LUCAS TÚLIO DE LACERDA

Falha muscular e duração da repetição na musculação: efeito sobre as respostas de hipertrofia, força muscular e atividade eletromiográfica

BELO HORIZONTE

Universidade Federal de Minas Gerais

Escola de Educação Física, Fisioterapia e Terapia Ocupacional

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Mauro Heleno Chagas

Prof. Dr. Mauro Heleno Chagas (orientador)
Escola de Educação Física, Fisioterapia e Terapia Ocupacional
Universidade Federal de Minas Gerais

Prof. Dr. Fernando Vitor Lima
Escola de Educação Física, Fisioterapia e Terapia Ocupacional
Universidade Federal de Minas Gerais

Prof. Dr. Eduardo Mendonça Pimenta
Escola de Educação Física, Fisioterapia e Terapia Ocupacional
Universidade Federal de Minas Gerais

Prof. Dr. Humberto Lameira Miranda
Universidade Federal do Rio de Janeiro

Prof. Dr. Fábio Lera Orsatti
Universidade Federal do Triângulo Mineiro

Belo Horizonte, 28 de fevereiro de 2020.

Resumo (Estudo 1)

O objetivo do presente estudo foi comparar o efeito do treinamento realizado até a falha (TFM) ou não falha muscular (TNFM) nos ganhos relativos de força e hipertrofia muscular (valores médios e individuais), bem como na amplitude do sinal eletromiográfico (EMG_{RMS}). Dez homens que não realizavam qualquer tipo de treinamento de força participaram do estudo. Cada membro inferior dos voluntários foi alocado em um dos protocolos de treinamento (equiparados pelo volume) realizados de forma unilateral no exercício extensor de joelhos. Ambos os protocolos foram realizados com 3-4 séries, pausa de 3 minutos e a 50-60% de uma repetição máxima (1RM). Foram medidas antes e após 14 semanas de treinamento as áreas de secção transversa (AST) dos músculos reto femoral e vasto lateral, força máxima dinâmica e isométrica (1RM e CIVM), resistência de força (número máximo de repetições a 70% de 1RM - NMR). Além disso, a ativação neuromuscular (EMG_{RMS} normalizada) foi mensurada na 2ª e 35ª sessões de treinamento. A análise das médias mostrou que ambos os protocolos induziram aumentos relativos similares de força e hipertrofia muscular. Entretanto, a análise dos dados individuais indica que o TNFM pode promover respostas similares ou até maiores de hipertrofia e resistência de força que o TFM, quando são realizados com mesmo volume. Além disso, as respostas de EMG_{RMS} normalizada avaliadas durante a 2ª e 35ª sessões de treinamento foram similares entre protocolos para os músculos reto femural e vasto lateral. Portanto, ambos os protocolos de treinamento, executados com mesmo número de repetições, produziram respostas semelhantes de desempenho de força máxima e ativação neuromuscular. Contudo, a execução do TNFM poderia ser uma estratégia de treinamento mais apropriada para aumentar a hipertrofia muscular (vasto lateral) e o desempenho de resistência de força em indivíduos não treinados quando comparado ao TFM.

PALAVRAS CHAVE: Falha muscular. Área de secção transversa. Desempenho de força muscular. Número de repetições. Eletromiografia.

Abstract (Study 1)

The aim of this study was to investigate the effects of muscle failure (MF) or not to MF (NMF) training on strength and muscle hypertrophy relative gains (average and individual data) as well as on normalized root mean square of the electromyographic signal (EMG_{RMS}). Ten men untrained in resistance training participated in the study. Each leg was allocated in 1 of 2 unilateral training protocols (MF or NMF with equal volume) on knee extension exercise. Both protocols were performed with 3-4 sets, 3 minutes' rest, and 55-60% of one repetition maximum (1RM). Rectus femoris and vastus lateralis muscles cross-sectional area (CSA), maximal muscle strength (1RM and maximal voluntary isometric contraction), and muscular endurance (maximum number of repetition) were assessed before and after 14 weeks. In addition, neuromuscular activation by normalized root mean square of the electromyographic signal (EMG_{RMS}) was measured in 2nd and 35th training sessions. The average results showed that both training protocols were similarly effective in inducing increases in strength and muscle hypertrophy gains. However, individual analysis data suggest that NMF protocol with equal volume may promote similar or even greater muscle hypertrophy (vastus lateralis) and muscular endurance performance when compared with MF protocol. Also, normalized EMG_{RMS} responses analyzed during 2nd and 35th sessions were similar in MF and NMF protocols for rectus femoris and vastus lateralis muscles. In conclusion, MF and NMF protocol conducted with the same total repetition numbers produced similar maximal muscle strength performance and neuromuscular activation. Nevertheless, NMF training could be a more appropriate strategy to increase muscle hypertrophy (vastus lateralis) and muscular endurance performance in untrained individuals when compared with MF.

KEY WORDS: Muscle failure. Muscle cross-sectional area. Strength performance. Repetition number. Electromyography.

Resumo (Estudo 2)

O objetivo do estudo foi comparar o efeito do treinamento realizado com diferentes durações da repetição até a falha muscular nos ganhos relativos de força de hipertrofia muscular (valores médios e individuais). Também, foi verificado o efeito dos protocolos de treinamento na relação entre amplitude do sinal eletromiográfico e ângulo de flexão de joelho (EMG_{RMS}-ângulo) e na relação força-ângulo. Dez homens que não realizavam qualquer tipo de treinamento de força participaram do estudo. Cada membro inferior dos voluntários foi alocado em um dos protocolos de treinamento (2-s ou 6-s) realizados de forma unilateral no exercício extensor de joelhos. Ambos os protocolos foram realizados com 3-4 séries, a 50-60% de uma repetição máxima (1RM) e pausa de 3 minutos. Foram medidas antes e após 14 semanas de treinamento as áreas de secção transversa (AST) dos músculos reto femoral e vasto lateral, força máxima dinâmica (1RM) e isométrica (CIVM) a 30º e 90º de flexão de joelho. Além disso, as curvas de amplitude EMG e força normalizada x ângulo foram mensuradas na 2ª e 35ª sessões de treinamento. Os principais resultados mostraram que o protocolo 6-s induziu a um maior aumento na CIVM a 30º de flexão de joelhos do que o protocolo 2-s. Contudo, não houve diferença entre protocolos no aumento do desempenho nos testes de CIVM a 90º de flexão de joelhos e 1RM. Considerando os dez sujeitos analisados no estudo, as repostas de hipertrofia (alteração na AST) do músculo reto femural entre protocolos de treinamento foram inconclusivas. Em contrapartida, é possível que o protocolo 2-s tenha resultado em uma maior hipertrofia do músculo vasto lateral. Adicionalmente, os valores de EMG_{RMS} normalizada x ângulo foram diferentes entre os protocolos em maior parte dos ângulos articulares analisados. Conforme os resultados apresentados, protocolos realizados com maior duração da repetição poderiam ser mais apropriados para promover ganhos superiores de força máxima com o joelho em posições mais encurtadas, porém uma menor duração da repetição induziria maior hipertrofia muscular.

KEY WORDS: Duração da repetição. Falha muscular. Área de secção transversa. Desempenho de força. Volume. Tempo sob tensão. Eletromiografia.

Abstract (Study 2)

The aim of this study was to investigate the effects of two 14-week resistance training protocols each with a different repetition duration performed to muscle failure on gains in strength and muscle hypertrophy (average and individual data) as well as on normalized root mean square of the electromyographic signal (EMG_{RMS}) and force-angle relationships. The left and right legs of ten untrained males were assigned to either one of the two protocols (2-s or 6-s RD) incorporating unilateral knee extension exercise. Both protocols were performed with 3-4 sets, 50-60% of the one-repetition maximum (1RM), and 3 min rest. Rectus femoris and vastus muscles cross-sectional areas (CSA), maximal voluntary isometric contraction (MVIC) at 30^o and 90^o of knee flexion and 1RM performance were assessed before and after training period. In addition, normalized EMG and force-angle relationships were assessed in the 2nd and 35th training sessions. The main results show that the 6-s RD protocol induced larger gains in MVIC in the 30^o of knee angle measurement than the 2-s RD protocol. Increases in MVIC in the 90^o of knee angle and 1RM were indifferent between the 2-s and 6-s RD protocols. For the rectus femoris muscle growth, inconclusive changes were found across the ten subjects. In contrast, the 2-s RD protocol may have resulted in superior vastus lateralis muscle hypertrophy. Moreover, different normalized EMG and force-angle values were detected between protocols over most of angles analyzed. Thus, performing longer RD could be a more appropriate strategy to provide greater gains in maximal muscle strength at shortened knee positions, although shorter RD would induce superior muscle hypertrophy.

