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DANYELLE CRISTINA SILVA PELET

INFLUÊNCIA DO TREINAMENTO DE FORÇA EM DIFERENTES INTESIDADES SOBRE O DECURSO TEMPORAL DA EDUCAÇÃO CRUZADA DE FORÇA E POTÊNCIA MUSCULARES

UBERABA – MG
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Tese apresentada ao Programa de Pós-Graduação em Ciências da Saúde, área de concentração Medicina Translacional, linha de pesquisa Aspectos clínicos, diagnósticos e terapêuticos das doenças, da Universidade Federal do Triângulo Mineiro, como requisito parcial para a defesa do título de Doutor em Ciências da Saúde.

Orientador: Prof. Dr. Fábio Lera Orsatti

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DEDICATÓRIA

À minha mãe, Enilce, mulher guerreira à quem herdei a serenidade. Ao meu pai, Luis, a quem herdei minha resistência. Ao meu irmão, Daniel, a quem devo minha resiliência. À Bella e Linda, minhas alegrias diárias.

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EPÍGRAFE

“O saber a gente aprende com os mestres e os livros. A sabedoria se aprende é com a vida e com os humildes.”

(Cora Coralina)

“Porque aprender a viver é que é o viver mesmo...Travessia perigosa, é a da vida. Sertão que se alteia e abaixa... O mais difícil não é um ser bom e proceder honesto, dificultoso mesmo, é um saber definido do que quer, e ter o poder de ir até o fundo da palavra.”

(Guimarães Rosa)

“Muita coisa que ontem parecia importante ou significativa, amanhã virará pó no filtro da memória. Mas o sorriso (...) ah, esse resistirá a todas as ciladas do tempo ...”

(Caio Fernando Abreu)

“... nada do que vivemos tem sentido, se não tocarmos o coração das pessoas. Muitas vezes basta ser: colo que acolhe, palavra que conforta, silêncio que respeita, alegria que contagia, lágrima que corre. E isso não é coisa de outro mundo: é o que dá sentido à vida. É o que faz com que ela não seja nem curta, nem longa demais, mas que seja intensa, verdadeira e pura...”

(Cora Coralina)

“Todos que testemunham tempos difíceis gostariam que nunca aquilo tivesse acontecido. Mas não cabe a nós decidir. O que nos cabe é decidir o que fazer com o tempo que nos é dado. Há outras forças em andamento nesse mundo além das forças do mal. No meio ao caos, estamos cada um destinado a cumprir nossa missão. Por mais difícil que pareça, se nos foi dada, é porque temos condições de cumprir.”

(Frase adaptada do Filme “O senhor dos anéis”)

“Quando não houver caminho
Mesmo sem amor, sem direção
A sós ninguém está sozinho
É caminhando que se faz o caminho”

(Sergio Britto)

“Tudo é uma questão de manter
A mente quieta
A espinha ereta
E o coração tranquilo”

(Walter Franco)

RESUMO

Educação cruzada são adaptações neurais que levam ao aumento da força em músculos não treinados homólogos e contralaterais após o treinamento unilateral. Objetivo: verificar o impacto do treinamento de força em diferentes intensidades sobre o decurso temporal da educação cruzada de força (dinâmica e isométrica máximas) e potência musculares. Métodos: cinquenta indivíduos foram aleatorizados em três grupos: treinamento de força de alta intensidade [G80: duas séries com 80% e duas séries com 40% de uma repetição máxima (1RM)], treinamento de força de baixa intensidade (G40: 4 séries com 40% de 1 RM) ou grupo controle (CG). G40 e G80 completaram quatro semanas de treinamento de força unilateral (TFU) de flexão de cotovelo, dinâmico, isoinercial, três vezes por semana, com a fase concêntrica rápida e a fase excêntrica controlada. A força muscular dinâmica máxima (uma repetição máxima =1RM), contração isométrica voluntária máxima (CIVM) e a potência (força x velocidade) muscular com carga a 40% e 80% de 1RM foram avaliados no início e após uma (semana 1) e quatro semanas (semana 4) de TFU. Resultados: no braço não treinado, o G80 aumentou progressivamente 1RM (início < semana 1 < semana 4; P <0,05), enquanto G40 mostrou aumento de 1RM somente na semana 4 (início = semana 1 <semana 4; P < 0,05). Não houve aumento da CIVM após uma semana de treinamento. Porém, após quatro semanas, apenas o G80 aumentou (P <0,05) a CIVM. A educação cruzada da potência muscular evoluiu igualmente nos testes de potência a 40 e 80% de 1RM. Após TFU com intensidade baixa, produziu aumento de potência em 1 semana, mantendo na semana 4. Já o TFU com resistências elevadas promoveu aumentos progressivos na potência muscular produzida a 40% e 80% de 1RM (início < semana 1 < semana 4; P < 0,05). Conclusão: Na fase inicial do TFU (uma semana), somente intensidades elevadas promovem educação cruzada de força dinâmica. Porém, o aumento da potência muscular é independente da intensidade. Já em 4 semanas (fase tardia), intensidades baixas de TFU promovem educação cruzada de força dinâmica e com intensidades elevadas há progressão do ganho de força e potência, além de ganho de força isométrica.

Palavras chave: adaptações contralaterais; treinamento de força; potência muscular, eletromiografia; educação cruzada; transferência cruzada; performance muscular, medicina física e reabilitação.

ABSTRACT

Cross education is a neural adaptation that occurs in the homologous muscles (contralateral muscles) after unilateral training, increasing muscle strength. Objective: To verify the impact of resistance training at different load intensities on the time course of cross-education of muscle strength (maximum dynamics, maximum isometric) and muscle power. Methods: Fifty subjects were randomized into three groups: higher-intensity strength training [G80: two series with 80% and two series with 40% of one maximum repetition (1RM)], lower-intensity strength training (G40: 4 series with 40% of 1 RM) or control group (CG). G40 and G80 completed four weeks of unilateral resistance training (URT) elbow flexion, three times a week, with the rapid concentric phase and the controlled eccentric phase. Maximum dynamic muscle strength (one repetition = 1RM), maximum voluntary isometric contraction (MVIC) and muscle power (strength x speed) at 40% and 80% of 1RM were assessed at baseline and after one (week 1) and four weeks (week 4) of URT. Results: in the untrained arm, G80 increased progressively by 1RM (baseline <week 1 <week 4; P <0.05), while G40 showed an increase of 1RM only in the week 4 (baseline =week 1 < week 4; P <0.05). There was no increase in MVIC after one week of training. However, after four weeks, only G80 increased (P <0.05) MVIC. The cross-education of muscle power equally evolved in the power tests at 40 and 80% of 1RM; with URT with lower intensity, produced an increase in muscle power in 1 week, maintaining it in week 4. In contrast, URT with higher resistance promoted progressive increases, starting from week 1, in the muscle power produced at 40% and 80% of 1RM, (baseline <week 1 <week 4; P <0.05). Conclusion: In the initial phase of the URT (one week), only higher-intensities URT promote cross-education of dynamic strength. However, the increase in muscle power is independent of intensity. In 4 weeks (later phase), lower-intensities URT promotes cross-education of dynamic strength. However, there is progression in the gain of muscle strength and muscle power until week 4 and isometric strength gain with higher-intensity URT.

Keywords: contralateral adaptations; strength training; muscle power, electromyography; cross education; cross transfer; muscle performance, physical and rehabilitation medicine.

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LISTA DE ABREVIATURAS

SNC	Sistema nervoso central
M1	Córtex motor primário
EMG	Eletromiografia
TFU	Treinamento de força unilateral
UST	Unilateral strength training
1 RM	Uma repetição máxima / one maximum repetition
CIVM	Contração isométrica voluntária máxima
MVIC	Maximum voluntary isometric contraction

ARTIGO 1

G40	Lower-intensity resistance training group
G80	Higher-intensity resistance training group
CG	Control group
1RM	One-repetition maximum
EMG	Electromyography
MVIC	Maximum voluntary isometric contraction
URTEP	Unilateral resistance training with external pacing
Week 1	After 1 week of training - Early phase responses
Week 4	After 1 week of training - Later phase responses

ARTIGO 2

EMG	Electromyography
1RM	One-repetition maximum
G40	Lower-intensity resistance training group
G80	Higher-intensity resistance training group
CG	Control group
URT	Unilateral resistance training
CIVM	Contração isométrica voluntária máxima
Week 1	After 1 week of training
Week 4	After 1 week of training

SUMÁRIO

1. INTRODUÇÃO

Em algumas disfunções neurais ou musculoesqueléticas, indivíduos ficam impossibilitados de movimentar um membro. Situações como essas levam a perda de força, atrofia e demais adaptações musculares do treinamento (ANDRUSHKO; GOULD; FARTHING, 2018). Neste sentido, a constante incidência de fraturas unilaterais (DELFT; GELDER; VRIES; VERMEULEN *et al.*, 2019) e acometimentos do sistema nervoso que afetam membros unilateralmente (WINSTEIN; STEIN; ARENA; BATES *et al.*, 2016) refletem a necessidade de estender e aperfeiçoar estudos que envolvam estratégias para recuperação/prevenção da perda da função muscular desses sujeitos. Dessa forma, a transferência cruzada ou educação cruzada vem sendo sugerida como uma estratégia de tratamento/prevenção da função muscular de sujeitos impossibilitados de movimentar um membro devido a alguma lesão (GREEN, LARA A.; GABRIEL, DAVID A., 2018).

Originalmente descrito por Scripture et al (SCRIPTURE, 1894), adaptações neuromusculares não intencionais, que ocorrem nos músculos homólogos, contralaterais ao membro que realiza exercício (CARROLL; HERBERT; MUNN; LEE *et al.*, 2006; CIRER-SASTRE; BELTRAN-GARRIDO; CORBI, 2017) é atualmente denominado de “transferência cruzada” (GOODWILL; KIDGELL, 2012) ou “educação cruzada” (DRAGERT; ZEHR, 2011; RUDDY; LEEMANS; WOOLLEY; WENDEROTH *et al.*, 2017). A identificação das origens da educação cruzada tem recebido atenção recentemente. Nesse contexto, as adaptações neurais tem sido o foco das evidências (LEE; CARROLL, 2007). Dentre elas, podemos destacar o aumento da excitabilidade corticoespinhal referente ao córtex não treinado, diminuição da inibição inter-hemisférica (LEE; HINDER; GANDEVIA; CARROLL, 2010) e aumento da atividade eletromiográfica do membro não treinado (CARR; YE; STOCK; BEMBEN *et al.*, 2019). Além disso, como adaptação neural à tarefas unilaterais, ocorre também a formação de engramas motores (HAMANO; SUGAWARA; YOSHIMOTO; SADATO, 2020) que podem ser acessados por ambos os hemisférios cerebrais, direito ou esquerdo (RUDDY; CARSON, 2013).

Como resultado da educação cruzada, observa-se aumento de força muscular (DRAGERT; ZEHR, 2013b; MUNN; HERBERT; HANCOCK; GANDEVIA, 2005), aceleração do movimento (RUDDY; RUDOLF; KALKMAN; KING *et al.*, 2016) e melhora das habilidades motoras (HOLPER; BIALLAS; WOLF, 2009) nos membros não treinados. Essas adaptações ocorrem em membros superiores e inferiores (GREEN, L. A.; GABRIEL, D. A., 2018), em músculos da mão, braço, joelho e tornozelo (CARR; YE; STOCK; BEMBEN *et* *al.*, 2019; COOMBS; FRAZER; HORVATH; PEARCE *et al.*, 2016; DRAGERT; ZEHR, 2013b; HARPUT; ULUSOY; YILDIZ; DEMIRCI *et al.*, 2019).

O treinamento de força (denominado também como treinamento resistido ou musculação) unilateral (TFU), dinâmico ou isométrico, é uma ferramenta comumente explorada na literatura para promover a educação cruzada. Porém, magnitudes diferentes de respostas vêm sendo reportadas. Após o TFU, observa-se aumento da força no braço contralateral entre 2,4% - 110,0% (GREEN, LARA A.; GABRIEL, DAVID A., 2018). Essa diferença na magnitude de resposta vem sendo atribuída à variações nos protocolos de treinamento entre os estudos (COLOMER-POVEDA; ROMERO-ARENAS; KELLER; HORTOBAGYI *et al.*, 2019). Particularmente, diferentes variáveis de treinamento (tipo de contração, intensidade, volume e velocidade de movimento) vêm sendo usadas pelos estudos (BEYER; FUKUDA; BOONE; WELLS *et al.*, 2016; COLOMER-POVEDA; ROMERO-ARENAS; KELLER; HORTOBAGYI *et al.*, 2019; FARTHING; CHILIBECK, 2003; MUNN; HERBERT; HANCOCK; GANDEVIA, 2005). Porém, ainda não está claro como e quais variáveis de treinamento podem interferir na magnitude de resposta da educação cruzada (COLOMER-POVEDA; ROMERO-ARENAS; KELLER; HORTOBAGYI *et al.*, 2019). Por esse motivo, ainda há dificuldade para estabelecer protocolos ideais, devido à falta de entendimento dos potencializadores (variáveis do treinamento) da educação cruzada.

Nesse contexto, uma questão ainda não respondida é se a intensidade de carga elevada do TFU é necessária para promover ou potencializar a educação cruzada da força muscular. Embora seja evidente a educação cruzada e adaptações neuromusculares (como aumento EMG e de excitabilidade corticoespinhal) (PEREZ; COHEN, 2008) dos estudos que realizaram TFU, poucos se concentraram no uso de intensidade baixa (CIRER-SASTRE; BELTRAN-GARRIDO; CORBI, 2017). Assim, a falta de estudos usando intensidade baixa e, principalmente, estudos que compararam diretamente o efeito de diferentes intensidades de carga do TFU sobre a educação cruzada dificulta uma conclusão sobre a necessidade de intensidades elevadas para promover ou maximizar a educação cruzada em ambientes de reabilitação.

Um outro aspecto necessário a ser explorado, pois pode auxiliar a guiar protocolos de intervenção, é o decurso temporal da educação cruzada. A falta de informação sobre quando, como e o que afetam essas mudanças nos parâmetros transferidos impede o planejamento tempo-eficiente em populações saudáveis e clínicas. Para o membro treinado, observa-se um aumento na força muscular (e adaptações neurais) após uma semana de treinamento (MASON; FRAZER; AVELA; PEARCE *et al.*, 2020). Porém, se essas adaptações são transferidas para o braço não treinado, no mesmo período, permanece incerto. Baseados na nossa revisão de literatura, apenas Carr et al (CARR; YE; STOCK; BEMBEN *et al.*, 2019), Hortobagyi et al. (HORTOBAGYI; RICHARDSON; LOMAREV; SHAMIM *et al.*, 2011) e Barss et al (BARSS; KLARNER; PEARCEY; SUN *et al.*, 2018) investigaram o efeito do treinamento isométrico sobre o decurso temporal das adaptações contralaterais e relataram um aumento significativo na força isométrica do músculo não treinado após duas, três e quatro semanas, respectivamente. Não está claro se a diferença no tempo entre os estudos decorre das diferenças amostrais (variabilidade interindividual) ou das diferentes magnitudes de respostas devido a variabilidade nos diferentes protocolos de treinamento. Além disso, a generalização dos resultados entre estudos é preocupante, pois há evidências de especificidades de movimento na educação cruzada (COOMBS; FRAZER; HORVATH; PEARCE *et al.*, 2016). Assim, os resultados dos estudos com treinamento isométricos podem não refletir os estudos com treinamento dinâmicos. Na literatura revisada por nós, o tempo mínimo de avaliação após TFU dinâmico foi de três semanas (GOODWILL; KIDGELL, 2012; MASON; FRAZER; HORVATH; PEARCE *et al.*, 2018). No entanto, é possível que a intensidade do treinamento afete o decurso temporal da educação cruzada. Vem sendo evidenciado uma relação positiva entre excitabilidade corticoespinhal contralateral e intensidade do TFU (PEREZ; COHEN, 2008). Essa maior ativação cruzada pode levar à adaptação neuroplástica, aumentado o drive neural motor (GREEN, L. A.; GABRIEL, D. A., 2018; HESTER; MAGRINI; COLQUHOUN; BARRERA-CURIEL *et al.*, 2019; RUDDY; CARSON, 2013) progressivamente (por mais tempo), podendo afetar o decurso temporal da educação cruzada. Assim, mais estudos investigando o papel da intensidade da carga sobre o decurso temporal da educação cruzada são necessários para ajudar na elaboração de protocolos eficientes.

A educação cruzada da força muscular máxima é umas adaptações contralaterais frequentemente estudadas e evidenciadas na literatura (CIRER-SASTRE; BELTRAN-GARRIDO; CORBI, 2017; GREEN, LARA A.; GABRIEL, DAVID A., 2018). Porém, a habilidade para realizar atividades da vida diária e esportivas não depende somente da força muscular máxima, mas também da capacidade do músculo produzir força dinâmica rapidamente [potência muscular (produto da força pela velocidade)] com diferentes resistências (NAIR; VASANTH; GOURIE-DEVI; TALY *et al.*, 2001; ORR; DE VOS; SINGH; ROSS *et al.*, 2006; WEYERSTRASS; STEWART; WESSELIUS; ZEEGERS, 2018). No entanto, se é possível transferir outras adaptações musculares além da força muscular máxima, como a velocidade, aceleração (mudança na velocidade dividido pela mudança no tempo) e potência musculares, ainda carecem de estudos. Dos poucos estudos que procuraram investigar a educação cruzada de produção de força dinâmica rápida, Ruddy et al. (RUDDY; RUDOLF; KALKMAN; KING *et al.*, 2016), Lee et al. (LEE; HINDER; GANDEVIA; CARROLL, 2010) e Hester et al (HESTER; MAGRINI; COLQUHOUN; BARRERA-CURIEL *et al.*, 2019) relataram aumento na aceleração do movimento e Kannus et al (KANNUS; ALOSA; COOK; JOHNSON *et al.*, 1992) relataram aumento da potência muscular (WATTS; MCKEOWN; DENHOLM; BAKER). Ruddy et al. (RUDDY; RUDOLF; KALKMAN; KING *et al.*, 2016) e Lee et al. (LEE; HINDER; GANDEVIA; CARROLL, 2010) observaram aumento da aceleração após uma sessão de exercícios balísticos, enquanto Hester et al. observaram aumento após 4 semanas de treinamento isocinético unilateral. Embora existam evidências de educação cruzada (agudo ou após algumas semanas) de parâmetros da capacidade de produção de força dinâmica rápida, nenhum estudo investigou o papel da intensidade da carga sobre o decurso temporal da educação cruzada da potência muscular, particularmente com diferentes resistências. Essa informação pode ser benéfica para planejar protocolos de tratamento/treinamento com mais eficiência.

2. REFERENCIAL TEÓRICO

2.1 TEORIAS PARA A EDUCAÇÃO CRUZADA

A hipótese humoral, em que fatores sanguíneos eram responsáveis por aumentar a força contralateral, foi inicialmente sugerida (YUE; COLE, 1992). Porém, mais tarde, essa hipótese foi refutada (BEYER; FUKUDA; BOONE; WELLS *et al.*, 2016). Depois, a hipótese postural em que ao contrair um lado do corpo, o lado oposto contrairia para manter sua estabilidade foi proposta (ZHOU, 2000). Porém, a estabilidade pode ser proveniente da adaptação neural precursora desse fenômeno observado no membro não treinado. Existe uma série de artigos sobre possíveis mecanismos neurais envolvendo a educação cruzada (LEE; CARROLL, 2007; MANCA; HORTOBAGYI; ROTHWELL; DERIU, 2018; RUDDY; CARSON, 2013). Contudo, dois principais modelos são sugeridos por Ruddy & Carson (RUDDY; CARSON, 2013) para explicar educação cruzada, são eles a ativação cruzada e o acesso bilateral (ou engramas motores).

2.1.1 Ativação cruzada

O modelo de “ativação cruzada" sugere que a execução unilateral de uma tarefa ou movimento dá origem a aumentos bilaterais na excitabilidade corticoespinhal de vias eferentes que se direcionam aos músculos do membro não treinado (homólogos). Esse aumento da excitabilidade ocorre devido a adaptações de circuitos neurais homólogos aos do córtex treinado (CARROLL; HERBERT; MUNN; LEE *et al.*, 2006; HORTOBAGYI; RICHARDSON; LOMAREV; SHAMIM *et al.*, 2011; LEE; HINDER; GANDEVIA; CARROLL, 2010; PEREZ; COHEN, 2008; RUDDY; CARSON, 2013). Portanto, áreas motoras do córtex não treinado (além do treinado) são ativadas durante movimento unilaterais. Observa-se ativação ipsilateral de córtex motor primário (M1) (ZULT; GOODALL; THOMAS; HORTOBAGYI *et al.*, 2015), córtex pré-motor (MANCA; HORTOBAGYI; CARROLL; ENOKA *et al.*, 2021), o lobo temporal (FARTHING; BOROWSKY; CHILIBECK; BINSTED *et al.*, 2007), área motora suplementar (RUDDY; LEEMANS; WOOLLEY; WENDEROTH *et al.*, 2017); (DIEDRICHSEN; WIESTLER; KRAKAUER, 2013), córtex sensorial primário, cerebelo, lobo parietal e córtex cingulado (DAI; LIU; SAHGAL; BROWN *et al.*, 2001; HORENSTEIN; LOWE; KOENIG; PHILLIPS, 2009).

Devido à interface entre o sistema límbico e sistema motor voluntário (córtex motor) realizada pelo córtex cingulado anterior (WINTERER; ADAMS; JONES; KNUTSON, 2002), a atividade do córtex não treinado registrada durante o movimento unilateral, pode ocorrer primeiro no córtex cingulado do hemisfério contralateral, então realiza sinapses neuronais, através das fibras transcalosas, em direção ao o córtex cingulado ipsilateral, e subsequentemente para outras áreas motoras (ipsilaterais) antes de influenciar as conexões eferentes de M1 (CARSON; WELSH; PAMBLANCO-VALERO, 2005). Essa conexão entre áreas motoras corticais têm participação dos tratos de fibras do corpo caloso (substância branca) (FLING; BENSON; SEIDLER, 2013).

Como processo originário da ativação nessas regiões referentes ao hemisfério não treinado, podem ocorrer a diminuição da inibição inter-hemisférica [avaliada pela redução da duração do período de silêncio (por estimulação magnética transcraniana)] (CARROLL; HERBERT; MUNN; LEE *et al.*, 2006; KIDGELL; FRAZER; DALY; RANTALAINEN *et al.*, 2015; LEE; HINDER; GANDEVIA; CARROLL, 2010; PEREZ; COHEN, 2008; RUDDY; CARSON, 2013) e a redução da inibição de circuitos intracorticais (inibição intracortical de curto intervalo (SICI) (HORTOBAGYI, 2005; KIDGELL; FRAZER; DALY; RANTALAINEN *et al.*, 2015; MANCA; HORTOBAGYI; CARROLL; ENOKA *et al.*, 2021).

Os interneurônios inibitórios no córtex motor podem estar envolvidos no processo de inibição inter-hemisférica e intracortical, modulando a ativação do córtex ipslateral e consequentemente a excitabilidade corticoespinhal durante o treinamento unilateral (BIANKI; SHRAMM, 1985; CARSON, 2006; HORTOBAGYI, 2005; PEREZ; COHEN, 2008; WERHAHN; KUNESCH; NOACHTAR; BENECKE *et al.*, 1999). Portanto, tanto a inibição inter-hemisférica ou intracortical, mediadas por interneurônios locais, podem levar a ativação cortical ipsilateral, aumentando a excitabilidade corticoespinhal, levando a alterações nas unidades motoras e adaptações musculares no membro não treinado (MANCA; HORTOBAGYI; CARROLL; ENOKA *et al.*, 2021; MANCA; HORTOBAGYI; ROTHWELL; DERIU, 2018).

