 1989; SELKOWITZ, 1999). Interestingly, for maximal conditions, the Aussie current was found to be more uncomfortable, which might be due to individual emotional factors such as apprehension about experiencing maximum discomfort when using the highest tolerated intensity (MEDEIROS et al., 2017). Laufer and Elboim (2008) demonstrated that the minimum perceived discomfort occurred with a 20% duty cycle. Liebano et al. (2013) reported conflicting results regarding the discomfort perception of different duty cycles. They found no difference in discomfort perception between 20%, 35%, and 50% duty cycles. Collectively, the conflicting results in perceived discomfort highlight the need for standardized evaluation methods that consider both the physical and emotional contexts influencing individual experiences during NMES in clinical settings.

The present study acknowledges some limitations. Our assessment was limited to healthy young participants with relatively low body mass indexes, which may not fully represent clinical populations and athletes. Additionally, since our study primarily focused on the acute effects of NMES currents, future studies should be conducted to investigate KFACs' chronic effects related to NMES-evoked torque, discomfort, and efficiency across different carrier frequencies and burst duty cycles in both healthy and clinical populations.

CONCLUSION

In conclusion, our study demonstrated that the Australian current outperforms the Russian current in terms of evoked torque and efficiency, both in maximum and submaximum conditions. While the Australian current may lead to greater discomfort in maximum conditions, it matches the Russian current in submaximum conditions for perceived disconfort. Finnaly, employing a 20% duty cycle enhances efficiency and reduces the required current intensity during submaximum conditions.

Table 2. Results of different NMES protocols for maximum and submaximum torque.

		AC10%	AC20%	RC10%	RC20%
MVIC max (N.m)	100%	76.70	76.55	71.74	76.39
		(67.65 - 85.74)	(68.35 - 84.74)	(64.28 - 79.20)	(68.18 - 84.59
Intensity (mA)	20%	41.26$^{\#,\$}$	37.63$^{i\#,\$}$	62.96$^{\#,\$}$	57.36$^{\#,\$}$
		(37.85 - 44.67)	(34.63 - 40.63)	(57.95 - 67.97)	(51.89 - 62.83)
	100%	71.00*	67.00*	92.95*	88.20*
		(63.57 - 78.42)	(60.69 - 73.40)	(86.11 - 99.79)	(79.60 - 96.80)
MEC (N.m)	20%	16.94$^{\#}$	16.34$^{\#}$	14.51$^{\#}$	15.30$^{\#}$
		(14.91 - 18.96)	(14.52 -18.16)	(12.86 - 16.16)	(13.74 - 16.85)
	100%	56.37*	56.09*	46.90*	47.64*
		(49.81 - 62.92)	(50.21 - 61.97)	(41.91 - 54.36)	(44.20 - 56.64)
Relative torque (%MVIC)	20%	22.27$^{\#}$	21.65$^{\#}$	20.32$^{\#}$	20.58$^{\#}$
		(21.21 - 23.33)	(20.37 - 22.93)	(19.32 - 21.32)	(18.98 - 22.18)
	100%	77.68	75.74	69.96	67.64
		(68.71 - 86.64)	(68.43 - 83.05)	(61.43 - 80.62)	(60.85 - 79.07)
NMES efficiency	20%	43.87$^{\#,\$}$	46.03$^{\#,\$}$	24.28$^{\#,\$}$	29.20$^{\#,\$}$
(Nm/mA)		(37.49 - 50.24)	(40.05 - 52.02)	(21.22 - 27.33)	(25.27 - 33.14)
	100%	85.23*	86.99*	51.71*	57.80*
		(72.38 - 98.06)	(77.81 - 96.16)	(45.93 - 59.94)	(52.25 - 68.12)
Discomfort (0, 10)	20%	3.42	3.39	3.72	3.78
		(2.77 - 4.06)	(2.72 - 4.07)	(2.98 - 4.46)	(3.06 - 4.50)
	100%	9.22*	9.27*	8.61*	9.07*
		(8.88 - 9.55)	(8.98 - 9.57)	(7.98 - 9.24)	(8.77 - 9.37)

Values are reported as mean (95% confidence interval). MVIC: Maximum voluntary isometric contraction; MEC: Maximum evoked contraction; NMES: Neuromuscular electrical stimulation; AC: Aussie currents; RC: Russian currents.

*: Difference between collapsed Aussie current and collapsed Russian current for the maximum protocol.

#: Difference between collapsed Aussie current and collapsed Russian current for the submaximal protocol. $: Difference between 10% duty cycle collapsed and 20% duty cycle collapsed for the submaximal protocol.

Table 3. Effect sizes.

		Effect size, ***d***						Among NMES currents		
		AC10% vs AC20%	**AC10% vs RC10%**	**AC10% vs RC20%**	**AC20% vs RC10%**	**AC20% vs RC20%**	**RC10% vs RC20%**	**Partial eta squared**	**Effect size, *F***	**Power**
Intensity	20% (currents)	0.34	1.53	1.07	1.86	1.36	0.32	0.71	1.59	1.00
	20% (duty cycle)	0.34	1.53	1.07	1.86	1.36	0.32	0.13	0.40	0.72
	100%	0.17	0.93	0.65	1.19	0.85	0.18	0.66	1.41	1.00
MEC	20%	0.09	0.39	0.27	0.32	0.18	0.14	0.19	0.49	0.89
	100%	0.01	0.39	0.28	0.39	0.28	0.11	0.15	0.43	0.79
Efficiency	20% (currents)	0.10	1.19	0.84	1.39	1.01	0.42	0.59	1.21	1.00
	20% (duty cycle)	0.10	1.19	0.84	1.39	1.01	0.42	0.12	0.37	0.67
	100%	0.04	0.95	0.71	1.27	0.94	0.29	0.44	0.89	0.99
Discomfort	20%	-	-	-	-	-	-	-	-	-
	100%	0.04	0.36	0.14	0.40	0.20	0.28	0.13	0.38	0.70

Effect sizes (*d*): trivial (<0.20); small (0.20-0.49); moderate (0.50-0.79); large (0.80-1.29); very large (>1.30).

Effect size (*f*): small (0.10-0.24); medium ((0.25-0.39); large (≥0.40).

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Artigo 3. Será submetido após avaliação da banca de Doutorado

AUSSIE KILOHERTZ FREQUENCY ALTERNATING CURRENT INDUCES LESS FATIGUE AND HIGH NEUROMUSCULAR EFFICIENCY THAN RUSSIAN CURRENT IN HEALTHY PEOPLE: A RANDOMIZED CROSSOVER TRIAL

Authors:

Karenina Arrais Guida Modesto[1], Priscila Karen Silva Raposo[2], Isabel de Almeida Paz[3], Marco Aurélio Vaz[4], João Luiz Quagliotti Durigan[5].

Affiliations:

1. Ph.D. Candidate, Department of Physical Education, University of Brasilia, Brasilia, Distrito Federal, Brazil
2. Undergraduate student, University of Brasilia, Faculty of Ceilândia, Laboratory of Muscle and Tendon Plasticity, Brasília, DF, Brazil
3. Ph.D. Candidate, Human Movement Sciences Program, ESEFID, Federal University of Rio Grande do Sul, Porto Alegre, RS, Brazil
4. Full Professor, Human Movement Sciences Program, ESEFID, Federal University of Rio Grande do Sul, Porto Alegre, RS, Brazil
5. Associate Professor, Rehabilitation Sciences Program, University of Brasilia, Brasilia, DF, Brazil

*** Correspondence:**

Ms. Karenina Arrais Guida Modesto

Ph.D. Candidate, Department of Physical Education, University of Brasilia, Brasilia, Distrito Federal, Brazil

ABSTRACT

Background: Muscular fatigue refers to a temporary decrease in the muscle's ability to generate force and perform an activity. The relationship between NMES and muscular fatigue is complex and depends on various elements. This involves identifying optimal stimulation parameters to minimize excessive fatigue, thereby developing more efficient treatment protocols that ensure positive therapeutic outcomes. **Objective:** Investigate the effects of four different NMES protocols applied to the triceps surae muscle on maximum evoked torque (MET), muscle fatigue , neuromuscular efficiency, sensory discomfort and spinal excitability. **Methods:** Using a cross-over design, four kHz-frequency alternating currents (KFACs), with 1 kHz (Aussie current) and 2.5 kHz (Russian current), and 10% and 20% of duty cycles, were randomly applied on the triceps surae muscle of healthy participants, with a minimum of seven days between sessions. The maximum evoked torque (MET), muscle fatigue (total torque-time integral - TTI, decline of TTI, fatigue index and number of contractions), neuromuscular efficiency, sensory discomfort and spinal excitability were measured. Statistics were conducted using a two-way mixed-model ANOVA with repeated measures [three levels: currents (Aussie and Russian) X duty cycle (10% and 20%) X time (pre and post)], followed by Tukey post-hoc test. **Results:** Forty-four participants (age 25.65 ± 6.55 years) were included. The Aussie currents produced higher evoked torque, a higher total sum for TTI, a lower decline in TTI (i.e., more contractions for a significant drop in evoked torque) and lower fatigue index. Only the soleus muscle showed a decrease between pre- and post-fatigue assessments for root mean square (RMS) and median frequency (MF) values. The gastrocnemius muscle exhibited a decrease between pre- and post-fatigue assessments and and differences between duty cycle where the 20% duty cycle presented higher values. The Aussie current demonstrated higher efficiency, both at pre and post assessments, as well as during fatigue. However, the Aussie current produced higher overall discomfort, with discomfort during fatigue being higher at the beginning of the protocol compared to the end. **Conclusion:** The Aussie current demonstrated advantage over the Russian current by inducing less fatigability and promoting high neuromuscular efficiency in healthy individuals, particularly with the 10% duty cycle. Despite a slightly higher discomfort level observed with the Aussie current, the between-currents similar discomfort during the fatigue protocols highlights the overall superiority of Aussie compared to the Russian current.

Keywords: Electrical Stimulation, Torque, Burst-Modulated Current, Duty Cycle, Alternated Current, Muscle Fatigue.

INTRODUCTION

Neuromuscular electrical stimulation (NMES) is used to evoked contractions, with common goals including the improvement of functionality and the promotion of cardiovascular health, muscle strength, and endurance. NMES has been used for patients undergoing recovery from neurological or musculoskeletal injuries (JONES et al., 2016; SALVINI et al., 2012), as well as for healthy participants (DA SILVA et al., 2015; DANTAS et al., 2015; GONDIN; COZZONE; BENDAHAN, 2011). In clinical settings, NMES-efficiency is determined by reaching maximum evoked torque (MET) with minimal current amplitude and tolerable discomfort (MEDEIROS et al., 2015, 2017; VAZ; FRASSON, 2018). In addition, it has been shown that the evoked torque is a key parameter for evaluating NMES efficiency (DAMO et al., 2021; MAFFIULETTI et al., 2018). However, the evoked torque produced by NMES tends to decrease quickly with repeated contractions, and the maximum voluntary isometric contraction (MVIC) generated after multiple NMES-evoked contractions is often lower than that of a rested muscle (MARTIN et al., 2016; NEYROUD et al., 2014), which is known as contraction fatigability. This reduction in the contractile ability to generate force during NMES diminishes the load on the neuromuscular and cardiovascular systems, which limits the potential benefits of NMES-based programs (BASTOS et al., 2021). Consequently, new approaches manipulating physical parameters and currents type have been developed to induce optimal NMES efficiency while mitigating NMES-evoked contraction fatigability.

A NMES commonly used in clinical practice is the kilohertz frequency alternating current (KFAC), which is delivered using medium-frequency current, with a carrier frequency ranging from 1 to 10 kHz and alternating biphasic sinusoidal waveform (DAMO et al., 2021; MODESTO et al., 2022; VAZ; FRASSON, 2018; WARD; CHUEN, 2009). High-level electrically induced contractions and increased skeletal muscle strength have been attributed to KFACs, which received increased attention since the 1970s, where a new type of NMES designed to minimize some of the traditional NMES limitations (i.e. muscle fatigue, and perceived discomfort - KOTS, 1977; WARD; SHKURATOVA, 2002) This current was named as Russian KFAC, delivered in brief bursts of alternating current at a “carrier frequency” of 2.5 kHz, with a burst frequency between 1 - 200 Hz (WARD; SHKURATOVA, 2002). Another type of KFAC was developed in Australia (and therefore named “Aussie current”), is commonly delivered with a carrier frequency of 1.0 kHz (1 to 200-Hz of burst frequency). Some authors have suggested that the carrier frequency offers a reasonable association between discomfort and force production and reduced muscle fatigue (WAR; LUCAS-TOUMBOUROU; MCCARTHY, 2009; WARD; ROBERTSON; IOANNOU, 2004).

While numerous studies have compared the efficiency, discomfort, and fatigue of KFAC to the other NMES-types (VAZ; FRASSON, 2018), only a few have focused on KFACs (MODESTO et al., 2022). Recently, a systematic review, which included 13 studies comparing different parameters of KFAC in terms of evoked torque, sensory discomfort, and muscle fatigue, revealed that only two studies investigated muscle fatigue (MODESTO et al., 2022). Parker and colleagues (2011) assessed contraction fatigue in eighteen healthy male volunteers with three 2.5-kHz KFACs: two modulated at 50 bursts per second (with a 10% burst duty cycle and 90% burst duty cycle) and one at 100 bursts per second (with a 10% burst duty cycle). The stimulation patterns had no impact on contraction fatigability. Different results were obtained by Laufer and Elboim (2008) using 2.5-kHz KFACs, with two modulated at 50 bursts per second with a 50% burst duty cycle and 20% burst duty cycle, and one modulated at 20 bursts per second with a 20% burst duty cycle, was observed no difference in the degree of fatigue was demonstrated between the KFACs that differed only in their burst frequencies (20 Hz versus 50 Hz). At the same time, the comparison between the KFACs with equal burst frequency (50 Hz) showed significantly greater fatigue when the burst duration included a higher duty cycle (50%), as opposed to the burst duration that included a lower duty cycle (20%). Whether contraction fatigability is reduced or NMES outcomes are improved when using different parameters of KFACs, however, is presently unclear.

Theoretically, KFAC with higher carrier frequencies should decrease the skin impedance and allow less electrical energy to be dissipated, thus generating higher evoked contractions (DANTAS et al., 2015; MEDEIROS et al., 2017; WARD; SHKURATOVA, 2002). Nevertheless, higher frequencies are known to increase muscle fatigue due to a disruption in action potential generation within the muscle fibers (JONES, 1996; PAZ et al., 2021; LAUFER; ELBOIM 2008). In addition, those studies (PARKER et al., 2011; LAUFER; ELBOIM, 2008) did not assess how carrier frequency manipulation can influence contraction fatigability. Manipulating the carrier frequency results in an inverse relationship between pulse duration and carrier frequency. Studies have suggested that wider pulses produce higher torque, supporting the notion that total charge is critical in generating NMES-evoked torque (MEDEIROS et al., 2017). Furthermore, wider pulses can activate more sensory axons compared to motor axons due to the longer current stimulus strength-duration time constant of sensory axons (BARSS et al., 2018). This mechanism triggers contractions through central pathways by delivering a larger sensory input to the central nervous system (CNS) (BARSS et al., 2018; BASTOS et al., 2021; COLLINS, 2007). Moreover, applying higher frequency (~100 Hz) increases the afferent volley to the spinal cord, enhancing the central or "reflex" contribution to electrically evoked contractions of ankle musculature compared to lower frequencies (DEAN; YATES; COLLINS, 2008; KLAKOWICZ; BALDWIN; COLLINS, 2006). While these ideas about motor unit recruitment during NMES provided the rationale for manipulating pulse duration and frequency (BARSS et al., 2018), the short-term effects on contraction fatigability while using different patterns of KFAC remain to be determined.

To the best of our knowledge, no study has concurrently compared possible differences in carrier frequency and burst duty cycle with a matched burst frequency and duration in terms of contraction fatigability and its origin considering both peripheral and central pathways. Studies have been conducted to explore the most effective NMES parameters in reducing fatigability and discomfort, enhancing CNS excitability for evoked contractions, and maximizing its benefits (BASTOS et al., 2021). Therefore, the purpose of this study was to determine the effects of four protocols using two KFACs (i.e., two carrier frequencies: 2.500 kHz/Russian current and 1000 kHz/Aussie current, with phase durations of 200 µs and 500µs, respectively) on fatigue index, spinal excitability, and perceived discomfort for the triceps surae muscle. We also aimed to investigate the impact of altering the carrier frequencies (2.500 kHz for Russian current and 1000 kHz for Aussie current) and manipulating the burst duty cycle (10% or 20%) with corresponding burst durations (2 ms or 4 ms) on these outcomes. We hypothesized that increasing the carrier frequency and burst duty cycle would induce a higher fatigability and discomfort with augmentation of spinal excitability. The ratios of maximal H-reflex (H_{max}) to M_{max} were also determined for triceps surae before and after NMES to discriminate whether different types of KFAC induced changes in spinal excitability, which could explain the mechanism of peripheral and central fatigue.