Key words: Repetition duration. Muscle failure. Muscle cross-sectional area. Strength performance. Training volume. Time-under-tension. Electromyography.

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LISTA DE ABREVIATURAS E SIGLAS

Português:

1RM - Teste de uma repetição máxima
AST - área de secção transversa
CIVM - Teste de contração isométrica voluntária máxima
EEFFTO - Escola de Educação Física, Fisioterapia e Terapia Ocupacional
EMG - Sinal eletromiográfico
NMR - Teste de resistência de força (número máximo de repetições a 70% de 1RM)
TCLE - Termo consentimento livre esclarecido
TFM - Treinamento realizado até a falha muscular
TNFM - Treinamento realizado sem alcançar a falha muscular
UFMG - Universidade Federal de Minas Gerais

Inglês:

1 RM - One repetition maximum test
RD - repetition duration
A/D - Analog/Digital
ANOVA - Analysis of variance
CI - Confidence interval
CSA - Cross-sectional area
d - Cohen´s d value
EMG - Surface electromyography
M - Mean
MF - Muscle failure
MNR - Muscular endurance test (maximum number of repetitions at 70% 1RM)
MVIC - Maximal voluntary isometric contraction
NMF - Not to muscle failure
PAR-Q - Physical Activity Readiness Questionnaire
RD - Repetition duration
RMS - Root mean square
ROM - Range of motion
RPE - Rating of perceived exertion

SD - Standard deviation

TE - Typical error

TUT - Time under tension

SUMÁRIO

1 INTRODUÇÃO

1.1 Treinamento realizado até a falha muscular *versus* não falha muscular (Estudo 1)

O treinamento de força conduzido até a falha muscular (TFM) tem sido utilizado como tentativa de maximizar as respostas de força e hipertrofia muscular (DRINKWATER *et al.* 2005; JACOBSON, 1981; ROONEY; HEBERT; BALNAVE, 1994; SCHOTT; MCCULLY; RUTHERFORD, 1995). A falha muscular pode ser definida como a incapacidade de realizar a amplitude de movimento completa em uma repetição devido à fadiga (IZQUIERDO *et al.*, 2006). No presente estudo, fadiga será entendida como a redução na capacidade de exercer força muscular (BIGLANG-RITCHIE; WOODS, 1984; GANDEVIA; 2001), sendo a falha muscular o momento que o exercício é interrompido. No treinamento de força na musculação, essa interrupção do exercício acontece, comumente, durante a ação muscular concêntrica de uma repetição (falha concêntrica) em protocolos de treinamento configurados com número máximo de repetições (FISHER *et al.*, 2011; WILLARDSON, 2007). Tem sido proposto que o elevado nível de fadiga promovido ao realizar repetições até a falha muscular seria determinante para aumentar o estímulo do treinamento de força (MARSHALL *et al.*, 2012; ROONEY; HEBERT; BALNAVE, 1994). Nesse sentido, estudos verificaram uma maior amplitude do sinal eletromiográfico (amplitude EMG) durante o TFM comparado ao treinamento realizado sem alcançar a falha muscular (TNFM) (LOONEY *et al.*, 2016; MARSHALL *et al.*, 2012), sendo esse resultado justificado pela tentativa de manutenção da força durante a execução de repetições até a falha muscular. Pelo menos em parte, esta maior amplitude EMG em protocolos de treinamento realizados até a falha muscular seria um indicativo da ocorrência de um recrutamento adicional de unidades motoras, mais especificamente, de unidades motoras rápidas (AKIMA; SAITO, 2013; CONWIT *et al.*, 2000; LOONEY *et al.*, 2016), que são compostas predominantemente por fibras musculares IIx (GREISING *et al.*, 2012; SALE, 1987). Dessa forma, considerando que as fibras musculares ativadas são aquelas que podem se adaptar ao treinamento (SPIERING *et al.*, 2008; WAKAHARA *et al.*, 2013) e que as fibras musculares IIx apresentam maiores ganhos de hipertrofia e força muscular comparado às do tipo I (DRINKWATER *et al.*, 2005; SCHOENFELD, 2013), é possível que TFM apresente-se superior ao TNMF, quando o objetivo seja maximizar as adaptações crônicas relacionadas ao treinamento de força na musculação.

Estudos de revisão de literatura indicam que o TFM é capaz de promover maiores ganhos de força muscular (FISHER *et al.*, 2011) e hipertrofia (FISHER; STEELE; SMITH, 2013) comparado ao TNMF. Entretanto, recentemente, Davies *et al.* (2016) realizaram uma metanálise sobre o efeito do TFM *versus* TNMF na resposta de força muscular e os resultados não reforçam a expectativa dos estudos anteriores. Os autores concluíram que ganhos similares de força muscular podem ser conseguidos com os dois tipos de protocolos de treinamento. Os estudos originais que investigaram essa temática apresentaram resultados contraditórios, sendo que alguns conferiram uma superioridade para os protocolos realizados até a falha muscular (DRINKWATER *et al.* 2005; GIESSING *et al.*, 2014; ROONEY; HEBERT; BALNAVE, 1994; OGASAWARA *et al.*, 2013) ou sem alcançar a falha muscular (IZQUIERDO-GABARREN *et al.*, 2010; KRAMER *et al.*, 1997; SANBORN *et al.*, 2000). Além disso, outros não relataram diferenças nas respostas de força muscular (FOLLAND *et al.*, 2002; IZQUIERDO *et al.*, 2006; MARTORELLI *et al.*, 2017; PRESTES *et al.*, 2019; SAMPSON; GROELLER, 2016) e hipertrofia (MARTORELLI *et al.*, 2017; NÓBREGA *et al.*, 2018; PRESTES *et al.*, 2019; SAMPSON; GROELLER, 2016) entre o TFM e TNMF. Dever ser ressaltado que, nos estudos citados acima, além da presença ou não da falha muscular, não houve a equiparação dos componentes da carga de treinamento, como por exemplo, a intensidade (GIESSING *et al.*, 2016; OGASAWARA *et al.*, 2013) e o volume (IZQUIERDO-GABARREN *et al.*, 2010; GIESSING *et al.*, 2016; NÓBREGA *et al.*, 2018; SAMPSON; GROELLER, 2016; SANBORN *et al.*, 2000). Além disso, também não foram equiparadas outras variáveis que configuram protocolos de treinamento na musculação, como a pausa entre séries (DRINKWATER *et al.* 2005; PRESTES *et al.*, 2017), a pausa entre repetições (FOLLAND *et al.*, 2002; GIESSING *et al.*, 2016; ROONEY; HEBERT; BALNAVE, 1994) e a duração da repetição (SAMPSON; GROELLER, 2016). Considerando que a falta de equiparação dos protocolos de treinamento investigados nos estudos acima mencionados poderia causar um viés nas respostas de força e hipertrofia muscular (ACSM, 2009; WERNBOM; AUGUSTSSON; THOMEÉ, 2007), não se pode concluir que os resultados encontrados foram devidos exclusivamente a terem ou não sido realizadas repetições até a falha muscular.

Portanto, baseado na literatura recente, ainda necessita ser esclarecido se a realização do treinamento de força até a falha muscular maximizaria as respostas de força e hipertrofia muscular. Além disso, é importante ressaltar que as questões metodológicas levantadas no parágrafo anterior aparecem como uma condição básica inicial que necessita ser considerada antes mesmo de outros aspectos neste contexto. Por exemplo, a controvérsia sobre um possível efeito distinto promovido pelo treinamento de força em indivíduos com diferentes níveis de treinamento (ex. treinados *vs.* não-treinados).

1.1.1 Objetivos

O objetivo principal do Estudo 1 foi investigar o efeito do TFM e do TNFM nos ganhos relativos de força e hipertrofia muscular, considerando os valores médios e individuais. Adicionalmente, o presente estudo teve com objetivo secundário comparar as respostas de amplitude do sinal eletromiográfico (EMG_{RMS}) promovidas pelo TFM e TNFM no início e no final do período de 14 semanas de treinamento.