2.1.2 Engramas motores e acesso bilateral

Acesso bilateral consiste em memórias armazenadas no sistema nervoso central (SNC) devido a estímulo externo, exercício ou tarefa unilateral que podem gerar projeções eferentes, podendo ser posteriormente utilizadas para realizar movimentos nos membros direito ou esquerdo (RUDDY; CARSON, 2013). Essas memórias são os engramas. Os engramas têm sido considerados como unidade básica da memória e refere-se às mudanças físicas e / ou químicas, em determinadas populações de células do sistema nervoso, que foram provocadas pela aprendizagem e estão subjacentes às associações de memória recém-formadas. Essas células podem ser ativadas, modificadas física ou quimicamente e reativadas por memória de recuperação (JOSSELYN; TONEGAWA, 2020). No caso de memória motora, são chamados de engramas motores. Esses são redes neurais (sinapses) formadas a partir do treinamento de determinados movimentos e que ocorrem, inclusive, em tarefas com pouca força (como apertar botões com o dedo) (HAMANO; SUGAWARA; YOSHIMOTO; SADATO, 2020) e que não precisam necessariamente gerar irradiação motora contralateral. Trinta minutos de treinamento são suficientes para formação de engramas motores (HAMANO; SUGAWARA; YOSHIMOTO; SADATO, 2020).

Esses engramas são formados em várias regiões corticais como córtex pré-motor dorsal (intimamente relacionado à aprendizagem motora geral e de sequência motora), área motora suplementar (relacionada ao movimento novo dinâmico, aprendizagem sequencial, funções cognitivas e propriedades motoras), córtex motor primário (M1; responsável por adaptação visuomotora, fase inicial do movimento, pela aprendizagem, retenção e sequenciação motora unilateral), entre outras áreas (CARROLL; LEE; HSU; SAYDE, 2008; FLING; BENSON; SEIDLER, 2013; HARDWICK; ROTTSCHY; MIALL; EICKHOFF, 2013; HINDER; SCHMIDT; GARRY; CARROLL *et al.*, 2011; RIEK; HINDER; CARSON, 2012; RUDDY; CARSON, 2013; VOLLMANN; CONDE; SEWERIN; TAUBERT *et al.*, 2013).

Os engramas podem estar localizados diferentemente, dependendo da tarefa. No córtex pré-motor, por exemplo, tarefas já aprendidas se encontram no hemisfério direito e tarefas novas no hemisfério esquerdo (HARDWICK; ROTTSCHY; MIALL; EICKHOFF, 2013; SCHUBOTZ; VON CRAMON, 2003). No entanto, esses novos circuitos (oriundos de exercício unilateral) podem ser formados no córtex treinado e um engrama paralelo ser formado no hemisfério oposto, não treinado, como uma espécie de leitura dessas memórias (FENTON; BURES, 1994), por meio de fibras transcalosas. Dessa forma a educação cruzada pela teoria do acesso bilateral não difere muito da ativação cruzada (RUDDY; CARSON, 2013). Independente se esse exercício for realizado apenas por um membro direito ou esquerdo, as redes neurais formadas pelo aprendizado, localizado em qualquer região do córtex cerebral, daria acesso a projeções eferentes para ambos os membros direito ou esquerdo (HARDWICK; ROTTSCHY; MIALL; EICKHOFF, 2013).

Esses engramas podem gerar um aumento da excitabilidade corticoespinhal de vias eferentes por ativação de novas regiões especificas após aprendizagem do movimento (SHEMMELL; RIEK; TRESILIAN; CARSON, 2007), o que pode ser observado em exames de neuroimagem (HONDA; DEIBER; IBANEZ; PASCUAL-LEONE *et al.*, 1998). Para que essa ativação de regiões corticais possa enviar informações para ambos os membros, as fibras do corpo caloso precisam estar íntegras para que o indivíduo possa aprender o movimento (BONZANO; TACCHINO; ROCCATAGLIATA; SORMANI *et al.*, 2011) e aumentar o desempenho no membro contralateral (RUDDY; LEEMANS; WOOLLEY; WENDEROTH *et al.*, 2017). Portanto, as fibras intra e inter-hemisféricas (corpo caloso) são importantes para a formação dos engramas e comunicação intra e inter-hemisférica, de forma a levar as projeções eferentes para o membro não treinado (BONZANO; TACCHINO; ROCCATAGLIATA; MANCARDI *et al.*, 2011; BONZANO; TACCHINO; ROCCATAGLIATA; SORMANI *et al.*, 2011; FIELDS, 2011).

Outro fator que pode estar relacionado com a formação dos engramas é a ativação do lobo temporal que subservem a memória semântica (FARTHING; BOROWSKY; CHILIBECK; BINSTED *et al.*, 2007) e também a ativação do sistema de neurônios espelho (ZULT; GOODALL; THOMAS; SOLNIK *et al.*, 2016; ZULT; HOWATSON; KADAR; FARTHING *et al.*, 2014). Ao ativar os neurônios espelho, quando um indivíduo visualiza um de seus membros realizando alguma atividade, pode fazer com que ele aproprie as sensações e ações motoras daquela imagem para o seu membro oposto (RAMACHANDRAN; CHUNHARAS; MARCUS; FURNISH *et al.*, 2018).

Essas projeções das áreas visuais relacionadas aos neurônios espelho são geneticamente predispostas e estão presentes em uma área cortical específica chamada F5. As ações ou sensações que atingem certas áreas visuais (de neurônios espelho) são dependentes de codificações no genoma do indivíduo. No entanto, a experiência motora desempenha um papel na preparação de regiões motoras para enviar projeções para áreas visuais (CASILE; CAGGIANO; FERRARI, 2011; COOK; BIRD; CATMUR; PRESS *et al.*, 2014; RIZZOLATTI; FADIGA, 1998). Portanto, além da predisposição genética, neurônios espelho são resultado de processo de aprendizagem associativa (aprendizagem motora). Em que cada neurônio pode se conectar com outro direta ou indiretamente, e essa arquitetura seria formada por estímulos visuais com representações motoras (BONAIUTO, 2014).

A redução na inibição intracortical do córtex motor primário (M1) pode ser o principal fator subjacente a quaisquer benefícios associados ao treinamento com espelho (REISSIG; PURI; GARRY; SUMMERS *et al.*, 2015; ZULT; GOODALL; THOMAS; HORTOBAGYI *et* *al.*, 2015). Teoricamente, observar a imagem de um membro realizando exercício pode ativar o circuito neurônios espelho (cópia do plano motor) e esse ser utilizado para ambos os membros (RUDDY; CARSON, 2013; ZULT; HOWATSON; KADAR; FARTHING *et al.*, 2014), contribuindo, assim, para a educação cruzada.

2.2 ELETROMIOGRAFIA (EMG) NA EDUCAÇÃO CRUZADA

Dentre as ferramentas de avaliação do sistema nervoso na educação cruzada, a eletromiografia (EMG) é uma das mais acessíveis e tem sido utilizada para avaliar as adaptações neuromusculares decorrentes do treinamento (AAGAARD, PER; SIMONSEN, ERIK B; ANDERSEN, JESPER L; MAGNUSSON, PETER *et al.*, 2002; MANCA; HORTOBÁGYI; ROTHWELL; DERIU, 2018). Nesse sentido, a amplitude do sinal EMG pode aumentar proporcionalmente à demanda de força (DE LUCA; GILMORE; KUZNETSOV; ROY, 2010).

O sensor do eletromiógrafo detecta a despolarização do sarcolema após excitação neural (FARINA, 2016). Apesar da maioria dos estudos relacionar o aumento da amplitude do sinal da EMG ao aumento do recrutamento das unidades motoras e da frequência de disparo (DE LUCA; GILMORE; KUZNETSOV; ROY, 2010) (AAGAARD, P.; SIMONSEN, E. B.; ANDERSEN, J. L.; MAGNUSSON, P. *et al.*, 2002), o aumento da atividade eletromiográfica pode representar também o aumento da sincronização das unidades motoras, velocidade de propagação da fibra muscular ou aumento dos potenciais de ação muscular (DIMITROVA; DIMITROV, 2003). Então, determinar a adaptação exata que ocorreu parece incerto, tornando razoável nomeá-las apenas como adaptações nas unidades motoras.

Mesmo sabendo do aumento da plasticidade neural na educação cruzada, concomitante ao aumento da força, o aumento da amplitude do sinal da EMG no membro oposto ao treinado ainda é controverso (DE LUCA; GILMORE; KUZNETSOV; ROY, 2010; MANCA; HORTOBAGYI; ROTHWELL; DERIU, 2018). Porém, no estudo de Carr et al (CARR; YE; STOCK; BEMBEN *et al.*, 2019), apesar dos autores não encontrarem aumento da amplitude EMG no pico da contração, encontraram um aumento na amplitude EMG do músculo no início do movimento concomitante ao aumento na taxa de desenvolvimento de força no braço não treinado. Esse aumento "inicial" da EMG parece ser um indicador que representa adaptações das unidades motoras no início da contração, relacionado à parâmetros rápidos do músculo após treinamento unilateral (ANDERSEN; ANDERSEN; ZEBIS; AAGAARD, 2010).

Adicionalmente, o aumento da amplitude do sinal eletromiográfico no início da contração pode ser um contribuinte para o aumento da potência muscular após o treinamento

(AAGAARD, P.; SIMONSEN, E. B.; ANDERSEN, J. L.; MAGNUSSON, P. *et al.*, 2002; ANDERSEN; ANDERSEN; ZEBIS; AAGAARD, 2010; DEL BALSO; CAFARELLI, 2007; VAN CUTSEM; DUCHATEAU; HAINAUT, 1998). Então, a amplitude da EMG, avaliada no início da contração, pode ser uma ferramenta útil para verificar alterações nas unidades motoras que ocorrem com a educação cruzada da potência muscular no membro não treinado.

2.3 IRRADIAÇÃO CONTRALATERAL OU ATIVIDADE ESPELHO

À ativação muscular involuntária dá-se o nome de irradiação motora (ADDAMO; FARROW; HOY; BRADSHAW *et al.*, 2009; HOY; FITZGERALD; BRADSHAW; ARMATAS *et al.*, 2004). Quando o registro da atividade EMG ocorre no membro contralateral pode ser chamada de irradiação contralateral (CERNACEK, 1961), movimento associado (TODOR; LAZARUS, 1986), movimento espelho ou atividade espelho (MAYSTON; HARRISON; STEPHENS, 1999) e é muito comum em populações neurológicas ou idosas, em que para compensar a demanda de atenção, regiões corticais adicionais são ativadas (ADDAMO; FARROW; HOY; BRADSHAW *et al.*, 2009). Já em adultos saudáveis a atividade espelho está ligada a tarefas envolvendo esforço com carga elevada (CERNACEK, 1961), fadiga ou diminuição de força muscular do indivíduo (ARANYI; ROSLER, 2002) podendo ser suprimida durante movimentos fáceis ou já familiarizados (ZIJDEWIND; KERNELL, 2001; CHEN et al. 2011). A origem fisiológica dessa relação da atividade espelho com a carga pode ocorrer porque há uma necessidade de cooperação bilateral dos membros, necessária para suportar cargas pesadas; diferentemente de atividades leves como a escrita em que não ter atividade espelho pode prevenir interferências no movimento fino (LIEPERT; DETTMERS; TERBORG; WEILLER, 2001).

Diante da possibilidade de induzir a irradiação motora com cargas elevadas (ARMATAS, 1996), é concebível que a ocorrência de atividade espelho pode ter alguma função relacionada à adaptações musculares do treinamento. Hellebrandt (HELLEBRANDT, 1951) foi o primeiro a identificar a atividade espelho como componente da educação cruzada. É possível associar essas duas variáveis (atividade espelho e educação cruzada), ao ser evidenciado que baixos percentuais de ativação muscular são capazes de produzir aumento de força no músculo correspondente (LAIDLAW; KORNATZ; KEEN; SUZUKI *et al.*, 1999). Sendo assim, alguns autores propuseram que essa ativação espelho com pequenos percentuais de atividade muscular poderiam levar a educação cruzada das adaptações do treinamento, como foi o caso de Andrushko et al e Magnus et al. que encontraram atividade espelho de 5,6 % e 3,1%, respectivamente (ANDRUSHKO; LANOVAZ; BJORKMAN; KONTULAINEN *et al.*, 2018; MAGNUS; BARSS; LANOVAZ; FARTHING, 2010). Ambos encontraram educação cruzada de força e especularam que a atividade espelho encontrada no braço contralateral estaria relacionada com o ganho de força muscular. Porém, a relação entre atividade espelho e educação cruzada ainda carece ser melhor explorada em novos estudos.

2.4 APLICABILIDADE DA EDUCAÇÃO CRUZADA

Em algumas situações patológicas, os indivíduos ficam impossibilitados de movimentar um de seus membros superiores e/ou inferiores. Essa situação pode ser permanente como em casos de hemiplegia (DRAGERT; ZEHR, 2013b) ou esclerose múltipla (MANCA; CABBOI; DRAGONE; GINATEMPO *et al.*, 2017) ou de forma temporária como em imobilizações por fratura (DELFT; GELDER; VRIES; VERMEULEN *et al.*, 2019) ou lesão nervosa periférica (FERNANDES; OLIVEIRA; PELET; CUNHA *et al.*, 2016). Situações como essas levam a perda de força, atrofia e das demais adaptações musculares obtidas com o treinamento físico (ANDRUSHKO; GOULD; FARTHING, 2018).

As reduções iniciais de força superam a atrofia, sugerindo uma contribuição neural importante à perda de força (HENDY; SPITTLE; KIDGELL, 2012). Caso o dano seja duradouro ou permanente, como em um acidente vascular encefálico, o indivíduo pode estabelecer uma incapacidade permanente naquele membro, levando a inúmeras perdas funcionais e gerando encargos sociais (WINSTEIN; STEIN; ARENA; BATES *et al.*, 2016). A possibilidade de não movimentar um dos membros pode levar ao sedentarismo, acumulando consequências prejudiciais para o organismo humano como hipertensão e obesidade (HASSAPIDOU; PAPADOPOULOU; VLAHAVAS; KAPANTAIS *et al.*, 2013). A hipótese da "simetria restauradora" da educação cruzada tem um impacto significativo para a resolução dessa questão (FARTHING; ZEHR, 2014). Nesses casos, a educação cruzada tem aplicabilidade no contexto de reabilitação física, pois o treino unilateral pode promover ganho ou manutenção da força (DRAGERT; ZEHR, 2013b) ou evitar a atrofia pelo desuso enquanto essa situação perdurar (ANDRUSHKO; GOULD; FARTHING, 2018).

Os pacientes então, podem se beneficiar da educação cruzada, realizando exercícios com o membro não lesado e, assim, conseguir adaptações para o lado contralateral lesado (DRAGERT; ZEHR, 2013a) e atenuação da perda de massa muscular (MAGNUS; BARSS; LANOVAZ; FARTHING, 2010). Isso evita uma possível situação de incapacidade, interrompendo o ciclo de sedentarismo que levaria a várias doenças precursoras da mortalidade. Além disso, parece que envelhecimento do sistema nervoso não é limitante da educação cruzada. Por isso, não só jovens, mas também idosos podem ser beneficiados (BARSS; PEARCEY; ZEHR, 2016; HESTER; MAGRINI; COLQUHOUN; BARRERA-CURIEL *et al.*, 2019).

Assim, o TFU pode ser amplamente incorporado pelos profissionais de saúde em programas de reabilitação para compensar perdas de força do membro lesionado e acelerar a recuperação (HENDY; SPITTLE; KIDGELL, 2012). Além disso, há evidências que as adaptações para o membro não treinado podem ser superiores em sujeitos lesados comparado aos saudáveis neurologicamente (DRAGERT; ZEHR, 2013b). Além disso, a educação cruzada com TFU é a uma alternativa viável de recuperação, pois o treino direto (no membro lesado) pode, muitas vezes, não ser aplicável ou ser um estímulo ineficiente para gerar adaptações musculares (DRAGERT; ZEHR, 2011; MANCA; CABBOI; DRAGONE; GINATEMPO *et al.*, 2017).

2. 5 A MAGNITUDE DA EDUCAÇÃO CRUZADA

A magnitude da força transferida para o outro membro é proporcional ao ganho de força do membro treinado (GREEN, L. A.; GABRIEL, D. A., 2018). O percentual de aumento varia entre 2,4% - 110,0% (GREEN, LARA A.; GABRIEL, DAVID A., 2018). Nesse contexto, fatores que afetam a força muscular do membro treinado apresentam importância substancial para o ganho de adaptações no membro contralateral homólogo.

2.6 VARIÁVEIS DO TREINAMENTO

2.6.1 Intensidade (carga)

Sugere-se que para induzir a educação cruzada de força muscular, o treinamento de força unilateral (TFU) deve ser realizado em intensidade de carga moderada a alta (COOMBS; FRAZER; HORVATH; PEARCE *et al.*, 2016; EHSANI; NODEHI-MOGHADAM; GHANDALI; AHMADIZADE, 2014; GREEN, L. A.; GABRIEL, D. A., 2018; HENDY; CHYE; TEO, 2017). Isso representa que durante o TFU a carga usada deva ser próxima do máximo, acima de 70% de uma repetição máxima (1RM) ou da contração isométrica voluntária máxima (CIVM). Exercícios com cargas elevadas ou contração voluntaria máxima podem desencadear pequenas contrações do membro contralateral ao realizar exercício unilateral, efeito este denominado como atividade espelho ou irradiação motora (overflow) (ADDAMO; FARROW; HOY; BRADSHAW *et al.*, 2009). Essa atividade espelho poderia contribuir para a educação cruzada por acesso bilateral, aumentando a força muscular (RUDDY; CARSON, 2013) ou atenuando a atrofia e perda de força durante o desuso (ANDRUSHKO; GOULD; FARTHING, 2018; MAGNUS; BARSS; LANOVAZ; FARTHING, 2010). Porém as evidências que a irradiação motora levaria a maiores resultados de educação cruzada ainda são controversas (RUDDY; RUDOLF; KALKMAN; KING *et al.*, 2016) e, portanto, mais estudos são necessários.

Perez e Cohen (PEREZ; COHEN, 2008) mostraram que a magnitude da ativação cruzada da via corticomotora está positivamente associada à intensidade da contração muscular. Porém, para que intensidade moderada a alta seja efetivamente integrada em um ambiente de reabilitação, são necessários estudos comparando os efeitos crônicos de diferentes intensidades na educação cruzada de força muscular. Baseados na nossa revisão de literatura, nenhum estudo procurou investigar os efeitos crônicos da intensidade do TFU sobre a educação cruzada (comparação direta entre diferentes intensidades de cargas). Além disso, nenhum dos estudos crônicos encontrados na revisão de literatura, que procurou investigar os efeitos do treinamento dinâmico isoinercial (resistência constante), usou intensidade inferior a 70% de 1RM (COLOMER-POVEDA; ROMERO-ARENAS; KELLER; HORTOBAGYI *et al.*, 2019). Porém, alguns estudos utilizando exercícios isométricos, observaram educação cruzada de força isométrica com cargas inferiores a 50% da CIVM (CIRER-SASTRE; BELTRAN-GARRIDO; CORBI, 2017). Assim, devido à alta inconsistência na literatura e a falta de estudos comparando diferentes intensidades, a conclusão que intensidade de carga mais elevada seria mais eficiente ou até mesmo necessária para promover uma educação cruzada de força muscular ainda permanece incerta, particularmente no treinamento de força dinâmico e isoinercial (COLOMER-POVEDA; ROMERO-ARENAS; KELLER; HORTOBAGYI *et al.*, 2019).

2.6.2 Velocidade do exercício

Alguns estudos sobre educação cruzada se preocuparam em determinar a cadência do exercício dinâmico. No estudo de Farthing e chilibeck (FARTHING; CHILIBECK, 2003) e Munn et al. (MUNN; HERBERT; HANCOCK; GANDEVIA, 2005), a educação cruzada ocorreu após exercícios com velocidade de contração mais rápida. Em contrapartida, Hortobagyi et al. (HORTOBAGYI; LAMBERT; HILL, 1997) e Holper et al. (HOLPER; BIALLAS; WOLF, 2009) encontraram que repetições lentas podem levar a maior educação cruzada. Para completar, Kidgell et al. (KIDGELL; FRAZER; DALY; RANTALAINEN *et al.*, 2015) encontraram maior magnitude de resposta de educação cruzada para o grupo que realizou exercício com fase excêntrica mais longa. Adicionalmente, Coombs et al. (COOMBS; FRAZER; HORVATH; PEARCE *et al.*, 2016) realizaram treino com fase excêntrica e concêntrica longa controlada e obtiveram êxito no ganho de força contralateral. Entretanto há evidências de que a potencialização da educação cruzada de força ocorre em exercícios com velocidade concêntrica rápida quando comparada à lenta (MUNN; HERBERT; HANCOCK; GANDEVIA, 2005). Por isso, manter a fase excêntrica lenta e realizar fase concêntrica rápida parece ser uma estratégia adequada promover a educação cruzada.

2.6.3 Novidade na tarefa

O grau de educação cruzada também depende de quão complexo é uma tarefa e quão inovador é para aqueles que a realizam (RUDDY; CARSON, 2013). Holper et al. (HOLPER; BIALLAS; WOLF, 2009) encontraram maior concentração de oxi-hemoglobina sanguínea cerebral em tarefas complexas comparada às simples, isso sugere que quanto mais desconhecida for a tarefa para o indivíduo que realiza, maior ativação do SNC, o que pode representar maior neuroplasticidade no SNC (FOSTER; STEVENTON; HELME; TOMASSINI *et al.*, 2020) e portanto resulta em maior educação cruzada. Por isso, qualquer tarefa que exija alguma habilidade nova do SNC pode ajudar na magnitude da transferência, como por exemplo, repetições controladas por um metrônomo (LEUNG; RANTALAINEN; TEO; KIDGELL, 2015). No estudo de Coombs et al (COOMBS; FRAZER; HORVATH; PEARCE *et al.*), realizar a tarefa em um determinado tempo programado por um metrônomo representou elemento novidade e complexidade que são importantes para a educação cruzada. Os circuitos neurais formados para a aquisição de novas habilidades parecem ser responsáveis por maior educação cruzada.

2.7 ESPECIFICIDADE

Considera-se que educação cruzada é dependente da especificidade do movimento. Beyer et al. (BEYER; FUKUDA; BOONE; WELLS *et al.*, 2016) encontraram que o treinamento de força com exercícios dinâmicos proporcionou maior aumento de força dinâmica do que de força isométrica no membro não treinado. Essa especificidade do tipo de contração também ocorreu nos estudos de Hortobagyi et al. (HORTOBAGYI; LAMBERT; HILL, 1997), Farthing & Chilibeck (FARTHING; CHILIBECK, 2003) e Zhou et al. (ZHOU. S, 2002). Além disso, Beyer et al. (BEYER; FUKUDA; BOONE; WELLS *et al.*, 2016) encontraram especificidade no tipo de exercício utilizado (*leg press* vs. extensão de joelhos). Farthing et al. (FARTHING; CHILIBECK, 2003) encontraram especificidade na velocidade de treino e Mason et al. (MASON; FRAZER; HORVATH; PEARCE *et al.*, 2018) encontraram especificidade com relação ao músculo, sendo o músculo homólogo agonista recebendo mais transferência de força do que o sinergista.

2.8 DIRECIONALIDADE

Alguns autores, interessados em verificar o papel da direcionalidade, investigaram se a educação cruzada poderia ocorrer independente de treinar o braço dominante ou não dominante. Farthing et al. (FARTHING; CHILIBECK; BINSTED, 2005) encontraram que treinar com braço dominante levaria a maior ganho de força no membro contralateral. Contudo, esses autores (FARTHING; CHILIBECK; BINSTED, 2005) têm sugerido que a educação cruzada pode ocorrer em ambas as direções se a tarefa for novidade para ambos os membros. Já Sainburg et al. (SAINBURG; SCHAEFER; YADAV, 2016) e Coombs et al. (COOMBS; FRAZER; HORVATH; PEARCE *et al.*), apesar de não encontrarem diferença na transferência de força entre os membro dominante ou não dominante após o treinamento, observaram diferença na redução da inibição corticoespinhal que foi mais pronunciada no M1 "destreinado" ipsilateral após treinamento com membro direito, comparado ao esquerdo. Farthing e Zehr (FARTHING; ZEHR, 2014) sugeriram que o efeito da direcionalidade pode variar dependendo da tarefa. Embora a direcionalidade do fenômeno de educação cruzada pareça existir, algumas evidências e fatores de confusão impedem essa afirmação.