METHODS

Trial design

This study was a randomized, cross-over, and double-blind study, comparing four different NMES protocols for generating muscle fatigue, efficiency, spinal excitability, and perceived sensory discomfort. Participants were informed about the purposes, benefits, and risks before enrollment, and all agreed to participate and signed the consent form. Approval was obtained (protocol number 47989121.6.0000.8093) from the Research Ethics Committee of the University of Brasilia (Faculty of Ceilândia) in accordance with the Helsinki Declaration of 1975. The primary outcome assessed in this study was the maximum evoked torque (MET), muscle fatigue (decline in torque-time integral - TTI, fatigue index and number of contractions) and neuromuscular efficiency, while sensory discomfort and spinal excitability were considered secondary outcomes. This study is part of a larger study registered at http://clinicaltrials.gov (NCT05061056).

Participants

To be included in the study, participants needed to be aged 18 to 40 years, and physically active, should presented a full range of motion and healthy functionality of the knee joint and should not have previous experience with NMES. Participants who were using non-steroidal anti-inflammatory drugs and nutritional supplements, presented skin lesions or skin allergies, had been previously diagnosed with neuromuscular diseases, or presented external fixation or metal implants in the lower limbs were not included in the study. In addition, participants who presented intolerance to NMES (due to fear or hypersensitivity to the stimulus) or did not achieve a minimum evoked torque of 20% of the maximal voluntary isometric contraction (MVIC) during NMES were also excluded.

Sample Size

The sample size was determined a priori using G*Power (version 3.1.3; University of Trier, Trier, Germany) with the level of significance set at $p = 0.05$ and power $(1-\beta) = 0.80$ to detect a large effect ($f2 > 0.5$). Thus, a sample of 44 individuals was defined as the appropriate number of subjects, based on the calculation with the highest value among the primary outcomes (for the larger project that was developed) (BELLEW et al., 2019; DANTAS et al., 2015; PAZ et al., 2021), taking into account a sample loss of 20% (BELLEW et al., 2019; PAZ et al., 2021).

Randomization and allocation concealment

Four conditions were randomly presented: 1) 500 µs of phase duration and low carrier frequency (1000 Hz – AC 10% or Aussie current at 10% of burst duty cycle); 2) 500 µs of phase duration and low carrier frequency (1000 Hz – AC 20% or Aussie current at 20% of burst duty cycle); 3) 200 µs of phase duration and high carrier frequency (2500

Hz – RC 10% or Russian current at 10% of burst duty cycle); 4) 200 µs of phase duration and high carrier frequency (2500 Hz – RC 20% or Russian current at 20% of burst duty cycle) **(Table 1 for further details)**. Computer-generated randomization sequences were created using the website www.random.org, which assigned the stimulation protocols to each participant in a sequential manner. The order of NMES conditions for each participant was prepared by a researcher (PKR).

Blinding

The researcher (KAGMP) responsible for administering the currents, as well as the participants, were unaware of the treatment assignments. To maintain this blinding, a different researcher (PKR) conducted the programming for each NMES session and concealed the NMES device panel using a black cover. This approach aimed to keep the parameters concealed from both the researcher (KAGMP) and the participants, except for the current intensity.

Table 1. Description of the physical parameters for the 4 types of electrical stimulation

Type of current	Carrier frequency (Hz)	Phase duration (µs)	Burst duration (ms)	Interburst duration (ms)	Burst duty cycle (%)	Burst frequency (Hz)
RC10%	2.500	200	2	18	10	50
RC20%	2.500	200	4	16	20	50
AC10%	1000	500	2	18	10	50
AC20%	1000	500	4	16	20	50

Legend. RC: Russian current. AC: Australian current.

Procedures

Participants took part in five sessions (a familiarization and four experimental), each session lasting ~2 hrs and with at least 7 days apart (DAMO et. al, 2021). Each participant was assessed in the same period of the day (2:00 and 7:00 p.m.) in the

Musculotendinous Plasticity Laboratory by the same assessor. They were asked to avoid stimulants (e.g., alcohol, caffeine, chocolate), and practice exercise on testing days. During the familiarization session, subjects were asked about previous recommendations and criteria for participation in the study. They were also introduced to the testing procedures and protocols. Height, body mass, and body mass index (BMI) measurements were recorded for each participant. The sequence of stimulation protocols was then randomized for each participant using the website www.randomizer.org. The maximum supported intensity for all NMES protocols was evaluated.

All five experimental sessions were preceded by a warm-up phase and a muscle fatigue phase generated by NMES (80 contractions evoked at 20% MVIC). Two MVICs were performed before and after the fatigue protocol to measure the greatest ankle joint torque. In addition, two maximum electrically evoked contractions were conducted during each randomized NMES protocol, to reach the maximum intensity tolerated by the participant, during which we recorded the MET value. Subsequently, the spinal excitability, measured through H-reflex and M-wave, was assessed both before and after the fatigue protocol, as illustrated in Figure 1. All NMES protocols were carried out on the participants' right side (DAMO et al., 2021), with 50 Hz bursts being delivered, as shown in the bottom panel of Figure 1 (see also Table 1). All currents were delivered with an “on” time of 8s (1s of ramp-up, 6 s of constant time, and 1s of decay) and an “off” time of 60s for recovery (MODESTO et al., 2019).

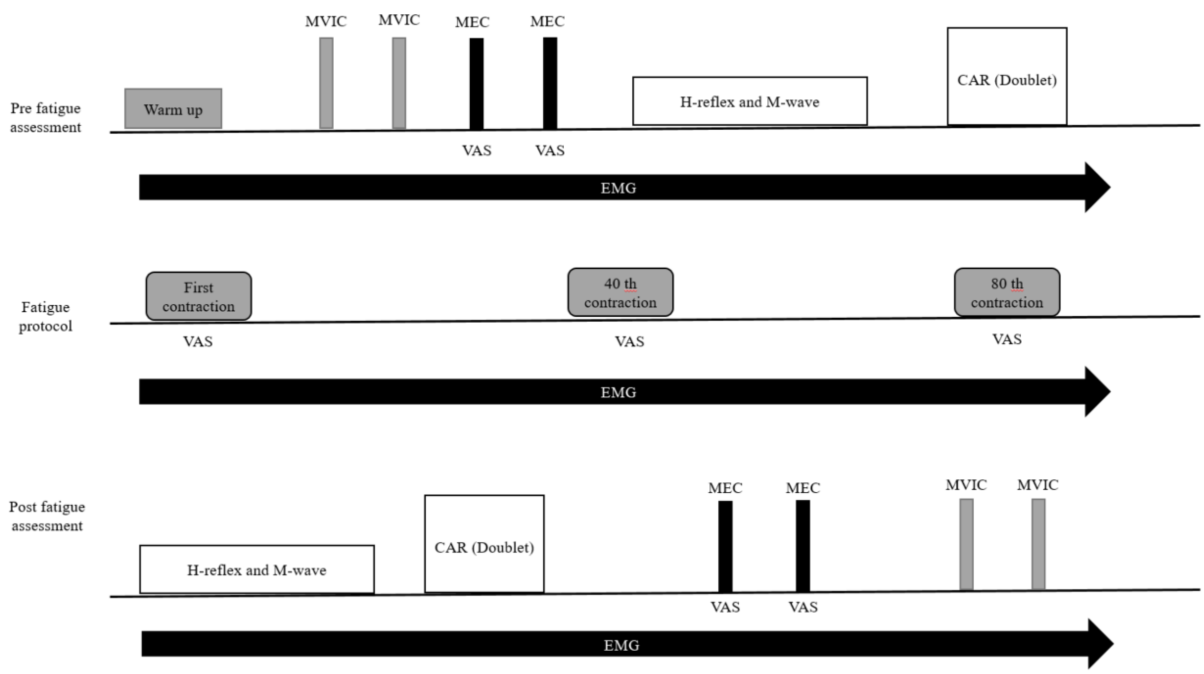


Figure 1. Pre-fatigue assessment: Comprising 2 MVICs with a 1-minute interval between contractions. After 1 minute of rest, two maximum evoked contractions were performed (with a 1-minute interval) and maximal evoked torque (MET) was obtained. The discomfort was evaluated through the visual analogue scale (VAS) simultaneously with the MET. Immediately after the fatigue protocol, spinal excitability assessment (H-reflex, M-wave, and central activation ratio - CAR) was carried out. Fatigue protocol: Following the assessment of spinal excitability (H-reflex, M-wave, and CAR), the fatigue protocol, consisting of 80 submaximal evoked torques (20% of the MVIC of the first evoked torque), was performed. The VAS was administered at the first, fortieth, and last evoked torque of the fatigue protocol. Post-fatigue assessment: Immediately after the fatigue protocol, spinal excitability (H-reflex, M-wave, and CAR) was re-evaluated. Following this, two additional MET were performed with a 1-minute interval between them. The VAS was again presented concurrently with the torques. Finally, 2 MVICs were performed with a 1-minute interval between them.

Outcomes

Primary outcomes were MET, muscle fatigue (total TTI, decline in TTI, fatigue index and number of contractions) and efficiency. Secondary outcomes were NMES-induced discomfort and spinal excitability.

Warm-up and Maximal Voluntary Isometric Contraction (MVIC)

Participants sat in the chair of an isometric dynamometer (Cefise, Nova Odessa, SP) with their right foot secured to the footplate, with the hip, knee and ankle at ~90^o (GROSPRÊTRE et al., 2018). Subsequently, six submaximal isometric contractions of plantar flexion were performed, each lasting 6 sec, with 10 sec of rest between contractions. After the warm-up phase, maintaining the same position, a 1-minute rest period was given. Following this rest period, two MVICs were performed for 6 sec each, with a 1-minute interval between them. The highest torque achieved during these MVICs was recorded. This phase was repeated at the end of the fatigue protocol in the same form.

Maximum evoked torque (MET)

Participants were instructed to relax the leg to avoid any voluntary contraction and were seated up right on the isometric dynamometer. Stimulation was produced using a neuromuscular electrical stimulator (version 2.0; Neurodyn, Ibramed, Amparo, SP, Brazil), connected to two pairs of 25 cm^2 self-adhesive electrodes (Valutrode, São Paulo, Brazil). The skin was trichotomized and cleansed with alcohol, and four electrodes were positioned on the triceps surae muscle group, two electrodes positioned below the knee line (which forms the popliteal fossa) close to the insertion of the medial and lateral gastrocnemius muscles, and two electrodes positioned approximately 5 cm from the beginning of the Achilles tendon as previously described (BOTTER et al., 2011). Two minutes after completing the MVICs' evaluation, two METs were evaluated using the maximum intensity tolerated by the individual for the NMES protocol applied according to the familiarization session. This assessment was repeated after the fatigue protocol as well.

Assessment of muscle fatigue

Total decline in Torque-Time Integral (TTI)

Torque-time integral (TTI) is the area under the torque-time curve and reflects isometric work (ROZAND et al., 2015; SAYENKO et al., 2014). The total TTI was calculated by adding the individual TTIs of each NMES-evoked torque obtained during the fatigue protocol (NEYROUD et al., 2019). The decline in TTI was expressed as a percentage decline in work from the initial TTI contraction for each NMES fatigue test (NEYROUD et al., 2014). The TTI decline was calculated from the ratio between the average TTI from the first 5 evoked torques and the average TTI of the last 5 evoked torques (PAZ et al., 2021).

Muscle fatigue index

Eighty contractions were elicited through NMES during the fatigue protocol and were recorded. Torques from each evoked contraction, from the first to the eightieth contraction, were expressed as a percentage of the MVIC in each NMES protocol. An average value was determined for the initial five evoked torques and for the final five evoked torques and the fatigue index was expressed as the result from the ratio between these two average values (ARPIN et al., 2019; PAZ et al., 2021) .

Number of contractions until a 50% drop in initial torque

Torques from the first to the eightieth evoked contractions were expressed as a percentage from the first evoked contraction's torque in each NMES protocol. At the point when there was a relative drop in the evoked torque up to 50% from the initial torque, the contraction number was recorded to identify at which moment in the NMES protocol fatigue was occurring (PAZ et al., 2021).

NMES-efficiency assessment

NMES-efficiency was calculated as the ratio between NMES-evoked torque/current intensity (Nm/mA) (DAMO et al., 2021; MEDEIROS et al., 2017; PETROFSKY et al., 2008). The NMES-efficiency was calculated for maximum MET values before and immediately after the fatigue protocol, and during the fatigue protocol.

Visual Analogue Scale (VAS)

The Visual Analog Scale (VAS) was used to evaluate sensory discomfort. This scale comprises numbers on a scale of 0 to 10, where 0 indicates the absence of discomfort, and 10 corresponds to the highest level of discomfort reported by the participant. The VAS was administered to the participants following the NMES-evoked contractions, during the familiarization sessions, and at all phases of the MET contractions, including the 1^{st}, 40^{th}, and 80^{th} contractions of the fatigue protocol.

Spinal excitability

Test for H Reflex and M wave

H-reflex and M-wave testing were performed immediately after the MET assessment. Recruitment curves (RCs) were collected using 1.0 ms of monophasic phase with a high-voltage stimulator (Nicolet Viking Quest EMG, Madison, USA). Forty stimuli were delivered at current intensities that varied pseudo-randomly from below the intensity that evoked any response (i.e., motor threshold) up to ∼1.4× the lowest intensity that produced M_{max} (8-12 s inter-stimulus interval). To capture the relative position and amplitude of the H-reflex curve relative to the M-wave curve, three outcome measures were calculated from each RC. The H_{max} to M_{max} ratio ($H_{max}:M_{max}$), was calculated as the mean amplitude of the three largest H-reflexes (H_{max}) divided by the amplitude of the single largest M-wave (M_{max}). M-wave amplitude from maximal H-reflexes (H_{max}) was calculated as the mean amplitude of the three M-waves that corresponded to the three largest H-reflexes (i.e. H_{max}).

Mechanical properties and central activation ratio (CAR)

The mechanical properties (torque and integral force versus time) of the plantar flexors and central activation ratio (CAR) were assessed using the twitch interpolation technique (DUCLAY; MARTIN, 2005; GROSPRÊTRE et al., 2018). The stimulation electrodes were positioned in the popliteal fossa over the tibial nerve (cathode, 8 mm self-adhesive electrode) and below the patella (anode, 5 X 10 cm self-adhesive electrode)

(DUCLAY; MARTIN, 2005; GROSPRÊTRE et al., 2018), in the position that provided the greatest visible contraction of the entire triceps surae muscle group. The best representative curve was determined for each subject's H-reflex, M-wave, and maximum stimulation intensity. A series of single-square-wave stimuli (duration 1 ms, maximum voltage 100 V) were applied by progressively increasing the current until there was no further increase in evoked isometric contraction response. The peak contractions (average of two contractions) were determined and their current intensity was considered as the maximum stimulation intensity. The paired stimuli (10ms intervals between two 1ms pulses) were delivered under isometric conditions (BABAULT et al., 2003), and were delivered to the tibial nerve before (double stimulus at rest), superimposed on the MVIC and after the MVIC (relaxation period) **(Figure 2)**. The CAR was quantified with the formula: CAR (%) = [maximum voluntary torque / (maximum voluntary torque + superimposed torque – maximum voluntary torque)] X 100 (KENT-BRAUN, 1999; PAJOUTAN; GHESMATY; SANGACHIN; CAVUOTO, 2017).

Electromyographic activity (EMG)

Electromyographic (EMG) activity was recorded with a portable surface EMG (Miotool, Miotec Equipamentos Biomédicos Ltda, Porto Alegre, Brasil) and an Octopus AMT-8 (Bortec Biomedical Ltd, Calgary, AB, Canada), with 14-bit resolution, <2LSB noise level and 110db of common rejection. The EMG signals were interfaced with the PowerLab 8/35 biological signal aggregator (AD Instruments, Dunedin, New Zealand) for processing in the LabChart Pro software (AD Instruments, Dunedin, New Zealand). The electrodes were positioned based on SENIAM - surface electromyography for non-invasive evaluation of the medial gastrocnemius (GM), lateral gastrocnemius (GL) and soleus (SL) muscles (HERMENS, 2000). The EMG was quantified using the root mean square (RMS) value, which was calculated over a 500 ms window (low cut-off frequency: 10 Hz and high cut-off frequency: 500 Hz) and the median frequency of the EMG power spectra (low-pass and cut-off frequency 50 Hz).

Fatigue protocol

Immediately following the assessment of the H-reflex and M-wave, the stimulation intensity gradually increased from 10 mA (DAMO et al., 2021) until 20% of the MVIC was reached (PAZ et al., 2021). The evoked torque was expressed as a percentage of the torque values obtained during the MVIC. The MET was normalized using the formula [(MET x voluntary torque (-1)) x 100] (DAMO et al., 2021). The fatigue protocol involved 80 evoked contractions at 20% of the MVIC (PAZ et al., 2021). Each contraction had a duration of 6 seconds with a 10-second rest interval between them, in accordance with Modesto et al. (2019). We kept the initial current intensity constant from the first contraction of the fatigue protocol, thus avoiding the progressive activation of motor units during fatigue.