1.2 Treinamento com diferentes durações da repetição até a falha muscular (Estudo 2)

Sabe-se que o TFM pode apresentar diferentes configurações, por exemplo, podendo ser prescrito com diferentes intensidades como já investigado em estudos anteriores (CLAFLIN *et al*., 2011; KEELER *et al*., 2011; NEILS *et al*., 2005; RANA *et al*.; 2008; TANIMOTO *et al*., 2008; TANIMOTO; ISHII, 2006; SCHUENKE *et al.*, 2012; YOUNG *et al*., 1993). Entretanto, no presente estudo será investigado o impacto de diferentes durações da repetição em protocolos de treinamento realizados até a falha muscular sobre as respostas de força e hipertrofia muscular, uma vez que esta questão ainda requer maior análise. Já foi demonstrado que protocolos com menor duração da repetição realizados até a falha muscular apresentam maior amplitude EMG (SAKAMOTO; SINCLAIR, 2012) comparado a protocolos executados com maior duração da repetição, também até a falha muscular. Como relatado anteriormente, o aumento da amplitude EMG pode indicar a ocorrência de maior recrutamento de unidades motoras (ex. rápidas) durante a realização de determinado protocolo de treinamento (HUNTER; DUCHATEAU; ENOKA, 2004; SUZUKI *et al.*, 2002) que, por sua vez, é apontada como uma importante resposta neuromuscular aguda que poderia estar associada com maiores ganhos de força e hipertrofia muscular (SCHOENFELD, 2014). Contudo, é importante ressaltar que, além do recrutamento de unidades motoras, outros fatores influenciam as respostas da amplitude EMG como a frequência de estimulação e sincronização de unidades motoras (HUNTER; DUCHATEAU; ENOKA, 2004; SUZUKI *et al.*, 2002).

Além disso, sabe-se que protocolos realizados com diferentes durações da repetição apresentam características mecânicas diferentes (TANIMOTO; ISHII, 2006; SAMPSON; DONOHOE; GROELLER, 2014), fator que está associado com as respostas de força e hipertrofia muscular causadas pelo treinamento de força. Durante protocolos de treinamento executados com menores durações da repetição, movimentos mais rápidos são realizados, consequentemente, acarretando em maiores picos de força nas repetições realizadas em comparação com protocolos realizados com maiores durações da repetição (SAMPSON; DONOHOE; GROELLER, 2014). Assim, considerando que a musculatura esquelética demonstra ser sensível à variação da tensão mecânica (GEHLERT *et al.*, 2015; MARTINEAU; GARDINER, 2001), o aumento da tensão muscular proporcionado pela maior aplicação de força a cada repetição se tornaria um fator importante para induzir adaptações neuromusculares (EARP *et al.*, 2015; SAMPSON; GROELLER, 2016). Dados do recente estudo de Sampson e Groeller (2016) reforçam esse raciocínio, uma vez que, apesar de terem sido realizados com um tempo sob tensão até três vezes menor, os protocolos realizados com as ações musculares concêntricas e excêntricas explosivas (3 séries de 4 repetições a 85% de 1RM, pausas de 3min) ou com ações concêntricas explosivas e excêntricas de 2s (3 séries de 4 repetições a 85% de 1RM, pausas de 3min) promoveram respostas similares de hipertrofia e de força máxima comparado com o protocolo executado com movimentos mais lentos e com duração da repetição controlada em 4s (3 séries de 6 repetições máximas a 85% de 1RM, pausas de 3min). Contudo, sabe-se que o volume de treinamento pode influenciar as respostas de força e hipertrofia muscular (ACSM, 2009; MITCHEL *et al.*, 2012; WERNBOM; AUGUSTSSON; THOMEÉ, 2007), principalmente quando os protocolos investigados não são executados até a falha muscular (DANKEL *et al.*, 2017). Ainda sobre o estudo de Sampson e Groller (2016), apesar da capacidade de realização de um maior número de repetições, consequentemente maior volume de treinamento durante protocolos com menores durações em relação a protocolos executados com maior duração da repetição (SAKAMOTO; SINCLAIR, 2006; 2012), apenas o protocolo com maior duração da repetição (4s) foi realizado até a falha muscular. Dessa forma, o protocolo com maior duração da repetição foi realizado com um maior volume de treinamento em relação aos demais protocolos. Nesse sentido, é possível que o maior volume de treinamento realizado pelo protocolo com duração da repetição de 4s, provavelmente, tenha sido um fator de equilíbrio em relação à maior magnitude da tensão mecânica e maior ativação muscular já verificadas durante protocolos com menor duração da repetição (LACERDA *et al*., 2016; SAKAMOTO; SINCLAIR, 2012; SAMPSON; DONOHOE; GROELLER, 2014), fazendo com que não fossem observadas diferenças nas respostas crônicas entre os protocolos investigados. Tendo como base o raciocínio acima exposto, o desenho experimental utilizado por Sampson e Groller (2016) não permite concluir sobre o efeito da manipulação da duração da repetição em protocolos realizados até a falha muscular. Portanto, considerando que a magnitude da tensão mecânica na musculatura e a ativação muscular seriam fatores determinantes para a ocorrência de adaptações neuromusculares, protocolos executados com menores durações da repetição podem apresentar respostas superiores de força e hipertrofia muscular quando comparados a protocolos realizados com maior duração da repetição.

Recentemente, Schoenfeld, Ogborn e Krieger (2015) realizaram uma metanálise sobre o efeito da manipulação da duração da repetição na hipertrofia muscular em protocolos de treinamento de força realizados até a falha muscular. Os autores concluíram que podem ser observadas respostas similares de hipertrofia muscular quando realizados protocolos com durações da repetição entre 0,5 e 8s, sugerindo que uma ampla faixa dessa variável pode ser empregada se o objetivo principal do treinamento for maximizar o ganho de massa muscular. Nos estudos incluídos nessa metanálise, além da duração da repetição, a intensidade foi manipulada nos protocolos de treinamento investigados (CLAFLIN *et al*., 2011; KEELER *et al*., 2011; NEILS *et al*., 2005; RANA *et al*.; 2008; TANIMOTO *et al*., 2008; SCHUENKE *et al*., 2012; YOUNG *et al*., 1993) ou apenas um dos protocolos foi realizado até a falha muscular (TANIMOTO; ISHII, 2006), assim os resultados encontrados podem ser atribuídos a manipulação conjunta da duração da repetição com essas outras duas variáveis. Tem sido sugerido que os ganhos de força muscular sejam principalmente influenciados pela intensidade do exercício (ex. % de 1RM) (MITCHELL *et al*.; 2012; SCHOENFELD *et al*.; 2015), além disso, sabe-se que as respostas de hipertrofia muscular promovidas por protocolos de treinamento podem ser influenciadas tanto pela intensidade (FRY, 2004) quanto duração da repetição (TANIMOTO; ISHII, 2006; TANIMOTO *et al*., 2008). Portanto, baseado na expectativa que a manipulação de diferentes variáveis poderia influenciar as respostas crônicas de protocolos de treinamento de força (ACSM, 2009;

WERNBOM; AUGUSTSSON; THOMEÉ, 2007), ainda permanece em aberto o efeito de protocolos equiparados pela intensidade, realizados até a falha muscular e com diferentes durações da repetição, nas respostas de hipertrofia e força muscular.

1.2.1 Objetivos

O objetivo principal do Estudo 2 foi comparar o efeito de dois protocolos de treinamento executados com diferentes durações da repetição (2-s e 6-s) e até a falha muscular nos ganhos relativos de força máxima e hipertrofia muscular (valores médios e individuais). Além disso, o objetivo secundário foi comparar as respostas de amplitude do sinal eletromiográfico e força por ângulo de flexão de joelho (EMG_{RMS}-ângulo e força-ângulo) durante a execução de ambos os protocolos de treinamento (2-s e 6-s) no início e no final do período de 14 semanas de treinamento.

2 ESTUDO 1

2.1 Informações do artigo 1

Título: Is performing repetitions to failure less important than volume for muscle hypertrophy and strength?

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Resumo: The aim of this study was to investigate the effects of muscle failure (MF) or not to MF (NMF) training on strength and muscle hypertrophy relative gains (average and individual data). Ten men untrained in resistance training participated in the study. Each leg was allocated in 1 of 2 unilateral training protocols (MF or NMF with equal volume) on knee extension exercise. Both protocols were performed with 3-4 sets, 3 minutes' rest, and 50-60% of one repetition maximum (1RM). Rectus femoris and vastus lateralis muscles cross-sectional area (CSA), maximal muscle strength (1RM and maximal voluntary isometric contraction), and muscular endurance (maximum number of repetition) were assessed before and after 14 weeks. In addition, neuromuscular activation by normalized root mean square of the electromyographic signal (EMG_{RMS}) was measured in 2nd and 35th training sessions. The average results showed that both training protocols were similarly effective in inducing increases in strength and muscle hypertrophy gains. However, individual analysis data suggest that NMF protocol with equal volume may promote similar or even greater muscle hypertrophy (vastus lateralis) and muscular endurance performance when compared with MF protocol. Also, normalized EMG_{RMS} responses analyzed during 2nd and 35th sessions were similar in MF and NMF protocols for rectus femoris and vastus lateralis muscles. In conclusion, MF and NMF protocol conducted with the same total repetition numbers produced similar maximal muscle strength performance and neuromuscular activation. Nevertheless, NMF training could be a more appropriate strategy to increase muscle hypertrophy (vastus lateralis) and muscular endurance performance in untrained individuals when compared with MF.