2.9. EFEITO DO SEXO NA EDUCAÇÃO CRUZADA

Após treinamento unilateral, Tracy et al. (TRACY; IVEY; HURLBUT; MARTEL *et al.*, 1999) encontraram maior educação cruzada em homens do que em mulheres. No entanto, Hubal et al. (HUBAL; GORDISH-DRESSMAN; THOMPSON; PRICE *et al.*, 2005), apesar de encontrar valores absolutos de incrementos na educação cruzada maiores em homens, a porcentagem encontrada foi maior em mulheres. Já Green et al. (GREEN, L. A.; GABRIEL,

D. A., 2018), não encontraram diferença na educação cruzada de força isométrica entre os sexos. No entanto, há diferenças claras na estrutura e fisiologia do sistema nervoso entre homens e mulheres que ainda carecem ser exploradas (BAKKER, 2019; LEUNG; RANTALAINEN; TEO; KIDGELL, 2015) e permitem algumas especulações acerca da educação cruzada, como a flutuação dos hormônios ovarianos que parece influenciar a neuroplasticidade nas mulheres (AMIN; MASON; CAVUS; KRYSTAL *et al.*, 2006; GUENNOUN; LABOMBARDA; GONZALEZ DENISELLE; LIERE *et al.*, 2015) e também podem alterar o desempenho no exercício e função muscular (MCNULTY; ELLIOTT-SALE; DOLAN; SWINTON *et al.*, 2020; ROMERO-MORALEDA; COSO; GUTIERREZ-HELLIN; RUIZ-MORENO *et al.*, 2019; SUNG; KIM, 2019). Nesse sentido, a oscilação hormonal das mulheres pode influenciar dos desfechos da educação cruzada, levando a diferenças na resposta entre homens e mulheres. Porém, a escassez de estudos comparando a diferença dos sexos na educação cruzada torna difícil uma definição.

2.10 TEMPO DE TREINO NECESSÁRIO PARA DESENVOLVER EDUCAÇÃO CRUZADA

As pesquisas se dividem em estudos agudos ou crônicos. Do ponto de vista agudo, observa-se alterações como o aumento da aceleração do movimento (velocidade dividida pelo tempo) no braço não exercitado e alterações na excitabilidade corticoespinhal no hemisfério contralateral (RUDDY; RUDOLF; KALKMAN; KING *et al.*, 2016). Do ponto de vista crônico, os estudos sobre educação cruzada têm duração de treinamento variável. O tempo de treinamento médio dos estudos crônicos varia de 3 a 12 semanas (COOMBS; FRAZER; HORVATH; PEARCE *et al.*, 2016; MAGNUS; ARNOLD; JOHNSTON; DAL-BELLO HAAS *et al.*, 2013; MAGNUS; BARSS; LANOVAZ; FARTHING, 2010; MASON; FRAZER; HORVATH; PEARCE *et al.*, 2018). Todos os estudos reportaram adaptações contralaterais (educação cruzada). Porém, o decurso temporal dessas adaptações não é mostrado nesses estudos crônicos.

No estudo de Ruddy et al. (RUDDY; RUDOLF; KALKMAN; KING *et al.*, 2016), houve transferência de habilidades da primeira para a segunda sessão, sugerindo que a longo prazo possa haver um acúmulo de adaptações. Car et al. (CARR; YE; STOCK; BEMBEN *et al.*, 2019) e Barss et al. (BARSS; KLARNER; PEARCEY; SUN *et al.*, 2018) investigaram a evolução temporal da educação cruzada durante o treinamento de força isométrico de curta duração. Os autores reportaram aumento na força isométrica do músculo não treinado após duas e quatro semanas de treinamento de força isométrica unilateral, respectivamente. No entanto, a utilização de apenas exercícios isométricos torna difícil a generalização do decurso temporal para outros tipos de treinamento e adaptações (força dinâmica) devido a especificidade da educação cruzada.

3. JUSTIFICATIVA

Apesar da vasta literatura sobre a educação cruzada, para que os protocolos de treinamento unilateral possam ser aplicados com êxito no ganho de adaptações contralaterais, são necessários ainda alguns esclarecimentos.

Um deles é a carga a ser utilizada. Devido à maior neuroplasticidade ocorrer em exercícios com intensidade alta de carga (PEREZ; COHEN, 2008), pode ser útil a identificação da necessidade do uso das intensidades elevadas de carga, no treinamento unilateral, para potencializar os efeitos do membro oposto. Por outro lado, para aqueles que tem alguma restrição para o uso de cargas elevadas, é necessário saber se o treinamento com intensidade baixa de carga é efetivo no ganho de adaptações contralaterais, sobretudo com uso de ritmo externo ao movimento (metrônomo), que pode auxiliar nas adaptações neurais (COOMBS; FRAZER; HORVATH; PEARCE *et al.*, 2016; HOLPER; BIALLAS; WOLF, 2009).

A educação cruzada de força máxima é bem evidenciada na literatura. Porém, a habilidade para realizar atividades da vida diária e esportivas não depende somente da força muscular máxima, mas também da capacidade do músculo produzir força dinâmica rapidamente (potência muscular) com diferentes resistências (CORMIE; MCGUIGAN; NEWTON, 2011; NAIR; VASANTH; GOURIE-DEVI; TALY *et al.*, 2001; ORR; DE VOS; SINGH; ROSS *et al.*, 2006; WEYERSTRASS; STEWART; WESSELIUS; ZEEGERS, 2018). No entanto, parâmetros da capacidade de produzir força rápida, como potência (produto da força pela velocidade) ainda são pouco explorados nos estudos sobre educação cruzada.

As diferenças neurofisiológicas, e no ganho de força, entre homens e mulheres e a oscilação hormonal durante o ciclo ovariano das mulheres, propõe que a educação cruzada possa se comportar de maneira diferente entre os sexos. Confirmar essa informação seria útil na elaboração de protocolos de treinamento/ reabilitação específicos e ainda carecem de estudos. Um outro esclarecimento que também auxiliaria na elaboração de protocolos de treinamento é sobre a especificidade da educação cruzada, com relação a obtenção de força dinâmica ou isométrica.

Por último, mas não menos importante, é o esclarecimento sobre o comportamento temporal da educação cruzada de força e potência musculares. Definir quando e como essas as mudanças nos parâmetros transferidos ocorrem pode ser benéfico para planejar protocolos com eficiência de tempo em populações saudáveis e clínicas. Ao programar um protocolo de treinamento para promover educação cruzada específicas (como aumento de potências muscular para atletas ou recuperação dessa qualidade após uma lesão) é de extrema importância saber o tempo e amplitude de tais transferências para planejar intervenções personalizadas e eficientes, com progressão bem definida baseadas em objetivos alcançáveis.

4. OBJETIVOS

4.1 OBJETIVO GERAL

Verificar o impacto do treinamento de força em diferentes intensidades sobre o decurso temporal da educação cruzada de força (dinâmica e isométrica máximas) e potência musculares.

4.2 OBJETIVOS ESPECÍFICOS

Artigo 1

1) comparar a extensão da transferência cruzada de força muscular do treinamento resistido unilateral (dinâmico) de carga alta versus baixa realizado com ritmo externo do movimento e 2) comparar decurso temporal das duas abordagens.

Artigo 2

1) verificar o decurso temporal da educação cruzada da potência muscular durante treinamento resistido unilateral em diferentes intensidades de carga e 2) identificar diferenças entre os sexos nas respostas da educação cruzada

5. MÉTODOS, RESULTADOS E DISCUSSÃO

A seção de materiais e métodos, resultados e discussão serão apresentados sob a forma de dois artigos científicos, produtos deste projeto de pesquisa.

5.1 ARTIGO 1

O artigo a seguir foi submetido (ANEXO A) e aceito (ANEXO B) pela revista “Applied Physiology, Nutrition, and Metabolism”, fator de impacto “3.455”. Doi para citação: 10.1139/apnm-2021-0088.

Effects of resistance training at different intensities of load on cross-education of muscle strength

Abstract

The objectives of this study were 1) to compare the extent of cross-transfer of high- versus low-load unilateral resistance training performed with external pacing of the movement (URTEP) and 2) to compare the time course of the two approaches. Fifty subjects were randomized to one of the following three groups: G80 [two sets at 80% and two sets at 40% of one maximum repetition (1RM), 1 concentric second and 3 eccentric seconds controlled by a metronome]; G40 (four sets at 40% of 1 RM, 1s and 3s controlled by a metronome); or CG (control group). At week 1, the G80 increased the elbow flexion 1RM ($P<0.05$) in contralateral arm. At week 4, both G80 and G40 increased the elbow flexion 1RM ($P<0.05$) in contralateral arm. However, a greater 1RM gain was observed in the G80 than in the G40 ($P< .05$). Thus, although higher-load URTEP seems to enhance the cross-education effect when compared to lower-load URTEP, the cross-education of dynamic strength can be achieved in the two approaches after four weeks. Many patients would benefit from cross-education of muscle strength through URPEP, even who are unable to exercise with high loads and in short periods of immobilization.

Keywords: Contralateral adaptations; Unilateral strength training; electromyography; Cross-Education; Cross-transfer; Strength training

Novelty bullets: (1) Unilateral resistance training promotes cross-education of dynamic muscle strength. (2) However, higher-load resistance training enhances the effects of cross-education of muscle strength.

INTRODUCTION

Cross-education or the cross-transfer effect is a neural adaptation that occur in untrained homologous and contralateral muscles after unilateral training, increasing the strength of the untrained muscles (Frazer et al. 2018; Ruddy and Carson 2013). Adaptations in cortical motor and non-motor regions, altering the neural drive to the contralateral muscles have been implicated in the underlying mechanisms of cross-education (Frazer et al. 2018; Ruddy and Carson 2013). Unilateral resistance training has been considered an effective strategy to promote cross-education of muscle strength (Colomer-Poveda et al. 2019; Frazer et al. 2018; Manca et al. 2017). Interestingly, a great variation in training stimuli (i.e. type, load, contraction type, and external pacing and velocity of movement) and magnitude of the cross-education effect on muscle strength has been reported (Colomer-Poveda et al. 2019; Frazer et al. 2018; Green and Gabriel 2018). Particularly, augmentation of activity in the ipsilateral and contralateral primary motor cortex, accompanied by elevation in the excitability of corticospinal output projections is observed in unilateral tasks that demand maximal levels of motor output (Hendy et al. 2017; Perez and Cohen 2008; Ruddy and Carson 2013). Indeed, Othman et al showed that low-load unilateral resistance training may be inadequate to induce an increase in contralateral muscle strength, particularly in elbow flexion (Ben Othman et al. 2018). For this reason, unilateral resistance training has preferably been performed with a higher intensity of load (> 50% of maximum muscle strength) to promote cross-education of muscle strength (Carroll et al. 2006; Cirer-Sastre et al. 2017; Colomer-Poveda et al. 2019). In this regard, many patients are unable to perform an exercise with high loads [(e.g., osteoarthritis, patellofemoral pain, stroke, hypertension (Frazer et al. 2018; Giles et al. 2017; Ruddy and Carson 2013; Sharman et al. 2015)] and, therefore, would not benefit from unilateral resistance training due to the need for high loads.

On the other hand, it has been shown that unilateral movement repetition in the absence of skill acquisition, even with higher intensity of load, may be inadequate to induce changes in ipsilateral corticospinal excitability (Leung et al. 2015) and contralateral muscle strength (Munn et al. 2005). Therefore, learning appears to be a necessary step to drive neuroplastic changes in the cortical regions, promoting cross-education of muscle strength (Leung et al. 2015; Ruddy and Carson 2013). In this sense, results from recent studies have shown that dynamic eccentric, when compared to dynamic concentric or static unilateral voluntary muscle contractions (Colomer-Poveda et al. 2019; Howatson et al. 2011; Uematsu et al. 2010), and externally paced movements (Colomer-Poveda et al. 2019; Leung et al. 2015, 2018) leading to greater increases in the excitability of the ipsilateral primary motor cortex and reductions in short-interval intracortical inhibition after both, acute and chronic unilateral resistance training. Therefore, if dynamic eccentric contraction and externally paced movements lead to greater activation of the ipsilateral brain areas, following the cross-activation model it is possible that dynamic low-load unilateral resistance training with external pacing of the movement (controlling eccentric contraction) could serve as a training stimulus for ipsilateral cortex adaptations and promote an increase in contralateral muscle strength.

Neural changes and ability to produce muscular strength and motor skill in the trained limb that previously occur following resistance and motor skill training, respectively, are rapid (first week of training) (Del Balso and Cafarelli 2007; Karni et al. 1998; Mason et al. 2020; Siddique et al. 2020). However, whether these adaptations (e.g., muscle strength) are transferred to the untrained arm at the same rate as that manifested in the trained arm remains uncertain.

There are very limited data regarding the time course of cross-limb strength improvements during short-term unilateral muscle strength training. Some studies have observed different time points in the onset of muscle strength increase of the contralateral muscle to the training limb after high-intensity isometric unilateral resistance training. Carr et al. (Carr et al. 2019), Hortobagyi et al. (Hortobagyi et al. 2011), and Barss et al. (Barss et al. 2018) reported a significant increase in isometric strength of the untrained muscle after two, three, and four weeks of unilateral isometric strength training, respectively. The different time points in the onset of muscle strength increase may suggest that factors other than the intensity of load may be responsible for the different rates at which these adaptations (e.g., muscle strength) manifest for the untrained, contralateral limb. Whereas Carr et al. provided visual force feedback and instructed the participant to produce force rapidly at contraction onset, the other studies did not report such training stimuli. Nevertheless, whether unilateral resistance training when planning to take into account training stimuli (i.e., dynamic eccentric unilateral voluntary muscle contractions and different strategies of pacing the movement with external auditory signal (Colomer-Poveda et al. 2019; Leung et al. 2015; Munn et al. 2005; Ruddy and Carson 2013)) may produce an early increase (i.e., in the first week of training) in muscle strength of (untrained) contralateral limb is uncertain.

Moreover, a progressive increase in strength of the contralateral muscle has been reported after the initial phase of high-load unilateral resistance training. It is possible that, in the later phase, higher-load unilateral resistance training promotes a greater increase in the strength of contralateral muscle than lower-load unilateral resistance training due to greater stimuli on cross-activation of the corticomotor pathway (Colomer-Poveda et al. 2019; Frazer et al. 2018; Ruddy and Carson 2013). Therefore, the objectives of this study were 1) to compare the extent of cross-transfer of high- versus low-load unilateral resistance training (dynamic) performed with external pacing of the movement (URTEP), and 2) to compare the time course of the two approaches.

METHODS

Experimental Approach to the Problem

In studies on cross-education of muscle function, more control can be achieved by randomizing subjects into groups (Carroll et al. 2006). To determine the contralateral effect of the URTEP, we used one of the three options suggested by Carroll et al 2006. According to Carroll et al 2006, a “possibility is to compare the strengths of untrained limbs of trained and untrained subjects after adjusting for baseline strength in an analysis of covariance.” (Carroll et al. 2006). Therefore, this randomized controlled study was a parallel, between-group design that included two groups that received unilateral dynamic resistance training (higher or lower intensity of load) and a control group that did not receive resistance training (Figure 1). First, participants were invited to take part in a day in which they were familiarized with resistance exercise on the Scott bench (dumbbell Scott curl). After a 48-hour interval, the one repetition maximum (1 RM) test was performed. After a 48-hour interval, a retest of 1 RM was performed. The 1RM test and retest were performed to eliminate intra-individual variability and reduce possible biases in increased strength by learning the tests. After 48h of 1RM retest, the maximum voluntary isometric contraction (MVIC) test was performed (three attempts were performed). When both arms were evaluated (Figure 1), the right arm was evaluated before the left one.

Following these assessments, we used a Medcalc® tool (Create random group) to assign cases to random groups. Each volunteer was randomized (taking into account gender: block randomization) into the three training groups: Low-load resistance training (G40), high-load resistance training (G80), and the control group (Edgcumbe et al.). All the individuals were right-handed. However, the volunteer's arms were randomized (taking into account the side: left or right) in the trained arm or transfer arm. Thus, a similar number of dominant and non-dominant arms were allocated to the training arm or transfer arm. In the control group (no exercise), the volunteer's arms were also randomized in the training control arm or transfer control arm.

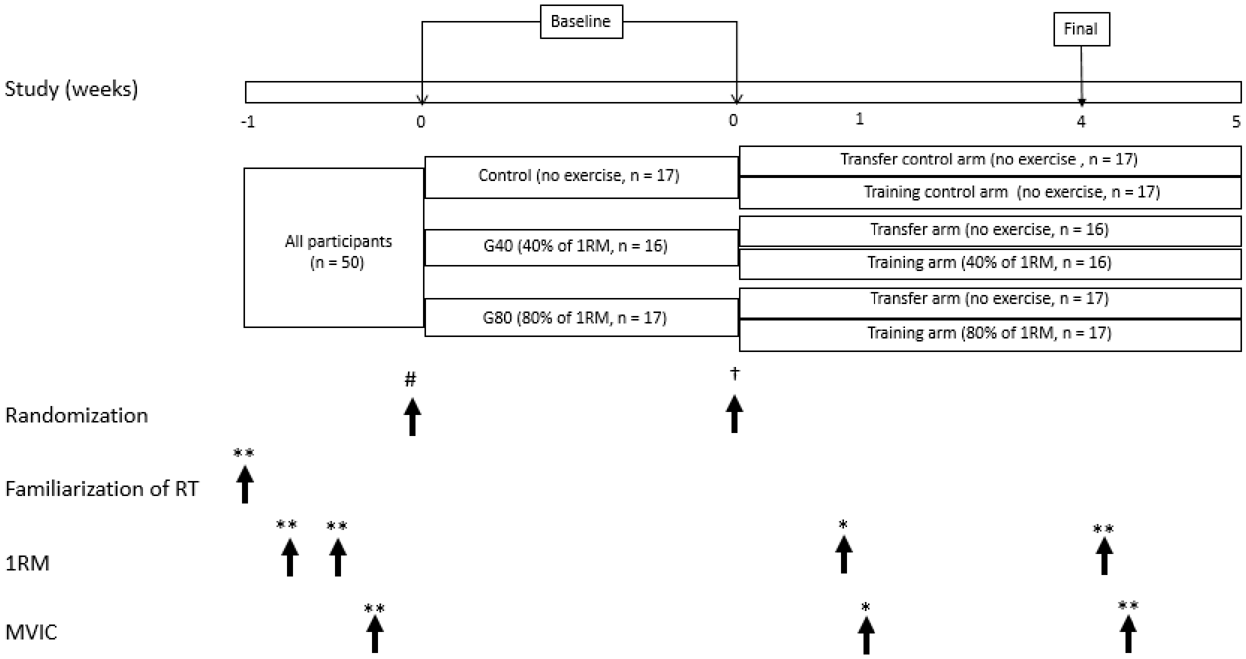

Figure. 1. Schematic overview of study design.

** = both arms, * = untrained arm (transfer arm) and transfer control arm, # = randomization of participants and † = randomization of arms (training or strength transfer)

In the training groups, each volunteer performed a dynamic URTEP (isoinertial) with only one arm (training arm). G40 or G80 performed dynamic URTEP (dumbbell Scott curl), three times per week, for four weeks. After one week of dynamic URTEP, 1RM and MVIC tests were performed again (both tests were separated by 48 hours) solely in the transfer arm and transfer control arm. After four weeks of dynamic URTEP, the 1RM and MVIC tests were performed again (both tests were separated by 48 hours) in all arms. All assessments and training sessions were performed by a physiotherapist.

All individuals performed all training sessions and assessments at the same time of day (afternoon or evening) to eliminate possible variations of the day. All evaluations were carried out in a laboratory with temperature (~21^{o}C) and noise controls.

Subjects

This study was approved by the local ethics committee (n. 73681617.0.0000.5154) and all participants were informed about the research procedures and signed an informed consent form before participation (annex C and appendix A).

A priori sample calculation was performed before starting the study. The sample size was calculated using G*Power software (version 3.1.9.2). The effect size was based on the cross-education of dynamic muscular strength reported in a meta-analysis (d = 0.65) (Green and Gabriel 2018). However, we decided to use a smaller effect (d = 0.40) to ensure a sample of sufficient size. The conversion from d to η^2 (eta squared) was performed using the formula suggested by Fritz et al (Fritz et al. 2012): $\eta^2 = \frac{d^2}{d^2+4}$. The power analysis demonstrated that at least 16 participants are needed for each group to detect a η^2 of 0.036 (effect size f = 0.19, test family f, repeated measures, within-between interaction). The alpha error was defined as 0.05 with a power of 80%, correlation among repeated measures of 0.6, and non-sphericity correction of 1.0.

Recruitment was carried out through social media, pamphlets, and invitations distributed in places with a large flow of people. Fifty healthy and right-handed participants (26 women, 24 men aged 19–41 years) volunteered to participate in the study and met the inclusion criteria. Inclusion criteria were: the volunteers had to be free of orthopedic and neurological diseases; had controlled blood pressure and glycemia; were untrained (did not engage in exercise programs over the last 6 months, neither recreational nor professionally); non-smoker; and did not take any medicine. Inclusion criteria were identified by a physiotherapist who administered an anamnesis (appendix B).

Since there is evidence that there is no difference in the occurrence of cross-transfer between the young and elderly (Bemben and Murphy 2001; Ehsani et al. 2014; Hester et al. 2019), we chose to form a sample comprising only young adults (from 19 to 41 years), in a way that become as homogeneous as possible.

Procedures

Dynamic strength - *One repetition maximum test (1RM)*

The dynamic strength of elbow flexion was evaluated using the 1RM test on the Scott bench (dumbbell Scott curl). The seat height was adjusted according to each subject's height and the subject's shoulder was positioned at 50 degrees of flexion. The test was performed with an elbow flexion range of motion from 30 to 120 degrees. A goniometer was used to measure joint angles. Then, to ensure the exact 90 degrees range of motion, a “piece of string” was positioned at the exact distance that the individual could extend and flex the elbow. Two rulers (millimeters) were positioned at both sides of the Scott bench to mark the position of the piece of string (Figure 2a). The same marks were used in all assessments and training to eliminate possible biases in movement range alteration. The contralateral arm was positioned similarly to the test arm but remained at rest.

Before the 1 RM test, a warm-up was performed using a subjective load with approximately 15 repetitions of ~30% of 1RM. After 1.5-min of rest, the load was increased, and twelve repetitions were performed with a subjective load of ~50 % of 1RM. After 1.5-min of rest, the load was increased, and five repetitions were performed with a subjective load of ~80 % of 1RM. After 3 to 5-min. of rest, the load was considerably increased, and the subjects were encouraged to overcome resistance using full motion. When the load was overestimated or underestimated, the subjects rested for 3 to 5-min. before a new attempt was performed with a lower or higher load, respectively. This procedure was performed to find the equivalent load of 1RM, which ranged between 2 and 5 attempts. Attempts were conducted with verbal encouragement from the evaluator, in a standardized way, inspiring the individual to perform maximum strength. The load that was adopted as the maximum load was the load used for the last time the exercises were performed with no more than one repetition by the subject.

Two tests (test and retest) of 1RM were performed with a 48-hour interval between the tests. However, the higher value was used for comparison between groups. The intraclass correlation coefficient for the test and retest of 1 RM of transfer arms (n = 50 arms) was 0.992 (CI95%: 0.996 - 0.982). The technical error of measurement (TEM) was 0.45 kg (CI95%: 0.34 kg - 0.55 kg).

Isometric strength - *Maximum voluntary isometric contractions (MVIC)*

The isometric strength of elbow flexion was evaluated by the MVIC. The MVIC was collected by a load cell, Metrolog brand, model SD20- analog; LP3D-TV4J serial; sensor: Alfa ZX500 load cell (S / N 1154470). The load cell was attached to a support on the wall. The traction was transferred to the load cell by a cable. The cable passed through a pulley to avoid an angular effect of force on a load cell. The cable was positioned to provide a 90-degree angle with the forearm. On the Scott bench, volunteers' elbows and shoulders were positioned to provide 90- and 50-degree angles, respectively (Figure 2b). While testing one arm, the other arm remained stabilized, using a belt extended along the device. The trunk was also stabilized.

In MVIC elbow flexor tests, the acquisition rate was performed every 1.57 millisecond. The software smoothed the data. Three MVIC of elbow flexion (5 seconds each) were performed for the same arm, with two minutes of rest between them. Data extraction was performed offline by Software SD20 Datalogger v4.0. To obtain the final MVIC (in kg.f) used for statistical analysis of the comparison between groups, the maximum strength registered by the equipment in each contraction was considered (the highest strength value of the 3168 acquisitions made in the 5 seconds of each MVIC), then the average of the highest values of the three contractions was calculated. The data were analyzed offline. The intraclass correlation coefficient for the three MVIC of transfer arms (n = 50 arms) was 0.977 (CI95%: 0.960 - 0.987). The technical error of measurement between the highest and lowest values was 2.23 kg (CI95%: 1.62 kg – 2.84 kg).