Statistical analysis

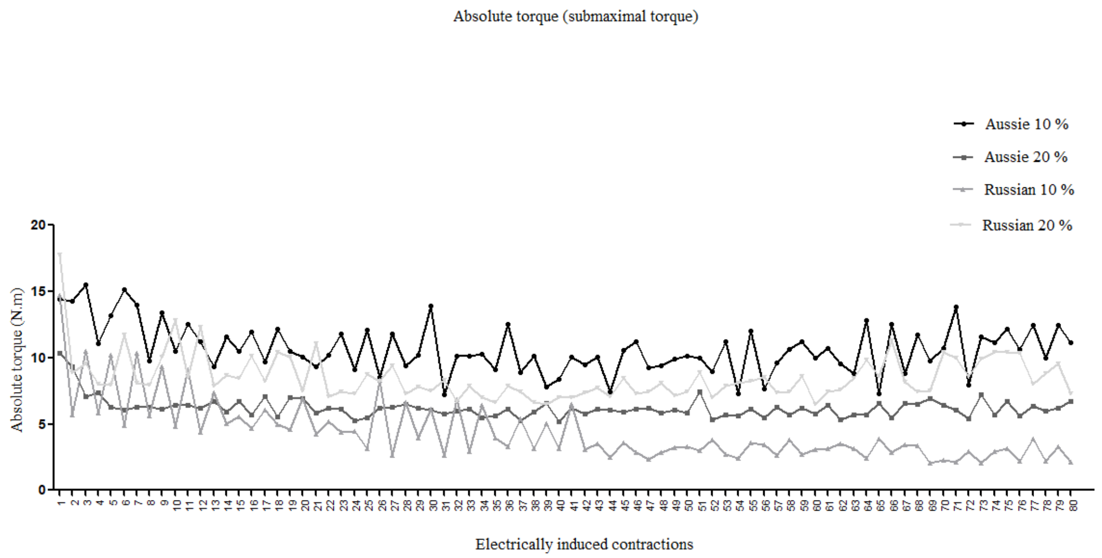
Values for MVIC, MET, muscle efficiency, TTI, h-reflex, m-wave, RMS, median frequency and VAS were reported as mean and standard deviation. We used parametric tests based on normal distribution (Shapiro-Wilk test) and homogenous variance (Levene's test) of the data. A two-way mixed-model ANOVA with repeated measures [three levels: currents (Aussie and Russian) X duty cycle (10% and 20%) X time (pre and post] was used to compare the different groups for the above-mentioned variables. In case of a significant effect of interaction, a Tukey post-hoc test was used. All statistics were performed using the STATISTIC program version 16. The graphics were performed using GraphPad Prism 6.0 software (San Diego, CA, USA).

RESULTS

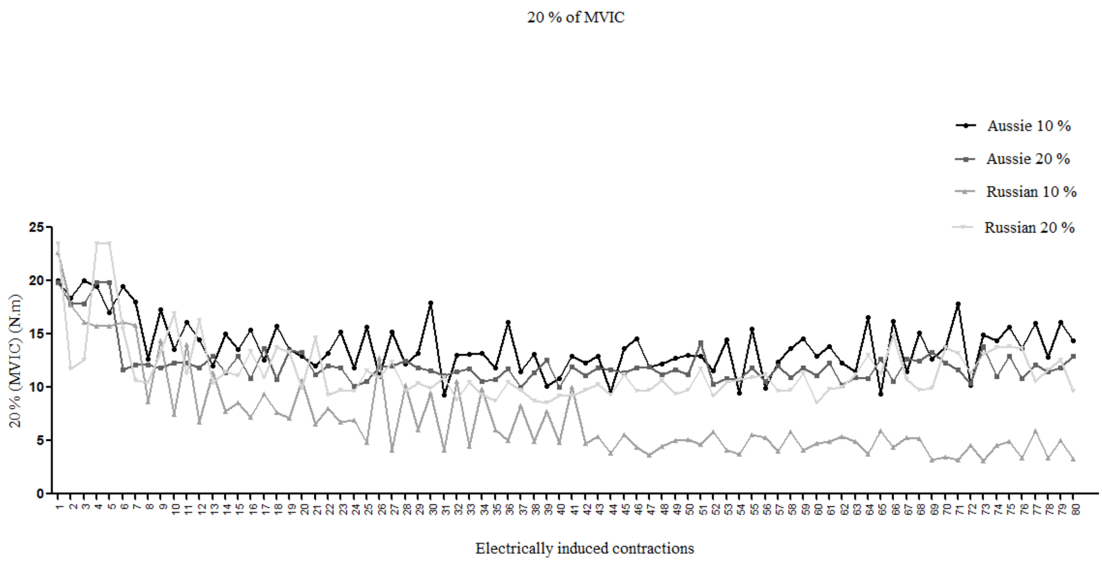
General Observation

The baseline characteristics (mean ± SD) of the 44 participants were as follows: age, 25.65 ± 6.55 years; body mass, 64.11 ± 11.95 kg; height, 167.67 ± 0.09 cm; and body mass index, 22.72 ± 3.30 kg/m². There were no adverse effects during the application of the four NMES protocols. All protocols presented a similar baseline for MVIC ($p = 0.225$, $F = 1.511$, ηρ2: 0.033, power: 0.225). Regarding MVICs pre- and post-fatigue, an interaction effect was found between current, duty cycle, and time ($p = 0.0353$, $F = 4.7223$, ηρ2: 0.0989, power = 0.5653). However, no main effect was found after the application of the Tukey post-hoc test ($p > 0.05$). There was no statistically significant difference for the TTI relative to MVIC ($p = 0.1361$, $F = 2.3115$, ηρ2: 0.0533, power: 0.3175). Figure 2 depicts the absolute torque curve (Figure 2.A), relative torque (20% of MVIC) (Figure 2.B), and the area under the curve represented by TTI (Figure 2.C) of the 80 electrically induced contractions elicited by the 4 fatigue protocols performed by a single male subject.

A


Absolute torque (submaximal torque)
Aussie 10 %
Aussie 20 %
Russian 10 %
Russian 20 %
Absolute torque (N.m)
Electrically induced contractions

B


20 % of MVIC
Aussie 10 %
Aussie 20 %
Russian 10 %
Russian 20 %
20 % (MVIC) (N.m)
Electrically induced contractions

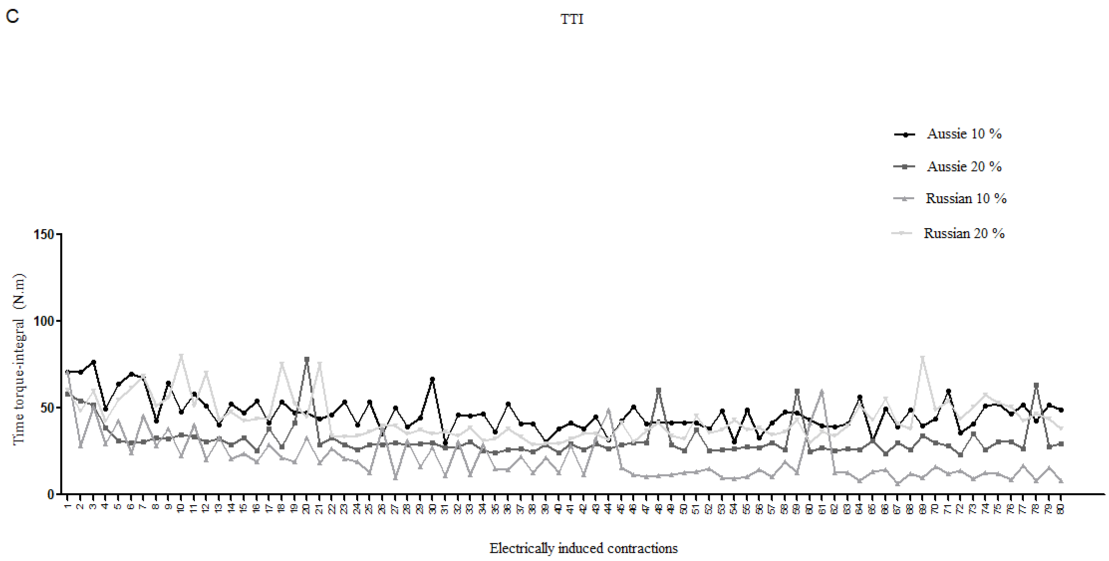


Figure 2. A: Depicts the absolute torque curve. **B:** Relative torque (20% of MVIC). **C:** Area under the curve represented by TTI. 80 electrically induced contractions elicited by the 4 fatigue protocols performed by a single male subject.

Total intensity and intensity during fatigue

No interaction was found for current and duty cycle in relation to total intensity and intensity during fatigue ($p = 0.875$, $F = 0{,}025$, $\eta_\rho^2 < 0.001$, power: 0.052; $p = 0.055$, $F = 0.356$, η_ρ^2: 0.008, power: 0.089, respectively). A main effect was found for current both for total intensity and intensity during fatigue ($p < 0.001$, $F = 85.681$, η_ρ^2: 0.665, power: 1.000; $p < 0.001$, $F = 109.735$, η_ρ^2: 0.718, power: 1.000, respectively). Russian conditions presented a higher total intensity when compared to the Aussie currents ($p < 0.001$; $p = 0.001$) (Figure 3.A). In terms of intensity during fatigue, the duty cycle had a significant effect ($p = 0.011$, $F = 6.911$, ηρ2: 0.138, power: 0.729), with the duty cycle of 20% resulting in lower intensity compared to a duty cycle of 10% ($p < 0.011$) (Figure 3.B).

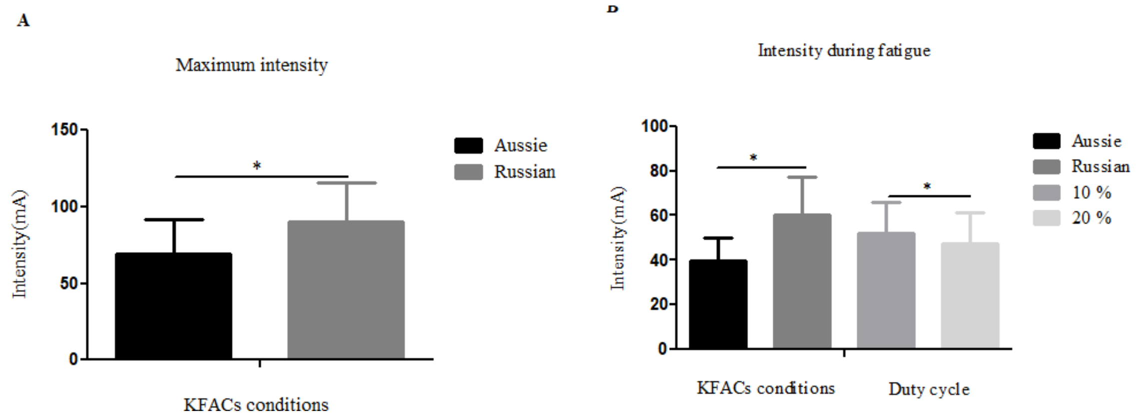


Figure 3. A: Aussie currents demonstrating lower current intensity compared to the Russian current protocols (p = 0.0001). **B:** Aussie currents showing a lower current intensity level when compared to the Russian current protocols (p = 0.0001), and the 20% duty cycle resulting in a lower current intensity when compared to the 10% duty cycle (p = 0.0265).

Maximal Evoked Torque (MET) and Torque-time integral (TTI)

Regarding MET, no significant interaction effect was found between current, duty cycle, and time (p = 0.0690, F = 3.4768, ηρ2: 0.0748, power = 0.4455). However, a main effect was observed for the current used (p = 0.0022, F = 10.6070, ηρ2: 0.1978, power: 0.8893), with the Aussie current protocols resulting in a higher MET compared to the Russian current protocols (p = 0.0023) (Figure 4.A). Regarding TTI relative to MET, no significant interaction effect was found between current, duty cycle, and time (p = 0.5899, F = 0.2950, ηρ2: 0.0069, power = 0.0828). However, a main effect was observed for the current used (p = 0.0074, F = 7.8988, ηρ2: 0.1582, power: 0.7839), with the Aussie current protocols resulting in a higher generation of TTI compared to the Russian current protocols (p = 0.0076) (Figure 4.B).

Fatigue protocol torque-time integral (TTI)

Total TTI

When considering the total TTI (total sum of individual TTIs) of the fatigue protocol, a significant interaction effect was found between current and duty cycle (p = 0.0173, F = 5.90, ηρ2: 0.0695, power = 0.6699). Moreover, a main effect was observed between Aussie 10% and Russian 10% (p = 0.0001), Aussie 10% and Russian 20% (p = 0.0001), Aussie 20% and Russian 10% (p = 0.0001), and Aussie 20% and Russian 20% (p = 0.0001) (Figure 4.D).

TTI decline

When considering the decline in TTI, no significant interaction effect was found between current, duty cycle, and time (p = 0.2791, F = 1.2013, ηρ2: 0.0271, power = 0.1884). However, a main effect was observed for the current used (p = 0.0236, F = 5.5024, ηρ2: 0.1134, power: 0.6304), with the Aussie currents resulting in a smaller drop in TTI when compared to the Russian current protocols (p = 0.0237) (Figure 4.E).

Fatigue Index

When considering the fatigue index, no significant interaction effect was found between current, duty cycle, and time (p = 0.7714, F = 0.085, ηρ2: 0.0019, power = 0.0594). However, a main effect was observed for the current used (p = 0.0015, F = 11.46, ηρ2: 0.2105, power: 0.9115), with the Aussie currents resulting in a smaller fatigue index when compared to the Russian current protocols (p = 0.0016) (Figure 4.F).

Number of contractions for a 50% drop in evoked torque

When examining the number of contractions until a drop of 50% was observed in the evoked torque, no significant interaction effect was found between current and duty cycle (p = 0.7742, F = 0.0852, ηρ2: 0.0056, power = 0.0586). However, a main effect was observed for the current used (p = 0.0171, F = 7.1774, ηρ2: 0.3236, power: 0.7070), with the Russian current protocols showing a faster decline to fifty percent of the initial MET compared to the Aussie current protocols (p = 0.0173) (Figure 4. C).

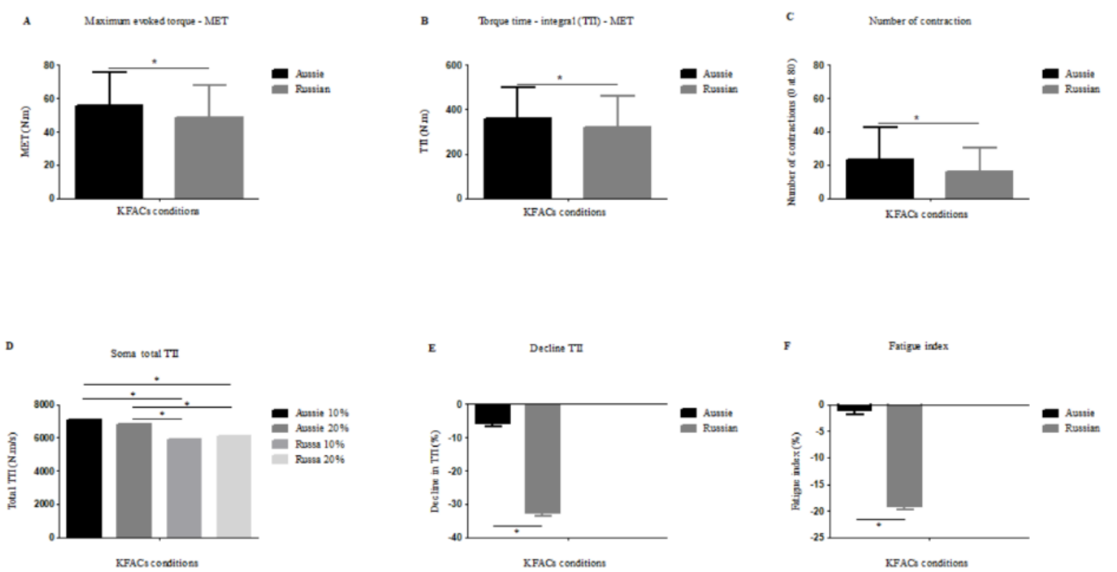


Figure 4. A: Aussie current protocols resulting in a higher generation of maximal evoked torque (MET) compared to the Russian current protocols (p = 0.0023). B: Aussie current protocols resulting in a higher torque-time integral (TTI) compared to the Russian current protocols (p = 0.0076). C: Russian current protocols showing a faster decline to fifty percent of the initial MET compared to the Aussie current protocols (p = 0.0173). D: Higher total TTI for the Aussie currents compared to the Russian currents. Aussie 10% and Russian 10% (p = 0.0001), Aussie 10% and Russian 20% (p = 0.0001), Aussie 20% and Russian 10% (p = 0.0001), and Aussie 20% and Russian 20% (p = 0.0001). E: Aussie currents resulting in a smaller drop in TTI when compared to the Russian current protocols (p = 0.0237). F: Aussie currents resulting in a smaller fatigue index when compared to the Russian current protocols (p = 0.0016).