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2.2 Artigo 1

Introduction

Resistance training performed to muscle failure (MF training) has been used as a strategy to maximize strength performance and muscle hypertrophy (36), which could be partially explained by the high level of effort required when performing repetitions to MF in all sets (36). In this sense, it has been reported that MF training heightens energy demands resulting in a greater metabolite accumulation (15). Although the mechanisms by which metabolic stress influences muscle hypertrophy have yet to be fully clarified, a integration of multiple local and systemic factors likely contribute to muscle development (e.g., increased fiber recruitment, elevated hormonal release, altered myokine production, cellular swelling and production of reactive oxygen species) (49). However, it is possible that a threshold exists for metabolic stress beyond which no further beneficial effects are observed (41). In addition, it has been previously suggested that MF training would induce a greater fatigue of the active motor units requiring additional higher threshold motor units to be recruited for the maintenance of force production to complete a given task (36,43). However, Nóbrega et al. (33) verified similar neuromuscular activation between protocols performed to MF and volitional interruption (repetitions performed to the point when participants voluntarily stop the exercise) with same intensity did not indicate the occurrence of an greater recruitment of motor units during MF training. Furthermore, given that MF and volitional interruption are two different criteria characterizing protocols performed with maximum repetition numbers, data from that study does not allow a better understanding about the effect of MF and not to muscle failure (NMF) protocols. Thus, despite limitations in the interpretation of data provided by surface electromyography (EMG) (45), understanding if MF and NMF protocols would have differing effects on neuromuscular activation could provide additional insight how they impact muscle strength and hypertrophy adaptations.

Review studies suggest that MF training could induce greater gains in strength and muscle hypertrophy when compared to NMF training (12). On the other hand, data from a recent meta-analysis published by Davies et al. (9) investigating MF vs. NMF training effects on maximal strength response, demonstrated that both training strategies provided similar muscle strength gains. Among the previous studies that showed contradictory results (MF vs. NMF), some reported superiority for MF (14,36), others reported support for NMF training (20) and some reported similar outcomes (21,28,33,35,42). These differences in observed results between studies could be partially due to interindividual differences in responsiveness to different training protocols (8). In fact, large variabilities of inter-individual responses have been reported for muscular strength and hypertrophy even when subjects perform standardized training protocols, hence studies with intra-individual experimental designs have been performed to minimize this problem (33). However, to the best of our knowledge, no study with an intra-individual design has evaluated the chronic effects of both training strategies (MF and NMF) utilizing individual analyses.

It should be emphasized that many studies that have investigated MF and NMF training effects did not equate the variables that configure the training protocols investigated, such as intensity (14) and volume (14,20,33). However, although it is known that both variables may have an influence on the chronic adaptations induced by resistance training (10,26), volume has not often been equalized between different protocols (14,20,33). Thus, considering previous studies that have not equated different training protocols makes it difficult to interpret their strength and muscle hypertrophy responses and makes it impossible to conclude that the results found in these studies were due only to performing repetitions to MF.

Given the importance of being able to equate training protocols when comparing chronic adaptations, some studies have tried to match the volume performed between MF and NMF protocols in order to account for this potential confounding factor (21,28,35,36,42). Recently, Martorelli et al. (28) observed that MF and NMF training, equated by load volumes (sets x repetitions x load) increased maximum strength, measured by one repetition maximum (1RM), and muscular endurance in young active women after five and 10 weeks of training. Additionally, Martorelli et al. (28) also demonstrated that the two groups with equal load volumes increased the elbow flexors muscle thickness throughout the training period, while a third group (lower volume load than the others) did not show an increase in muscle thickness. Although there were no statistically significant differences between groups utilizing the same load volumes, the relative changes substantially favored MF when compared to MNF training (17.5% versus 8.5%, respectively) (28). Nevertheless, the large interindividual variability (CV~ 20%) may impair the possibility to detect differences between protocols. In the study of Da Silva et al. (42), performed with a resembling experimental design to the study mentioned above, both MF and NMF training (equated by load volume) provided similar increases in quadriceps muscle thickness and 1RM test performance for elderly men. In addition, no significant muscle hypertrophy was observed in a third group that did not train to MF and performed less volume than the other two training groups (42). These results suggests that load volumes may be a determinant variable when investigating the effect of MF training (41). Still regarding the study of Da Silva et al. (42), despite the similar load volumes, the average repetition numbers performed were different between MF and NMF protocols in at least 10 of the 12 training weeks. The relative differences in the average repetition numbers ranged from 4.5 to 20%, which was higher for the MF protocol in most training weeks, therefore, it is not possible to assume that the volume was equated for both training groups. However, despite the unequal volumes, it is important to emphasize the similar impact of MF and NMF protocols observed in the adaptations of muscle strength and hypertrophy. Also, another aspect that may have influenced the results found by Da Silva et al. (42) concerns the fact that in addition to resistance training, all groups performed the same endurance training program which may have caused a bias in the training groups responses given that the combination may induce an interference effect (mainly in strength gains) compared to resistance training only (7). This interference effect may be even more pronounced when both training programs are performed in the same training session as in the aforementioned study (31). Thus, based on the contradictory outcomes and the methodological limitations found in the studies that investigated this issue, the chronic adaptations provided by MF and NMF training still need better clarification.

Therefore, the aim of this study was to investigate the effects of performing MF or NMF training on strength and muscle hypertrophy relative gains (average and individual data). A secondary aim was to verify the effects of these training strategies on EMG amplitude responses. It was hypothesized that increases in muscle strength and hypertrophy, as well as in neuromuscular activation (before and after training period) would be similar between the two equalized protocols.

Methods

Experimental Approach to the Problem

In the present study, an intra-individual experimental design was used. Volunteers performed two different seated unilateral knee extension training protocols (MF or NMF) for 14 weeks, with each lower limb performing one of the protocols. Pre- and post-test measures included: maximal voluntary isometric contraction (MVIC), one repetition maximum (1RM) and maximum number of repetition (MNR) tests. It was used a design in which each participant's lower limb was allocated in a randomized and balanced way, according to lower limb dominance, to one of the two training protocols. In order to balance the use of the lower limb between protocols, half of volunteers performed the MF protocol with their preferred limb while the other volunteers performed the NMF protocol with their preferred limb. This procedure aimed to minimize the influence of possible strength discrepancies between limbs and the impact on the neuromuscular responses induced by the two training protocols. To determine lower limb dominance the voluntaries were asked: - If you would shoot a ball on a target, which leg would you use to shoot the ball? - .

In session 1, volunteers were familiarized with all the procedures, limb dominance was determined, and training protocols were assigned to each limb. In the next session, ultrasound images were recorded to determine rectus femoris and vastus lateralis muscles cross sectional areas (CSA). Sessions 3 and 4 were separated by at least 48h and the MVIC, 1RM and MNR tests were performed. In sessions 5 to 39 (14 weeks of training period), volunteers performed five training sessions per week, with each session separated by a minimum period of 24 h. Two or three weekly training sessions were performed with each limb, alternating the limb to be trained throughout the sessions. Thus, a minimum interval of 48 h was given between sessions for the same limb. In sessions 6 and 39, the rectus femoris and vastus lateralis neuromuscular activation were assessed through surface EMG on each lower limb while participants performed their respective training protocols. After 72-120h following the last training session (session 40), the same ultrasound procedures were performed as in session 2. Finally, in session 41, the MVIC, 1RM and MNR post-tests were executed for both lower limbs.

Subjects

The sample size calculation was performed by using the software G.Power for Windows version 3.1.9.2 (Düsseldorf, Germany) and by following the guidelines proposed by Beck (2), with a priori statistical power (1 - ß) of 0,8 and 5% significance level. Ten males aged between 18 and 30 years (mean ± SD: age = 23.7 ± 4.9 years; height = 1.77 ± 0.09 m; body mass = 80.1 ± 20.1 kg; body fat percentage = 20.5 ± 8.5%) participated in this study. The inclusion criteria for participation were: (1) no resistance training (RT) during the last six months; (2) no functional limitations that would influence the 1RM test or the training protocols; and (3) no use of pharmacological substances or ergogenics supplements, and no other modes of resistance exercise during the study period. Subjects were informed about the study aims, procedures, and risks and signed an informed consent form. The local ethics committee of the university approved this study which complied with international standards. Additionally, each subject was instructed not to do any physical activity immediately before the testing sessions and to maintain the same dietary practices before each session.