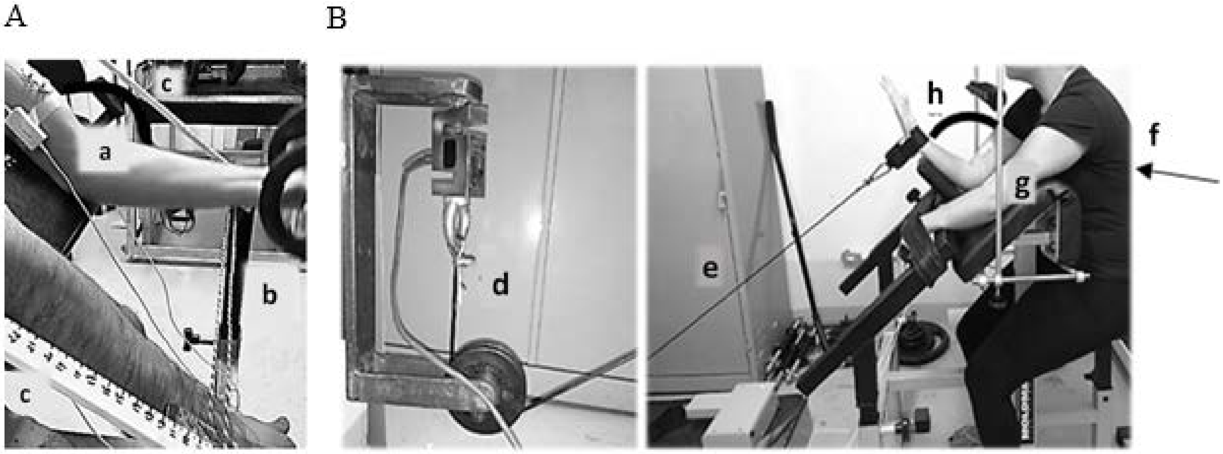

Figure 2. Apparatus used to perform the 1RM (A) and MVIC (B) tests. a = elbow flexion range of motion from 30 to 120 degrees, and b = "Piece of String" to show maximum elbow extension, c = rulers (millimeter) were positioned at both sides of the Scott bench, d = load cell was attached to a support on the wall; e = cable passed through a pulley; f = 50 degrees of shoulder flexion and g = face protection apparatus and h = Fixed at 90 º elbow flexion.

Surface electromyography

The evaluation of muscle activation was performed by the recording of electromyographic signals, the surface electromyography (sEMG), of the biceps brachii (and also the biceps brachii contralateral to determine irradiation) and triceps brachii muscles (antagonist), during the CVIM and 1RM tests. In order to analyze the sEMG data of the 1 RM tests, we considered the contraction before the failure (the only complete one). For the sEMG analysis of the MVIC tests (the MVIC test was performed 48 hrs after 1 RM test), we used the average of the three contractions.

The equipment used was the Miotoll Uro 200/400 [Miotec® biomedical equipment], with four channels (gain of 100x, 14-bit A / D converter, 2000 Hz acquisition rate, common-mode rejection ratio of 110dB, noise level < 2 low significative bit, and 20pF//1010 ohm input impedance) and an entry for a reference electrode. Initially, the skin was prepared by shaving the hair, cleaning it with alcohol and skin abrasion, following the recommendations of SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) (SENIAM 2017) . The location of the sensor on the muscle was the line between the medial acromion and the fossa cubit at 1/3 from the fossa cubit, in which the subject had his/her elbow flexed at a 90 ° angle and the dorsal side of the forearm was horizontally down (Hermens et al. 1999). The sensor location was confirmed by palpation of the muscle belly using the manual muscle strength test (Kendall et al. 2005). In each muscle, a pair of adhesive and disposable electrodes (Ag/AgCl: 44mm long, 21mm wide, 20mm between poles/Double Trace brand/Double Trace model LH-ED4020) were used. The reference electrode was placed on the medial malleolus of the left leg, also using adhesive electrodes. All electrodes were affixed with anti-allergenic microporous tape.

After positioning the electrodes, a 20-second resting collection was performed to check for the presence of electrical and electromagnetic noise. To do this, a collection was made using a computer, the Myosystem electromyograph and the load cell disconnected from the power grid and disconnected cell phones. This procedure is necessary because electrical or electromagnetic signals generate noise in the electromyography signal (De Luca et al. 2010). Each pair of electrodes was connected to the same electromyography channel for all collections (baseline, week 1 and week 4).

After data collection, signal processing was performed using the Miotec Suit 1.0 software in which the window (region) of the signal to be processed was defined. This window was bounded between the beginning and the end of the contraction (1 RM and MVIC). sEMG signals were rectified and smoothed using the root mean (Jiang et al.) squared with a 20ms smoothing window. sEMG signals were analyzed considering their amplitude peak. The bandpass filter (4th order butterworth) from 10 Hz to 500 Hz in addition to the 60 Hz filter (notch) for the electrical network was performed to eliminate noise (De Luca et al. 2010). A collection in maximum voluntary isometric contractions of 3 seconds was performed 5 minutes before the start of each 1 RM test just to normalize the sEMG data of 1RM (Not part of the MVIC calculation). For the sEMG of MVIC test (performed 48 hrs after 1 RM test), we used the non-normalized RMS peak value.

Inter-limb transfer

The magnitude of inter-limb transfer (how much of the training effect was transferred to the untrained limb) was calculated in all volunteers as suggested by Green and Gabriel (Green and Gabriel 2018).

Inter-limb Transfer = (untrained arm % gain/trained arm % gain) x 100

Negative inter-limb transfer values were considered zero.

Strength training protocol

The subjects underwent isoinertial dynamic URTEP (elbow flexion) on the Scott bench with dumbbell for four weeks, 3 times a week, on Mondays, Wednesdays and Fridays. Only one arm of each volunteer performed the resistance training protocol. During the training, the contralateral arm remained at rest and was extended on the Scott bench.

The G40 group performed four series of 15 repetitions at 40% of 1 RM and the G80 group consisted of 4 series, the first with 15 repetitions at 40% of 1 RM, the second with 8 repetitions at 80% of 1RM, the third equal to the first and the last with 7 repetitions at 80% of 1RM. The repetitions were done in this way to equalize the training volumes between groups G40 and G80. The load was increased by 5% after the second week (load progression).

In both groups, the strategies of pacing the movement were 1 concentric second and 3 eccentric seconds controlled by an external auditory signal (metronome). Two minutes of rest were allowed between sets. The range of motion of the elbow during training was 30 ° to 120 °. The range of motion was guaranteed by a goniometer and a piece of string that limits the movement between 30 ° to 120 °. The piece of string offered no resistance or movement assistance.

The training was done individually, with a scheduled time, in a covered court used only for research, without interference from music or other noise.

Statistical analysis

Data were presented as means and standard deviation or confidence interval of 95% (CI95%). To verify the effect of the groups (GC, G40, and G80), time (baseline[pre], after one week [inter] and after 4 weeks [post]) and group versus time interaction, we used the mixed ANOVA. The effects were analyzed with confounding variables as covariates (age, sex, and trained arm side) in Mixed-ANOVA. Afterwards, ANCOVA, correcting the gains (delta, Δ) by the baseline values, age, sex, and trained arm side, was used to compare the group. Levene and Mauchly tests were used to verify homogeneity of variances and specificity assumption, respectively. The LSD was used as post hoc analysis.

To determine whether a change in the dynamic strength of the untrained arm across the intervention (pre and post) within the individual was associated with the change in isometric strength of the untrained arm across the intervention, we used multiple regression as recommended by Bland and Altman (Bland and Altman 1995).

The reliability analysis of the test and retest of 1RM and MVIC was made by the intraclass correlation coefficient, by the two-way mixed model and absolute agreement (single measure). Technical errors of measurement (TEM) were calculated by using the following formula: $\sqrt{\Sigma d^2/2n}$ (where "d" is the estimated difference between measures and "n" is the number of participants). The standard error of the measure (Van Cutsem et al.) was calculated as SEM = SD × $\sqrt{1\text{-ICC}}$. CI95% of TEM was calculated as TEM ± (1.96 x SEM).

The program used for statistical analysis was SPSS statistics version 23. The statistical model was interpreted using the P-value (< 0.05) and CI95%.

RESULTS

There were 8 women and 9 men in the CG; 8 women and 8 men in the G40 and 8 women and 9 men in the G80. Concerning the arm side that performed the training, in GC and G80, 9 subjects trained the dominant arm and 8 the non-dominant one and in the G40 group, 8 individuals trained the dominant arm and 8 the non-dominant arm. The average age (years) of the subjects was similar between the groups, in which 29.6 ± 6.4 were in the CG, 27.0 ± 3.7 in the G40, and 27.8 ± 3.9 in the G80. Weight (kg) and height (cm) were 70.8 ± 14.9 and 155.6 ± 47.3 in the CG, 67.4 ± 9.3 and 167.2± 7.6 in the G40, and 70.6 ± 14.9 and 168.2 ± 8.0 in the G80, respectively. Schooling (time of study in years) was 15.5 ± 3.8 in the CG, 15.3 ± 1.8 in the G40, and 14.8 ± 1.6 in the G80.

Transfer arm adaptations

The values (means and standard deviation) of 1RM, MVIC, and sEMG amplitude at baseline, week 1, and week 4 are shown in Table 1. The statistical model (Mixed ANOVA) revealed $P < 0.05$ for the time by group interaction in the tests of 1RM [$F(4) = 18.9$ and P <

0.001] and MVIC [F(4) = 4.4 and P = 0.003] and sEMG amplitude during the 1RM [F(4) = 4.8 and P = 0.002]. The post hoc analysis revealed (P < 0.05) that after one week of URTEP the 1RM increased in the G40 e G80, but not in the CG. After four weeks of URTEP, only the G80 increased 1RM when compared to week 1. The MVIC increased only the G80 in week 4 when compared to baseline. The sEMG amplitude during the 1RM test increased as early as week 1 in the G80, while in the G40 only in week 4. There was no effect of time by group interaction in the MVIC test for sEMG amplitude.

Table 1. 1RM, MVIC, and peak of sEMG amplitude of transfer arm at baseline, week 1 and week 4.

		GC	G40	G80	P group)	P (time)	P (group x time)
1RM (kg)	**Baseline**	14.1±2.9	12.8±3.0	12.9±2.8	0.778	0.568	<0.001
	Week 1	13.9±2.9	13.6 ±2.9*	14.3±2.8*			
	Week 4	13.9±2.8	14.00±2.9*	15.2±2.8*†			
sEMG amplitude (MVIC %)	**Baseline**	100±27	77±27	66±26	0.864	0.395	0.002
	Week 1	88±33	89±32	95±32*			
	Week 4	80±35*	98±35*	96±34*			
MVIC (kg.f)	**Baseline**	30.0±6.7	27.8±6.6	27.3±6.5	0.900	0.221	0.003
	Week 1	28.6±5.8	28.4±5.8	28.5±5,7			
	Week 4	29.1±6.8	28.5±6.7	30.2±6.6*†			
sEMG amplitude (µV)	**Baseline**	943±552	911±548	726±540	0.278	0.383	0.128
	Week 1	965±593	945±588	672±577			
	Week 4	803±482	1108±476	799±470			

These values are presented as mean ± SD or CI95%. 1RM: one-repetition maximum test; sEMG: surface electromyography; MVIC: maximal voluntary isometric contraction. * indicates significant difference from baseline; † indicates significant difference from week 1. The values were adjusted to the confoundment factor (age, trained arm side, and sex).

1RM change scores (means and CI95%) at week 1 and week 4 are shown in Figure 3A. At week 1, the statistical model (ANCOVA and post hoc) revealed [F(2) = 13.1, P < 0.001, η^2 =0.36, and observed power = 1.0] that 1RM change scores were higher in the G80 and G40 than the CG, with no difference between the trained groups [GC = -0.2 kg (CI95%: -0.7 – 0.2 kg), G40 = 0.8 kg (CI95%: 04-1.3 kg) and G80 = 1.4 kg (CI95%: 1.0 -1.8 kg)]. However, only the G80 produced an increase in dynamic strength (CI95%: 1.0 -1.8 kg) in the untrained arm that did not cross the upper limit of the TEM confidence interval (0.55kg). At week 4, ANCOVA [F(2) = 30.8, P < 0.001, η^2 =0.51, and observed power = 1.0] and post hoc revealed that 1RM change score was higher in the G80 than in the G40 and CG. Also, 1RM change score was higher in the G40 than in the CG. [GC = -0.2 kg (CI95%: -0.6 – 0.3 kg), G40 = 1.1 kg (CI95%: 0.7-1.6 kg) and G80 = 2.2 kg (CI95%: 1.8 -2.6 kg)].

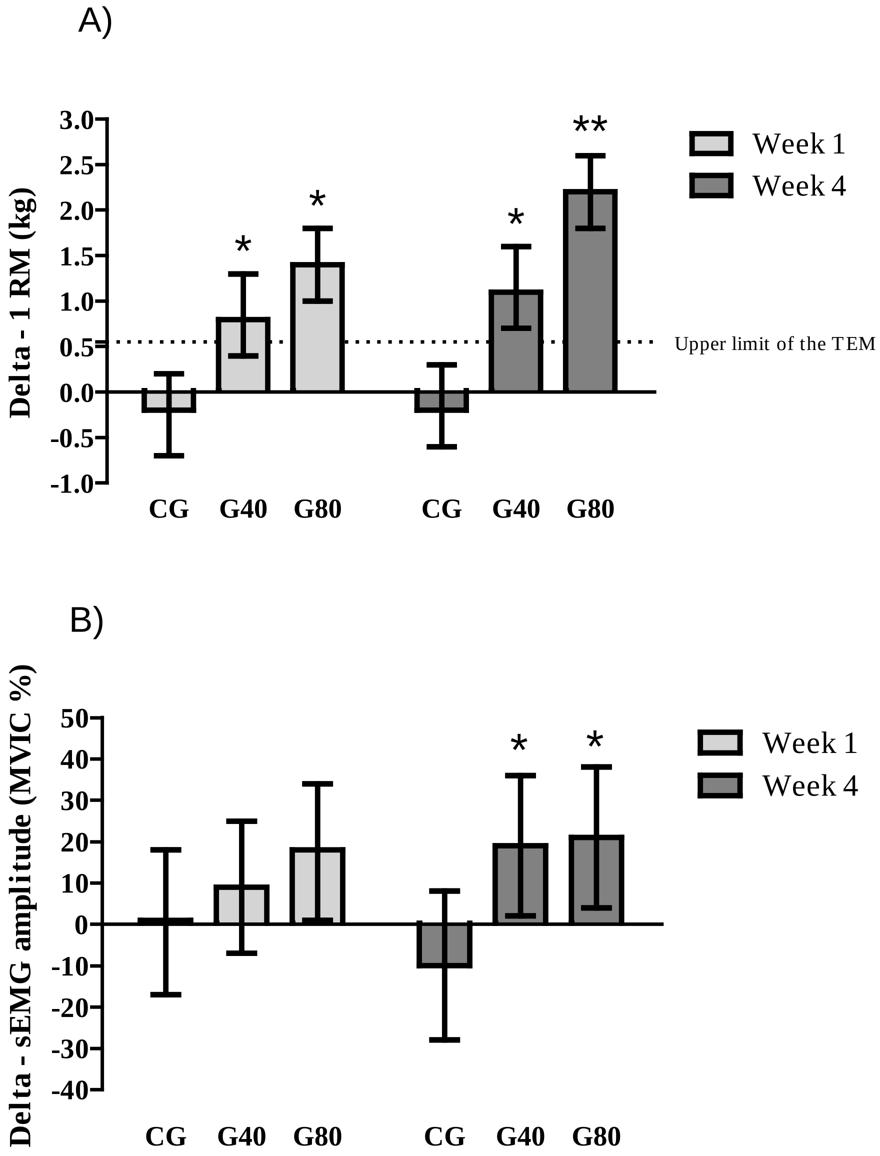

Figure 3. Effect of intensity of load on change (deltas) of 1RM (A) and sEMG amplitude (B) of transfer arm after one and four weeks of URT. Means and IC95%. * indicates significant difference from the GC; ** indicates significant difference from the G40.

sEMG amplitude change scores (MVIC %) at week 1 and week 4 are shown in Figure 3B. At week 1, the statistical model (ANCOVA) revealed [F(2) = 0.9, P = 0.414, η^2 =0.13] that there was no difference in sEMG amplitude change scores among groups [GC = 0.8 % (CI95%: -16.5 – 18.1 %), G40 = 9.1 % (CI95%: -7.1 – 25.2 %) and G80 = 17.7 % (CI95%: 1.4 – 34.0 %)]. However, only the G80 produced an increase in sEMG amplitude change (CI95%: 1.4 – 34.0 %) in the untrained arm that did not cross value zero. At week 4, ANCOVA [F(2) = 3.3, P = 0.047, and observed power = 0.6] and post hoc revealed that sEMG amplitude change scores were higher in the G80 and G40 than the CG, with no difference between the trained groups [GC = -9.9 % (CI95%: -28.0 – 8.0 %), G40 = 19.1 % (CI95%: 2.2 – 35.9 %) and G80 = 20.7 % (CI95%: 3.7 – 37.7 %)].

Sex effect on transfer arm adaptations

Sex effect on sEMG amplitude and 1RM change scores (means and CI95%) at week 1 and week 4 are shown in Figure 4 A. At week 1, the statistical model (ANCOVA) revealed no interaction [F(2) = 1.2, P = 0.302, η^2 =0.06] between sex and group in the 1 RM changes [GC: men = -0.3 kg (CI95%: -1.1 – 0.5 kg) and women = -0.1 kg (CI95%: -0.8 – 0.5 kg), G40: men = 1.0 kg (CI95%: 0.4 - 1.7 kg) and women = 0.6 kg (CI95%: -0.1 - 1.3 kg), and G80: men = 1.8 kg (CI95%: 1.1 – 2.5 kg) and women = 1.0 kg (CI95%: 0.3 – 1.7 kg)]. At week 4, ANCOVA [F(2) = 3.9, P = 0.028, η^2 = 0.16, and observed power = 0.67] and post hoc revealed that 1RM change score was higher in the men than in the women at both intensities of load (G40 and C80) [GC: men = -0.1 kg (CI95%: -0.8 – 0.7 kg) and women = -0.3 kg (CI95%: -0.9 – 0.3 kg), G40: men = 1.6 kg (CI95%: 1.0 – 2.3 kg) and women = 0.7 kg (CI95%: 0.0 - 1.3 kg), and G80: men = 3.1 kg (CI95%: 2.4 – 3.8 kg) and women = 1.4 kg (CI95%: 0.7 – 2.0 kg)].

There was no interaction (P > 0,05) between sex and group on the change scores of 1RM sEMG amplitude (MVIC %) (figure 4 B) and isometric strength at weeks 1 and 4.

Trained arm adaptations

The statistical model (Mixed ANOVA) revealed P < 0.001 [F(2) = 46.8] for the time by group interaction in the 1RM test. The post hoc analysis revealed (P < 0.05) that after four weeks of URTEP the 1RM increased in the G40 e G80, but not in the CG. ANCOVA revealed [F(2) = 46.5, P < 0.001, η^2 = 0.61, and observed power = 1.0] that 1RM change scores were different among the groups. 1RM change score was higher in the G80 than in the G40 and CG. Also, 1RM change score was higher in the G40 than in the CG. [GC = -0.4 kg (CI95%: -0.9 – 0.1 kg), G40 = 1.5 kg (CI95%: 1.1 – 2.0 kg) and G80 = 2.7 kg (CI95%: 2.3 – 3.2 kg)].

The statistical model (Mixed ANOVA) revealed P < 0.001 [F(2) = 46.8] for the time by group interaction in the test of MIVC. The post hoc analysis revealed (P < 0.05) that after four weeks of URTEP the MIVC increased in the G40 e G80, but not in the CG. ANCOVA revealed [F(2) = 8.2 , P = 0.001, η^2 = 0.22, and observed power = 0.95] that MIVC change scores were different among the groups. MIVC change score was higher in the G80 and G40 than in the CG, with no difference between the trained groups [GC = -1.5 kg (CI95%: -3.1 – 0.05 kg), G40 = 2.1 kg (CI95%: 0.5 – 3.7 kg) and G80 = 2.6 kg (CI95%: 1.1 – 4.1 kg)].

Sex effect on trained arm adaptations

ANCOVA [F(2) = 7.8, P = 0.001, η^2 = 0.28, and observed power = 0.94] and post hoc revealed that 1RM change score was higher in the men than in the women only in the G80 [GC: men = -0.0 kg (CI95%: -0.7 – 0.7 kg) and women = -0.7 kg (CI95%: -1.3 – -0.1 kg), G40: men = 1.9 kg (CI95%: 1.2 – 2.5 kg) and women = 1.2 kg (CI95%: 0.6 - 1.9 kg), and G80:

men = 4.1 kg (CI95%: 3.4 – 4.8 kg) and women = 1.5 kg (CI95%: 0.8 – 2.2 kg)]. There was no interaction (P > 0,05) between sex and group on the isometric strength change scores.

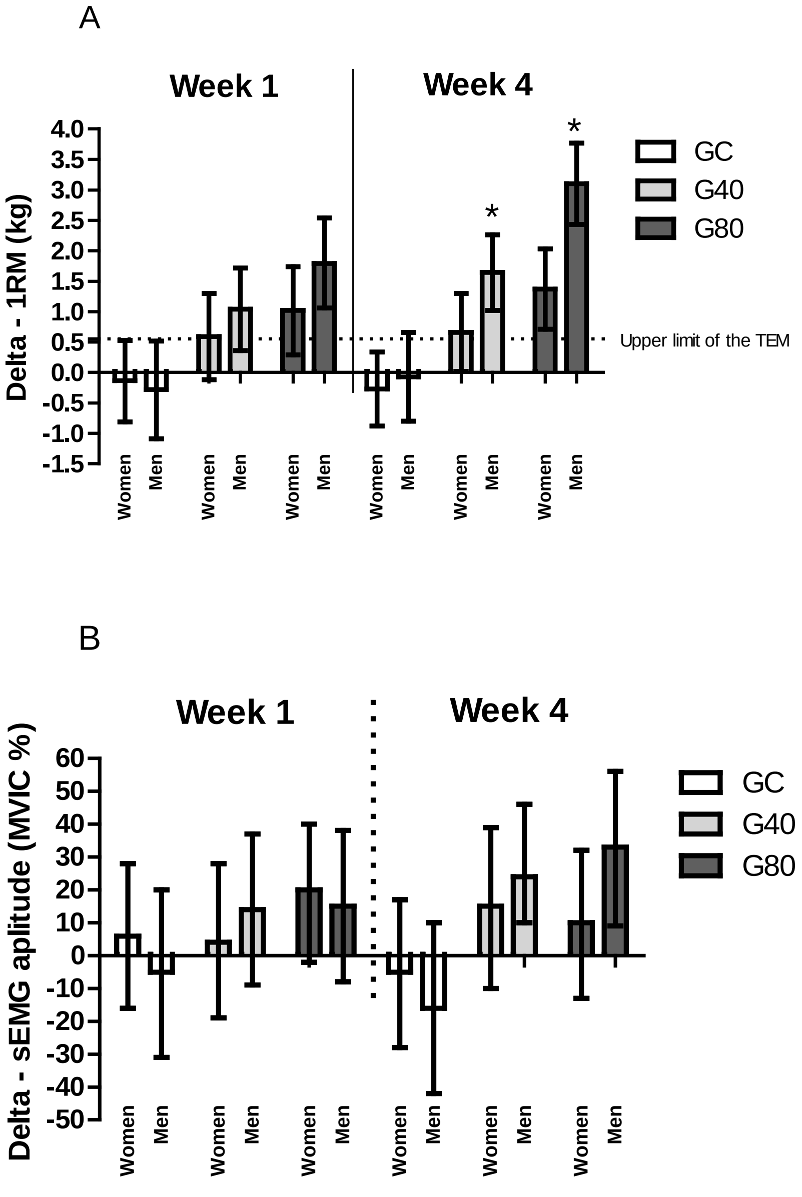

Figure 4. Effect of sex at different intensities of load on change (deltas) of 1RM (A) and sEMG amplitude (B) of transfer arm after one and four weeks of URT. Means and IC95%. * indicates significant difference from the women.