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

In terms of RMS, there was no significant interaction effect between current, duty cycle, and time for GM, GL, and SOL (p = 0.3263, F = 0.9864, ηρ2: 0.0229, power = 0.1629; p = 0.1245, F = 2.4569, ηρ2: 0.0552, power = 0.3344; p = 0.7577, F = 0.0963, ηρ2: 0.0022, p = 0.0606, respectively) (Figure 5. B and C). However, a significant main effect for time was found in SOL (p < 0.0000, F = 2459, ηρ2: 0.3638, power = 0.9980), indicating a decrease in the signal between the pre- and post-evaluations (p = 0.0001) (Figure 5.C). Regarding MF, no significant interaction effect was found between current, duty cycle, and time for GM, GL, and SOL (p = 0.8518, F = 0.035, ηρ2: 0.0008, power = 0.0538; p = 0.4740, F = 0.522, ηρ2: 0.0122, power = 0.1087; p = 0.3353, F = 0.950, ηρ2: 0.0221, power = 0.1586, respectively). However, significant main effects were observed in GM and GL for duty cycle (p = 0.0098, F = 7.318, ηρ2: 0.1483, power = 0.7526; p = 0.0009, F = 12.553, ηρ2: 0.2301, power = 0.9333, respectively), where the 10% duty cycle presented a lower MF value when compared to the 20% duty cycle (p = 0.0099 and p = 0.0011, respectively). Similarly, there was a time effect (p < 0.0000, F = 23.819, ηρ2: 0.3618, power = 0.9974; p = 0.0032, F = 9.780, ηρ2: 0.1888, power = 0.8632, respectively), with a decrease in MF values between the pre and post assessments (p = 0.0001 and p = 0.0033, respectively). Additionally, a significant main effect for time was found in SOL (p < 0.0000, F = 29.523, ηρ2: 0.4127, power = 0.9995), indicating a decrease in the signal MF between the pre- and post-evaluations (p = 0.0001) (Figure 5.D, 4.E and 4.F).

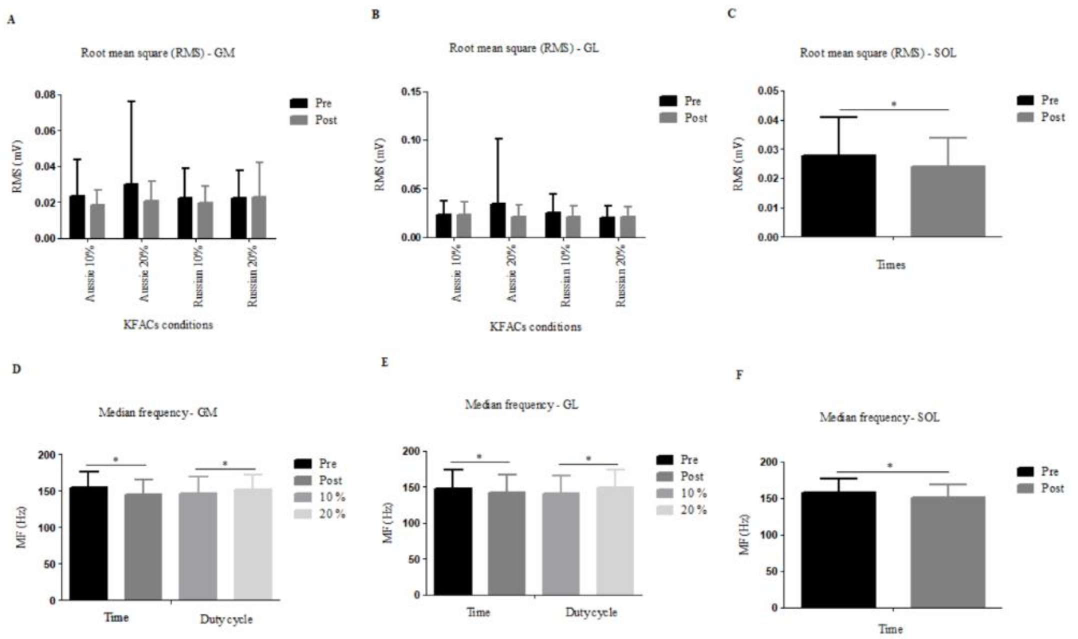


Figure 5. A: No difference in root mean square (RMS) values between protocols for GM **B:** No between-protocols difference for RMS in GL. **C:** Difference in SOL showing a decrease in RMS between the pre and post evaluations ($p < 0.001$). **D:** Difference in GM showing a decrease in median frequency (MF) between the pre and post evaluations ($p < 0.001$) and the 10% duty cycle's MF being smaller than duty cycle 20% ($p = 0.009$). **E:** Difference in GL showing a decrease in MF between the pre and post evaluations ($p < 0.003$) and the duty cycle with MF in the 10% being smaller than the 20% duty cycle ($p = 0.001$). **F:** Difference in SOL showing a decrease in MF between the pre and post evaluations ($p < 0.001$).

Efficiency during fatigue

Regarding efficiency during the fatigue protocol, no significant interaction effect was found between current, duty cycle, and time ($p = 0.9979$, $F = 0.0000$, $\eta\rho2$: 0.0000, power = 0.0500). However, a significant main effect was observed for the current used ($p < 0.0000$, $F = 79.6684$, $\eta\rho2$: 0.6494, power: 1.0000), with the Aussie currents demonstrating higher efficiency compared to the Russian current protocols ($p = 0.0001$) (Figure 6.A).

Discomfort

When considering total discomfort, no significant interaction effect was found between current, duty cycle, and time ($p = 0.9629$, $F = 0.002$, $\eta\rho2$: 0.0000, power = 0.0502). However, a main effect was observed for the current used ($p = 0.0396$, $F = 4.508$, $\eta\rho2$: 0.0969, power: 0.5456), with the Aussie currents resulting in a higher level of discomfort when compared to the Russian current protocols ($p = 0.0397$) (Figure 6.B).

As for discomfort during the fatigue protocol, no significant interaction effect was found between current, duty cycle, and time (p = 0.8744, F = 0.1344, ηρ2: 0.0039, power = 0.0698). However, a significant main effect was observed for time (p < 0.0000, F = 19.8437, ηρ2: 0.3685, power: 0.9999), with discomfort decreasing from the 1st to the 40th contraction (p = 0.0002) and from the 40th to the 80th contraction (p = 0.0001) (Figure 6.C).

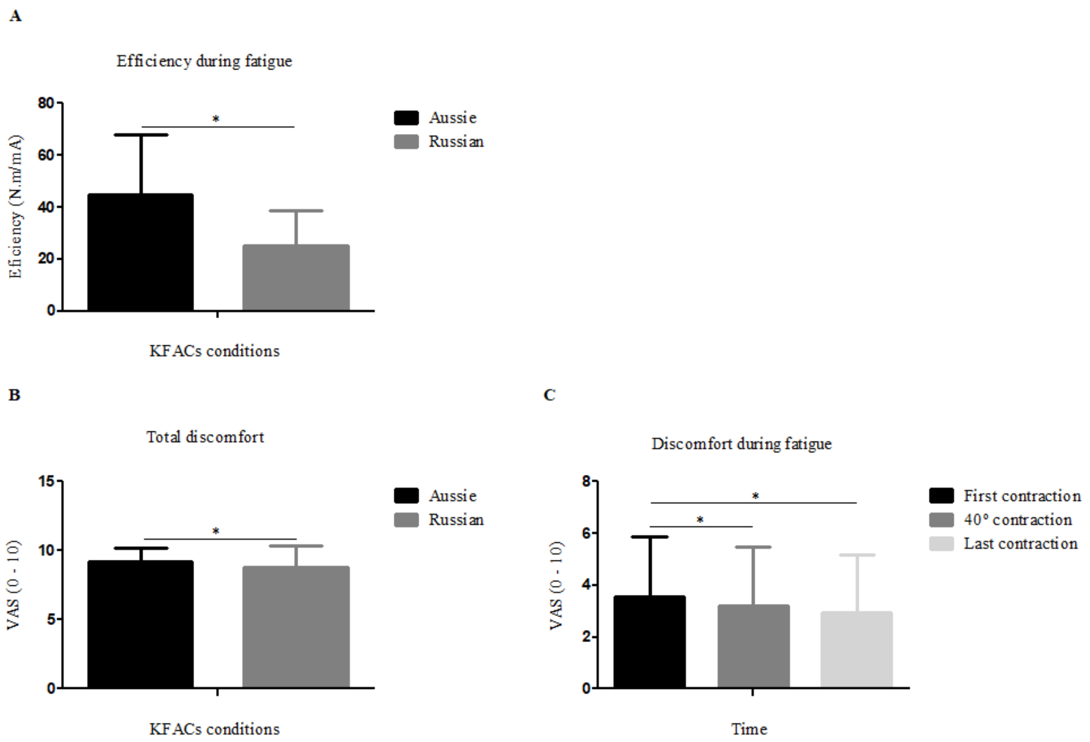


Figure 6. A: Aussie currents demonstrating higher efficiency compared to the Russian current protocols (p = 0.0001). **B:** Aussie currents resulting in a higher level of discomfort when compared to the Russian current protocols (p = 0.0397). **C:** Discomfort being lower at 40th compared to the first contraction (p = 0.0002) and at the last contraction compared to the 40th (p = 0.0001).

Spinal excitability

As for H-reflex, no significant interaction effect was found between current, duty cycle, and time for GM and GL (p = 0.2181, F = 1.5633, ηρ2: 0.0358, power = 0.2309; p = 0.3950, F = 0.7384, ηρ2: 0.0172, power = 0.1338, respectively). However, a main effect was observed in GM for currents and time (p = 0.0183, F = 6.0225, ηρ2: 0.1254, power = 0.6692) between Aussie 10% post and Aussie 20% post (p = 0.0001), Russian 10% post and Russian 20% post (p = 0.0002), and Aussie 10% post and Russian 20% post (p =

0.0001). Additionally, a main effect for time was found in GL ($p < 0.00001$, F = 31.5179, ηρ2: 0.4287, power = 0.9997), with an increase in the post-value compared to the pre-value (p = 0.0001). For SOL, an interaction effect was found between current, duty cycle, and time (p = 0.0125, F = 6.7972, ηρ2: 0.1364, power = 0.7219) between Aussie 20% post and Russian 20% post (p = 0.0186) (Figures 7. A, B and C).

Concerning M-wave, no significant interaction effect was found between current, duty cycle, and time for GM, GL, and SOL (p = 0.8060, F = 0.061, ηρ2: 0.0014, power = 0.0567; p = 0.5904, F = 0.294, ηρ2: 0.0069, power = 0.0827; p = 0.6933, F = 0.158, ηρ2: 0.0036, power = 0.0674, respectively). However, a main effect for time was found in SOL ($p < 0.00001$, F = 88.651, ηρ2: 0.6733, power = 1.0000), indicating a higher pre-value compared to the post-value (p = 0.0001).

Finally, regarding the relationship between H-reflex and M-wave, no significant interaction effect was found between current, duty cycle, and time for GM and GL (p = 0.8122, F = 0.0571, ηρ2: 0.0013, power = 0.0562; p = 0.3209, F = 1.0089, ηρ2: 0.0234, power = 0.1655, respectively). However, a main effect was observed in GM for currents and time (p = 0.0073, F = 7.9480, ηρ2: 0.1591, power = 0.7864) between Aussie 10% post and Aussie 20% post (p = 0.0001), Aussie 10% post and Russian 20% post (p = 0.0001), and Russian 10% post and Russian 20% post (p = 0.0117). In addition, there was a main effect for time in GL (p = 0.0005, F = 13.8546, ηρ2: 0.2480, power = 0.9531), with a lower pre-value compared to the post-value (p = 0.0006). For SOL, an interaction effect was found between current, duty cycle, and time (p = 0.0138, F = 6.5858, ηρ2: 0.1328, power = 0.7083), showing a decrease between the pre and post evaluations for Aussie 20% (p = 0.0033) and Russian 10% currents (p = 0.0007) (Figure 7.D, E and F).

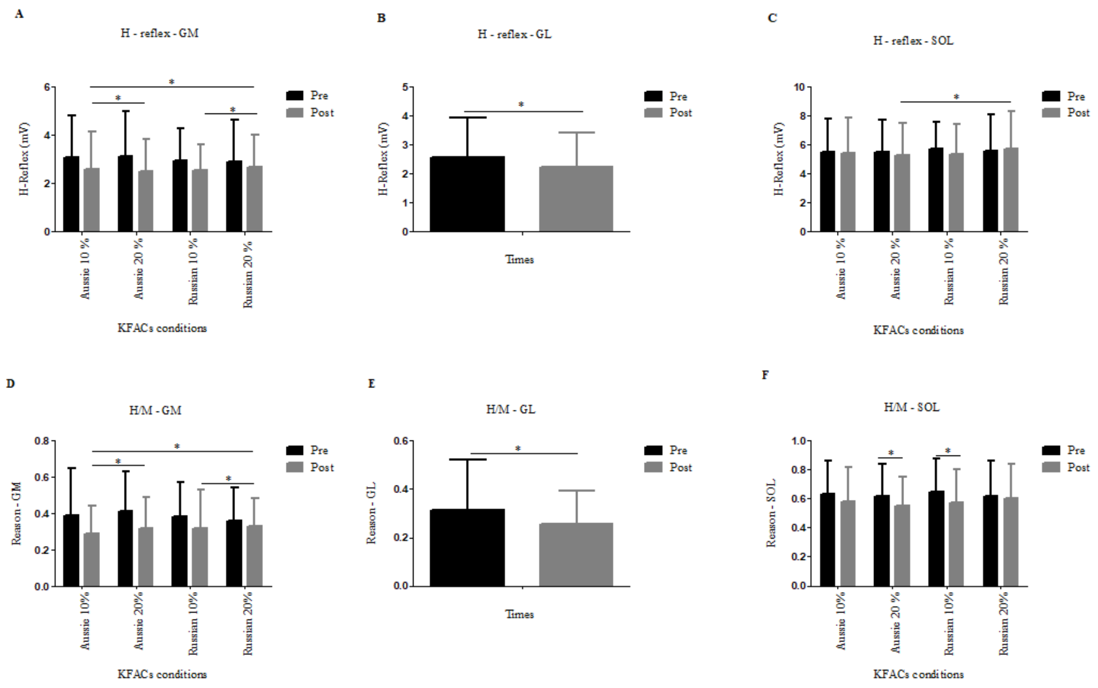


Figure 7. A: Difference in GM's H-reflex between Aussie 10% post and Aussie 20% post (p = 0.0001), Russian 10% post and Russian 20% post (p = 0.0002), and Aussie 10% post and Russian 20% post (p = 0.0001). **B:** Difference in GL's H-reflex with a decrease in the post-value compared to the pre-value (p = 0.0001). **C:** Difference in SOL's H-reflex between Aussie 20% post and Russian 20% post (p = 0.0186). **D:** Difference in GM's H/M between Aussie 10% post and Aussie 20% post (p = 0.0001), Aussie 10% post and Russian 20% post (p = 0.0001), and Russian 10% post and Russian 20% post (p = 0.0117). **E:** Difference in GL's H/M with a decrease in the post-value compared to the pre-value (p = 0.0006). **F:** Difference in SOL's H/M showing a decrease between the pre and post evaluations for Aussie 20% (p = 0.0033) and Russian 10% currents (p = 0.0007).

Mechanical properties and central activation ratio (CAR)

Regarding CAR, no significant interaction effect was found between current, duty cycle, and time (p = 0.0573, F = 3.81, ηρ2: 0.0814, power = 0.4797).

DISCUSSION

To the best of our knowledge, this study is the first to summarize differences in carrier frequency (2.5 kHz for Russian current and 1 kHz for Aussie current) and burst duty cycle (2 ms or 4 ms) with a matched burst frequency and duration on both peripheral and central pathways for contraction fatigability. The effects of different KFAC types demonstrated that Aussie (with a lower carrier frequency) induced less fatigability and higher NMES efficiency compared to higher carrier frequencies (Russian current).

NMES-induced fatigue was reduced when using a 20% duty cycle compared to the 10% duty cycle. Our data did not show a clear effect on central activation during NMES-induced fatigue, suggesting that all effects on contraction fatigability are peripheral. Although Aussie current induced greater perceived discomfort after NMES-induced fatigue, there was no significant difference in discomfort during the fatigue protocol. These findings may provide clinicians with valuable information to design more effective and rational NMES strategies by manipulating KFAC parameters to reduce both contraction fatigability and discomfort without expecting differences in central nervous system excitability for the rehabilitation of impaired muscles.

We conducted an 80 NMES-induced contraction protocol similar to another fatigue study that compared alternating current to pulsed current (PAZ et al., 2021). The torque-time integral (TTI) was utilized to evaluate fatigue, as it has been used to assess motor unit fatigue by reflecting work performed by the activated motor units (NEYROUD et al., 2014; ROZAND et al., 2015). Our findings indicated that the Aussie current demonstrated higher total TTI, lower fatigue index, and a greater number of contractions in our 20% MVIC fatigue protocol compared to the Russian current. This suggests a higher mechanical output from the activated motor unit pool with the Aussie current than with the Russian current.