Procedures

Experimental Session 1(anthropometric measurements). After receiving information about the study and giving written consent, the volunteers answered the Physical Activity Readiness Questionnaire (PAR-Q) and were submitted to an anamnesis in order to verify possible limitations related to participating in the study. In addition, height, body mass and fat percentage (skinfold thickness) measurements also were performed. Immediately afterwards, the volunteers were positioned on the seated knee extension machine (Master; Minas Gerais, Brazil) in order to maintain the hip at an angle of 110º (angle between the backrest and the equipment seat). The lateral epicondyle of the femur was aligned with the rotational axis of the device and the distal support of the device placed approximately 3 cm above the medial malleolus. These positions were registered to future replication during the subsequent tests and training sessions. All tests sessions were performed at the same time of the day for each volunteer.

Experimental Sessions 2 and 40 (ultrasound measurements). During these sessions, ultrasound images were recorded in order to analyze the CSA of rectus femoris and vastus lateralis muscles. The acquisition procedure for the CSA images were performed as described by Noorkoiv at al. (34). Initially, volunteers remained lying in dorsal decubitus position on a stretcher for 15 minutes. During this period, the anterior regions of both thighs were marked to identify the points where the images were later acquired by the ultrasound equipment. In sequence, the major trochanters and lateral epicondyles of the femurs were identified and femur length was measured (Figure 1A). From the proximal extremity, 40, 50, 60 and 70% of femur length were identified and marked on volunteer's thigh by using a tape measure and a pachymeter positioned parallel to the thigh. Then a line with a microporous adhesive tape was positioned 2cm from each percentage point on the thigh (Figure 1B) to delimitate the location where the probe guide of the ultrasound would be placed during image acquisition (Figure 1C). Finally, the distances between the intercondylar line and each percentage point on the thighs were recorded for post-test replication. The procedures used to acquire images in the pre-test were the same for the post-test session (40th session) which was completed after 72 h following the last training session.

- PLEASE INSERT FIGURE 1 HERE -

An ultrasound (MindRay DC-7, Shenzhen, China) was used in extended-field-of-view mode, with a 4 cm linear transducer. The equipment was configured with 10 MHz frequency, acquisition rate of 21 frames/s, depth of image capture ranging from 7.7 and 9.7 cm, gain between 50 and 64 dB. The settings were adjusted for each volunteer in order to produce the clearest images of the analyzed muscles. The same trained evaluator (~ 120h of training and 600 images acquired before of the study) performed the acquisition of two images at each percentage of femur length (40, 50, 60 and 70%). The probe was placed transversely in parallel to intercondylar line using a coupled guide on the volunteer's thigh (Figure 1C). This procedure was performed with constant speed (controlled by metronome) and lasted between 12 and 15 s, varying according to the volunteer's thigh circumference. Sixteen images per volunteer were obtained for rectus femoris and vastus lateralis muscles CSA analysis (8 pre-test + 8 post-test). Afterwards, CSA of each muscle scan were manually demarcated by a blinded examiner using specific software (OsiriX MD 6.0, Bernex, Switzerland) (Figure 2). For data analysis, the rectus femoris and vastus lateralis muscle CSA mean values were calculated using two images acquired at each percentage of femur length. Finally, based on the lengths of 40, 50, 60 and 70% of the femur, the sum of four CSAs of each analyzed muscle were calculated, generating a single CSA value per muscle. This was used in the statistical analysis. For ICC calculations, the two CSA measures of the rectus femoris and vastus lateralis in each lower limb for pre and post-test sessions were considered. The intra-rater reliability values found in these sessions were up to 0.99 for both analyzed muscles.

- PLEASE INSERT FIGURE 2 HERE -

Although it is commonly used in literature, CSA measured at a single point on a muscles length may not adequately represent the entire muscle hypertrophic response (1). Thus, the CSA analysis using several points along the muscle length should provide a more accurate depiction of the hypertrophic muscle response (1).

Experimental Sessions 3, 4 and 41 (strength tests). Strength tests were executed during the third session in order to familiarize the subjects with procedures that would be performed during the following session. After positioning the volunteer in the equipment, a familiarization MVIC test was performed which consisted of two attempts of 5 s in duration at knee flexion angle of 60° (knee extended = 0º), the knee-joint angle that has been reported as the position where maximum isometric force occurs for the seated knee extension exercise. MVIC tests were performed with both lower limbs with 2-minute rest periods between each attempt. Testing order was randomized between limbs and that order was maintained during the post-test session. The highest peak force value registered for each attempt was used in later analyses. During the MVIC test, a verbal signal was given and the volunteer applied maximum force against the fixed lever of the knee extensor machine. Visual feedback of the force trace was provided as well as verbal stimuli from the evaluators to achieve maximum strength.

The 1RM test familiarization was performed 10 minutes after the completion of the MVIC test. Initially, according to procedures described in Lacerda et al. (24,25), subjects performed 10 repetitions without any weight on the equipment. The 1RM was determined in concentric mode within a maximum of 6 attempts, with 5-minutes rest periods between each attempt (25). In addition, a 5-minute rest period was given between the tests executed with each of the lower limbs.

After the 1RM test, volunteers rested for 10-minutes and then performed the MNR test. This test consisted of a single set to MF at 70% 1RM, and the subjects completed each repetition in 4s (2s concentric and 2s eccentric). Considering that the repetition duration influences the maximum number of repetitions performed (37), this procedure attempted to standardize this variable for both pre and post-training MNR outcomes. The subjects were verbally encouraged by the researchers to perform the maximum number of repetitions and this value represented muscular endurance. The ROM in 1RM, MNR tests and training protocols was maintained at 70º, with 30º and 100º of knee-joint angles corresponding maximum and minimum angular positions, respectively.

In session 4, the MVIC, 1RM and MNR tests executed in the familiarization session were repeated. These tests were also repeated in the 41st experimental session after a maximum interval of 48h following session 40 (ultrasound measurements). The data measured in sessions 4 and 41 were used for statistical analysis. Based on familiarization and pre-test sessions data, the ICC intersession values observed were 0.97 (MICV), 0.98 (1RM) and 0.68 (MNR), respectively.

Experimental Sessions 5 to 39 (training period). After the initial testing period, the 14-week training began (35 training sessions). It is worth noting that all participants completed 100% of the training sessions. The overall experimental protocol consisted of 3-4 sets (each repetition 3 s concentric and 3 s eccentric) at 50-60% 1RM with 3-minute rest periods between sets and the protocols complied with recommendations for resistance training and muscle hypertrophy. Additionally, training protocols with similar concentric and eccentric durations were investigated previously in of our laboratory (24,25).

All protocols started the training period by performing 3 sets at 50% of 1RM. At week 3 (6th training session), the intensity was increased to 60% of 1RM. In addition, one set was added at week 9 (20th training session), so the volunteers started the study by performing three sets and ending with four sets. In the present study, the training load configuration and progression were controlled, considering that the manipulation of other variables in addition to MF could lead to a bias in the responses induced by both training protocols.

Every two weeks, also beginning in the third week (6th training session), 1RM tests were re-assessed before the first weekly training session with each of the lower limbs. These procedures aimed to maintain the relative intensity (50-60% 1RM) within the proposed training protocol settings throughout 14 weeks of training. A 10-minute rest period separated the 1RM test and the start of the training session. During these sessions, the 1RM test occurred at the same time of day as the pre-test in order to standardize the circadian rhythm that can influence strength performance.

An initial pilot study was conducted to test the feasibility of the MF and NMF protocols with volume equated. In MF training, all sets were performed until the subjects were unable to execute the concentric action of the pre-established ROM (70°). In order to equate the volume between the MF and NMF training protocols, the total number of repetitions performed in MF training from the previous training session was divided by the number of sets to be completed (3 or 4 sets), resulting in a mean number of repetitions per set. This procedure allowed a homogeneous distribution of the total repetition numbers throughout the sets in NMF protocol. When the total number of repetitions performed during the MF protocol was not a multiple of the number of sets, one repetition was added in the first and/or second set in order to maintain the same number of repetitions in the NMF protocol.

To ensure that the subjects always performed the MF protocol with the maximal number of repetitions, an estimated-repetitions-to-failure scale with 11 points ('0' to '10 or greater') was used to estimate the number of repetitions that volunteers would still be able to perform at the end of each set. According to Hackett et al. (16), an estimated-repetitions-to-failure score of ‘10 or greater’ indicates that the participant can complete 10 or more repetitions, while a score of ‘0’ indicated that the participant can complete no additional repetitions. In addition, a repetition was removed in the last set of the NMF protocol when the volunteers reported at the end of the penultimate set that they could not perform any further repetition (score ‘0’). This procedure was used to minimize the possibility of volunteers reaching MF in the last set, and proved to be effective, since MF occurred in only 0.8% of the set performed in NMF protocol.