Magnitude of inter-limb transfer

The magnitude of inter-limb transfer was significantly higher in the G80 when compared to the G40 in 1RM (G80: 95.3 ± 7.7% vs. G40: 62.6 ± 12.0%, difference = 32.6 %, 95% CI: 4.5 % to 60.6 % and P = 0.023) and also in MVIC (G80:119,86 ± 4,12 % vs. G40: 32,39 ± 6,67%, difference = 87,46 %, 95% CI: 43,86% - 116,01%).

Correlation between 1RM and MVIC gains in the Untrained arm

In one week, the 1RM gain in the untrained arm was not significantly associated with the MVIC gain in the untrained arm (B = 0.165, 95% CI: -0.002; 0.331, R^2 = 0.11 and P = 0.053). However, in four weeks, the 1RM gain in the untrained arm was significantly associated with the MVIC gain in the untrained arm (B = 0.384, 95% CI: 0.225; 0.542, R^2 = 0.43 and P <0.001).

Correlation between muscle strength gains of the trained and the untrained arm.

One RM gain in the untrained arm was significantly associated with the 1RM gain in the trained arm in the G80 (R^2=0.95; P<0.001), G40 (R^2=0.55; P=0.001), men (R^2=0.85; P<0.001), and women (R^2=0.76; P<0.001). Also, MVIC gain in the untrained arm was significantly associated with the MVIC gain in the trained arm in the G80 (R2=0.64; P<0.001), men (R^2=0.28; P=0.002) and women (R^2=0.23; P=0.011), but no in the G40 (R^2=0.002; P=0.882).

Change of antagonist activation during 1RM

There was no change [Mixed ANOVA, group by time interaction: F(4) = 1.3 , P = 0.253] in the sEMG amplitude (μV) of antagonist muscle (triceps bracii) during the 1RM test at baseline and after one and four weeks of URTEP (CG: baseline = 221.7±98.2, week 1 = 216.7±88.7 and week 4 = 218.1±84.4; G40: baseline = 241.3±148.5, week 1 = 295.4±140.3 and week 4 = 304.7±120.7; G80: baseline = 188.9± 110.6, week 1 = 170.4± 113.4and week 4 = 194.6±64.7).

DISCUSSION

This study sought 1) to investigate the extent of cross-transfer of high- vs low-load URTEP and 2) to compare the time course of the two approaches. The main findings show that low-load URTEP may promote cross-education of muscle strength in the later phase (four weeks). This is important because many patients who are unable to exercise with high loads [e.g., osteoarthritis, patellofemoral pain, stroke, and hypertension] would benefit from cross-education of muscle strength with low-load URPEP (Frazer et al. 2018; Giles et al. 2017; Ruddy and Carson 2013; Sharman et al. 2015). However, high-load URTEP seems to promote cross-education of muscle strength in the early phase (one week). This is important because even in short periods of immobilization, high-load URTEP can be effective in promoting cross-education and preventing loss of muscle strength (Frazer et al. 2018; Ruddy and Carson 2013). Moreover, the use of high loads seems to enhance the cross-education of muscle strength in four weeks of dynamic resistance training (Frazer et al. 2018; Ruddy and Carson 2013).

We observed an increase in muscle strength of the contralateral to the trained arm (transfer arm) after one and four weeks of URT in the low-load URTEP (G40). However, this difference was higher than the upper limit of TEM (0.55 kg) only at week four. As TEM helps to indicate the minimum necessary difference above the evaluator's repeated measurement error, we have strong evidence to accept increased muscle strength only after 4 weeks of low-load URTEP. The observed increase was 8.6% in muscle strength of the transfer arm in the low-load URTEP. This value of cross-education is lower than the recent estimates of 12% reported by Manca et al. (Manca et al. 2017) and 18% by Green and Gabriel (Green and Gabriel 2018). This may be due to the lower load used in the G40 because the magnitude of cross-activation of the corticomotor pathway is associated with the intensity of load of the unilateral contraction (Perez and Cohen 2008). Indeed, in the current study, the high-load URTEP (G80) increased the muscle strength of the transfer arm by 18%.

The increase in muscle strength in the low-load URTEP was accompanied by an increase in sEMG amplitude (table 1 and figure 3). As it has been shown that bilateral increases in corticospinal excitability during unilateral exercise may not occur in lower-load URT (Green and Gabriel 2018; Hendy et al. 2017; Muellbacher et al. 2000), another training stimulus may have been responsible for the cross-education in lower-load URTEP (Frazer et al. 2018; Ruddy and Carson 2013). The inclusion of externally paced movements, controlling the velocity of contraction (fast concentric and slow eccentric contractions), may have contributed to these cross-education adaptations because these training stimuli lead to greater increases in the excitability of ipsilateral primary motor cortex and reductions in short-interval intracortical inhibition after unilateral resistance training (Colomer-Poveda et al. 2019; Howatson et al. 2011; Leung et al. 2015, 2018; Uematsu et al. 2010). It is possible that the inclusion of controlled velocity of contraction generated greater neural resources needed to program and plan eccentric contractions (Fang et al. 2001). In addition, the synchronized contractions to an external auditory signal used in the current study may have contributed to both reduced intracortical inhibition (Leung et al. 2015, 2018; Stinear and Byblow 2003) and increased corticospinal excitability (Ackerley et al. 2007; Jantzen et al. 2009; Leung et al. 2015, 2018).

Some studies have observed a significant increase in isometric strength of the untrained muscle from 2 weeks (Barss et al. 2018; Carr et al. 2019; Hortobagyi et al. 2011). However, studies using dynamic unilateral resistance training have not assessed dynamic muscle strength before three weeks of intervention (Coombs et al. 2016; Goodwill and Kidgell 2012; Mason et al. 2018). To better translate resistance training in rehabilitation settings, it is necessary to determine the time course of cross-education of muscle strength. In the current study, while low-load URTEP promoted cross-education of muscle strength after four weeks, high-load URTEP promoted cross-education of muscle strength after one week. This is important because it is possible to adapt the resistance training protocol depending on the immobilization time of limb. That is, even in short periods of immobilization (i.e., one week), URTEP (i.e., high-load) can be effective in promoting cross-education and preventing loss of muscle strength.

Cross-activation during unilateral resistance training may lead to neuroplastic adaptations in both cortices that increases the output produced by the motor command (Green and Gabriel 2018; Hortobagyi et al. 2011; Ruddy and Carson 2013). Thus, an approach that may offer insight regarding the cross-education is related to training-related motor unit adaptations in the untrained homologous muscle. In this sense, we observed that high-load URTEP increased maximal sEMG amplitude of biceps during the 1RM test from baseline to week 1. Besides, we did not observe any change in the sEMG amplitude of the antagonist muscles during the 1 RM test. This finding is consistent with that of Del Balso and Cafarelli who showed neural changes and ability to produce muscular strength in trained limb after three sessions (one week) of resistance training (Del Balso and Cafarelli 2007). Indeed, bilateral increases in corticospinal excitability during unilateral exercise are observed in higher-load resistance training (Green and Gabriel 2018; Hendy et al. 2017; Muellbacher et al. 2000). Our results corroborate with previous studies that suggest that intensity of load may be an important training stimulus in cross-activation of the corticomotor pathway (Green and Gabriel 2018; Hendy et al. 2017; Hortobagyi et al. 2011; Muellbacher et al. 2000; Ruddy and Carson 2013). Consequently, this may lead to neuroplastic adaptation that increases the output produced by the motor command, potentially explaining the enhancement of cross-education of muscle strength (Green and Gabriel 2018; Hortobagyi et al. 2011; Ruddy and Carson 2013) in the early and later phase of URTEP. Although caution is necessary when attempting to deduce the neural drive to muscle from interference EMG recordings (Enoka and Duchateau 2015), some studies have shown greater efferent neural drive (i.e., V-wave) (Green and Gabriel 2018) and voluntary activation (Lee et al. 2009) for the untrained limb following unilateral training.

Isometric strength (MVIC)

In our study, there was not enough evidence to support that URTEP increases isometric muscle strength. Although there was an increase in isometric strength in the transfer arm only after four weeks of dynamic URTEP (Table 1), the magnitude of increase of MIVC in the G80 was not superior to the TEM (2.23 kg.f and CI95%: 1.62 – 2.84 kg.f). Moreover, at week one, the changes in isometric and dynamic strength consequent to the unilateral dynamic resistance training were unrelated (only 11% of common variance, $P = 0.052$). At week four, although the dynamic strength gain was significantly associated with the isometric strength gain in the transfer arm (0.43% and $P < 0.001$), this association did not validate the concept of "generality" of cross-education of muscle strength because for this it would be necessary to have a correlation of $R^2 = 0.50$ or greater (Baker et al. 1994).

It is known that there are physiological and biomechanical differences between isometric and dynamic movements. In dynamic movements, there is a greater connection of cross-bridges (Fenwick et al. 2017; Kruger et al. 2019) and a higher discharge rate for motor units (Kallio et al. 2013; Maffiuletti et al. 2016) compared to isometric movements. Also, in dynamic movement, there is an activation of antagonists (Aagaard et al. 2000) while in isometric movement, the agonist is recruited predominantly and the antagonist plays a very small role (Bampouras et al. 2017). This suggests that the mechanisms that contribute to enhanced cross-education of dynamic strength seem unrelated to the mechanisms that contribute to enhanced cross-education of isometric strength in the early phase of URT (Ruddy and Carson 2013). However, further work is required to establish the viability of our speculations.

Effect of sex on cross-education

Although the effect of sex on cross-education has not been observed by other studies (Green and Gabriel 2018), surprisingly, in the sub-analysis of the data, we observed an effect of sex on cross-education of dynamic strength. Therefore, a possible effect of sex is uncertain and we can only speculate on such mechanisms. Neuroactive steroids, such as estradiol and progesterone modulate the function of multiple neurotransmitter systems. While estradiol enhances N-methyl-D-aspartate receptor activity (enhancing neuronal excitability), progesterone enhances gamma-aminobutyric acid ($GABA_A$, an inhibitory neurotransmitter) activity (Amin et al. 2006; Guennoun et al. 2015). Particularly, GABA has been proposed as one element contributing to local cortical changes during fast motor learning (Floyer-Lea et al. 2006). In this sense, Inghilleri et al reported that motor evoked potential increased on day 14 of the menstrual cycle, but not on day 1 (when estradiol and progesterone level are low), after repetitive transcranial magnetic stimulation over cortex motor (Inghilleri et al. 2004). In addition to neural adaptations and also related to them, changes in exercise performance and muscle function of the woman is also reduced in the initial follicular phase, compared to when estrogen is highest in the ovulatory period (McNulty et al. 2020; Romero-Moraleda et al. 2019; Sung and Kim 2019). However, not all studies have observed the effect of sex on exercise-induced neuroplasticity (El-Sayes et al. 2019). Thus, further studies are still needed to establish the role of sex on cross-education.

This study has limitations. First, this study was not blinded. The examiner who performed the anamnesis and evaluations also supervised the training. However, we use controls that may have reduced the bias. For instance, test and retest, supervision and monitoring of evaluations by other researchers blinded to the participants, TEM, and limitation of the maximum elbow amplitude by a piece of string in the 1 RM tests and during the training, allowing the same angle for all individuals and all tests. Also, measurement of angles by a goniometer, timed time for isometry and rest time in MVIC, and standardized verbal command. Second, we did not control the volunteers' diet, but we made sure that none of them were on a diet to impair muscle performance. Third, labor activity was not controlled in detail; however, we take care that individuals had similar activities, with function office activities. Moreover, all volunteers were instructed to avoid possible heavy manual labor for the duration of the research. Fourth, sEMG of synergist and postural muscles and cortical sites were not measured. Moreover, the interpretation of sEMG has limitations (Enoka and Duchateau 2015). Therefore, the results of sEMG data should be interpreted with caution. Fifth, we did not check the phase of the menstrual cycle of the women.

In short, the finding of our study suggests that in the early phase of URTEP (i.e., one week), cross-education of dynamic strength may be promoted particularly by high-load URTEP (80% of 1RM). In the later phase (four weeks), cross-education of dynamic strength may be achieved in both loads (40% or 80% of 1RM). However, high-load URTEP seems to enhance the cross-education effect when compared to low-load URTEP in four weeks. Moreover, the generality of cross-education of isometric strength needs to be considered with caution. URTEP dos not seems to be the best option to promote cross-education of isometric strength. Finally, the effect of sex observed in the present study suggests a lower magnitude of cross-education of muscle strength in women. However, these findings were obtained from sub-analyses and therefore need to be interpreted with caution. This is an important issue for future research.

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CONFLICTS OF INTEREST

None of the authors have conflicts of interest.

AUTHOR CONTRIBUTIONS

DP and FO conceived, designed and conducted the study. FO performed randomization. DP enrolled participants, and assigned participants to interventions. DP and FO analyzed the data and wrote the manuscript. All authors approved the manuscript.

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5.2 ARTIGO 2

O artigo a seguir foi submetido à revista “Human Movement Science”, fator de impacto “2.096” (ANEXO D).

Unilateral resistance training promotes cross-education of muscle power: a study of the efficacy of load intensity

Abstract

Objective: To verify the time course of cross-education of muscle power during unilateral resistance training at differents intensities. Methods: Fifty volunteers were randomized into three groups: higher-intensity resistance training (G80: two sets at 80% and two sets at 40% of one-repetition maximum [1RM]), lower-intensity resistance training (G40: with 4 sets at 40% of 1 RM), or control group (CG). G40 and G80 completed four weeks of unilateral resistance training (URT) of elbow flexion, three times a week, with a rapid concentric phase. The power test, *in watts,* with 40% and 80% of 1RM were evaluated at the beginning, after one e four weeks in the contralateral arm (transfer arm). The rate of electromyographic (EMG) rise (RER), in % of peak amplitude / s, of biceps brachii muscle of transfer arm was evaluated between the first 50 ms and 250 ms during power tests. Results: In the G40, muscular power at 40% and 80% of 1RM increased at week 1, with no progression to week 4 (baseline < week 1 = week 4; P < 0.05). In the G80, the muscular power at 40 and 80% of 1 RM increased progressively from baseline to week 4 (baseline <week 1 <week 4; P <0.05). In the G80, but not G40, RER (50-200 ms) showed significant improvements at weeks 1 and 4. Conclusion: in the early phase (i.e., in one week), URT promotes cross-education of muscle power regardless of load intensity. However, only higher-intensity URT increases RER and enhances cross-education of muscle power in the later phase (in four weeks).

Keywords: Cross-education; Cross-transfer; Resistance training; electromyography; Strength training, muscle performance

INTRODUCTION

The contralateral adaptation in the homologous muscles, of upper or lower limbs, after unilateral resistance training (URT), is called cross-transfer or cross-education (Boyes, Yee, Lanovaz, & Farthing, 2017; Dragert & Zehr, 2013). This phenomenon can be useful as a tool by health professionals to rehabilitate patients unable to move a limb due to fracture immobilization (Delft, Gelder, Vries, Vermeulen, & Bloemers, 2019; Magnus, Barss, Lanovaz, & Farthing, 2010), stroke hemiplegia (Winstein, et al., 2016) or multiple sclerosis (Manca, Dragone, Dvir, & Deriu, 2017), promoting the recovery of muscle function and therefore function in activities of daily living, or preventing loss of muscle function due to disuse (Andrushko, Gould, & Farthing, 2018; Manca, Cabboi, et al., 2017). Cross-education of maximum muscle strength (particularly isometric) is one of the best-studied contralateral adaptations and is well evidenced in the literature (Cirer-Sastre, Beltran-Garrido, & Corbi, 2017; Lara A. Green & David A. Gabriel, 2018). However, the ability to perform daily living and sports activities depends not only on maximum muscle strength but also on the ability of the muscle to produce dynamic strength quickly (muscle power) with different resistances (Nair, et al., 2001; Orr, et al., 2006; Weyerstrass, Stewart, Wesselius, & Zeegers, 2018). Power is the product of force by velocity and, therefore, the increase in power is given by the increase in force (mass multiplied by acceleration), velocity (distance divided by the change in time), or both. However, whether it is possible to transfer other muscle adaptations, beyond the maximum muscle strength, such as muscle power against different resistances, still needs studies.

Few studies investigate the cross-education of rapid dynamic strength (Ruddy, et al., 2016; Lee, Hinder, Gandevia, & Carroll, 2010; Hester, et al., 2019; Kannus, et al., 1992). These authors reported an increase in movement acceleration and muscle power after ballistic and isoknetic exercise sessions and everyone getting cross-educated. Although there is evidence of cross-education (acute or after a few weeks) of parameters of the ability to produce rapid dynamic strength, none of these studies has focused on the temporal action of this cross-education. Defining when and how changes in transferred parameters occur can be beneficial to plan protocols with time efficiency in healthy and clinical populations. In order to assist in the prescription of unilateral training, it is known that the oscillation of ovarian hormones in women and their neurophysiological difference in relation to men may suggest different in neural and muscular responses and therefore in cross-education between the sexes (Bakker, 2019; Leung, Rantalainen, Teo, & Kidgell, 2015; McNulty, et al., 2020; Romero-Moraleda, et al., 2019; Sung & Kim, 2019). Confirming and understanding this difference could also contribute to making specific unilateral exercise protocols. When programming a training protocol to promote specific cross-education (such as increasing muscle power for athletes or recovering this quality after an injury) is extremely important to know the time and extent of such adaptations to plan personalized and efficient interventions, with defined based on achievable goals.

An important methodological aspect is that the cross-education studies explore different training protocols (i.e., different intensities, volumes, exercises, tasks) (Cirer-Sastre, et al., 2017; Colomer-Poveda, Romero-Arenas, Keller, Hortobagyi, & Marquez, 2019; Lara A. Green & David A. Gabriel, 2018). These differences make it difficult to conclude about possible training variables that are "enhancers" of cross-education, particularly on the ability to produce rapid dynamic strength. However, it has been suggested that higher load intensities [closer to the one-repetition maximum (RM), such as > 70 %] may enhance cross-education due to greater activation of corticospinal communication pathways (Perez & Cohen, 2008). Thus, it seems that protocols with different intensities, but similar training volumes (i.e., high load with few repetitions or low load with more repetitions), promote different magnitudes of cross-education. This information is important since the knowledge of enhancing variables allows the development of more efficient protocols. On the other hand, it will be useful to know if the lower load intensity (< 50% of 1RM) is effective, especially for individuals with some restrictions on the use of higher load on the healthy limb. Therefore, the objective of this study was (1) to verify the time course of the cross-education of muscle power during URT at different load intensities and (2) identify differences between sexes in responses of cross-education

METHODS

Experimental Approach to the Problem

In this randomized and controlled study, we used a Medcalc® tool (Create random groups) to assign cases to groups at random. Each volunteer was randomized (taking into account sex: block randomization) for one of the three groups: lower intensity training (G40), higher intensity training (G80), and control group (CG). Afterward, the volunteer's arms were randomized (taking into account the left or right side) for the conditions: trained arm or transfer arm (table 1). Thus, one arm performed the group condition (GC, G40, or G80) and the other arm was used to assess the effects of cross-education (figure 1).

Initially, the volunteers were invited to familiarize with the elbow flexion exercise on a Scott bench (dumbbell Scott curl). After a 48-hour interval, the test of one-maximum repetition (1 RM) of elbow flexion was performed. Then, the 1RM retest was performed after a 48-hour interval. The 1RM test and retest were performed to reduce intra-individual variability and possible bias in increasing strength by learning the test. After 48 hours of the 1RM retest, the participants were invited to perform the muscle power test.

Table 1. Absolute frequency or mean (±SD) for the characterization variables of the subjects, divided by training groups.

	GC	G40	G80	P group
Gender (M/F)	08/09	08/08	08/09	0.98
APT (R/L)	09/08	08/08	09/08	0.98
SBP (mmhg)	120,15(±11,4)	116,23(±12,66)	119,75(±14,98)	0.641
DBP (mmhg)	74,15(±7,12)	72,46(±7,94)	79,27(±9,61)	0.177
BPM	76,08(±12,24)	79,72(±13,55)	71,73(±11,31)	0.169
Dynamometry (kgf)	39,33(±12,30)	36,15(±9,38)	32,51(±13,52)	0.631
Sedentary lifestyle (months)	25,52(±8,24)	21(±7,57)	20,64(±7,00)	0.879

M: male; F: female; Y:yes; N:no; APT: arm that performed training; R: right; L: left. Age (in full years); SBP: systolic blood in millimeters of mercury; DBP: diastolic blood pressure pressure. BPM: beats per minute; TSY: time of study in years. Chi-square was used for comparison between groups for categorical variables. Kruskal-Wallis was used for comparison between group for numerical variables. Considered as a statistical difference p <0,005. G80= high-load resistance training; G40= Low-load resistance training; GC= control group

In the G40 and G80, each volunteer performed a isoinertial URT with only one arm (training arm), on a Scott bench (dumbbell Scott curl). The other arm of the volunteer was considered the transfer arm (cross-education). The CG did not perform the URT. However, one arm of the GC volunteers was considered a control for the trained arms of the G40 and G80. The other arm of the volunteers of the GC was considered the control arm for the transfer arms of the G40 and G80. The G40 and G80 performed URT three times a week, for four weeks. After one week (week 1) and four weeks (week 4) of URT, the power tests were performed again, with the same load (in kg) as the first test. All assessments were performed in the laboratory with noise and temperature control (~ 21 °) and were performed at the same hour day (afternoon or evening) to standardize possible variations in the circadian cycle by each participant.

The initial (baseline) and final (week 4) assessments were performed on both arms and the right arm was evaluated before the left. At week 1, only the transfer arm was assessed.

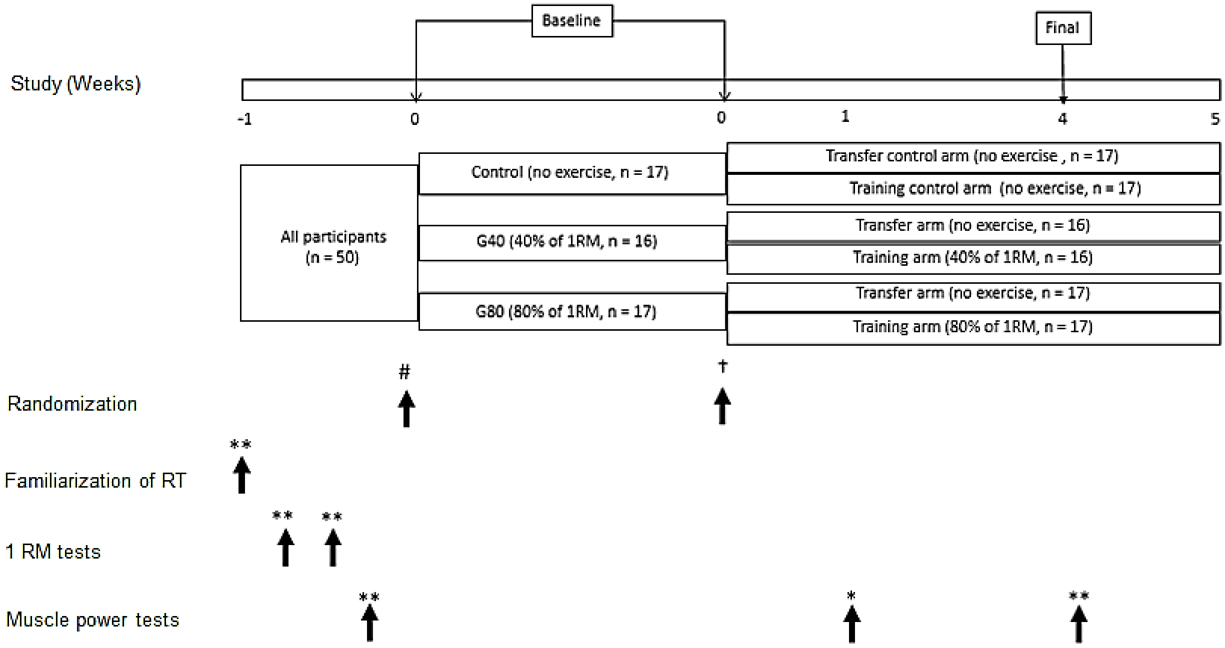

Figure 1. **Schematic representation of the study design**. GC: control group; G40: lower intensity training; G80: higher intensity training; 1 RM: one-maximum repetition; RT: resistance training; ** = both arms; * = untrained arm (transfer arm) and transfer control arm; # = randomization of participants and † = randomization of arms (training or strength transfer)

Participants

This study was approved by the local ethics committee (n.73681617.0.0000.5154) and all participants (volunteers) signed the free and informed consent form before participation and after being informed about the research procedures (annex C and appendix A).