A previous study has shown a significantly greater contraction fatigability for the Russian current (2.5 kHz) compared to the other current (IIJIMA et al., 2018; PAZ et al., 2021; YOCHEVED LAUFER, ELBOIM, 2008), and these results seemingly follow a fatigue pattern associated with a phenomenon known as "high-frequency fatigue" (JONES, 1996). This contraction fatigability was described as a failure in the propagation of action potentials within the muscle fibers (WESTERBLAD et al., 1990). The occurrence of this mechanism can be confirmed after identifying Ca2+ gradients within the fibers, indicating a lack of activation in central regions due to failure in internal action potential propagation (JONES, 1996; WESTERBLAD et al., 1990), as observed after KFAC protocols (LAUFER; ELBOIM, 2008). One could argue that this failure in propagation is related to an increase in the excitability threshold of motor axons due to repetitive activation, leading to a reduction in the number of recruited motor units (MATKOWSKI; LEPERS; MARTIN, 2015; WARD, 2009). Thus, the Aussie current would be favored by the lower number of cycles per second because, regardless of the duty cycle used, the Aussie current showed a higher total TTI. The Russian current may have led to a reduction in the number of recruited motor units compared to the Aussie current due to changes in axonal excitability threshold. This is indicated by a higher number of pulses leading to repetitive activation of motor neurons, resulting in decreased response to excitatory synaptic stimuli and contributing to a greater loss of force (TAYLOR et al., 2016; WAN et al., 2017). The longer pulse duration (500 μs) associated with the Aussie current could likely facilitate greater activation of sensory axons as well, which may explain why it exhibited lower fatigue (BASTOS et al., 2021) due to the increased recruitment of motor units via reflex pathways.

Two different studies examined contraction fatigability using KFACs (PARKER et al., 2011; LAUFER; ELBOIM, 2008). Laufer and Elboim (2008) used a KFAC (2.5 kHz) with 3 burst frequencies and 3 duty cycles (50 Hz – 50%, 50 Hz – 20%, and 20 Hz – 20%). They observed no difference in the degree of fatigue between KFACs that differed only in their burst frequencies (20 Hz versus 50 Hz) and not in their total cycles per second (25 cycles per second). Meanwhile, the comparison between the two currents with equal burst frequencies (50 Hz) showed significantly greater fatigue when the burst duration was longer and included 25 cycles per burst (50 Hz – 50%), as opposed to the shorter burst duration with 10 cycles per burst (50 Hz – 20%). Thus, the contraction fatigability rate induced by KFAC was clearly related to the total number of pulses (cycles per burst) delivered rather than the number of bursts (burst frequency). In contrast, Parker et al. (2011) used a KFAC (2.5 kHz) with 3 burst frequencies and 3 duty cycles (50 Hz – 10%, 50 Hz – 90%, and 100 Hz – 10%) and found no difference in fatigue between the stimulation patterns, only that shorter duty cycles (50 Hz – 10% vs 100 Hz – 10%) produced stronger electrically elicited muscle contractions (PARKER et al., 2011). However, these studies did not use different carrier frequencies in their comparison, modifying only the burst frequency or duty cycle.

Our study is the first to compare only KFACs regarding contraction fatigability, maintaining burst frequency, repeating duty cycles (10% and 20%), and modifying only the carrier frequency of the currents. Based on Laufer and Elboim (2008), who showed that NMES-induced contraction fatigability was influenced by the number of cycles per second delivered to the muscle rather than the number of bursts per second, our study supports the findings of Laufer and Elboim (2008). This is because the Russian current exhibited a higher fatigue rate compared to the Aussie current. This condition can be explained by the number of cycles per second delivered to the muscle, with burst frequency kept at 50 Hz and equal duty cycles (10% and 20%) applied for both currents. Therefore, the Russian current may have a greater frequency of cycles per second compared to the Aussie current. Another factor that could account for these findings is the carrier frequency of each current (Aussie: 1 kHz; Russian: 2.5 kHz). According to Parker et al., higher carrier frequencies and/or longer duty cycles can elevate the number of cycles (or action potentials) per second delivered to the muscle and increase muscle fatigue, as long as burst frequency remains consistently constant (PARKER et al., 2011). This is evident in our study, as it not only demonstrates a disparity in fatigue between the Aussie and Russian currents across most analyzed variables, but also reveals a variance in duty cycles (10% and 20%), with the 20% duty cycle resulting in higher fatigue (lower median frequency for the gastrocnemius muscles post-fatigue). Laufer and Elboim (2008) proposed that an action potential occurred every 5 cycles within each burst; therefore, the 50 Hz current (20% duty cycle) with 10 cycles per burst and 50 bursts per second had the same total number of action potentials as the 20 Hz current (20% duty cycle), with 25 cycles per burst and only 20 bursts per second (a total of –100 action potentials). Using this rationale, a current with a relatively lengthy burst duration (25 cycles) at a burst frequency of 50 Hz could have generated a total of 250 action potentials.

In our study, it can be observed that the 10% duty cycles determined a lower number of action potentials compared to the 20% duty cycles. This is evident from the median frequency results, particularly for the gastrocnemius muscles. Despite using the same burst frequency (50 Hz) for all protocols, longer burst durations present in the 20% duty cycles with 10 cycles per burst showed a higher level of fatigue due to a decrease in action potential speed compared to shorter burst durations found in the 10% duty cycles with only 5 cycles per burst. Therefore, it appears that fatigue is more closely associated with the total number of cycles per second rather than just focusing on individual bursts (LAUFER; ELBOIM, 2008). From our findings, we believe that carrier frequency could contribute to an increase in cycle count and have a stronger association with fatigue based on differences seen between currents, overriding any significant difference attributed solely to duty cycle, especially noticeable for gastrocnemius muscles and specifically within median frequencies. In addition, a decrease in pre- and post-assessment values for RMS and MF for the SOL muscle, indicates a reduction in the activation of muscle fibers and in the speed of the action potential passing through the fiber (BANDPEI et al., 2014; ESPOSITO; ORIZIO; VEICSTEINAS, 1998), as a general indicator of contraction fatigability between KFAC protocols. Regarding the duty cycle, shorter duty cycles result in higher evoked torque, possibly because burst durations exceeding 4 ms can generate an excessive number of action potentials, leading to neurotransmitter depletion, signal propagation failure, or nerve conduction blockage, resulting in synaptic fatigue (SZECSI; FORNUSEK, 2014; LIEBANO; WASZCZUK; CORRÊA, 2013). Thus, shorter duty cycles with longer inter-burst intervals allow the delivery of a higher current amplitude (MODESTO et al., 2022). This aligns with the findings of Parker et al. (2011), where higher MET values were demonstrated when using shorter duty cycles (10%) with burst/inter-burst durations (2/18 and 1/9) compared to longer duty cycles (90%) with burst/inter-burst durations (18/2).

The intrinsic relationship between carrier frequency and pulse duration should be considered since the carrier frequency is inversely proportional to pulse duration (WARD; ROBERTSON; IOANNOU, 2004). This fact may explain why lower carrier frequencies result in higher torques. The variation in the diameter of motor axons that innervate skeletal muscle fibers influences the recruitment of motor units (LI; BAK, 1976; WARD; ROBERTSON; IOANNOU, 2004). Wider pulses have the ability to engage larger-diameter axons, resulting in higher torque production (LI; BAK, 1976; MEDEIROS et al., 2017; WARD; ROBERTSON; IOANNOU, 2004). These pulses may also activate a wide range of sensory neurons, stimulating motor neurons through reflex pathways and recruiting more motor units (BARSS et al., 2018; BASTOS et al., 2021). For example, Medeiros et al. (2017) used two pulsed currents (500 µs and 200 µs) and two KFACs (500 µs and 200 µs) and demonstrated that NMES with a longer pulse duration evoked higher torque, regardless of the carrier frequency. This can be demonstrated in our study, where the Aussie current, with a pulse duration of 500 µs, showed higher MET values when compared to the Russian current, which has a pulse duration of 200 µs. Therefore, variations observed in torque production associated with KFAC carrier frequencies may not be exclusively attributable to these carrier frequencies, but also depend on the current’s pulse duration. However, Medeiros et al. (2017) did not assess fatigue, making it impossible to observe whether pulse duration could indeed influence muscle fatigue beyond evoked torque. We could speculate that a longer pulse duration (500 µs) might enable greater activation of sensory axons (BASTOS et al., 2021). In our study, no significant differences were observed for the H-reflex that could confirm an increase in sensory inputs. However, modifications may occur at the level of the cerebral cortex, which could be better explained through studies involving transcranial stimulation. While no statistically significant differences were found between the applied protocols for the H-reflex that could confirm an increase in sensory inputs, sensory inputs may occur at the level of the cerebral cortex. This could be better explained through studies involving transcranial motor-evoked potential (MEP) in further investigations.

Fatigue can occur through two pathways, peripheral or central, where peripheral mechanisms involve those below the spinal cord or at the site of stimulation, and central mechanisms encompass all contributions from the brain and spinal cord (BARSS et al., 2018). Conventional NMES generates contractions predominantly by activating motor axons under the stimulation electrodes, thus via a peripheral pathway (BARSS et al., 2018), with the sensory voltage sent to the spinal cord being relatively small. Consequently, the central contribution to the evoked force is reduced when NMES is applied over a muscle belly, and contractions are predominantly generated by peripheral pathways (BARSS et al., 2018). This aligns with our study, as the calculation of central contribution (CAR), a method applied for central contribution calculation (DE OLIVEIRA et al., 2018; KENT-BRAUN, 1999; PAJOUTAN; GHESMATY; SANGACHIN; CAVUOTO, 2017), showed no difference for any of the applied protocols. This could be explained by the fact that, in our study, NMES was applied conventionally, i.e., on the muscle belly with direct activation of the motor axon, and not on the nerve trunk. Applying NMES on the nerve trunk would activate central pathways and approach force generation following the Henneman’s Size Principle, which could decrease the fatigue generated by the stimulation protocols (BARSS et al., 2018; BERGQUIST et al., 2014).

Carrier frequency, pulse duration, and duty cycle are factors that influence the efficiency of the used current, as these parameters are linked to torque generation. An efficient current is one that can generate maximum evoked force using the lowest current intensity tolerated during stimulation (DAMO et al., 2021). Our findings show that the Aussie current demonstrates higher efficiency during the fatigue protocol application, corroborating previous studies demonstrating that currents with lower carrier frequencies exhibit better efficiency (SELKOWITZ; ROSSMAN; FITZPATRICK, 2009), lower duty cycles provide better current efficiency (MCLODA; CARMACK, 2000), and longer pulse durations present better efficiency (DAMO et al., 2021).

Current intensity is influenced by the presence of the skin and subcutaneous adipose tissue, which act as capacitive barriers to electrical flow; thus, increasing the NMES frequency aims to progressively reduce the impedance of these barriers (WARD; ROBERTSON; MAKOWSKI, 2002). At kilohertz levels, lower impedance is expected, resulting in less dissipation of electrical energy in the superficial epidermis (VAZ;

FRASSON, 2018). Less energy dissipation would provide a greater amount of electrical energy available to stimulate the underlying tissue in the context of KFAC. Additionally, the response of nerve fibers to successive kilohertz frequency pulses produced by each cycle of alternating current is expected to summate and produce a single action potential in response to each KFAC burst (WARD; ROBERTSON; MAKOWSKI, 2002). This action potential would activate a larger proportion of motor axons due to the higher electrical energy of KFAC. Therefore, the higher the carrier frequency, the more efficient the stimulation of deeper-located nerves would be. If indeed true, then KFACs with higher carrier frequencies should be more efficient than those with lower carrier frequencies (e.g., 4.0 kHz > 2.5 kHz > 1.0 kHz). However, the available evidence does not support this conclusion (MODESTO et al., 2022), as indicated by a recent systematic review that suggests that lower carrier frequencies provide higher evoked torque (MODESTO et al., 2022), consistent with the findings of our study.

Another way to determine current efficiency is to compare the current intensity of different types of NMES when the muscle is generating the same amount of force. In this case, the more efficient NMES is the one that requires less current intensity to generate a specific predefined amount of evoked force (SELKOWITZ; ROSSMAN; FITZPATRICK, 2009; VAZ; FRASSON, 2018). In the present study, it was demonstrated that the Aussie current generated a higher evoked torque with a lower amount of energy (current intensity) applied to the tissue for torques evoked during the fatigue protocol. This shows that the condition in the context of KFACs, where higher carrier frequencies are more efficient, is not supported.

NMES-induced discomfort can be a limiting factor for the effectiveness of NMES application. According to Modesto et al. (2022), the lowest discomfort perception occurs with frequencies between 2.5 kHz and 5 kHz and duty cycles below 50%. Indeed, our study show that the Aussie current (1 kHz) appears to elicit more discomfort under maximum conditions (maximum evoked contraction) compared to the Russian current. However, during the fatigue protocol, there was no difference between the currents, only a difference in the onset, middle, and end of discomfort perception over time. The variance in results can be explained by the emotional dimension of discomfort perception, resulting in individual variability, where past negative experiences with NMES, fear, apprehension, and anxiety levels can influence perceived discomfort related to NMES (DELITTO et al., 1992; MEDEIROS et al., 2017). Apparently, there is an increase in tolerance to NMES with repeated sessions. In other words, healthy individuals may condition themselves to tolerate electrically induced contractions in the quadriceps muscles when repeatedly exposed to NMES (ALON; SMITH, 2005).

LIMITATIONS

The study has certain limitations. The prolonged duration (2-3 min) between the end of the fatigue protocol and the MVIC assessment may have impacted the absence of strength loss between pre-assessment and post-assessment of MVIC. Our use of only short duty cycles (10% and 20%) may have restricted detection of differences between duty cycles that might have been apparent with a protocol featuring longer cycles, such as 50% or more. Additionally, since we did not assess MET through transcranial stimulation, it did not allow us to evaluate sensory inputs in the cerebral cortex to assess the possible effects of KFAC on central fatigue.

CONCLUSION

The Aussie current demonstrate advantage over the Russian current by inducing less fatigability and promoting higher neuromuscular efficiency in healthy individuals, particularly with 10% duty cycles. Despite a slightly higher level of discomfort associated with Aussie, the absence of a significant difference in discomfort during fatigue protocols highlights the overall superiority of Aussie compared to the Russian Current.

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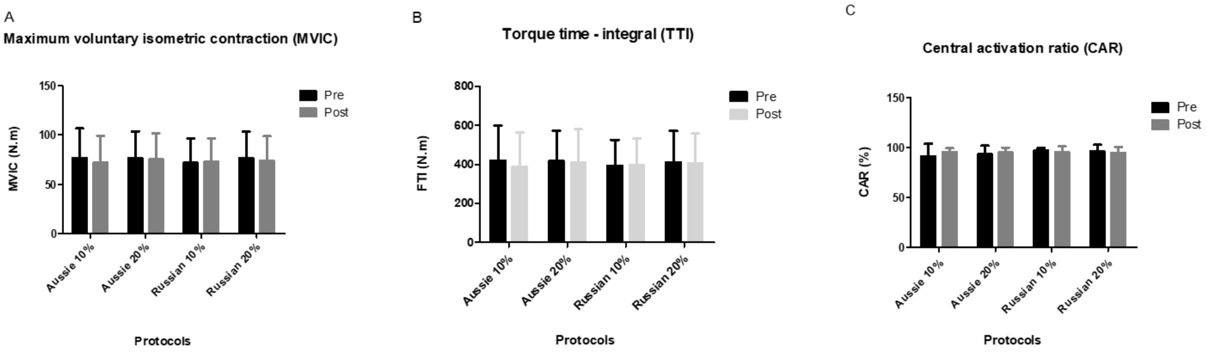
SUPPLEMENTARY MATERIAL I



CONCLUSÃO GERAL

Ao final da elaboração desses 3 artigos concluímos que para a programação de protocolos de estimulação elétrica neuromuscular com melhor eficiência desse método terapêutico sugere-se que ao usar correntes alternadas com frequências em quilohertz buscando maior geração de torque com menor desconforto e menor fadiga de contração o mais indicado é utilizar frequências portadoras de 1 kHz com duração de pulsos de 500 µs e iclos de trabalho de 20% com duração de bursts de 4 ms e interbursts de 16 ms, tanto em condições máximas como submáximas. A provável fadiga gerada na utilização da corrente será preferencialmente periférica.

ANEXOS

UNIVERSIDADE DE BRASÍLIA – UnB

FACULDADE DE CEILÂNDIA

Termo de Consentimento Livre e Esclarecido - TCLE

Convidamos o(a) Senhor(a) a participar do projeto de pesquisa **Estimulação elétrica neuromuscular: Comparação de frequências portadoras, durações de bursts e ciclos de trabalhos na geração de torque evocado, desconforto sensorial, fadiga muscular e extração periférica de oxigênio**, sob a responsabilidade da pesquisadora Karenina Arrais Guida Modesto. Trata-se de uma pesquisa que utiliza como terapia a estimulação elétrica neuromuscular, mediante contrações musculares para melhoraria da fraqueza no musculo da panturrilha. Esse estudo procura entender qual a melhor forma de realizar essa estimulação elétrica com menor desconforto e "cansaço" do músculo para que várias pessoas possam ser beneficiadas com esta terapia.

Assim o objetivo deste estudo é comparar os efeitos de 4 diferentes tipos de estimulação elétrica na panturrilha de indivíduos saudáveis para força, fadiga muscular, consumo de oxigênio do músculo e desconforto para o indivíduo.