The Borg 15-Category Scale for rating of perceived exertion (RPE) was also used to measure the volunteers’ subjective perception of effort at the end of each set for both training protocols. The procedure for the establishment of the low (‘7’ score) and high (‘19’ score) anchors for each individual's perceived exertion was read to volunteers during performing one repetition in unilateral knee extension exercise without adding weight to the equipment and in NMR test, respectively. In this manner, volunteers established a perceptual relationship for the 7 to 19 range on the Borg 15-Category Scale based on the sensations that they perceived after performing one repetition with the free weight and immediately after NMR test. According to Gearhart et al. (13), standard instructions for the use of the RPE scale were read before the start of each training session and the volunteers estimated their effort sensation after each set. The participants were asked to assign a RPE score for the local effort from the active muscles. These subjective perceptions were recorded immediately after the end of each set and the mean RPE value was calculated and used in the statistical analysis as mean perceived exertion of the training session.

Experimental Sessions 6 and 39 (2nd and 35th training sessions) (electromyography measurements). The surface electromyography procedure (Biovision, Wehrheim, Germany) followed the recommendations of Hermens et al. (18). Bipolar surface electrodes (Ag/AgCl - 3M-2223, Brazil) were placed parallel to the muscle fibers on the rectus femoris and vastus lateralis muscles. The skin areas were shaved and cleaned with alcohol and a cotton pad before placing the electrodes in pairs, 2 cm apart from their centers at the point of the greatest muscle area. The ground electrode was fixed to the patella. After the electrodes were attached, a silk paper was used to register their positions, as well as the patella and relevant marks on the skin. In addition, the volunteer’s two lower limbs were photographed with the electrodes positioned. These procedures performed in 2nd training session aimed at mapping the electrode positions on the thigh, allowing reproducibility in the 35th training session.

To measure the ROM and the muscle action durations during both protocols, the angular displacement was recorded using a potentiometer coupled to the rotational axis of the mechanical arm of the knee extension equipment for all training sessions. The potentiometer raw data were converted into angular displacement data and filtered through a 4th-order Butterworth low-pass filter with a cutoff frequency of 10 Hz. The duration of each muscle action was comprised of the time spent between the maximum (100° of knee flexion) and minimum (30° of knee flexion) angular positions, thus the concentric duration corresponded to the period between the maximum and minimum angular positions while the eccentric duration corresponded to the minimum and maximum angular positions. Additionally, concentric/eccentric and repetition durations were determined throughout the angular displacement time. The data provided by the potentiometer also allowed the volunteers to have online access to the duration and ROM data of each muscle action on a laptop screen during all training sessions and tests (24,25). In addition, a metronome was used to help volunteers maintain pre-established repetition durations.

The electromyographic and potentiometer signals were synchronized and converted using an A/D board (Biovision, Wehrheim, Germany) and sampled at a frequency of 4,000 Hz. Appropriate software (DasyLab 11.0; Measurement Computing Corporation, Massachusetts, USA) was used to record and treat the data. The electromyographic data acquisition was amplified 500 times and filtered (4nd-order Butterworth band-pass filter of 20–500 Hz) to calculate the EMG amplitude as the root mean square (EMG_{RMS}). Before commencing each training session (2nd or 35th), subjects were asked to perform a MVIC test for 5 s on the knee extension machine exercise at 60° knee flexion (controlled by the potentiometer). The EMG_{RMS} value found during the MVIC test was then used as a reference for the normalization of the subsequent protocol measurements (normalization test). The mean EMG_{RMS} of concentric muscle actions for each protocol was then calculated. These values were divided by the respective reference values previously described, generating the normalized EMG_{RMS} per protocol. The mean for each of the two protocols of EMG_{RMS} was used in the statistical analysis as the mean neuromuscular activation for each training session. For EMG_{RMS} acquisition during training sessions 2 and 35, participants performed 3 sets with 50% of the most recent 1RM value for each protocol.

The $ICC_{[3,\ 1]}$ interprotocol was calculated using the EMG_{RMS} values obtained during the normalization test from experimental sessions 6 and 39. This procedure aimed to evaluate the reliability of EMG_{RMS} measurements in different lower limbs of the same individual, hence the feasibility of comparing the EMG_{RMS} responses of the two training protocols in this study. The EMG_{RMS} inter-protocol values for both sessions were 0.84 for the rectus femoris and 0.80 for the vastus lateralis.

Statistical Analysis

Statistical analysis was performed with SPSS for Windows version 20.0 (SPSS, Inc., Illinois, USA). Initially, paired sample t-tests were implemented to test for differences in absolute baseline values for all variables analyzed and no differences were identified between protocols. In addition, both protocols demonstrated increases in CSA, 1RM, MVIC and MNR, hence, analysis of relative data were used instead. Therefore, considering the purpose of the study to verify the change caused by training protocols performed until MF or MFN, initially, the CSA, MVIC, 1RM and MNR tests performance data were transformed into relative responses ((Pos-test - Pre-test) / Pre-test * 100). Data are presented as mean ± *SD*, as well as 95% confidence interval [CI] and individual values. The normality and homogeneity of variances were verified using Shapiro-Wilk and Levene’s tests, respectively. Cohen`s d values were calculated using the equation $d = (M_{MF} - M_{NMF}) / ((SD_{MF} + SD_{NMF}) / 2)$, in which M_{MF} is the mean of the MF protocol, M_{NMF} is the mean of the NMF protocol, and SD is the standard deviation in each protocol. These values are reported to reflect the magnitude of the differences in each treatment where ≤ 0.20 was considered “trivial”; 0.21-0.49 “small”; 0.50-0.79 “moderate” and ≥ 0.80 “large”. The intra-rater reliability was verified by the intraclass correlation coefficient ($ICC_{[3, 1]}$).

To compare the CSA relative responses between both training protocols was performed a paired sample t-test for each muscle were performed. In addition, the maximum isometric strength (MVIC), dynamic strength (1RM), and strength endurance (MNR) relative responses also were compared using paired sample t-tests.

To analyze the EMG_{RMS} normalized data for the rectus femoris and vastus lateralis muscles, the mean from the three sets obtained during the 6th and 39th sessions (2nd and 35th training sessions) were used for both protocols. A two-way (protocol x session) ANOVA with repeated measures assessed the normalized EMG_{RMS} for each muscle. When necessary, a post hoc Bonferroni honest significant difference test was used to identify the differences reported in the ANOVA’s. One individual was removed from the EMG_{RMS} analysis due to technical problems in data collection (n = 9).

The individual analyses for CSA, 1RM, MVIC, MNR and EMG_{RMS} tests were calculated according to Damas at al. (8). Therefore, if an individual had a difference from the relative response from MF and NMF training within 2 typical errors (2TE), no difference in the response between protocols was considered. The typical error (TE) was calculated using the equation TE = SDdiff / √2, in which SDdiff is the standard deviation of the difference scores observed between the two measurement performed.

In view of the control variables adopted in this study, paired sample t-tests were used to compare the repetition durations (training sessions and MNR tests) and range of motion between training protocols. Finally, considering that the total number of repetitions, the estimated-repetitions-to-failure and the RPE data (for session) do not meet the precepts for a parametric analysis, Mann-Whitney-Wilcoxon tests were used to compare the responses of these variables for both protocols. These data are presented as median and interquartile range values. Probability was set at $p \leq 0.05$ for statistical significance for all tests.

Results

CSA

The relative response for the rectus femoris muscle CSA showed no significant difference between MF (15.89 ± 11.71%, CI = [8.63 – 23.15]) and NFM protocols (20.11 ± 10.32%, CI = [14.49 – 27.29]) ($t_9 = -1.10$, $p = 0.30$, $d = -0.38$) (Figure 3A). Also, no significant difference was observed between protocols for the vastus lateralis muscle CSA (MF: 15.06 ± 14.20%, CI = [6.26 – 23.86]; NFM: 21.30 ± 16.90%, CI = [10.82 – 31.77]) ($t_9 = -1.90$, $p = 0.08$, $d = -0.40$) (Figure 3B). Typical error values for rectus femoris and vastus lateralis muscles CSA were 1.96% and 2.94%, respectively. Two pre-test CSA measurements in each lower limb were used to calculate the TE. Individual analyses of the rectus femoris muscle CSA verified that 4 individuals (40% of the sample) responded more for NMF, 3 individuals (30% of the sample) responded more for MF, and the remaining 3 individuals (30% of the sample) showed no difference in the hypertrophic responses between training protocols (the difference was within

2TE = 3.92%) (Figure 3A). Regarding the vastus lateralis muscle CSA, it was observed that 4 individuals (40% of the sample) responded more for NMF, the other 6 individuals (60% of the sample) showed no difference in the hypertrophic responses between training protocols (2TE = 5.87%) (Figure 3B).