A priori sample calculation was performed before starting the study. The sample size was calculated using G*Power software (version 3.1.9.7). We use a small effect (d = 0.4) to ensure a sample of sufficient size. The conversion from d to η^2 (eta squared) was performed using the formula suggested by Fritz et al (Fritz, Morris, & Richler, 2012): $\eta^2 = \frac{d^2}{d^2+4}$. G*Power demonstrated that at least 16 participants are needed for each group to detect a η2 of 0.04 (effect size f = 0.21, test family f, repeated measures, with-between interaction). The alpha error was defined as 0.05 with the power of 80%, correlation among repeated measures of 0.5, and non-sphericity correction of 1.0.

Fifty healthy and right-handed participants (26 women, 24 men aged 19 to 41 years) volunteered for this study and met the inclusion criteria. Although there is no evidence of a difference in the occurrence of cross-education between young and old (Bemben & Murphy, 2001; Ehsani, Nodehi-Moghadam, Ghandali, &

Ahmadizade, 2014; Hester, et al., 2019), the sample of this study was composed only of young adults (from 19 to 41 years old). The inclusion criteria, identified by anamnesis by a physiotherapist (appendix B), were: be untrained (not having exercised in the last 6 months, neither recreational nor professionally), no acute or chronic injury, whether related to the musculoskeletal system or injury to the central or peripheral nervous system, blood pressure and blood glucose controlled, no smoker, and no use of medication. The exclusion criteria were: missing a training session, without replacement in up to a maximum of one week. Seven volunteers fit into this situation and were replaced by other participants who were also randomized en block.

Procedures

Power test at 40 and 80% of 1RM

Muscle power was assessed during elbow flexion movements (concentric phase), on the Scott Bench (with range of motion of 30 ° to 120º), by an isoinertial dynamometer (linear encoder, 4.0 Peak Power software, Peak Power®, Cefise, New Odessa, SP, Brazil). The settings and calibrations followed the manufacturer's specifications. The isoinertial dynamometer recorded the time and linear distance of the movement in the frequency of 30 Hz (maximum permitted by the equipment).

The isoinertial dynamometer was positioned on the floor, the transducer string (encoder - which detected the movements) passed through a pulley attached to the wall (figure 2 – a,b) and was attached to the forearm of the volunteer by a Velcro. The transducer string was positioned at a 90° angle with the forearm, while the elbow was positioned at a 90° angle of elbow flexion (Figure 2).

The first power test was performed at 40% of 1RM and the second test at 80% of 1RM, with a rest interval between loads of 3 minutes. For each load, 3 attempts were performed, with an interval of 30 seconds between movements. All volunteers were encouraged by a verbal command to perform each repetition as fast as strong as possible (Figure 2 – c).

To ensure the range of the test of 30 to 120 ° and protect the face and hands of the volunteer, an adjustable apparatus was built and coupled to the Scott bench (Figure 2 - e). This apparatus was of metal bars, surrounded by a soft material (cushion). This apparatus was positioned in front of the face of the volunteer, but adjusted so that the movement ended at 120° of elbow flexion (figure 2 - f). The height of the seat of Scott bench was also adjusted according to the height of each individual so that he could have his shoulders at 50 ° of flexion (Figure 2 – d). A goniometer was used to measure the joint angles. The volunteers were instructed not to raise the shoulder of the limb who performed the attempt, during the test. In addition, the bar belonging to the manufactured apparatus ensured that individuals did not change the angle of the shoulder.

The data was extracted offline using equipment software. For data analysis, the average of the average power (AP) of the 3 attempts with loads at 40 and 80% of 1 RM was used.

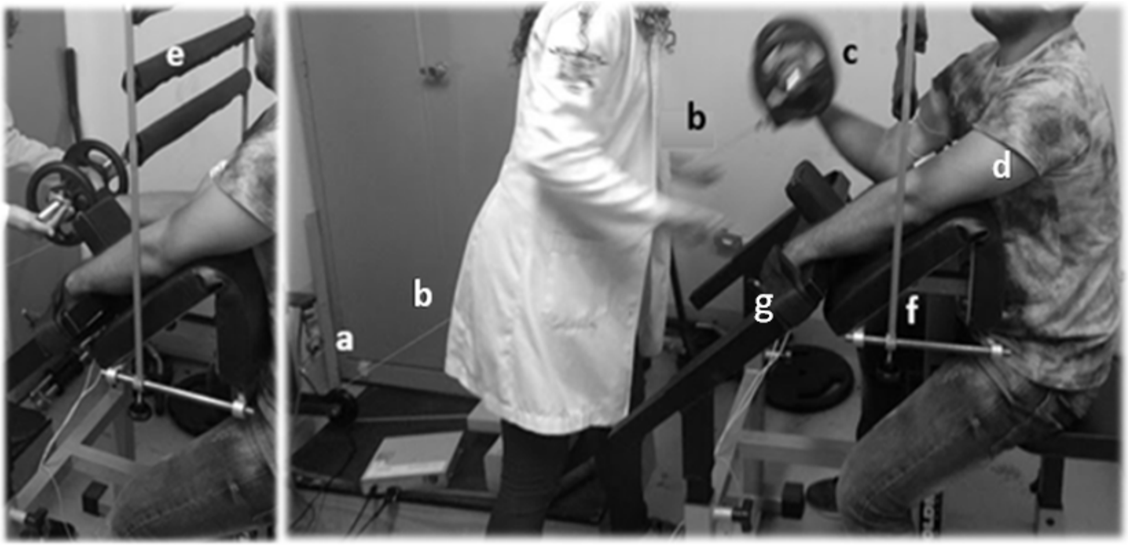

Figure 2. Apparatus used to perform the power test at 40% and 80% of 1 RM. a: pulley; b: encoder (cable with motion sensor) that passes through the pulley and is connected to the participant's wrist; c: load that will reach the apparatus; d: 50 degrees of shoulder flexion; e: facial protection apparatus that will receive the impact of the load; f: rail that allows you to adjust the apparatus to exactly 120 degrees of flexion; g: contralateral arm stabilization belt

*Surface electromyograp*hy *(sEMG)*

The recording of electromyographic signals, using sEMG, was used to evaluate the muscular activity of the biceps brachii, during the power tests with loads at 40 and 80% of 1RM.

The location of the sensor on the muscle was the line between the medial acromion and the fossa cubit at 1/3 from the fossa cubit, in which the volunteer had his/her elbow flexed at 90 ° angle and the dorsal side of the forearm was horizontally down (SENIAM, 2017). The sensor location was confirmed by palpation of the muscle belly using the manual muscle strength test according to Kendal *et al* (Kendall, McCreary, Provance, Rodgers, & Romani, 2005). Initially, the skin was prepared by shaving the hair, cleaning it with alcohol, and skin abrasion, following the recommendations of SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles)(SENIAM, 2017). In each muscle, a pair of adhesive and disposable electrodes (Ag/AgCl: 44mm long, 21mm wide, 20mm between poles/Double Trace brand/Double Trace model LH-ED4020) were used. Each pair of electrodes was connected to the same electromyography channel for all collections (baseline, week 1, and week 4). The reference electrode was placed on the medial malleolus of the left leg, also using adhesive electrodes. All electrodes were affixed with anti-allergenic microporous tape. The same researcher placed the electrodes in the three evaluation moments (baseline, week 1 and week 4).

After positioning the electrodes, a 20-second resting collection was performed to check for the presence of electrical and electromagnetic noise. The collection was performed with all precautionary measures to eliminate electrical or electromagnetic signals that generate noise in the electromyography signal (De Luca, Gilmore, Kuznetsov, & Roy, 2010). We consider the ideal resting value to start collections, with an average RMS of up to 12 microvolts. In the sequence, the power tests were performed and the EMG record was performed, for each of the 3 attempts, with the two loads.

Miotoll Uro 200/400 from the company Miotec® biomedical equipment, was the equipment used. It has four channels (gain of 100x, 14-bit A / D converter, 2000 Hz acquisition rate, common-mode rejection ratio of 110dB, noise level < 2 low significative bit, and 20pF//1010 ohm input impedance) and an entry for a reference electrode.

After data collection, signal processing was performed offline using the Miotec Suit 1.0 software. sEMG signals were rectified and smoothed using the root mean squared with a 20ms smoothing window. The bandpass filter (4th order Butterworth) from 10 Hz to 500 Hz in addition to the 60 Hz filter (notch) for the electrical network was performed to eliminate noise (De Luca, et al., 2010).

For the sEMG analysis, first, with the rectified signal, a windowing of 300 ms was made in the rest period in this collection, corresponding to 10 seconds before the beginning of each attempt of the power test. From this window, we collected the peak RMS and the standard deviation. The onsets of the trial were defined as the point at which the signal exceeded the baseline by two standard deviations of the peak RMS of this window of rest. Then, the signal was smoothed and then we performed the rate of electromyographic rise (RER) calculation, that was quantified from the linear slope of the electromyographic amplitude-time curve (Δ peak RMS amplitude / Δtime) at time intervals of 0–50, 0-100, 0-150, and 0–200 ms from onset (initial sEMG) (Carr, Ye, Stock, Bemben, & DeFreitas, 2019). These peak RMS values (of the beginning of the contraction) were normalized to the peak RMS of total contractions (attempts) and expressed as a percentage (%) of peak RMS (% µV) (figure 3). The RER measurement unit was expressed in % of peak amplitude RMS / seconds (%µV/s). For the final analysis we used the average of the RER among the 3 attempts.

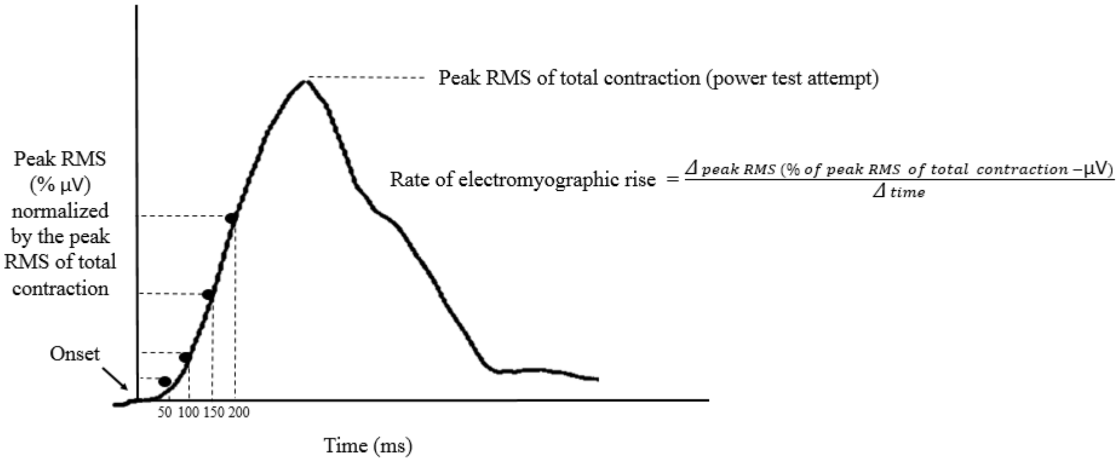

Figure 3. Schematic drawing of the EMG evaluation moments. The percentage of the peak RMS (peak of total contraction) of 4 moments of muscle contraction was collected, every 50 ms, from the onset of muscle contraction. The rate of electromyography rise was performed by the ratio of the percentage of the RMS peak acquired at each point and the time to reach each percentage of the EMG

The mirror activity was assessed by collecting sEMG from the contralateral arm to which the power test was performed (figure 4 - b). The was extracted from windows (figure 4 - d) which corresponded temporally the beginning to the end of the contraction of the biceps that performed the power test (figure 4 - a). For mirror activity analysis, we considered the highest sEMG amplitude peak among the three repetitions of the power test. The rest sEMG amplitude was determined in a window of 300 ms, 10 seconds before the start of the power test (figure 4 - c).

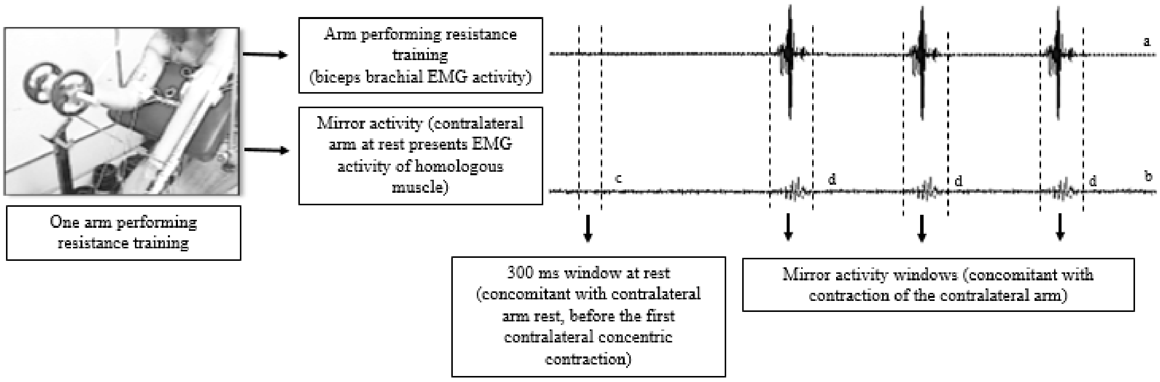

Figure 4. Schematic representation of the definition of the EMG acquisition window for evaluation of mirror activity. Line “a” represents the electromyographic signal line of the collection of the arm that was performing the test (resistance exercise); line “b” represents the collection of the contralateral arm at rest, in which the acquisition windows for rest and mirror activity were selected. The letter “c” represents the window for acquiring the moment at muscular rest, which is found in line “b”. And the letter "d", represents the mirror activity acquisition window, which is also found in line "b".

Dynamic strength - *One repetition maximum test (1RM)*

The 1RM test was performed to determine the individual load used in the power test at 40% and 80% of 1RM and to determine the training loads. The test was performed on the Scott bench and the elbow flexion range of motion was 30 to 120 degrees (0° to full elbow extension)(figure 5 –a). The seat height was adjusted according to the height of each volunteers and the shoulder of each individual was positioned at 50 degrees of flexion (figure 5 -b). A goniometer was used to measure the joint angles. Then, a "string" was placed at the exact distance, to guarantee the exact range of 90 degrees of movement, in which the individual could extend and flex the elbow (figure 5 –c). Two rulers (millimeters) were placed on both sides of the Scott bench to mark the position of the string (figure 5-d). The same marks were used in all evaluations and training to eliminate possible biases in altering the range of motion. The contralateral arm was positioned similarly to the test arm but remained at rest.

Before the 1RM test, three sets of warm-up exercises were performed with 1.5 min rest between its, the first performed using a subjective load with approximately 15 repetitions of ~ 30% of 1RM, the second with twelve repetitions performed with a subjective load of ~ 50% of 1RM and in the third the load was increased and five repetitions were performed with a subjective load of ~ 80% of 1RM. After 3 to 5 min. at rest, volunteers were encouraged to overcome the load using one full movement. When the load was overestimated or underestimated, the volunteers rested for 3 to 5 minutes and a new attempt was made with a lower or higher load, respectively. This procedure was performed to find the load equivalent to 1RM, which varied between 2 and 5 attempts (Franco, Carneiro, de Sousa, Gomes, & Orsatti, 2019). The load that was adopted as the maximum load was the load used for the last time the exercises were performed with no more than one full repetition by the volunteer.

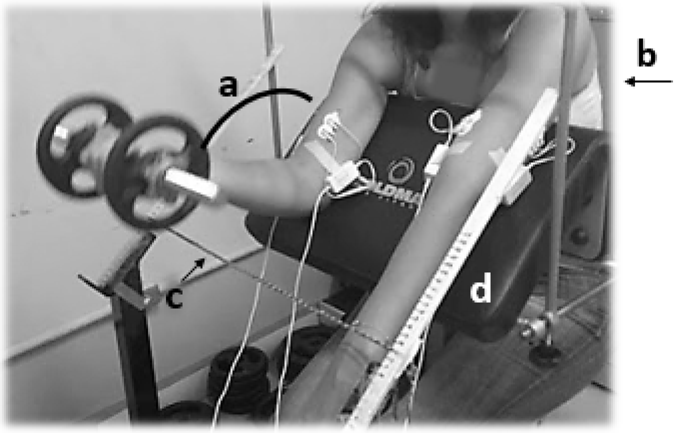

Figure 5. Apparatus used to perform the 1RM test (used to calculate the power test load). a: volunteers's shoulder positioned at 50 degrees of flexion; b: range of motion of elbow flexion from 30 to 120 degrees; c: "string" to show the maximum elbow extension; d: Two rulers (millimeter) positioned on both sides

Two 1RM tests were performed (test and retest) with an interval of 48 hours between them. The highest value between these two evaluations was used for the analyzes in this study. Regarding the test and retest results in the CG, just 2 volunteers (11.76% of the individuals) reduced their strength, 6 increased (35.29%) and 52.94% maintained their strength between the two tests. In G40, 13 (81.25%) maintained strength and 3 (18.85%) increased, and in G80 6 (35.39%) increased strength and 11 (64.70%) maintained it.

Resistance training protocol

The intervention consisted of isoinertial dynamic URT (elbow flexion) on the Scott bench with dumbbells, 3 times a week (Monday, Wednesday and Friday), for four weeks. Only one arm of each volunteer performed strength training protocol. concomitantly, the contralateral arm remained at rest and extended at Scott bench. The training was individual, in the covered court, used only for research, without the interference of music or other noise, with a scheduled time previously.

The G40 group performed 4 sets of 15 repetitions at 40% of 1RM and the G80 group protocol consisted of 4 sets, the first with 15 repetitions at 40% of 1RM, the second with 8 repetitions at 80% of 1RM, the third equal for the first and the last with 7 repetitions at 80% of 1RM. The repetitions were determined in this way to equalize the training volumes between the two training groups. The volume of training was calculated by multiplying the load percentage by the number of repetitions and the number of sets.

In G40 and G80, the strategies for stimulating movement were 1 second concentric and 3 seconds eccentric controlled by an external auditory signal (metronome). The range of motion of the elbow during training was from 30 ° to 120 °, this angle was guaranteed by a goniometer and a string that limits the movement between 30 ° and 120 °. The string offered no resistance or movement assistance. Two minutes of rest were allowed between sets. From the third week of training, an adjustment of 5% under the initial training load was performed for all volunteers.

Self-reported fatigue remained similar in sessions 1 and 12 ($P = 0.862$), demonstrating that the load adjustment was adequate (table 2). With equalized volumes, the loads from both training protocols (G40 and G80) offered the same fatigue ($p = 0.895$). Fatigue in session 1 was 6.4 ± 0.46; 95% CI: 5.45-7.36 for G80 and 5.78 ± 0.46; 95% CI: 4.82 - 6.73) for G40; and fatigue in session 12 was 5.12 ± 0.57; 95% CI: 3.95 - 6.29 for G80 and 5.59 ± 0.57; 95% CI: 4.42-6.76 for G40 (table2).

All individuals performed all training sessions at the same time of day (afternoon or evening) to standardize possible changes arising from the circadian cycle.

Table 2. Intensity of self-reported fatigue (graded from 0 to 10) after the 1st and 12th unilateral training session. Considering initial fatigue as zero, before starting training.

	Intensity of self-reported fatigue (graded 0 to 10)			
	G80	**G40**	**P group**	**P time**
After 1st session	6.41 (5.45-7.36)	5.78 (4.82- 6.73)	0.352	0.862
After 12th session	5.12 (3.95-6.29)	5.59 (4.42-6.76)	0.567	

Estimates are presented on mean ± 95% CI. G80= high-load resistance training. G40= Low-load resistance training

Statistical analysis

Mixed ANOVA was used to verify the effect of the groups (GC, G40, and G80) and time (baseline [pre], after one week [inter] and after 4 weeks [post]) interaction for the data of power and RER. The effects of sex were analyzed by performing mixed ANOVA (sex and time interaction), combining training groups (G40 + G80). To verify the effect of mirror activity between sexes (irradiation, sex, and time interaction) and loads (irradiation, load, and time interaction) a mixed ANOVA was used. Levene and Mauchly tests were used to verify the homogeneity of variances and the assumption of sphericity, respectively. LSD was used as a post hoc analysis. The statistical model was interpreted using the P value (<0.05) and 95% CI. Data were presented as a mean and 95% confidence interval (95% CI). The program used for statistical analysis was SPSS statistics version 23.

RESULTS

Fifty healthy and right-handed volunteers (26 women, 24 men aged 19 to 41 years) aged 28.2 ± 4.9 years, body mass of 69.6 ± 13.0 kg, height of 163.5 ± 28.6 cm, and schooling of 15.3 ± 2.3 years completed the study. The volunteers had blood pressure and heart rate within the parameters of normality and had similar characteristics in the three groups (CG, G40 and G80) with respect dynamometry and sedentary lifestyle (table 1).

Transfer arm (cross-education)

Power output and sEMG - movement with load at 40% of 1RM.

Mixed ANOVA revealed a difference in the course of muscle power between the training groups over time (group vs moment interaction, P = 0.001) (table 3). The G40 increased the power from the baseline to week

1, which remained until week 4. The G80 also increases the power from the baseline to week 1; however, the power was progressively increased from week 1 to week 4. There were no changes for the CG.

There was also a time by group interaction to $RER_{0\text{-}50\ ms}$ ($P < 0.001$), $RER_{0\text{-}100\ ms}$ ($P < 0.001$), $RER_{0\text{-}150\ ms}$ ($P = 0.004$), and $RER_{0\text{-}200\ ms}$ ($P <0.001$)(table 4). The G80 increased the $RER_{0\text{-}50\ ms}$, $RER_{0\text{-}100\ ms}$ RER, $RER_{0\text{-}150\ ms,}$ and $RER_{0\text{-}200\ ms}$ at week 1, which remained until week 4. The G40 did not change RER and the CG decreased the RER.

Power output and sEMG - movement with load at 80% of 1RM.

Mixed ANOVA revealed a time-by-group interaction to the power output at 80% of 1RM (P = 0.028) (table 3). The G40 increased the power from the baseline to week 1, which remained until week 4. The G80 also increased the power from the baseline to week 1; however, the power was progressively increased from week 1 to week 4. There were no changes for the CG.

There was a time by group interaction to RER0-50 ms (P < 0.001), RER0-100 ms, (P < 0.001), RER0-150 ms (P < 0.001), and RER0-200 ms (P <0.001) (table 4). The G80 increased the RER0-50 ms, RER0-100 ms RER, RER0-150 ms, and RER0-200 ms at week 1, which remained until week 4. The G40 increased the RER0-150 ms at week 1, which decreased to baseline values at week 4. GC decreased the RER.

Trained arm

Power output - movement with load at 40% and 80% of 1RM.

There was a time by group interaction to power output at 40% (P < 0.001) and 80% of 1RM (P = 0.005) (table 3). Both G40 and G80 increase the power at 40% and 80% from the baseline to week 4. There were no changes for the CG. There were no changes for the CG.

Effect of sex on changes in power output at 40% and 80% of 1RM

Transfer arm.

*T*here was a sex-by-time interaction to the power output at 40% of 1RM in combined training groups (Table 5). While the women increased the power at 40% of 1 RM from week 1 to week 4, the men progressively increased the power at 40% of 1 RM from baseline to week 4 (baseline< week1 < week4).

There was also a sex-by-time interaction to the power output at 80% of 1RM (Table 5). The men increased the power at 80% from week 1 to week 4. The women increased the power at 80% of 1 RM from baseline to week 1, which (power) returned to baseline values at week 4.

There was no effect of sex on RER.

Trained arm.

When the training groups were combined, there was an sex-by-time interaction to the power output at 80% of 1RM (Table 5). Only the men increased the power at 80% from baseline to week 4.

Mirror activity (coactivation of the resting arm during power test)

Load.

There was no effect of load on mirror activity (non-normalized peak RMS amplitude) at baseline and after four weeks of RT (table 6).

Sex.

There was load, moment, and time interaction, suggesting an effect of sex on mirror activity (baseline and week 4) (table 6). Although both men and women increased mirror activity, the women showed an attenuated activation at baseline, but not at week 4.