O(a) senhor(a) receberá todos os esclarecimentos necessários antes e no decorrer da pesquisa e lhe asseguramos que seu nome não aparecerá, sendo mantido o mais rigoroso sigilo pela omissão total de quaisquer informações que permitam identificá-lo(a).

A sua participação se dará por meio de avaliações diversas, onde você terá várias das suas habilidades físicas e fisiológicas avaliadas como a força do joelho, desconforto sensorial, fadiga muscular ("cansaço do músculo") e consumo de oxigênio. Importante ressaltar que nenhum dos procedimentos da pesquisa será invasivo. Todos os procedimentos serão realizados na Universidade de Brasília – Faculdade de Ceilândia. A sua participação será dividida em 6 encontros ao laboratório, sendo um encontro por semana.

Dessa forma:

Familiarização

- Primeiramente faremos algumas perguntas com relação a sua saúde, e caso haja alguma pergunta que o(a) senhor(a) não queira responder ou cause qualquer tipo de constrangimento a entrevista será interrompida. Caso possa, continuaremos com a entrevista e realizaremos uma avaliação. A avaliação será para que o senhor (a) se familiarize com o protocolo e procedimentos do estudo. Será composta pela verificação das medidas antropométricas (peso, altura e IMC), familiarização com os os tipos de estimulação elétrica. A entrevista e a avaliação tem duração de aproximadamente 1 hora.

Encontros 1, 2, 3, 4 e 5: Intervenção

- Serão compostos por um aquecimento físico, foça máxima, contração do músculo feita pela estimulação elétrica, sensação de desconforto, avaliação da fadiga ("cansaço do músculo") e consumo de oxigênio feito pelo músculo. Os encontros 1, 2, 3, 4 e 5 serão compostos de forma iguais, exceto pelo protocolo de estimulação que será diferente para cada encontro, assim o senhor participará dos 4 tipos diferentes de protocolos de estimulação elétrica. As etapas de aquecimento e força máxima terão duração média de 10 minutos. A de estimulação elétrica terá duração média de 20 minutos. A avaliação do desconforto sensorial terá duração de 3 minutos. E as etapas de avaliação de fadiga muscular e consumo de oxigênio ocorrerá durante todo o experimento. O intervalo entre cada encontro será de 7 dias entre eles. Todos os encontros terão duração de no máximo 1 hora.

O(a) Senhor(a) poderá se recusar a responder (ou participar de qualquer procedimento) qualquer questão que lhe traga constrangimento, podendo desistir de participar da pesquisa em qualquer momento sem nenhum prejuízo para o(a) senhor(a).

Riscos

Os riscos decorrentes de sua participação na pesquisa são: Durante as avaliações de força máxima poderá ocorrer um aumento da sua pressão arterial e frequência cardíaca como comumente esperado durante atividades físicas desta magnitude. Tanto a pressão arterial quanto a frequência cardíaca serão monitorados antes, durante e imediatamente após a realização do teste. Caso quaisquer alterações fora dos padrões de normalidade sejam observadas, ou caso o(a) senhor(a) não se sinta confortável para continuar, o teste será interrompido imediatamente e todas as medidas de cuidados para a sua saúde serão providenciados. Durante os procedimentos que envolvem estimulação elétrica, poderá ocorrer fadiga muscular ("cansaço do músculo"), desconforto sensorial e dor muscular de início tardio. Caso quaisquer alterações fora dos padrões de normalidade sejam observadas, ou caso o(a) senhor(a) não se sinta confortável para continuar, o teste será interrompido imediatamente e todas as medidas de cuidados para a sua saúde serão providenciados. As dores musculares de início tardio poderão ser minimizadas com aplicação de compressa de gelo, e repouso. Caso os sintomas se exacerbem, os pesquisadores se responsabilizarão por providenciar o atendimento médico emergencial e laboratorial necessários. O(a) Senhor(a) poderá se recusar a responder (ou participar de qualquer procedimento) qualquer questão que lhe traga constrangimento, podendo desistir de participar da pesquisa em qualquer momento sem nenhum prejuízo para o(a) senhor(a).

Benefícios

Caso o senhor (a) aceite participar do estudo estará colaborando para o aumento dos conhecimentos a respeito dos benefícios da estimulação elétrica. Isso poderá levar a melhores resultados nos tratamentos fisioterapêuticos. Os benefícios para os participantes será conhecer sua força muscular de forma voluntária e evocada pela estimulação elétrica, conhecer seus aspectos eletrotrofisiológicos assim como seus aspectos e características neurais e musculares e possíveis alterações eletrofisiológicas e musculares caso presente no participante.

Quaisquer despesas pessoais para o participante relacionadas diretamente ao projeto de pesquisa (tais como, passagem para o local da pesquisa, alimentação no local da pesquisa ou exames para realização da pesquisa) serão absorvidas pelo orçamento do projeto. Sua participação é voluntária, isto é, não há pagamento por sua colaboração.

Caso haja algum dano direto ou indireto decorrente de sua participação nessa pesquisa, você receberá assistência integral e gratuita, pelo tempo que for necessário, obedecendo os dispositivos legais vigentes no Brasil. Caso você/senhor/senhora sinta algum desconforto relacionado aos procedimentos adotados durante a pesquisa, o senhor(a) pode procurar o pesquisador responsável para que possamos ajudá-lo.

Os resultados da pesquisa serão divulgados na Universidade de Brasília-UnB, podendo ser publicados posteriormente. Os dados e materiais serão utilizados somente para esta pesquisa e ficarão sob a guarda do pesquisador por um período de cinco anos. Após isso, serão destruídos.

Se o(a) Senhor(a) tiver qualquer dúvida em relação à pesquisa, por favor telefone para: Karenina Arrais Guida Modesto (61) 982030936, na Universidade de Brasília- UnB no telefone (61) 996794277, disponível inclusive para ligação a cobrar ou ainda pelo e-mail kareninag.87@gmail.com.

Este projeto foi aprovado pelo Comitê de Ética em Pesquisa da Faculdade de Ceilândia (CEP/FCE) da Universidade de Brasília. O CEP é composto por profissionais de diferentes áreas cuja função é defender os interesses dos participantes da pesquisa em sua integridade e dignidade e contribuir no desenvolvimento da pesquisa dentro de padrões éticos. As dúvidas com relação à assinatura do TCLE ou os direitos do participante da pesquisa podem ser esclarecidas pelo telefone (61) 3107-8434 ou do e-mail cep.fce@gmail.com, horário de atendimento das 14h:00 às 18h:00, de segunda a sexta-feira. O CEP/FCE se localiza na Faculdade de Ceilândia, Sala AT07/66 – Prédio da Unidade de Ensino e Docência (UED) – Universidade de Brasília - Centro Metropolitano, conjunto A, lote 01, Brasília - DF. CEP: 72220-900.

Caso concorde em participar, pedimos que assine este documento que foi elaborado em duas vias, uma ficará com o pesquisador responsável e a outra com o Senhor(a).

____

Nome / assinatura

____

Pesquisador Responsável

Brasília, ___ de __________de _________.

REVISÃO SISTEMÁTICA

https://pubmed.ncbi.nlm.nih.gov/35121683/

Am J Phys Med Rehabil. 2023 Feb 1;102(2):175-183. doi: 10.1097/PHM.0000000000001982.
Epub 2022 Feb 3.

Effects of Kilohertz Frequency, Burst Duty Cycle, and Burst Duration on Evoked Torque, Perceived Discomfort and Muscle Fatigue: A Systematic Review

Karenina Arrais Guida Modesto [1], Júlia Aguillar Ivo Bastos, Marco Aurélio Vaz, João Luiz Quagliotti Durigan

Affiliations + expand

PMID: 35121683 DOI: 10.1097/PHM.0000000000001982

Abstract

Kilohertz-frequency alternating current is used to minimize muscle atrophy and muscle weakness and improve muscle performance. However, no systematic reviews have evaluated the best Kilohertz-frequency alternating current parameters for this purpose. We investigated the effects of the carrier frequency, burst duty cycles, and burst durations on evoked torque, perceived discomfort, and muscle fatigue. A search of eight data sources by two independent reviewers resulted in 13 peer-reviewed studies being selected, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, and rated using the PEDro scale to evaluate the methodological quality of the studies. Most studies showed that carrier frequencies up to 1 kHz evoked higher torque, while carrier frequencies between 2.5 and 5 kHz resulted in lower perceived discomfort. In addition, most studies showed that shorter burst duty cycles (10%-50%) induced higher evoked torque and lower perceived discomfort. Methodological quality scores ranged from 5 to 8 on the PEDro scale. We conclude that Kilohertz-frequency alternating current develops greater evoked torque for carrier frequencies between 1 and 2.5 kHz and burst duty cycles less than 50%. Lower perceived discomfort was generated using Kilohertz-frequency alternating currents between 2.5 and 5 kHz and burst duty cycles less than 50%.

Conflict of interest statement

Financial disclosure statements have been obtained, and no conflicts of interest have been reported by the authors or by any individuals in control of the content of this article.

UNIVERSITY of York
Centre for Reviews and Dissemination

Systematic review

A list of fields that can be edited in an update can be found here

1. * Review title. [1 change]

Give the title of the review in English

Effects of Kilohertz Frequency, Burst Duty Cycle, and Burst Duration on Evoked Torque, Perceived Discomfort and Muscle Fatigue: a Systematic Review

2. Original language title.

For reviews in languages other than English, give the title in the original language. This will be displayed with the English language title.

3. * Anticipated or actual start date.

Give the date the systematic review started or is expected to start.

02/11/2020

4. * Anticipated completion date.

Give the date by which the review is expected to be completed.

04/01/2021

5. * Stage of review at time of this submission. [2 changes]

This field uses answers to initial screening questions. It cannot be edited until after registration.

Tick the boxes to show which review tasks have been started and which have been completed.

Update this field each time any amendments are made to a published record.

The review has not yet started: No

Review stage	Started	Completed
Preliminary searches	Yes	Yes
Piloting of the study selection process	Yes	Yes
Formal screening of search results against eligibility criteria	Yes	Yes
Data extraction	Yes	Yes
Risk of bias (quality) assessment	Yes	Yes
Data analysis	Yes	Yes

Provide any other relevant information about the stage of the review here.

6. * Named contact.

The named contact is the guarantor for the accuracy of the information in the register record. This may be any member of the review team.

Karenina Modesto

Email salutation (e.g. "Dr Smith" or "Joanne") for correspondence:

Ms Modesto

7. * Named contact email.

Give the electronic email address of the named contact.

kareninag.87@gmail.com

8. Named contact address

Give the full institutional/organisational postal address for the named contact.

SHCES 207 Bloco D aptÂº 405 Cruzeiro Novo

9. Named contact phone number.

Give the telephone number for the named contact, including international dialling code.

+5561982030936

10. * Organisational affiliation of the review. [1 change]

Full title of the organisational affiliations for this review and website address if available. This field may be completed as 'None' if the review is not affiliated to any organisation.

Universidade de Brasília

Organisation web address:

[1 change] 11. * Review team members and their organisational affiliations.

Give the personal details and the organisational affiliations of each member of the review team. Affiliation refers to groups or organisations to which review team members belong. **NOTE: email and country now MUST be entered for each person, unless you are amending a published record.**

Ms Karenina Modesto. Universidade de Brasilia
Miss Julia Bastos. Universidade de Brasilia
Professor João Durigan. Universidade de Brasilia
Marco Aurélio Vaz. Universidade Federal do Rio Grande do Sul

12. * Funding sources/sponsors.

Details of the individuals, organizations, groups, companies or other legal entities who have funded or sponsored the review.

There are no funders

Grant number(s)

State the funder, grant or award number and the date of award

13. * Conflicts of interest.

List actual or perceived conflicts of interest (financial or academic).

None

14. Collaborators.

Give the name and affiliation of any individuals or organisations who are working on the review but who are not listed as review team members. **NOTE: email and country must be completed for each person, unless you are amending a published record.**

15. * Review question.

State the review question(s) clearly and precisely. It may be appropriate to break very broad questions down into a series of related more specific questions. Questions may be framed or refined using PI(E)COS or similar where relevant.

Whats is the best neuromuscular electrical stimulation strategy based on carrier frequency, burst duty cycle and burst duration for the maximum electrically induced contraction, reduce of muscle fatigue and perceived discomfort individuals with neurological or musculoskeletal injury and healthy participants?

16. Searches. [1 change]

State the sources that will be searched (e.g. Medline). Give the search dates, and any restrictions (e.g. language or publication date). Do NOT enter the full search strategy (it may be provided as a link or attachment below.)

Data base: PubMed, MEDLINE (BVS), Web of Science (all databases), Scientific Electronic Library Online (SciELO), EBSCO (Academic Search Premier, CINAHL, SPORTDiscus), LILACS (BVS), Physiotherapy Evidence Database (PEDro), Cochrane Central Register of Controlled Trials (CENTRAL), and Embase (via Ovid).

("Healthy Volunteers"[MeSH Terms] OR "Healthy Subjects"[Title/Abstract]) OR ("stroke"[MeSH Terms] OR "stroke/pathology"[MeSH Terms] OR "parkinson disease"[MeSH Terms] OR "spinal cord injuries"[MeSH Terms] OR "spinal cord ischemia"[MeSH Terms] OR "spinal cord lateral horn"[MeSH Terms] OR spinal cord injury[MeSH Terms] OR "paralysis"[MeSH Terms] OR "multiple sclerosis"[MeSH Terms] OR cerebral palsy[MeSH Terms] OR "muscular dystrophies"[MeSH Terms] OR "muscular atrophy"[MeSH Terms] OR "muscular atrophy, spinal"[MeSH Terms] OR "muscular diseases"[MeSH Terms] OR "muscular disorders, atrophic"[MeSH Terms] OR "noncommunicable diseases"[MeSH Terms] OR “osteoarthritis”[MeSH Terms] “arthritis"[Title/Abstract]) AND ("Electric Stimulation"[MeSH Terms] OR "Electric Stimulation Therapy"[MeSH Terms] OR "Neuromuscular electrical stimulation"[Title/Abstract] OR "NMES"[Title/Abstract] OR "Functional electrical stimulation"[Title/Abstract] OR "Alternating current"[Title/Abstract] OR "Pulsed current"[Title/Abstract] OR "Russian current"[Title/Abstract] OR "Middle-frequency stimulation"[Title/Abstract] OR "Low-frequency stimulation"[Title/Abstract] OR "Burst duty cycle"[Title/Abstract] OR "Duty cycle"[Title/Abstract] OR "Burst"[Title/Abstract] OR "Burst"[Title/Abstract]) AND ("Torque"[MeSH Terms] OR "Muscle Strength"[MeSH Terms] OR "Isometric Contraction"[MeSH Terms] OR "MVIC"[Title/Abstract] OR "Strengthening"[Title/Abstract] OR "Fatigue"[MeSH Terms] OR "Muscle Fatigue"[MeSH Terms] OR "Pain"[MeSH Terms] OR "Pain Perception"[MeSH Terms] OR "Visual Analog Scale"[MeSH Terms] OR "Pain Measurement"[MeSH Terms]). To absorb a greater number of articles, these terms were combined in each database.

17. URL to search strategy.

Upload a file with your search strategy, or an example of a search strategy for a specific database, (including the keywords) in pdf or word format. In doing so you are consenting to the file being made publicly accessible. Or provide a URL or link to the strategy. Do NOT provide links to your search **results**.

Alternatively, upload your search strategy to CRD in pdf format. Please note that by doing so you are consenting to the file being made publicly accessible.

Do not make this file publicly available until the review is complete

18. * Condition or domain being studied.

Give a short description of the disease, condition or healthcare domain being studied in your systematic review.

The interventions will be performed in individuals with neurological or musculoskeletal injury and health participants.

19. * Participants/population.

Specify the participants or populations being studied in the review. The preferred format includes details of both inclusion and exclusion criteria.

The inclusion criteria will be: 1) randomized controlled trials with parallel or cross over design. 2) Population: individuals with neurological or musculoskeletal injury and participants and health participants, without restriction of gender and age; 3) Intervention: carrier frequency, burst duty cycle and burst duration; 4) Comparator: different carrier frequency, burst duty cycle and burst duration 5) Outcome: Maximum electrically induced contraction, sensory discomfort and muscle fatigue.

20. * Intervention(s), exposure(s).

Give full and clear descriptions or definitions of the interventions or the exposures to be reviewed. The preferred format includes details of both inclusion and exclusion criteria.

Effects of carrier frequency, burst duty cycle and burst duration on maximum electrically induced contraction, sensory discomfort and muscle fatigue.

21. * Comparator(s)/control.

Where relevant, give details of the alternatives against which the intervention/exposure will be compared (e.g. another intervention or a non-exposed control group). The preferred format includes details of both inclusion and exclusion criteria.

There is no use of a control group. The parameters are compared to each other according to the carrier frequency, burst duty cycle and burst duration.

22. * Types of study to be included.

Give details of the study designs (e.g. RCT) that are eligible for inclusion in the review. The preferred format includes both inclusion and exclusion criteria. If there are no restrictions on the types of study, this should be stated.