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1RM, MVIC and MNR

Concerning the strength performance tests, paired sample t-tests indicated no significant differences between MF and NMF protocols for the 1 RM (MF: 12.68 ± 12.53%, CI = [4.91 – 20.44]; NMF: 15.02 ± 12.87%, CI = [7.04 – 22.99]) (t_9 = - 0.61, p = 0.55, d = - 0.18) (Figure 4A), MVIC (MF: 13.85 ± 8.30%, CI = [8.70 – 18.99]; NMF: 14.96 ± 9.03%, CI = [9.36 – 20.56]) (t_9 = - 0.40, p = 0.70, d = - 0.13) (Figure 4B), and MNR performance (MF: 14.27 ± 21.11%, CI = [1.19 – 27.35]; NMF: 31.44 ± 34.53%, CI = [10.04 – 52.84]) (t_9 = - 1.58, p = 0.15, d = - 0.60) (Figure 4C).

The TE values were 3.18% (1RM), 3.69% (MVIC), and 16.10% (MNR) and were obtained from measures during the third (familiarization) and fourth (pre-test) sessions. A minimal interval of 48h was observed among sessions for each strength tests procedures. The individual analyses for the 1 RM tests showed that 2 individuals (20% of the sample) responded more for NMF, 1 individual (10% of the sample) responded more for MF, and the remaining 7 individuals (70% of the sample) showed no difference in maximal dynamic strength performance between training protocols (2TE = 6.36%) (Figure 4A). Similarly, for the MVIC relative response, it was observed that 2 individuals (20% of the sample) responded more for NMF, 1 individual (10% of the sample) responded more for MF, and the other 7 individuals (70% of the sample) showed no difference in maximal isometric strength performance between training protocols (2TE = 7.39%) (Figure 4B). Finally, regarding the MNR test performance, 5 individuals (50% of the sample) responded more for NMF, 1 individual (10% of the sample) responded more for MF, and the other 4 individuals (40% of the sample) showed no difference in muscular endurance performance between training protocols (2TE = 32.10%) (Figure 4C).

- PLEASE INSERT FIGURE 4 HERE -

$\mathbf{EMG_{RMS}}$ normalized

There were no statistically significant differences in the neuromuscular activation between the MF and NMF training protocols during the 2nd (rectus femoris - MF: 72.39 ± 16.72%, CI = [62.03 – 82.75]; NMF: 68.42 ± 23.75%, CI = [53.70 – 83.14]) (vastus lateralis – MF: 66.26 ± 12.05%, CI = [58.79 – 73.73]; NMF: 63.07 ± 19.40%, CI = [51.05 – 75.10]) and the 35th training sessions (rectus femoris - MF: 64.33 ± 14.43%, CI = [55.39 – 73.27]; NMF: 58.49 ± 19.65%, CI = [46.31 – 70.67]) (vastus lateralis - MF: 70.09 ± 19.20%, CI = [58.19 – 81.99]; NMF: 62.22 ± 11.83%, CI = [54.89 – 69.55]) (Figure 5 AB). More specifically, no significant interaction (time x protocol) was observed for the normalized EMG_{RMS} data for the rectus femoris ($F_{1,8} = 0.12$; $p = 0.74$) and vastus lateralis muscles ($F_{1,8} = 0.29$, $p = 0.60$). There were also no significant main effects for time ($F_{1,8} = 1.76$; $p = 0.22$; $d = 0.48$) ($F_{1,8} = 0.08$, $p = 0.78$, $d = -0.10$) and for protocol ($F_{1,8} = 0.65$, $p = 0.44$, $d = -0.26$) ($F_{1,8} = 1.56$, $p = 0.25$, $d = 0.35$) for the rectus femoris and vastus lateralis muscles, respectively.

In addition, the TE values for EMG_{RMS} were 15.60% (rectus femoris) and 20.10% (vastus lateralis). The EMG_{RMS} values for the MVIC tests performed during the fourth (pre-test) and 2nd training session were used for the TE calculation. Similar to strength measures, a minimal interval of 48h was observed among sessions for each EMG tests procedures. Regarding EMG_{RMS} of the rectus femoris during the 2nd training session, individual analyses verified that 2 individuals (22% of the sample) responded more for MF, while the other 7 individuals (78% of the sample) showed no difference in the EMG responses between training protocols (2TE = 31.20%) (Figure 5 A). In the 35th training session, all 9 individuals (100% of the sample) showed no difference in the EMG_{RMS} for the rectus femoris between training protocols (Figure 5 B). Similarly, for EMG_{RMS} for the vastus lateralis during the 2nd and 35th training sessions, all 9 individuals (100% of the sample) showed no difference in the EMG_{RMS} for the rectus femoris between training protocols (2TE = 40.20%) (Figure 5 C and D).

- PLEASE INSERT FIGURE 5 HERE -

Repetition duration, ROM, total number of repetitions and RPE

Concerning the control variables analyzed in this study, the MF and NMF protocols had similar repetition durations during the training sessions (MF: 5.99 ± 0.27 s; NMF: 6.00 ± 0.31 s) (t = 0.50, p = 0.88, d = - 0.03) and MNR tests (MF: 4.00 ± 0.28 s; NMF: 3.99 ± 0.26 s) (t = 0.12, p = 0.90, d = 0.04). In addition, no significant differences were found for the average ROM between the MF and NMF protocols (MF: 71.14 ± 1.40°; NMF: 71.09 ± 1.27°) (t = 0.88, p = 0.37, d = 0.03). Regarding the total number of repetitions for each training protocol, Mann-Whitney-Wilcoxon test indicated differences between the MF (Total repetitions = 739 [826-668]; 1st set = 8 [9-7], 2nd set = 6 [7-5], last set (3rd or 4th) = 5 [6-4]) and NMF protocols (Total repetitions = 734 [816-656]; 1st set = 6 [7-6], 2nd set = 6 [7-6], last set (3rd or 4th) = 6 [6-5]) (U = - 2.67; p = 0.01; d = 0.08), however, the magnitude of the difference between median values was less than 0.7% and deemed as trivial based on ES. For estimated-repetitions-to-failure, significant differences were verified between the MF (Session = 0 [0-0]; 1st set = 0 [0-0], 2nd set = 0 [0-0], last set (3rd or 4th) = 0 [0-0]) and NMF protocols (Session = 1 [2-0]; 1st set = 2 [2-1], 2nd set = 1 [2-0], last set (3rd or 4th) = 0 [1-0]) (U = - 27.70; p = 0.0001; d = 1.36). Finally, we observed significantly higher RPE values for the MF protocol (Session = 19 [19-19]; 1st set = 19 [19-19], 2nd set = 19 [19-19], last set (3rd or 4th) = 19 [19-19]) compared to the NMF protocol (Session = 17 [18-15]; 1st set = 15 [17-15], 2nd set = 17 [18-16], last set (3rd or 4th) = 18 [19-17]) (U = - 24.30; p = 0.0001; d = 1.20).

Discussion

The purpose of this study was to compare the strength and muscle hypertrophy responses induced by MF or NMF training, as well as the level of activation of the rectus femoris and vastus lateralis muscles. To the best of our knowledge, no other studies have compared lower limbs chronic adaptations between different training protocols performed to MF or to NMF with equal training volumes, and analyzing average and individual data. The main results showed that both training protocols were similarly effective at inducing increases in strength and muscle hypertrophy gains, confirming the study hypothesis. Also, the normalized neuromuscular activation, in both rectus femoris and vastus lateralis muscles, was similar in MF and NMF protocols analyzed during the 2nd and 35th sessions, hence, the protocols promoted a similar neuromuscular demand. Overall, for untrained individuals, it is possible suggest that an increased volume may be a more important variable than performing repetitions to MF for the chronic adaptations associated with resistance training. However, it is important that NMF training be performed with a relatively high degree of effort. Still on the effect of volume on chronic adaptations, Da Silva et al. (42) also showed similar strength and muscle hypertrophy gains for MF and NMF training when volumes were equalized. Additionally, these protocols were superior to a lower volume training program based on muscle hypertrophic response but not for maximal strength performance. Thus, training volume probably has a greater impact on muscle hypertrophy gains than on strength performance gains (28,42).