DISCUSSION

The ability of the muscle to produce dynamic strength quickly (muscle power) with different resistances is a key element to perform daily living and sports activities (Nair, et al., 2001; Orr, et al., 2006; Weyerstrass, et al., 2018). To our knowledge, only one study has evaluated the effect of URT on cross-education of muscle power. Although Kannus et al. (Kannus, et al., 1992) observed an increase in muscle power in the non-exercised limb after seven weeks of URT (maximal isometric and isokinetic contractions), information on time course and the role of RT variables on cross-education of muscle power are lacking. Knowledge of the time and extent of such adaptations can be serviceable for plan personalized and efficient interventions, with defined progression based on achievable goals. In this sense, the major finding of this study is that in the early phase (i.e., one week), URT promotes cross-education of muscle power with different resistances regardless of load intensity. However, only higher-intensity URT increases RER and enhances cross-education of muscle power in the later phase (four weeks). Therefore, this study may allow the development of more efficient interventions to promote cross-education of muscle power.

Table 3. Effect of interventions on the power output (watts) of elbow flexion at 40% and 80% of 1 RM, at baseline, week 1 and week 4.

	GC			G40			G80			P Group	P Time	P Interaction
	Baseline	W1	W4	Baseline	W1	W4	Baseline	W1	W4			
Transfer arm												
40% of 1RM (watts)	53.6 (44.3; 62.8)	53.9 (43.6; 64.3)	53.3 (42.6; 64.0)	39.5 (29.9; 49.0)	44.7* (34.0; 55.4)	46.3* (35.3; 57.4)	38.7 (29.2; 48.3)	43.9* (33.2; 54.6)	49.1*† (38.0; 60.1)	0.279	<0.001	0.001
80% of 1RM (watts)	61.2 (49.3; 73.1)	62.9 (51.5; 74.2)	59.6 (46.1; 73.1)	45.5 (33.3; 57.8)	51.0* (39.4; 62.7)	54.0* (40.1; 67.9)	52.4 (40.5; 64.3)	57.5* (46.2; 68.8)	63.5*† (50.0; 77.0)	0.418	0.002	0.028
Trained arm												
40% of 1RM (watts)	50.5 (40.6; 60.4)	-	47.9 (37.3; 58.4)	37.8 (27.6; 47.9)	-	50.6* (39.8; 61.5)	44.2 (34.4; 54.1)	-	50.6* (40.1; 61.1)	0.778	<0.001	<0.001
80% of 1RM (watts)	55.7 (45.6; 65.9)	-	54.6 (43.3; 66.0)	47.0 (36.5; 57.4)	-	55.2* (43.4; 66.9)	54.2 (44.1; 64.3)	-	63.1* (51.7; 74.5)	0.603	<0.001	0.005

Estimates are presented on mean ± 95% CI. One-maximum repetition (1RM). Week 1 (W1) and week 4 (W4). * = P <0.05 from baseline. † = P <0.05 from Week1. G80= high-load resistance training. G40= Low-load resistance training. GC= control group

Table 4. Effect of interventions on rate of EMG rise (RER) of the biceps brachii (transfer arm) during the movement with 40% and 80% of 1 RM, at baseline, week 1 and week 4.

		GC			G40			G80					
		Baseline	**W1**	**W4**	**Baseline**	**W1**	**W4**	**Baseline**	**W1**	**W4**	**P Group**	**P Time**	**P Interaction**
testing with 40% of 1RM - % of peak RMS amplitude/s - (%µV/s)	*0-50 ms*	421.6 (354.2; 489.0)	343.3* (281.7; 404.9)	295.5* (235.1; 355.9)	257.9 (192.1; 323.7)	270.1 (209.9; 330.2)	254.7 (195.7; 313.6)	228.8 (161.4; 296.2)	320.1* (258.5; 381.7)	352.5* (292.1; 412.9)	0.023	0.886	<0.001
	0-100 ms	347.9 (303.6; 392.2)	290.5* (240.0; 341.1)	259.4* (208.7; 310.2)	221.5 (177.3; 265.8)	239.2 (189.5; 288.9)	231.1 (181.5; 280.6)	166.7 (122.4; 211.0)	281.6* (231.0; 332.1)	310.5* (259.8; 361.3)	0.033	0.212	<0.001
	0-150 ms	346.2 (287.6; 404.7)	296.5 (248.9; 344.1)	268.6* (220.9; 316.2)	227.8 (169.8; 285.9)	256.9 (209.7; 304.1)	246.2 (199.6; 292.9)	207.5 (148.9; 266.0)	290.0* (242.4; 337.6)	312.3* (264.6; 359.9)	0.093	0.443	0.001
	0-200 ms	332.7 (297.1; 368.3)	291.7 (248.5; 334.9)	269.5* (227.5; 311.4)	232.4 (195.8; 269.1)	266.9 (224.0; 309.7)	259.9 (218.2; 301.5)	193.1 (157.5; 228.7)	290.2* (247.0; 333.3)	305.0* (263.0; 346.9)	0.128	0.013	<0.001
Testing with 80% of 1RM - % of peak RMS amplitude / s - (%µV/s)	*0-50 ms*	419.4 (359.2; 479.7)	321.9* (238.9; 404.9)	252.8* (179.1; 326.5)	270.5 (208.3; 332.7)	337.4 (251.7; 423.2)	295.3 (219.2; 371.4)	242.1 (181.9; 302.4)	372.5* (289.5; 455.5)	389.6* (315.9; 463.2)	0.651	0.294	<0.001
	0-100 ms	328.4 (286.6; 370.2)	256.1* (198.0; 314.3)	205.1* (155.8; 254.4)	213.5 (170.4; 256.7)	273.3 (213.2; 333.3)	233.2 (182.2; 284.1)	178.7 (137.0; 220.5)	307.1* (249.0; 365.3)	307.4* (258.1; 356.7)	0.615	0.047	<0.001
	0-150 ms	311.4 (273.9; 348.8)	265.3 (213.8; 316.9)	208.0*† (165.1; 251.0)	209.0 (170.3; 247.7)	266.6* (213.4; 319.8)	231.9 (187.5; 276.2)	181.3 (143.9; 218.8)	302.9* (251.3; 354.4)	298.9* (256.0; 341.9)	0.521	0.005	<0.001
	0-200 ms	293.0 (256.4; 329.5)	265.1 (221.8; 308.4)	217.1*† (179.0; 255.2)	228.1 (190.4; 265.9)	260.8 (216.1; 305.5)	237.0 (197.7; 276.3)	193.2 (156.6;) 229.7	290.2* (246.9; 333.5)	287.9* (249.9; 326.0)	0.732	0.014	<0.001

Estimates are presented on average ± 95% CI. One-repetition maximum (1RM). Week 1 (W1) and week 4 (W4). * = P <0.05 from baseline. † = P <0.05 from W1. G80= high-load resistance training. G40= Low-load resistance training. GC= control group

Table 5. Effect of sex (subanalysis) on power output (watts) of elbow flexion with 40% and 80% of 1 RM in the training groups (G40 and G80) combined at baseline, week 1 and week 4.

		G40+G80			
		Baseline	**W1**	**W4**	**P Sex x Time**
Braço transferência					
40% de 1RM (watts)	*Homens*	50.0 (44.6; 55.3)	58.2* (52.6; 63.8)	62.4*† (55.3; 69.5)	0.010
	Mulheres	29.5 (24.5; 34.5)	32.0 (26.8; 37.2)	34.7*† (28.0; 41.4)	
80% de 1RM (watts)	*Homens*	66.2 (59.9; 72.6)	68.6 (61.3; 75.9)	79.7*† (71.5; 88.0)	0.010
	Mulheres	32.9 (26.7; 39.1)	41.0* (33.9; 48.0)	39.3 (31.3; 47.3)	
Braço treinado					
40% de 1RM (watts)	*Homens*	55.8 (50.0; 61.5)	-	65.8 (58.6; 73.1)	0.790
	Mulheres	27.3 (21.7; 32.9)	-	36.3 (29.2; 43.3)	
80% de 1RM (watts)	*Homens*	66.1 (59.1; 73.2)	-	79.5* (72.5; 86.5)	0.009
	Mulheres	36.2 (29.3; 43.0)	-	40.2 (33.4; 47.0)	

Estimates are presented on average ± 95% CI. One-repetition maximum (1RM). week 1 (W1) and week 4 (W4). * = P <0.05 from baseline. † = P <0.05 from W1. G80= high-load resistance training. G40= Low-load resistance training.

Table 6. Effect of sex and load on mirror activation (amplitude of non-normalized EMG, µV) of the biceps brachii (transfer arm) during movement of the contralateral arm (elbow flexion) with 40% and 80% of 1 RM, at baseline and week 4.

		Baseline		**W4**		
		Rest	**During movement (of the contralateral arm)**	**Rest**	**During movement (of the contralateral arm)**	**P**
Load						
	40% of 1RM µV	14.1 (13.5; 14.6)	19.0 (17.8; 20.2)	14.0 (13.4; 14.5)	19.3 (18.1; 20.5)	Load = 0.889 Time (baseline x Week 4) = 0.851 Load x Time = 0.927 **Moment (Rest x During movement) < 0.001** Load x Moment = 0.433 Moment x Time = 0.495 Load x Moment x Time = 0.799
	80% of 1RM µV	14.3 (13.8; 14.9)	18.9 (17.7; 20.1)	14.3 (13.8; 14.8)	19.0 (17.8; 20.2)	
Sex						
	Men µV	14.5 (14.0; 15.1)	20.4* (19.2; 21.5)	14.3 (13.7; 14.8)	19.2* (18.0; 20.5)	Sex = 0.011 Time (baseline x Week 4) = 0.915 Sex x Time =0.068 **Moment (Rest x During movement) < 0.001** Sex x Moment = 0.099 Moment x Time = 0.556 **Sex x Moment x Time = 0.008**
	Women µV	13.9 (13.4; 14.5)	17.6*‡ (16.5; 18.8)	14.0 (13.5; 14.5)	19.1* (17.9; 20.3)	

Estimates are presented on average ± 95% CI. One-repetition maximum (1RM). * = P <0.05 from baseline. ‡ = P <0.05 from men.

Moreover, this study identifies the effect of sex on cross-education of muscular power with higher resistances. Only men promote cross-education of muscular power with higher resistances (80% of 1 RM), suggesting that the propensity for cross-education of muscular power with higher resistances during a short period of URT (four weeks) may depend on aspects related to sex.

Transfer arm (cross-education)

Power output and sEMG

Both groups (G40 and G80) increased the power output with lower resistance by ≅13% and with higher resistance by ≅11% after one week of URT (table 3). These results suggest that it is possible to promote cross-education of muscle power in the early phase (week 1) regardless of the intensity used during URT. However, only higher-intensity URT enhanced cross-education of muscle power in the later phase, increasing the muscle power output with lower resistance by ≅27% and with higher resistance by ≅21% after 4 weeks of URT. Although the specificity of cross-education is reported in relation to type of contraction (isometric and dynamic isoinertial or isokinetic) (Beyer, et al., 2016; Hortobagyi, Lambert, & Hill, 1997), type of exercise (Beyer, et al., 2016), movement velocity (Farthing & Chilibeck, 2003), and trained muscle (Kannus, et al., 1992; Mason, et al., 2018), the adaptations observed in our study were not specific to the intensity of load. The G40 and G80 promoted cross-education of muscle power regardless of the resistance used in the power test. These findings are partially consistent with that of Kannus et al (Kannus, et al., 1992) who reported a similar increase in muscle power (of the non-exercised limb) in different velocities (60^o/s and 240^o/s)/resistance after higher-intensity URT. Thus, our results suggest that higher-intensity URT (G80) is superior to lower-intensity (G40) URT to promote cross-education of muscle power regardless of the resistance used in the power test.

Given that muscle hypertrophy cannot occur with cross-education, neural adaptation appears to be the only mechanism for increasing muscle power in the untrained limb (Cormie, McGuigan, & Newton, 2011). Muscle power output is dependent on the magnitude of the initial phase of rising muscle force (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002; Andersen, Andersen, Zebis, & Aagaard, 2010). The initial phase of rising muscle force (< 150 ms) seems to be strongly influenced by the discharge properties of the activated motor units (Aagaard, et al., 2002; Andersen, et al., 2010). Therefore, it is thought that increased motor unit activity at the initial phase of muscle contraction is a contributor to the increase in muscle power (Del Balso & Cafarelli, 2007; Van Cutsem, Duchateau, & Hainaut, 1998). It has been shown that the increase in amplitude EMG may occur concomitantly with the increase in muscle power/strength after training. (Hammami, Gaamouri, Shephard,

& Chelly, 2019; Lanza, Balshaw, & Folland, 2019). This increase in EMG amplitude may represent changes in motor unit activation, such as intramuscular synchronism, increased recruitment of motor units or increased firing frequency (De Luca, et al., 2010; Dimitrova & Dimitrov, 2003; Vigotsky, et al., 2017). In the current study, only the G80 increases RER. Similarly, Carr et al.(Carr, et al., 2019) have also reported increased RER for the contralateral limb following short-term unilateral isometric strength training. Perez and Cohen (Perez & Cohen, 2008) showed that the magnitude of cross-activation of the corticomotor pathway is associated with the intensity of the unilateral isometric contraction. Recently, Hendy et al.(Hendy, Chye, & Teo, 2017) showed that only muscle strength higher than 50% of maximum voluntary isometric contraction produced significant cross-activation of the corticomotor pathway. Although this increase in RER occurred without progression for week 4. Apparently, training maintains this neural plasticity, which in turn leads to a continuous increase in cross-education of muscle power. Similar result between electromyography and muscle strength gain were found for the trained member (Doguet, et al., 2017; Mason, et al., 2020). Taking together, these findings may explain our result and support that higher-intensity URT enhances cross-education of muscle power. In addition, neural adaptations in synergistic and antagonistic muscles, which were not performed in this study, could explain both the continuity of muscle adaptations in the untrained limb in G80 (in 4 weeks) and the cross-education of muscle power in G40, as it did not changes in agonist EMG were seen (Aagaard, et al., 2000; Bampouras, Reeves, Baltzopoulos, & Maganaris, 2017; Brochner Nielsen, et al., 2018).

In the current study, at week 1, cross-education of muscle power was observed regardless of the URT program used (G40 and G80). This leads us to think that other characteristics of the training, such as controlled time and use of the metronome, may have contributed to these adaptations (Holper, Biallas, & Wolf, 2009; Leung, et al., 2015; Ruddy & Carson, 2013), generating motor memory (engram) with training (Hamano, Sugawara, Yoshimoto, & Sadato, 2020; Ruddy & Carson, 2013) to perform the exercise. That way, in our study, the URT with lower intensities did not promote an increase in the RER, which directs the origin of these adaptations to the formation of engrams (Orban de Xivry & Shadmehr, 2014; Ruddy & Carson, 2013) and not activation of corticomotor pathways in G40. This is an important issue for future research.

Mirror activity and difference among sexes

In the sub-analysis of the data, we observed an effect of sex on cross-education of muscle power (table 4). Cross-adaptation occurred earlier in men than in women (in week 1) when muscle power was assessed with low resistance (40% of 1RM). Moreover, a greater magnitude of power gain (cross-education) at 40% of 1RM was observed in the men than in the women (men = 24.8% vs. women = 17.6%). When muscle power was assessed with high resistance (80% of 1RM), cross-adaptation occurred only in the men. Interestingly, this was also observed in the trained arm. Thus, these findings suggest that cross-education was facilitated in men when compared to women.

Although the effect of sex on cross-education is not clear (El-Sayes, et al., 2019), fluctuation in ovarian hormones seems to influence neuroplasticity in women. Neuroactive steroids, such as estradiol and progesterone modulate the function of multiple neurotransmitter systems (Amin, et al., 2006; Guennoun, et al., 2015). In this sense, the oscillation of hormones during the menstrual cycle can influence cross-education responses. For instance, Inghilleri et al. (Inghilleri, et al., 2004) using repetitive transcranial magnetic stimulation over cortex motor observed that motor evoked potential increased on day 14 of the menstrual cycle, but not on day 1 (when estradiol and progesterone level are low). Since we don’t control women’s menstrual cycle, it may be likely that the women trained in an unfavorable hormonal environment (due to fluctuation of ovarian hormones) to promote neuroplasticity, resulting in attenuated cross-education. Our results corroborate the study by Tracy et al.(Tracy, et al., 1999) who also showed greater cross-education in men, despite the study by Green et al.(L. A. Green & D. A. Gabriel, 2018) did not show any difference between the sexes. More research is needed to identify the effect of sex on cross-education.

Mirror activity is well evidenced in unilateral movements (Addamo, Farrow, Hoy, Bradshaw, & Georgiou-Karistianis, 2009). Hellebrandt (Hellebrandt, 1951) was the first to identify mirror activity as a component of cross-education. Even small percentages of muscle activation are capable of producing increased strength in the corresponding muscle (Laidlaw, Kornatz, Keen, Suzuki, & Enoka, 1999). Andrushko et al. and Magnus et al. (Andrushko, Lanovaz, Bjorkman, Kontulainen, & Farthing, 2018; Magnus, et al., 2010) found cross-education of muscle strength and speculated that mirror activity found in the contralateral member was related to the gain in muscle strength. In the present study, we observed an effect of sex on mirror activity. The women showed an attenuated mirror activation at baseline, but not at week 4. However, if the smaller mirror activity at baseline contributed to the lack of cross-education in women, it is still unclear. Further studies are needed to confirm this statement.

Limitations

As limitations, we have that the equipment used for muscular power evaluation has a maximum data acquisition rate of 30Hz, which does not guarantee the accuracy of the data. In addition, this study was not blinded, so the examiner who performed the evaluations also supervised the training. Due to these factors, we try to control the evaluations as much as possible, especially in the power test (with the delimitation of the maximum elbow amplitude by an apparatus made especially for the study, allowing the same angle for all individuals and for all tests). In this study, we used electromyography, which is an indicator of nervous system activity, but this tool has its limitations, such as electrode interference during dynamic movements, the existence of different amounts of adipose tissue among the volunteers, which can impair the electrical signal. There was also no record of the muscular activity of antagonist and synergistic muscles, which limits the verification of their participation in gaining muscle adaptations; and it can be done in future studies for further clarification about neuromuscular adaptations in cross-education of rapid strength. As our population was young, this restricts the generalization of findings for children or the elderly. We also did not control the volunteers' diet, but they were asked to maintain their nutritional habits. Volunteers' work activity was not controlled, however, we selected volunteers with similar work activities, such as office duties. In addition, all volunteers were instructed to avoid possible heavy manual activities during research.

In conclusion, the findings of our study suggest that in the early phase (i.e., one week), URT promotes cross-education of muscle power regardless of load intensity. However, only higher-intensity URT increases RER and enhances cross-education of muscle power in the later phase (four weeks). Cross-education of muscle power is facilitated in men when compared to women.

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6. CONSIDERAÇÕES FINAIS

O conhecimento dos potencializadores da educação cruzada em diferentes manifestações da força muscular e seu decurso temporal são determinantes na elaboração de protocolos de reabilitação/intervenção por profissionais de saúde para beneficiar indivíduos incapazes de movimentar um membro devido a imobilização por fratura (DELFT; GELDER; VRIES; VERMEULEN *et al.*, 2019; MAGNUS; BARSS; LANOVAZ; FARTHING, 2010), hemiplegia por acidente vascular cerebral (WINSTEIN; STEIN; ARENA; BATES *et al.*, 2016), esclerose múltipla (MANCA; DVIR; DRAGONE; MUREDDU *et al.*, 2017) entre outros.

Os nossos estudos sugerem que esses pacientes podem se beneficiar do TFU (dinâmico e isoinercial) com intensidades baixas (40% de 1RM), com efeitos de educação cruzada com respostas rápidas (uma semana) para potência muscular e mais tardias para força muscular específica. Isso é importante para muitos pacientes que são impossibilitados de se exercitar com cargas elevadas (como em casos de osteoartrite, dor patelofemoral e hipertensão)(FRAZER; PEARCE; HOWATSON; THOMAS *et al.*, 2018; GILES; WEBSTER; MCCLELLAND; COOK, 2017; SHARMAN; LA GERCHE; COOMBES, 2015). Porém, os nossos estudos também sugerem que a intensidade alta (80% de 1 RM) do TFU promove educação cruzada de força de forma mais rápida (uma semana) e é um potencializador da educação cruzada da força e potência musculares, possibilitando ganhos progressivos (após uma semana). Além disso, temos alguma evidência que intensidades altas de treinamento unilateral também podem promover ganhos de força não específica (força isométrica). Portanto, a intensidade alta de carga é uma variável do treinamento que deve ser considerada ao planejar protocolos para educação cruzada em populações saudáveis e clínicas. Adicionalmente, os homens parecem apresentar resultados na educação cruzada mais cedo e mais expressivos que as mulheres, o que necessita de maior investigação em estudos futuros.

7. CONCLUSÕES

Na fase inicial do TFU (uma semana), somente intensidades de carga elevadas promovem educação cruzada de força dinâmica. Porém, o aumento da potência muscular é independente da intensidade do treinamento. Já em 4 semanas (fase tardia), intensidades baixas de carga no TFU promovem educação cruzada de força dinâmica e com intensidades elevadas de carga há progressão do ganho de força e potência, além de ter alguma evidência no ganho de força isométrica. Além disso, a educação cruzada é facilitada nos homens quando comparados às mulheres.

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9. APÊNDICES

9.1 APÊNDICE A - TERMO DE ESCLARECIMENTO PARTICIPANTES MAIORES DE IDADE

Título do Projeto:

TRANSFERÊNCIA CRUZADA DAS ADAPTAÇÕES MUSCULARES DO TREINAMENTO DE FORÇA AO LONGO DO TEMPO E INFLUÊNCIA DE DOIS PROTOCOLO DE TREINAMENTO (SIMPLES E COMPLEXO)

Você está sendo convidado (a) a participar do estudo: TRANSFERÊNCIA CRUZADA DAS ADAPTAÇÕES MUSCULARES DO TREINAMENTO DE FORÇA AO LONGO DO TEMPO E INFLUÊNCIA DE DOIS PROTOCOLOS DE TREINAMENTO (SIMPLES E COMPLEXO). Transferência cruzada é um fenômeno em que, ao treinar apenas um lado do corpo, é possível obter aumento de força também no lado que não realizou exercícios (Por exemplo, um indivíduo pode realizar exercícios apenas com o braço direito e conseguir aumento de força não só no lado direito, mas também no esquerdo). Isso pode ser útil para indivíduos que, após lesão, conseguem movimentar ou exercitar apenas um lado do corpo. Os avanços na área da saúde ocorrem através de estudos como este, por isso a sua participação é importante. Os objetivos deste estudo serão: (1)Verificar se um treino mais complexo (alta e baixa carga) do músculo bíceps braquial acarretaria em maior transferência cruzada. (2) Verificar se há efeito acumulativo (crônico) das adaptações contralaterais (transferência cruzada) no treinamento unilateral do músculo bíceps braquial durante seis semanas. Caso você participe, será direcionado (a) a um dos dois grupos de treinamento, por sorteio, sendo que os grupos serão: Exercícios com carga fixa ou variável. É importante ressaltar que você não poderá trocar de grupo até o final da pesquisa. Você poderá obter todas as informações que quiser e poderá não participar da pesquisa ou retirar seu consentimento a qualquer momento. Serão realizados exames para avaliação da força, potência, atividade elétrica muscular. Não será feito nenhum procedimento que possa gerar danos a você, porém é possível que você apresente dores musculares devido ao treinamento com os exercícios físicos ou avaliação, mas todos os desconfortos serão mínimos e desaparecerão ao decorrer da pesquisa. Espera-se que os benefícios decorrentes da participação nesta pesquisa sejam: adaptações musculares relacionadas ao treinamento do musculo especifico. Não haverá grandes benefícios da saúde em geral pois não será realizado um treinamento completo. Pela sua participação no estudo, você não receberá qualquer valor em dinheiro, mas terá a garantia de que todas as despesas necessárias para a realização da pesquisa não serão de sua responsabilidade. Seu nome não aparecerá em qualquer momento do estudo, pois você será identificado com um número.