Randomized controlled trials (RCTs) and Cross Over that presented the effects of neuromuscular electrical stimulation in individuals with neurological or musculoskeletal injury and health participants.

23. Context.

Give summary details of the setting or other relevant characteristics, which help define the inclusion or exclusion criteria.

24. * Main outcome(s).
[1 change]

Give the pre-specified main (most important) outcomes of the review, including details of how the outcome is defined and measured and when these measurement are made, if these are part of the review inclusion criteria.

Sensory discomfort
Maximum electrically induced contraction

Measures of effect

Please specify the effect measure(s) for you main outcome(s) e.g. relative risks, odds ratios, risk difference, and/or 'number needed to treat.

Mean difference between measurements and groups

25. * Additional outcome(s).
[1 change]

List the pre-specified additional outcomes of the review, with a similar level of detail to that required for main outcomes. Where there are no additional outcomes please state 'None' or 'Not applicable' as appropriate to the review

Muscle fatigue

Measures of effect

Please specify the effect measure(s) for you additional outcome(s) e.g. relative risks, odds ratios, risk difference, and/or 'number needed to treat.

Mean difference between measurements and groups

26. * Data extraction (selection and coding).

Describe how studies will be selected for inclusion. State what data will be extracted or obtained. State how this will be done and recorded.

The papers searched from the strategy will be independently analyzed by two authors, regarding the eligibility criteria by reading the title and abstract. Unable to define eligibility at this stage, a second stage of reading the full article will be conducted. With the end of the search process and application of eligibility criteria, the authors will resolve, by discussion, any disagreement regarding the number of reviews included. After this, a manual search will be perform in the references of the included articles to obtain other potential papers. Data extraction will be conducted independently by two authors using a data extraction template containing the following information from the included articles: Title, year, participants, interventions, comparator, outcome, databases, included studies, scales of methodological quality used, method of extraction and data synthesis, methodological limitations and level of recommendation of evidence.

27. * Risk of bias (quality) assessment.

State which characteristics of the studies will be assessed and/or any formal risk of bias/quality assessment tools that will be used.

The evaluation of the methodological quality of the studies were performed by two authors independently. The selected studies were analyzed using one instruments: 1) PEDro scale, which includes quantitatively 11 items: Specified eligibility criteria, randomization and random allocation, allocation concealment, baseline similarity, blinding of the subject, therapist blinding, assessor blinding, follow-up adequacy, intent-to-treat analysis, statistical analysis between groups, and one-time estimates reports and measures of variability.

28. * Strategy for data synthesis.

Describe the methods you plan to use to synthesise data. This **must not be generic text** but should be **specific to your review** and describe how the proposed approach will be applied to your data. If meta-analysis is planned, describe the models to be used, methods to explore statistical heterogeneity, and software package to be used.

The data will be described regarding sample characteristics, age, sex, supervision status, intervention characteristic, mean and standard deviation pre- and post-intervention. Data from each study will be converted into mean differences (and 95%CI) between groups and pooled using a random – effects model. Statistical heterogeneity of data will be determined by I^2 test and interpreted according to Higgins et al (Higgins et al., 2003), which considers values above 25 and 50% as moderate and high heterogeneity, respectively. A p-value 0.05 will be considered significant. All analyses were conducted using Review Manager Software version 5.3.

29. * Analysis of subgroups or subsets.

State any planned investigation of ‘subgroups’. Be clear and specific about which type of study or participant will be included in each group or covariate investigated. State the planned analytic approach.

There will be no division of subgroups.

30. * Type and method of review.

Select the type of review, review method and health area from the lists below.

Type of review

Cost effectiveness

No

Diagnostic

No

Epidemiologic

No

Individual patient data (IPD) meta-analysis

No

Intervention

Yes

Living systematic review

No

Meta-analysis

Yes

Methodology

No

Narrative synthesis

No

Network meta-analysis

No

Pre-clinical

No

Prevention

No

Prognostic

No

Prospective meta-analysis (PMA)

No

Review of reviews

No

Service delivery

No

Synthesis of qualitative studies

No

Systematic review

Yes

Other

No

Health area of the review

Alcohol/substance misuse/abuse

No

Blood and immune system

No

Cancer

No

Cardiovascular

No

Care of the elderly

No

Child health

No

Complementary therapies

No

COVID-19

No

Crime and justice

No

Dental

No

Digestive system

No

Ear, nose and throat

No

Education

No

Endocrine and metabolic disorders

No

Eye disorders

No

General interest

No

Genetics

No

Health inequalities/health equity

No

Infections and infestations

No

International development

No

Mental health and behavioural conditions

No

Musculoskeletal

Yes

Neurological

No

Nursing

No

Obstetrics and gynaecology

No

Oral health

No

Palliative care

No

Perioperative care

No

Physiotherapy

Yes

Pregnancy and childbirth

No

Public health (including social determinants of health)

No

Rehabilitation

Yes

Respiratory disorders

No

Service delivery

No

Skin disorders

No

Social care

No

Surgery

No

Tropical Medicine

No

Urological

No

Wounds, injuries and accidents

No

Violence and abuse

No

31. Language.

Select each language individually to add it to the list below, use the bin icon to remove any added in error.

English

There is an English language summary.

32. * Country.

Select the country in which the review is being carried out. For multi-national collaborations select all the countries involved.

Brazil

33. Other registration details.

Name any other organisation where the systematic review title or protocol is registered (e.g. Campbell, or The Joanna Briggs Institute) together with any unique identification number assigned by them. If extracted data will be stored and made available through a repository such as the Systematic Review Data Repository (SRDR), details and a link should be included here. If none, leave blank.

34. Reference and/or URL for published protocol.

If the protocol for this review is published provide details (authors, title and journal details, preferably in Vancouver format)

Add web link to the published protocol.

Or, upload your published protocol here in pdf format. Note that the upload will be publicly accessible.

No I do not make this file publicly available until the review is complete

Please note that the information required in the PROSPERO registration form must be completed in full even if access to a protocol is given.

35. Dissemination plans.

Do you intend to publish the review on completion?

No

Give brief details of plans for communicating review findings.?

36. Keywords.

Give words or phrases that best describe the review. Separate keywords with a semicolon or new line. Keywords help PROSPERO users find your review (keywords do not appear in the public record but are included in searches). Be as specific and precise as possible. Avoid acronyms and abbreviations unless these are in wide use.

37. Details of any existing review of the same topic by the same authors.

If you are registering an update of an existing review give details of the earlier versions and include a full bibliographic reference, if available.

38. * Current review status.

Update review status when the review is completed and when it is published.New registrations must be ongoing so this field is not editable for initial submission.

Please provide anticipated publication date

Review_Ongoing

39. Any additional information.

Provide any other information relevant to the registration of this review.

40. Details of final report/publication(s) or preprints if available.

Leave empty until publication details are available OR you have a link to a preprint (NOTE: this field is not editable for initial submission). List authors, title and journal details preferably in Vancouver format.

Give the link to the published review or preprint.

ClinicalTrials.gov PRS
Protocol Registration and Results System

ClinicalTrials.gov PRS DRAFT Receipt (Working Version)
Last Update: 05/23/2023 08:24

ClinicalTrials.gov ID: NCT05061056

Study Identification

Unique Protocol ID: 47989121.6.0000.8093

Brief Title: Effects of Neuromuscular Electrical Stimulation Parameters on Torque, Fatigue, and Oxygen Extraction (NMES)

Official Title: Neuromuscular Electrical Stimulation: Comparison of Carrier Frequencies, Bursts Durations and Duty Cycles in the Generation of Evoked Torque, Sensory Discomfort, Muscle Fatigue and Peripheral Oxygen Extraction

Secondary IDs:

Study Status

Record Verification: May 2023

Overall Status: Completed

Study Start: November 2, 2021 [Actual]

Primary Completion: May 22, 2022 [Actual]

Study Completion: May 22, 2022 [Actual]

Sponsor/Collaborators

Sponsor: University of Brasilia

Responsible Party: Principal Investigator
Investigator: João Luiz Q. Durigan [asiqueira]
Official Title: Associate professor
Affiliation: University of Brasilia

Collaborators:

Oversight

U.S. FDA-regulated Drug: No

U.S. FDA-regulated Device: No

U.S. FDA IND/IDE: No

Human Subjects Review: Board Status: Approved
Approval Number: CAAE: 47989121.6.0000.8093
Board Name: Comitê de Ética em Pesquisa da Faculdade de Ceilândia (CEP/FCE)
Board Affiliation: University of Brasília
Phone: 55613107-8418
Email: Comitê de Ética FCE <cep.fce@gmail.com>

Address:

Ceilândia Sul Campus Universitário - Centro Metropolitano - Brasília, DF, 72220-275

Data Monitoring: Yes

FDA Regulated Intervention: No

Study Description

Brief Summary: Neuromuscular Electrical Stimulation (NMES) can minimize muscle atrophy, complications related to muscle disuse and improved neuromuscular performance. However, it is still unclear the influence of specific physical parameters, including carrier frequency, burst duration, and duty cycle regarding the greater generation of evoked torque, sensory discomfort, muscle fatigue, and peripheral oxygen extraction. Thus, the aim of this study is to compare the effects of different NMES protocols applied to the triceps surae muscle for evoked torque, muscle fatigue, sensory discomfort, and peripheral oxygen extraction in healthy individuals. This is a crossover, experimental, randomized, double-blind trial composed of apparently healthy participants. All NMES protocols will be tested on the same individual with randomization of the sequence of intervention protocols. There will be a total of 6 encounters with seven days between them. Session 1 will evaluate the anthropometric measures, the maximum intensity for each intervention protocol, and the sequence of intervention protocols for each individual will be randomized. Sessions 2, 3, 4, and 5 will be composed equally with the assessment of the maximum voluntary and evoked joint torque of the triceps surae muscle through the isokinetic dynamometer, evaluation of muscle fatigue through the H-reflex, M-wave, fatigue index, time-torque-integral, and recruitment curve, evaluation of peripheral oxygen extraction through NIRS (Near Infrared Spectroscopy), electromyographic signals to assessed the RMS (root mean square) and the median frequency, evaluation of the level of sensory discomfort through the Visual Analog Pain Scale and finally by the NMES protocol. The 6th session will be the replication of the 2nd session of each individual. The EENM protocols will be as follows: CR10% (Russian Current with 2500 Hz, modulated in bursts of 50 Hz, 200 μs and 10% duty cycle - 2 ms bursts and 18 ms interbusrts), CR20% (Russian Current with 2500 Hz, modulated in bursts of 50 Hz, 200 μs and 20% of duty cycle - 4 ms bursts and 16 ms interbusrts), CA10% (Aussie current with 1000 Hz, modulated in bursts of 50 Hz, 500 μs and 10% duty cycle - 2 ms of bursts and 18 ms interbusrts), CA20% (Aussie current with 1000 Hz, modulated in bursts of 50 Hz, 500 μs and 20% of duty cycle - 4 ms of bursts and 16 ms interbusrts) all protocols will be performed on the triceps surae muscle.

Detailed Description: This is a crossover, experimental, randomized, double-blind trial composed of apparently healthy participants. The objective is to compare the effects of different NMES protocols applied to the triceps surae muscle for evoked torque, muscle fatigue, sensory discomfort, and peripheral oxygen extraction. The effects of the types of neuromuscular electrical stimulation (NMES) protocols on the aforementioned outcomes will be evaluated in the same participant by randomizing the sequences of interventions for each visit in the laboratory. The study is considered double-blind, as individuals will not know the sequence of the protocols applied. The evaluator will also not know which protocol will be used at the time of the intervention. It will consist of a total of 6 sessions with seven days between them. In the first session, anthropometry, the maximum intensity level for each electrical stimulation protocol as well as the protocol sequence for each individual will be evaluated. From the second to the fifth session, the following will be considered: voluntary and evoked maximum joint torque of the triceps surae muscle, muscle fatigue through the evaluation of the H-reflex, M-wave, fatigue index, torque-time-integral and recruitment curve, peripheral oxygen extraction, electromyographic signals through RMS (root mean square) and median frequency, and level of sensory discomfort with the Visual Analog Scale (VAS). The last session will consist of the same electrical stimulation protocol from the second session of assessment. From the second to the fifth session will be composed by the following evaluation sequence: warm-up with six submaximal contractions with 6 seconds of duration and 10 seconds of rest between them; then the assessment of muscle fatigue; then three maximal isometric contractions, then three maximal evoked contractions; fatigue protocol at 20% of the maximum isometric contraction (this fatigue protocol will use the NMES sequence randomized in the first session, except on the fifth day that the NMES protocol used will be the same as the second day); after the fatigue protocol, three maximum evoked contractions will be performed again; then three maximal isometric contractions and at the end, the muscle fatigue evaluation will be performed again. The NMES protocols will be CR10% (Russian Current with 2500 Hz, modulated in bursts of 50 Hz, 200 μs and 10% duty cycle - 2 ms bursts and 18 ms interbusrts), CR20% (Russian Current with 2500 Hz, modulated in bursts of 50 Hz, 200 μs and 20% of duty cycle - 4 ms of bursts and interbusrts of 16 ms), CA10% (Aussie current with 1000 Hz, modulated in bursts of 50 Hz, 500 μs and 10% duty cycle - 2 ms bursts and 18 ms interbusrts), CA20% (Aussie current with 1000 Hz, modulated in bursts of 50 Hz, 500 μs and 20% duty cycle - 4 ms bursts and 16 interbusrts) ms) all protocols will be performed on the triceps surae muscle.

Conditions

Conditions: Fatigue

Keywords: Healthy Young
Electric Stimulation Therapy
Evoked torque
Sensory discomfort
Peripheral oxygen extraction

Study Design

Study Type: Interventional

Primary Purpose: Other

Study Phase: N/A

Interventional Study Model: Crossover Assignment

Number of Arms: 4

Masking: Double (Participant, Investigator)

Allocation: Randomized

Enrollment: 44 [Actual]

Arms and Interventions

Arms	Assigned Interventions
Experimental: Russian current 10% Subjects will receive a interventions (Russian Current at 10% duty cycle). Evoked torque, muscle fatigue, sensory discomfort, and peripheral oxygen extraction will be evaluated.	Russian current 10% Russian current with 2500 Hz, modulated in bursts of 50 Hz, 200 μs and 10% duty cycle - 2 ms bursts and 18 ms interbusrts

Arms	Assigned Interventions
Experimental: Russian current 20% Subjects will receive a interventions (Russian Current at 20% duty cycle). Evoked torque, muscle fatigue, sensory discomfort, and peripheral oxygen extraction will be evaluated.	Russian current 20% Russian current with 2500 Hz, modulated in bursts of 50 Hz, 200 µs and 20% duty cycle - 4 ms bursts and 16 ms interbusrts
Experimental: Aussie current 10% Subjects will receive a interventions (Aussie Current at 10% duty cycle). Evoked torque, muscle fatigue, sensory discomfort, and peripheral oxygen extraction will be evaluated.	Aussie current 10% Aussie current with 1000 Hz, modulated in bursts of 50 Hz, 500 µs and 10% duty cycle - 2 ms bursts and 18 ms interbusrts
Experimental: Aussie current 20% Subjects will receive a interventions (Aussie Current at 20% duty cycle). Evoked torque, muscle fatigue, sensory discomfort, and peripheral oxygen extraction will be evaluated.	Aussie current 20% Aussie current with 1000 Hz, modulated in bursts of 50 Hz, 500 µs and 20% duty cycle - 4 ms bursts and 16 ms interbusrts

Outcome Measures

Primary Outcome Measure:

1. Submaximal voluntary isometric contraction of the triceps surae
   Expressed in muscle strength, assessed using an isokinetic dynamometer

   [Time Frame: 2 minutes]
2. Maximum voluntary isometric contraction of the triceps surae
   Expressed in muscle strength, assessed using an isokinetic dynamometer

   [Time Frame: 5 minutes]
3. Maximum evoked torque
   Expressed by the description of muscle strength generated by electrical stimulation assessed by the isokinetic dynamometer

   [Time Frame: 5 minutes]
4. Torque evoked during the fatigue protocol
   Expressed by the description of muscle strength generated by electrical stimulation assessed by the isokinetic dynamometer

   [Time Frame: 20 minutes]
5. Peripheral oxygen extraction
   Expressed by peripheral oxygen consumption assessed by near-infrared spectroscopy from the beginning to the end of the sessions

   [Time Frame: 40 minutes]
6. Muscle fatigue assessment before the muscle fatigue protocol
   Expressed by mechanical properties of plantar flexors and central activation relationship using the contraction interpolation technique

   [Time Frame: 10 minutes]
7. Assessment of muscle fatigue during the muscle fatigue protocol
   Expressed by the muscle fatigue index through the decline in torque evoked from the beginning to the end of the protocol

   [Time Frame: 20 minutes]
8. Muscle fatigue assessment during the muscle fatigue protocol
   Expressed by the decline in torque-time-integral from the beginning to the end of the protocol

   [Time Frame: 20 minutes]

9. Electromyographic signals
   Expressed by the raw values of RMS and Median Frequency within a range of 500 ms throughout the entire session

   [Time Frame: 40 minutes]

Secondary Outcome Measure:

10. Sensory discomfort during maximum evoked torques
    Measured through the Visual Analog Scale (1 - 10 cm) where 0 represents no discomfort and 10 represents greater discomfort

    [Time Frame: 10 seconds]

11. Sensory discomfort during fatigue protocol
    Measured through the Visual Analog Scale (1 - 10 cm) where 0 represents no discomfort and 10 represents greater discomfort

    [Time Frame: 10 seconds]

Eligibility

Minimum Age: 18 Years

Maximum Age: 40 Years

Sex: All

Gender Based: No

Accepts Healthy Volunteers: Yes

Criteria: Inclusion Criteria:

- Female and male, aged between 18-40 years,
- Be classified as physically active according to the International Physical Activity Questionnaire (IPAQ),
- The practice of just recreational physical activity,
- Achieve a minimum torque of 20% of the MVIC during the NMES
- Be at least three months without strength training

Exclusion Criteria:

- Present musculoskeletal dysfunction that may interfere with the tests, present intolerance to NMES in the triceps surae muscle,
- Use analgesics, antidepressants, tranquilizers, or other centrally acting agents
- Present cardiovascular or peripheral vascular problems, chronic diseases, neurological or muscle disorders that may impair the complete execution of the study design by the volunteer

Contacts/Locations

Central Contact Person: João Durigan, PhD
Telephone: 55 61 3107-8450
Email: joaodurigan@gmail.com

Central Contact Backup: Rita Durigan, PhD
Telephone: 55 61 3107-8450
Email: marqueti@gmail.com

Study Officials: João Durigan, PhD
Study Principal Investigator
University of Brasilia

Locations: **Brazil**
João Luiz Q. Durigan
Brasília, Brasil, Brazil, 72220900
Contact: Karenina Modesto 61982030936 kareninag.87@gmail.com
Contact: Karenina Modesto +5561982030936 Ext. Modesto kareninag.87@gmail.com
Sub-Investigator: Karenina Modesto

IPDSharing

Plan to Share IPD: No

References

Citations:
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Links:

Available IPD/Information:

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Estimulação Elétrica Neuromuscular: Comparação de frequências portadoras, durações de bursts e ciclos de trabalho na geração de torque evocado, desconforto sensorial, fadiga muscular e extração periférica de oxigênio.