Contatos do pesquisadores

Nome: Danyelle Cristina Silva Pelet
E-mail: danyellepelet@hotmail.com
Telefone: (34) 99259-2145
Endereço: Rua Silvério Gomes Caetano, 61 Bairro Fabrício
CEP: 38067-216, Uberaba-MG

Nome: Fábio Lera Orsatti
E-mail: fabiorsatti@gmail.com
Telefone: (34) 9203-2366
Endereço: Programa de Pós-Graduação em Educação Física (UFTM),
Avenida Tutunas, n°490 – Tutunas,
CEP 38061-500, Uberaba, MG
Fones: (34) 3700-6634
Ramal: 6634

TERMO DE CONSENTIMENTO LIVRE, APÓS ESCLARECIMENTO

TÍTULO DO PROJETO: TRANSFERÊNCIA CRUZADA DAS ADAPTAÇÕES MUSCULARES DO TREINAMENTO DE FORÇA AO LONGO DO TEMPO E INFLUÊNCIA DE DOIS PROTOCOLOS DE TREINAMENTO (SIMPLES E COMPLEXO)

Eu, ____, li e/ou ouvi o esclarecimento acima e compreendi para que serve o estudo e a quais procedimentos serei submetido. A explicação que recebi esclarece os riscos e benefícios do estudo. Eu entendi que sou livre para interromper minha participação a qualquer momento, sem justificar minha decisão e que isso não afetará o tratamento/serviço que estou recebendo. Sei que meu nome não será divulgado, que não terei despesas e não receberei dinheiro para participar do estudo. Concordo em participar do estudo**,** “TRANSFERÊNCIA CRUZADA DAS ADAPTAÇÕES MUSCULARES DO TREINAMENTO DE FORÇA AO LONGO DO TEMPO E INFLUÊNCIA DE DOIS PROTOCOLOS DE TREINAEMENTO (SIMPLES E COMPLEXO)”, e receberei uma via assinada deste documento.

Uberaba, .../ ..../...............

____

Assinatura do voluntário

______________________________ ______________________________

Assinatura do pesquisador responsável Assinatura do pesquisador assistente

Telefone de contato dos pesquisadores:

Fábio Lera Orsatti – (034) 99203-2366,
Danyelle Cristina Silva Pelet- (034) 99259-2145.

9.2 APÊNDICE B - FICHA DE AVALIAÇÃO (ANAMNESE)

CARACTERIZAÇÃO DOS SUJEITOS DA PESQUISA

Nome:

Data da avaliação:

Nome do avaliador:

Data de Nascimento:

Pressão arterial:

Preensão Palmar:

Peso: Altura:

Pratica atividade física ( ) sim ( ) Não

Quais:____

Tempo de sedentarismo ( ) 1 mês ( ) 3 meses ( )6 meses ( ) 1 ano ou mais

Quais esportes ou atividades físicas já praticou? ______________________________

Cirurgias prévias: ( ) sim ( ) Não
Quais:____

Fraturas prévias: ( ) sim ( ) Não

Quais:____

Doenças atuais :

( )cardiovasculares
( )AVC
( )Parkinson
( ) lesão nervosa Periférica
( )miopatias
( )artrite ou artrose
( )tendinites ou tenossinovites
( )neuropatias
( )outras Quais: ______________________________

Doenças prévias:

( )cardiovasculares
( )AVC
( )Parkinson
( ) lesão nervosa Periférica
( )miopatias
( )artrite ou artrose
( )tendinites ou tenossinovites
( )neuropatias
( )outras Quais: ______________

10. ANEXOS

10.1 ANEXO A

COMPROVANTE DE SUBMISSÃO À REVISTA “APPLIED PHYSIOLOGY, NUTRITION, AND METABOLISM” (ARTIGO 1)

01-Feb-2021

Dear Dr. Orsatti and co-authors: Thank you for submitting to Applied Physiology, Nutrition, and Metabolism.

Your submission has been processed by the editorial office and is currently under consideration for review by the editorial board.

Manuscript ID: apnm-2021-0088

Title: Effects of resistance training at different intensities on the time course of cross-education of muscle strength

Contributing Authors: PELET, DANYELLE CRISTINA; Orsatti, Fábio. Please mention the above manuscript ID in all future correspondence with the editorial office. You may view the status of your manuscript at any time by logging in to your Author Center at https://mc06.manuscriptcentral.com/apnm-pubs. Statements endorsed on submission are listed below my signature block. Please contact the editorial office if you believe any of them to be inaccurate or untrue. Best of luck with your submission.

Sincerely,

Rhonda Wilson

Editorial Assistant for Applied Physiology, Nutrition, and Metabolism apnm@cdnsciencepub.com

10.2 ANEXO B

DECISÃO DA REVISTA “APPLIED PHYSIOLOGY, NUTRITION, AND METABOLISM” – ARTIGO ACEITO PARA PUBLICAÇÃO – ARTIGO 1

10-May-2021

Dear Prof. Orsatti and co-authors:

It is a pleasure to accept your manuscript entitled "Effects of resistance training at different intensities of load on cross-education of muscle strength" in its current form for publication in Applied Physiology, Nutrition, and Metabolism.

Your manuscript will be returned to your Author Center so that you can supply completed forms, production files, and publishing preferences. You will receive an email entitled "Please Submit Production Files" with instructions from our editorial office.

Thank you.

Sincerely,

Dr. Daniel Moore
Associate Editor, Applied Physiology, Nutrition, and Metabolism

We strive to continuously improve our service to authors. We invite you to participate in a brief survey to share your experience of our submission and peer review process:
https://www.surveymonkey.com/r/XTLFK7M

Are you already a member of APNM’s sponsoring societies? Consider joining now!
Canadian Society for Exercise Physiology: http://www.csep.ca/en/membership/membership-overview

Canadian Nutrition Society: https://cns-scn.ca/membership/become-a-member/join-cns-today

Reviewer(s)' Comments to Author:

Reviewer: 2

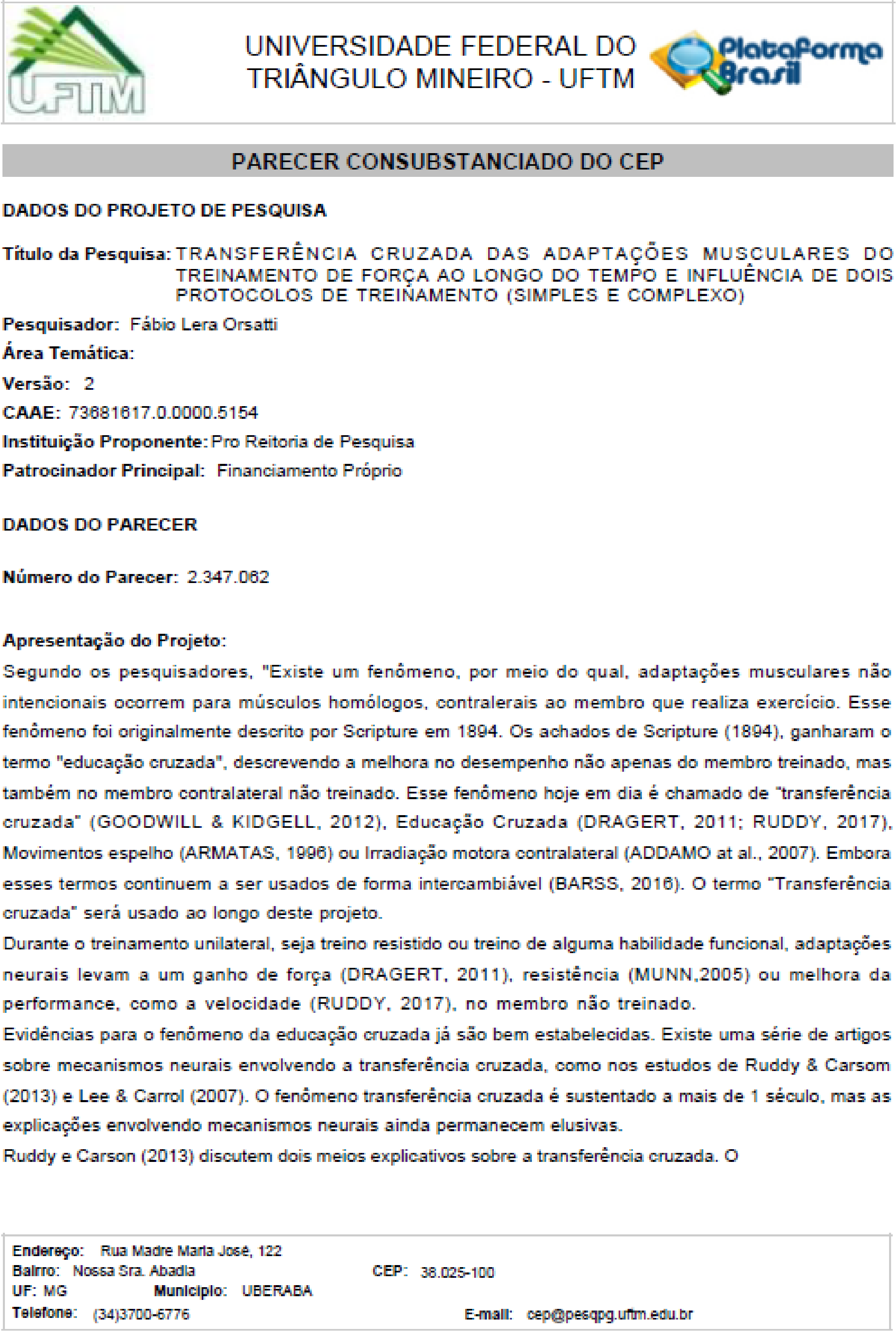
Comments to the Author
No further comments as the Authors succedeed in satisfying all the major and minor revisions raised at round 1.

Reviewer: 3

Comments to the Author
No further comments. My concerns have been addressed. Good job

10.3 ANEXO C

PARECER CONSUBSTANCIADO DO CEP



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PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: TRANSFERÊNCIA CRUZADA DAS ADAPTAÇÕES MUSCULARES DO TREINAMENTO DE FORÇA AO LONGO DO TEMPO E INFLUÊNCIA DE DOIS PROTOCOLOS DE TREINAMENTO (SIMPLES E COMPLEXO)

Pesquisador: Fábio Lera Orsatti

Área Temática:

Versão: 2

CAAE: 73681617.0.0000.5154

Instituição Proponente: Pro Reitoria de Pesquisa

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 2.347.062

Apresentação do Projeto:

Segundo os pesquisadores, "Existe um fenômeno, por meio do qual, adaptações musculares não intencionais ocorrem para músculos homólogos, contralerais ao membro que realiza exercício. Esse fenômeno foi originalmente descrito por Scripture em 1894. Os achados de Scripture (1894), ganharam o termo "educação cruzada", descrevendo a melhora no desempenho não apenas do membro treinado, mas também no membro contralateral não treinado. Esse fenômeno hoje em dia é chamado de "transferência cruzada" (GOODWILL & KIDGELL, 2012), Educação Cruzada (DRAGERT, 2011; RUDDY, 2017), Movimentos espelho (ARMATAS, 1996) ou Irradiação motora contralateral (ADDAMO at al., 2007). Embora esses termos continuem a ser usados de forma intercambiável (BARSS, 2016). O termo "Transferência cruzada" será usado ao longo deste projeto.

Durante o treinamento unilateral, seja treino resistido ou treino de alguma habilidade funcional, adaptações neurais levam a um ganho de força (DRAGERT, 2011), resistência (MUNN,2005) ou melhora da performance, como a velocidade (RUDDY, 2017), no membro não treinado.

Evidências para o fenômeno da educação cruzada já são bem estabelecidas. Existe uma série de artigos sobre mecanismos neurais envolvendo a transferência cruzada, como nos estudos de Ruddy & Carsom (2013) e Lee & Carrol (2007). O fenômeno transferência cruzada é sustentado a mais de 1 século, mas as explicações envolvendo mecanismos neurais ainda permanecem elusivas.

Ruddy e Carson (2013) discutem dois meios explicativos sobre a transferência cruzada. O primeiro, modelo de "ativação cruzada", defende que a execução unilateral de uma tarefa de movimento dá origem a aumentos bilaterais na excitabilidade corticospinal devido adaptações simultâneas em circuitos neurais que se projetam para os músculos do membro não treinado. Outro modelo é o "acesso bilateral" que defende que memórias guardadas no Sistema Nervoso Central (SNC) devido a um estímulo externo (circuitos neurais que constituem centro de controle de movimento), no caso o exercício ou tarefa unilateral, podem ser posteriormente utilizados bilateralmente. Já Hendy, Spittle e Kidgell (2012) defendem que o treino unilateral parece contribuir para o ganho de força contralateral por meio de conexões inter-hemisféricas e fibras corticoespinais ipsilaterais". As perguntas de pesquisa são: "1. Por quanto tempo um sujeito continua ganhando força contralateral durante treino unilateral? Essa resposta é aguda ou vai aumentando à medida que o estímulo continua? 2. Se a novidade no exercício é preditor de aumento na transferência cruzada, um estimulo de carga variável (alta e baixa) poderia funcionar como fator complexidade/novidade no treinamento, levando a maior transferência cruzada?"

Objetivo da Pesquisa:

Constam: "1. Verificar se um treino mais complexo (alta e baixa carga) do músculo bíceps braquial acarretaria em maior transferência cruzada para o bíceps contralateral.

2. Verificar se há efeito acumulativo (crônico) das adaptações contralaterais (transferência cruzada) no treinamento unilateral do m. bíceps braquial durante seis semanas".

Avaliação dos Riscos e Benefícios:

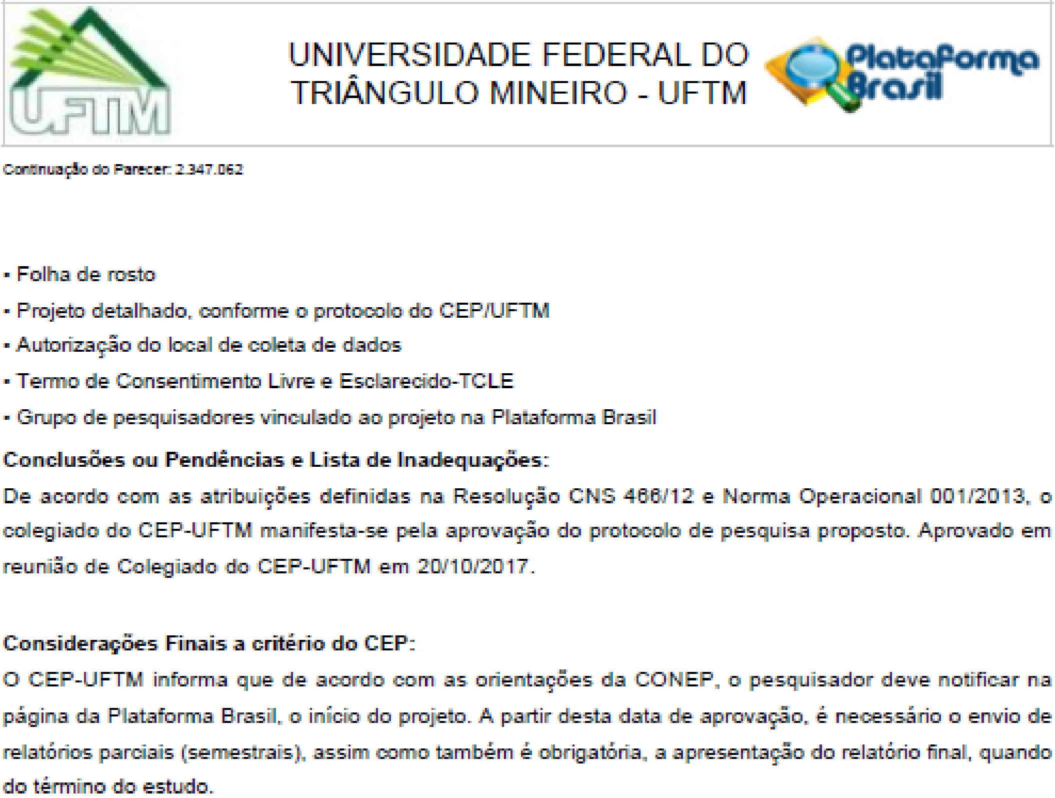
Segundo os pesquisadores, "Nesse trabalho espera-se que não haja a possibilidade de danos de dimensão física, psíquica, moral, intelectual, social, cultural ou espiritual do ser humano. Protocolos semelhantes já foram utilizados anteriormente em pesquisas e publicações comprovando-se sua prática benéfica. Todos as participantes serão submetidas à uma avaliação inicial para triagem de forma a segurar quaisquer condições de saúde que impeçam a prática do exercício de forma segura. O Período de abstenção do treinamento de um membro será curto, não prejudicando o sujeito da pesquisa pela ausência do treinamento de um dos membros".

Comentários e Considerações sobre a Pesquisa:

Pesquisa de relevância temática ao verificar se um treino mais complexo (alta e baixa carga) do músculo bíceps braquial acarretaria em maior transferência cruzada para o bíceps contralateral.

Considerações sobre os Termos de apresentação obrigatória:

Foram apresentados os seguintes termos:



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Continuação do Parecer: 2.347.062

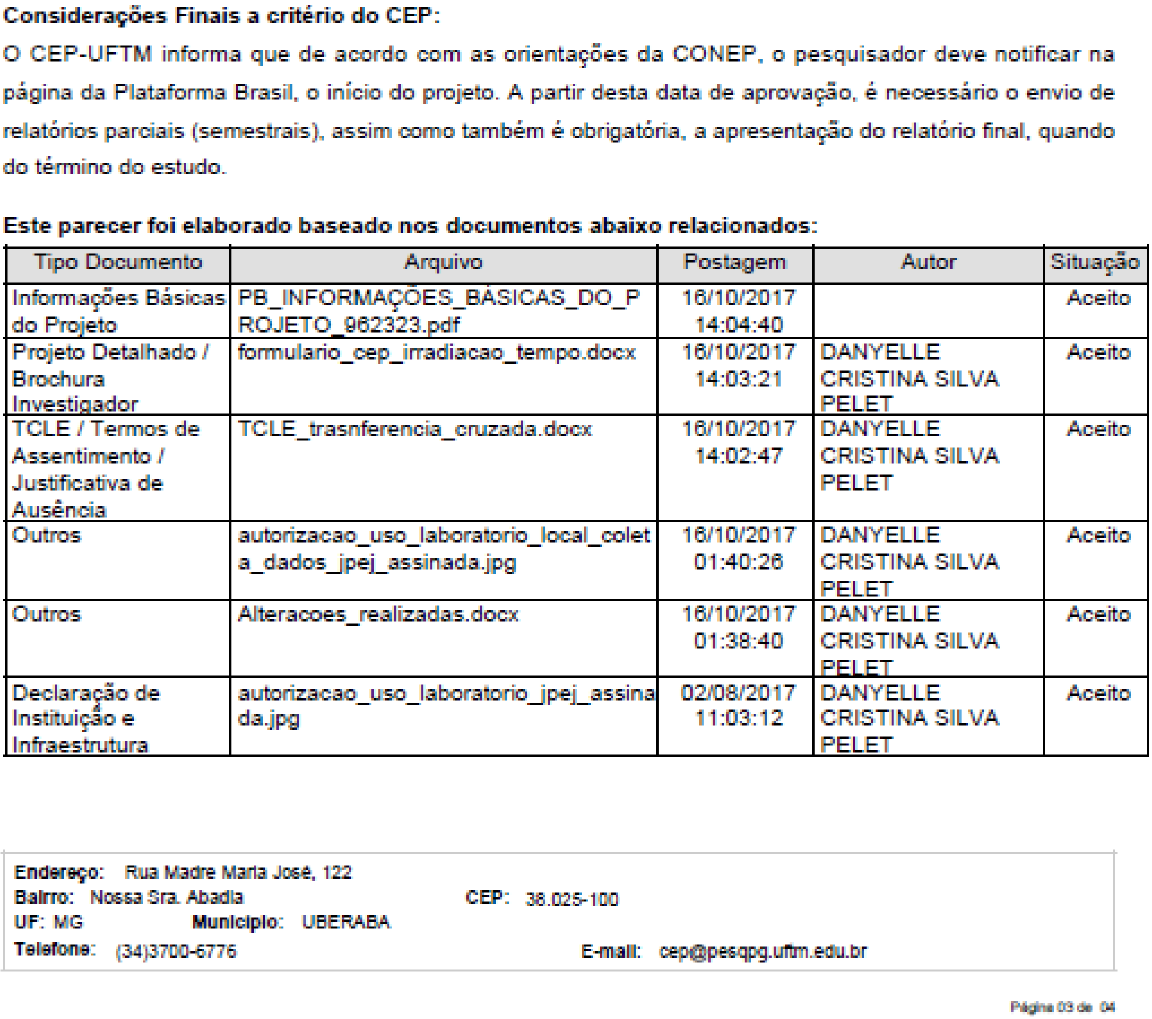
- Folha de rosto
- Projeto detalhado, conforme o protocolo do CEP/UFTM
- Autorização do local de coleta de dados
- Termo de Consentimento Livre e Esclarecido-TCLE
- Grupo de pesquisadores vinculado ao projeto na Plataforma Brasil

Conclusões ou Pendências e Lista de Inadequações:

De acordo com as atribuições definidas na Resolução CNS 466/12 e Norma Operacional 001/2013, o colegiado do CEP-UFTM manifesta-se pela aprovação do protocolo de pesquisa proposto. Aprovado em reunião de Colegiado do CEP-UFTM em 20/10/2017.

Considerações Finais a critério do CEP:

O CEP-UFTM informa que de acordo com as orientações da CONEP, o pesquisador deve notificar na página da Plataforma Brasil, o início do projeto. A partir desta data de aprovação, é necessário o envio de relatórios parciais (semestrais), assim como também é obrigatória, a apresentação do relatório final, quando do término do estudo.



Considerações Finais a critério do CEP:

O CEP-UFTM informa que de acordo com as orientações da CONEP, o pesquisador deve notificar na página da Plataforma Brasil, o início do projeto. A partir desta data de aprovação, é necessário o envio de relatórios parciais (semestrais), assim como também é obrigatória, a apresentação do relatório final, quando do término do estudo.

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_962323.pdf	16/10/2017 14:04:40		Aceito
Projeto Detalhado / Brochura Investigador	formulario_cep_irradiacao_tempo.docx	16/10/2017 14:03:21	DANYELLE CRISTINA SILVA PELET	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE_trasnferencia_cruzada.docx	16/10/2017 14:02:47	DANYELLE CRISTINA SILVA PELET	Aceito
Outros	autorizacao_uso_laboratorio_local_coleta_dados_jpej_assinada.jpg	16/10/2017 01:40:26	DANYELLE CRISTINA SILVA PELET	Aceito
Outros	Alteracoes_realizadas.docx	16/10/2017 01:38:40	DANYELLE CRISTINA SILVA PELET	Aceito
Declaração de Instituição e Infraestrutura	autorizacao_uso_laboratorio_jpej_assinada.jpg	02/08/2017 11:03:12	DANYELLE CRISTINA SILVA PELET	Aceito

Endereço: Rua Madre Maria José, 122
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Telefone: (34)3700-6776 **E-mail:** cep@pesqpg.uftm.edu.br

Página 03 de 04

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Continuação do Parecer: 2.347.062

Folha de Rosto	folhaderostrodigitalizadapd.pdf	26/07/2017 17:53:30	DANYELLE CRISTINA SILVA PELET	Aceito

Situação do Parecer:
Aprovado

Necessita Apreciação da CONEP:
Não

UBERABA, 24 de Outubro de 2017

Assinado por:
Alessandra Cavalcanti de Albuquerque e Souza
(Coordenador)

10.4 ANEXO D

COMPROVANTE DE SUBMISSÃO À REVISTA “HUMAN MOVEMENT SCIENCE” – ARTIGO 2

Manuscript Number: HMS-D-21-00185
Unilateral resistance training promotes cross-education of muscle power: a study of the efficacy of load Intensity

Dear Ms PELET,
The above referenced manuscript will be handled by Editor-in-Chief Professor Mark Williams. To track the status of your manuscript, please log into Editorial Manager at https://www.editorialmanager.com/hms/. Thank you for submitting your work to this journal.

Kind regards,
Human Movement Science

Manuscript Number: HMS-D-21-00185 Unilateral resistance training promotes cross-education of muscle power: a study of the efficacy of load Intensity

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Your above referenced submission has been assigned a manuscript number: HMS-D-21-00185. To track the status of your manuscript, please log in as an author at https://www.editorialmanager.com/hms/, and navigate to the "Submissions Being Processed" folder.
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Unilateral resistance training promotes cross-education of muscle power: a study of the efficacy of load Intensity

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Human Movement Science