Pesquisador: KARENINA ARRAIS GUIDA MODESTO PRADO

Área Temática:

Versão: 3

CAAE: 47989121.6.0000.8093

Instituição Proponente: Faculdade de Educação Física - UnB

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 4.890.338

Apresentação do Projeto:

"Introdução: A Estimulação Elétrica Neuromuscular (EENM) pode minimizar a atrofia muscular, as complicações relativas ao desuso muscular e colaborar na melhora do desempenho neuromuscular Há enorme esforço para se determinar qual a influência da frequência portadora (número de pulsos por segundo), duração do burst (tempo em que dura a passagem de um burts) e ciclo de trabalho (razão entre a duração do burst e a soma dos tempos de burts e interburst ou razão entre tempo ON e OFF da passagem total da corrente) da EENM no que tange a maior geração de torque evocado, desconforto sensorial, fadiga muscular e extração periférica de oxigênio. Além disso, o estresse metabólico também está ligado ao ganho de força muscular, sendo um importante aspecto a ser avaliado além dos parâmetros físicos da EENM. Porém, ainda não está claro o papel da frequência portadora, duração de burst e ciclo de trabalho em correntes de média frequência na geração de torque evocado, desconforto sensorial, fadiga muscular e extração periférica de oxigênio. Objetivo: Comparar os efeitos de diferentes protocolos de EENM aplicada no músculo tríceps sural para torque evocado, fadiga muscular, desconforto sensorial e extração periférica de oxigênio em indivíduos saudáveis. Métodos: Trata-se de um ensaio crossover, experimental, randomizado e duplo-cego composto por participantes aparentemente saudáveis. Será composto por um total de 6 encontros com 7 dias de intervalo entre eles a serem realizados na Faculdade de Ceilândia da Universidade de Brasília. Serão avaliados: torque articular voluntário e evocado do músculo tríceps sural, fadiga muscular (reflexo H, onda M, índice de fadiga, tempo integral de torque e curva de recrutamento), extração periférica de oxigênio, sinais eletromiográficos (RMS, frequência mediana) e nível de desconforto sensorial. Serão considerados desfechos primários o torque evocado, fadiga muscular e extração periférica de oxigênio e como desfechos secundários o desconforto sensorial. Serão utilizados 4 protocolos distintos de EENM: CR10% (Corrente Russa com 2500 Hz, modulada em bursts de 50 Hz, 200 µs e 10 % de ciclo de trabalho - 2 ms de bursts e interbusrts de 18 ms), CR20% (Corrente Russa com 2500 Hz, modulada em bursts de 50 Hz, 200 µs e 20 % de ciclo de trabalho - 4 ms de bursts e interbusrts de 16 ms), CA10% (Corrente Aussie com 1000 Hz, modulada em bursts de 50 Hz, 500 µs e 10 % de ciclo de trabalho - 2 ms de bursts e interbusrts de 18 ms), CA20% (Corrente Aussie com 1000 Hz, modulada em bursts de 50 Hz, 500 µs e 20 % de ciclo de trabalho - 4 ms de bursts e interbusrts de 16 ms) todos os protocolos serão realizados no músculo tríceps sural. Resultados esperados: Acredita-se que a menor frequência portadora e os menores ciclos de trabalho irão gerar maior torque evocado e menor fadiga muscular. Não haverá diferença para o desconforto sensorial independentemente do protocolo de EENM utilizado. Haverá maior demanda metabólica (maior utilização de oxigênio) para os protocolos que gerarem maior torque evocado."

CRITÉRIOS DE INCLUSÃO

"Os integrantes da amostra serão recrutados pelo método de amostragem não probabilística de conveniência, por meio de panfletos distribuídos na Universidade de Brasília e por meio de convite verbal. Os critérios de inclusão do estudo são: sexo feminino e masculino, idade entre 18-40 anos, ser classificado como fisicamente ativo de acordo com o Questionário Internacional de Atividade Física (IPAQ), prática de atividade física apenas recreacional, alcançar torque mínimo de 20% da CIVM durante a EENM e estar a pelo menos 3 meses sem praticar treinamento de força."

CRITÉRIOS DE EXCLUSÃO

""apresentar algum tipo de disfunção músculo esquelética que possa interferir nos testes, apresentar intolerância à EENM no músculo tríceps sural, fazer uso de analgésicos, antidepressivos, tranquilizantes ou outros agentes de ação central e apresentar problemas cardiovasculares ou vasculares periféricos, doenças crônicas, afecções neurológicas ou musculares que venham a prejudicar a execução completa do delineamento desse estudo por parte do voluntário."

Objetivo da Pesquisa:

"Comparar os efeitos de 4 protocolos diferentes de EENM aplicada no músculo tríceps sural na geração de torque evocado, fadiga muscular, desconforto sensorial e extração periférica de oxigênio no músculo tríceps sural de indivíduos saudáveis."

OBJETIVOS ESPECÍFICOS

"- Comparar 4 protocolos de correntes alternadas: Corrente Russa com dois protocolos diferentes (2.500 Hz, modulada em bursts de 50 Hz, 200 µs e 10 % de ciclo de trabalho com duração de 2 ms de bursts e interbusrts de 18 ms; 2.500 Hz, modulada em bursts de 50 Hz, 200 µs e 20 % de ciclo de trabalho com duração de 4 ms de bursts e interbusrts de 16 ms, Corrente Australiana com dois protocolos diferentes (1000 Hz, modulada em bursts de 50 Hz, 500 µs e 10 % de ciclo de trabalho com duração de 2 ms de bursts e interbusrts de 18 ms; 1000 Hz, modulada em bursts de 50 Hz, 500 µs e 20 % de ciclo de trabalho com duração de 4 ms de bursts e interbusrts de 16 ms para o torque evocado, desconforto sensorial, fadiga muscular e extração periférica de oxigênio no músculo tríceps sural de indivíduos saudáveis."

Avaliação dos Riscos e Benefícios:

RISCOS

"Durante as avaliações de contração voluntária máxima, poderá haver um aumento da pressão arterial e frequência cardíaca como comumente esperado durante atividades físicas desta magnitude. Tanto a pressão arterial quanto a frequência serão monitorados antes, durante e imediatamente após a realização dos testes. Caso quaisquer alterações fora dos padrões de normalidade sejam observadas, ou caso o indivíduo não se sinta confortável para continuar, o teste será interrompido imediatamente e todas as medidas de cuidados para a saúde do participante serão providenciadas.

Durante os procedimentos que envolvem eletroestimulação, poderá haver fadiga muscular, desconforto sensorial e dor muscular de início tardia (após o treinamento). Caso quaisquer alterações fora dos padrões de normalidade sejam observadas, ou caso o indivíduo não se sinta confortável para continuar, o teste será interrompido imediatamente e todas as medidas de cuidados para saúde do participante serão providenciadas. As dores musculares de início tardio poderão ser minimizadas com aplicação de compressa de gelo, e repouso. Caso os sintomas se exacerbem, os pesquisadores se responsabilizarão por providenciar o atendimento médico emergencial e laboratorial necessários.

O participante poderá se recusar a responder (ou participar de qualquer procedimento) qualquer questão que cause algum constrangimento, podendo o indivíduo desistir de participar da pesquisa em qualquer momento sem nenhum prejuízo para o participante."

BENEFÍCIOS

"Os resultados do presente projeto possibilitarão o aumento quanto ao conhecimento a respeito dos benefícios de diferentes técnicas de EENM mais indicados para maiores adaptações neuromusculares. Isso poderá levar a melhores resultados nos tratamentos de fisioterapia, em especial quando o objetivo for fortalecimento muscular. Os benefícios para os participantes será conhecer sua força muscular de forma voluntária e evocada pela estimulação elétrica, conhecer seus aspectos eletrotrofisiológicos assim como seus aspectos e características neurais e musculares e possíveis alterações eletrofisiológicas e musculares caso presente no participante."

Comentários e Considerações sobre a Pesquisa:

Trata-se de um projeto de Doutorado Programa de Pós-Graduação em Educação Física da aluna Karenina Arrais Guida Modesto sob orientação do prof João Luiz Quaglioti Durigan e coorientação do prof Marco Aurélio Vaz.

Colaboradores: Júlia Aguillar Ivo Bastos; Leandro Gomes de Jesus Ferreira; Álvaro de Almeida Ventura; Gerson Cipriano Júnior.

NÚMERO AMOSTRAL = 44

** Há 4 grupos:

"- Corrente Russa 10% (CR10%): 2500 Hz, modulada em bursts de 50 Hz, 200 s de fase (400 s deduração de pulso) e 10 % de ciclo de trabalho (2 ms de bursts e interbusrts de 18 ms).

- Corrente Russa 20% (CR20%): 2500 Hz, modulada em bursts de 50 Hz, 200 s de fase (400 s deduração de pulso) e 20 % de ciclo de trabalho (4 ms de bursts e interbusrts de 16 ms).

- Corrente Aussie 10% (CA10%): 1000 Hz, modulada em bursts de 50 Hz, 500 s de fase (1ms de duração de pulso) e 10 % de ciclo de trabalho (2 ms de bursts e interbusrts de 18 ms).

- Corrente Aussie 20% (CA20%): 1000 Hz, modulada em bursts de 50 Hz, 500 s de fase (1 ms de duração de pulso) e 20 % de ciclo de trabalho (4 ms de bursts e interbusrts de 16 ms).

Considerações sobre os Termos de apresentação obrigatória:

Todos os documentos foram adequadamente apresentados.

Recomendações:

Não há.

Conclusões ou Pendências e Lista de Inadequações:

Projeto aprovado.

Considerações Finais a critério do CEP:

Protocolo de pesquisa em consonância com a Resolução 466/12 do Conselho Nacional de Saúde. Cabe ressaltar que compete ao pesquisador responsável: desenvolver o projeto conforme delineado; elaborar e apresentar os relatórios parciais e final; apresentar dados solicitados pelo CEP ou pela CONEP a qualquer momento; manter os dados da pesquisa em arquivo, físico ou digital, sob sua guarda e responsabilidade, por um período de 5 anos após o término da pesquisa; encaminhar os resultados da pesquisa para publicação, com os devidos créditos aos pesquisadores associados e ao pessoal técnico integrante do projeto; e justificar fundamentadamente, perante o CEP ou a CONEP, interrupção do projeto ou a não publicação dos resultados.

Deve-se levar em conta, neste momento de pandemia de COVID-19, as orientações da Instituição onde os dados serão coletados e que isto deve ser levado em consideração para reorganizar o cronograma, caso necessário. Deve-se comunicar ao CEP, por meio de relatório parcial, as dificuldades encontradas na coleta.

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_1761647.pdf	21/07/2021 18:24:25		Aceito
Outros	Projeto_atualizado_2.docx	21/07/2021 18:22:57	KARENINA ARRAIS GUIDA MODESTO PRADO	Aceito
Outros	TCLE_atualizado_2.doc	21/07/2021 18:22:36	KARENINA ARRAIS GUIDA MODESTO PRADO	Aceito
Outros	Carta_pendencia.doc	21/07/2021 18:22:02	KARENINA ARRAIS GUIDA MODESTO PRADO	Aceito
Outros	TCLE_atualizado.doc	13/07/2021 15:24:39	KARENINA ARRAIS GUIDA MODESTO PRADO	Aceito
Outros	Cronograma_atualizado.doc	13/07/2021	KARENINA ARRAIS	Aceito

Outros	Cronograma_atualizado.doc	15:24:11	GUIDA MODESTO PRADO	Aceito
Outros	Orcamento_atualizado.doc	13/07/2021 15:23:42	KARENINA ARRAIS GUIDA MODESTO PRADO	Aceito
Outros	Projeto_atualizado.docx	13/07/2021 15:23:08	KARENINA ARRAIS GUIDA MODESTO PRADO	Aceito
Outros	carta_para_encaminhamento_de_pendencias_Durigan.doc	13/07/2021 15:21:54	KARENINA ARRAIS GUIDA MODESTO PRADO	Aceito
Folha de Rosto	Folha_de_rosto.pdf	10/07/2021 14:34:57	KARENINA ARRAIS GUIDA MODESTO PRADO	Aceito
Outros	Documentos_FEF.pdf	10/06/2021 16:31:45	KARENINA ARRAIS GUIDA MODESTO PRADO	Aceito
Outros	Lattes_Leandro.pdf	10/06/2021 16:24:11	KARENINA ARRAIS GUIDA MODESTO PRADO	Aceito
Outros	Lattes_Alvaro.pdf	10/06/2021 16:23:47	KARENINA ARRAIS GUIDA MODESTO PRADO	Aceito
Outros	Termo_de_responsabilidade.doc	10/06/2021 16:20:07	KARENINA ARRAIS GUIDA MODESTO PRADO	Aceito
Declaração de concordância	Termo_participante.pdf	09/06/2021 15:03:22	KARENINA ARRAIS GUIDA MODESTO PRADO	Aceito
Declaração de Instituição e Infraestrutura	Termo_proponente.pdf	09/06/2021 15:03:01	KARENINA ARRAIS GUIDA MODESTO PRADO	Aceito
Outros	Lattes_Marco.pdf	31/05/2021 15:03:35	KARENINA ARRAIS GUIDA MODESTO PRADO	Aceito
Outros	Lattes_Karenina.pdf	31/05/2021 15:03:10	KARENINA ARRAIS GUIDA MODESTO PRADO	Aceito
Outros	Lattes_Julia.pdf	31/05/2021 15:02:52	KARENINA ARRAIS GUIDA MODESTO PRADO	Aceito
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Outros	Lattes_Gerson.pdf	31/05/2021 15:01:42	KARENINA ARRAIS GUIDA MODESTO PRADO	Aceito
Declaração de	Carta_encaminhamento.doc	31/05/2021	KARENINA ARRAIS	Aceito

Pesquisadores	Carta_encaminhamento.doc	11:46:42	GUIDA MODESTO PRADO	Aceito
Outros	Termo_de_responsabilidade.pdf	27/05/2021 15:47:58	KARENINA ARRAIS GUIDA MODESTO PRADO	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE_submissao.doc	27/05/2021 15:47:13	KARENINA ARRAIS GUIDA MODESTO PRADO	Aceito
Projeto Detalhado / Brochura Investigador	Projeto.docx	27/05/2021 15:46:41	KARENINA ARRAIS GUIDA MODESTO PRADO	Aceito
Orçamento	Orcamento.doc	27/05/2021 15:46:19	KARENINA ARRAIS GUIDA MODESTO PRADO	Aceito
Declaração de Pesquisadores	Carta_de_encaminhamento.pdf	27/05/2021 15:45:36	KARENINA ARRAIS GUIDA MODESTO PRADO	Aceito
Cronograma	Cronograma.doc	27/05/2021 15:45:15	KARENINA ARRAIS GUIDA MODESTO PRADO	Aceito

Situação do Parecer:

Aprovado

Necessita Apreciação da CONEP:

Não

BRASILIA, 06 de Agosto de 2021

Assinado por:
Danielle Kaiser de Souza
(Coordenador(a))