The rectus femoris muscles of each trained leg had a similar average hypertrophy response for both MF and NMF protocols after 35 training sessions, with a small effect size (d = - 0.38). In agreement with the average hypertrophic responses, the individual analyses demonstrated that a significant proportion of participants showed no difference between protocols (30% of the participants for rectus femoris). Nevertheless, some individuals greatly increased the rectus femoris muscle CSA in response to MF (40% of the participants) while others responded better to the NMF training (30% of the participants). A similar average hypertrophy response (p = 0.08) was also verified for the vastus lateralis muscle, also with a small effect size (d = - 0.40). In addition, 60% of the participants showed no difference between MF and NMF protocols for this muscle. Conversely, 40% of the participants had a greater hypertrophic response to the NMF protocol, and no one responded more to the MF protocol. Therefore, the vastus lateralis hypertrophy individual responses suggest that NMF training with equal volume may promote similar or even greater muscle hypertrophy when compared to MF training. Recent studies found similar hypertrophic responses for MF and NMF training, specifically when attempting to match volume between protocols (28,33,42). Thus, taken together, the results of the present study and previous investigations (28,33,42) indicate that the assumption that MF training maximizes muscle hypertrophy is not supported, as speculated in some previous reviews (12). In fact, it has been shown that protocols performed with repetitions to MF induce greater metabolic disturbance (decreased ATP/ ADP, ATP/AMP, and ATP/IMP ratios and lower pH's) compared to submaximal repetitions (15). Regarding the association between hypertrophy and metabolic stress, it has been proposed that an accumulation of metabolites may increase the hormone concentrations related to muscle growth, which would make the environment more favorable for anabolism, thus enabling a subsequent accumulation of muscle proteins (32). It should be emphasized that changes in the AMP/ATP ratio may also activate AMPK kinase (AMPK) (17), which decreases activation of protein kinases in the mammalian target of rapamycin (mTOR) signal transduction pathway (5). Whereas mTOR is involved in the protein synthesis process, a reduced activity could be detrimental to muscle hypertrophy gains. The elevation of post-exercise hormone responses would also increase the likelihood of hormone-receptor binding, initiating a cascade of intracellular events that could favor muscle growth (23). It is also suggested that acute elevations in hormone concentrations after resistance exercise would have a greater association with muscle tissue growth and remodeling than any hormonal changes measured at rest during a training period (23). According to Schoenfeld (40), an elevated metabolic stress may induce peaks in insulin-like growth factor (IGF-1), growth hormone (GH) and testosterone, thereby providing an increase in post-exercise muscular proteins synthesis. However, metabolic and hormonal responses were not analyzed in this study, yet, the similar hypertrophic responses between MF and NFM protocols reinforces the reasoning that there is a threshold for metabolic stress beyond which no further beneficial effects are realized (41). Therefore, the high level of effort required to perform repetitions to MF in all sets was not able to promote a sufficient training stimulus to provide greater chronic adaptations compared to the NFM protocol (36).

The similar normalized EMG_{RMS} (average and individual responses) for the MF and NFM protocols in the current study did not confirm the premise that training to MF requires additional motor unit recruitment for the maintenance of force production to complete the task. For example, it was previously suggested that training to MF could result in increases in neuromuscular activation, in part due to additional recruitment of motor units for the maintenance of force production to complete the task (36,38). Reinforcing this expectation, Burd et al. (6) observed a higher protein synthesis response after the execution of a protocol to MF compared to NMF. According to the authors, the increased protein synthesis response they observed could be related to higher motor unit recruitment necessary to perform repetitions to MF. The present findings are similar to a recent study conducted with untrained individuals (33), and may be explained by the EMG amplitude reaching a plateau at some repetitions before MF (44). Conversely, for trained individuals, protocols performed to MF might result in increased neuromuscular activation, which could explain the greater increases in strength and muscle hypertrophy after this training strategy. Given that the EMG amplitude would not truly reflect the recruitment of motor units (45), other factors such as increased firing frequency and motor unit synchronization may also influence neuromuscular activation and should not be disregarded in the interpretation of these outcomes. It is noteworthy that in a study using the automatic decomposition of surface EMG into motor unit action potential trains, the authors reported that higher threshold motor units were recruited when the vastus lateralis muscle was in a fatigued state (43).

In agreement with the CSA responses, the average maximal dynamic strength performance (1RM test) was similar for MF and NMF protocols, and had a small effect size (0.18). The 1RM test individual analyses showed that 70% of the sample did not respond differently to the two protocols. As observed in this study, the absence of additional maximal dynamic strength increases due to performing repetitions to MF has been shown in meta-analysis completed by Davies et al. (9). Therefore, MF training is not necessary to maximize strength gains, confirming the hypothesis presented by previous studies reporting that training intensity, rather than volume, explains improvements in maximal strength adaptations (27). Given that a greater metabolic demand and neuromuscular fatigue was occurred in MF training, requiring a longer recovery period between training sessions (15), it could be argued that subsequent training sessions could have been affected so that training would result at a lower intensity or volume (9). Thus, the effectiveness of both MF and NMF training modes on maximal strength would be influenced by the ability to recover and allow for progressive overload which may induce different implications for practitioners based on their performance and training experience (9). Nevertheless, the impact of these assumptions still needs to be verified in future studies.

It has been reported that re-evaluation of 1RM tests every two weeks to adjust training intensities may cause a bias in the protocols effect on an individual's performance for this test (29). These repeated measurements could promote the acquisition of a similar motor pattern to perform 1RM test, making it possible that differences between training protocols would not be found (3). Therefore, MVIC tests become a valid alternative to investigate the effects of different training protocols on muscle strength responses. However, the relative increases in the MVIC test performance also were similar for the two training protocols investigated (effect size 0.13). The MVIC test individual analyses have shown that 70% of the sample did not respond differently to the two protocols and this finding is in agreement with previous studies (36,42).

Regarding muscular endurance, no differences were observed between MF and NMF protocols ($p = 0.15$). However, the medium effect size (- 0.60) suggests that it might be possible that the protocols analyzed have provided distinct effects on muscular endurance performance. Also, the individual analyses reveal that a significant proportion of participants showed no difference between MF and NMF protocols (40% of participants). Nevertheless, some individuals greatly increased muscular endurance performance in response to NMF (50% of participants) but only one had better responses to MF training (10% of participants). The individual analysis responses suggest that NMF training with equal volumes as MF training induces a similar or even greater muscular endurance gain when compared to MF training. Based on these data, it may be speculated that the subjects who responded better to the NMF training would be more sensitive to fatigue associated with biochemical changes when performing repetitions to MF (e.g., reduced capacity to regenerate ATP), which decrease force and power production during successive sets (15), but this argument needs to be better clarified. It is important to note that the effect of MF training on muscular endurance gains may be dependent on the muscle group trained, training status, and gender (28). Studies investigating the impact of MF and NMF protocols on lower limbs muscular endurance performance found divergent outcomes (21,35). Izquierdo et al. (21) observed similar gains for both training modes, but in a recent study by Prestes et al. (35) the MF protocol (rest-pause) was superior to the NMF protocol (traditional multiple-set) for muscular endurance in trained individuals. It has been suggested that performing repetitions to MF would be necessary to improve the capacity to tolerate muscle fatigue (21,28), consequently, it may induce greater increases in muscular endurance performance when compared to NMF protocol (21). In addition, it has been reported that RPE (obtained immediately after completion of the sets) has been used to investigate the physiological mechanisms of fatigue associated with resistance exercise (22). However, the higher RPE values during the MF protocol compared to the NMF protocol in this study, and others (11,39), do not corroborate the assumption that an elevated fatigue response would also provide greater muscular endurance performance. According to Santos et al. (39), a possible explanation would be that the higher repetition numbers performed in the initial sets during MF protocols could result in greater RPE values, but if an effort threshold exists to increase the motor unit recruitment and metabolic stress, then the impact of repetitions performed to MF may be dependent on the number of sets being executed. Thus, this impact would be greater in a single-set MF protocol, but during multiple sets, the accumulation of fatigue also may result in elevated efforts in the later sets for NMF protocols (11,39). Therefore, it is possible that both protocols analyzed in this study required similar efforts and muscle fatigue levels following the last set, inducing similar muscular endurance responses. However, based on the contradictory results found in the literature and inconclusive results found in the current study, it is not possible to confirm or refute the expectation of a superior muscular endurance response of MF training compared to NMF training.

A limitation of the intra-individual experimental design is a possible cross-training or cross education effect (4). There is evidence in the literature indicating that the cross-training effect, if it occurs, could be restricted to neural parameters and muscle strength gains but not morphological changes (e.g., CSA) (4). Additionally, the hormonal responses have also not been considered an important factor for the cross-training effect (30). Beyer et al. (4) found an increase in muscle mass only in the trained limb despite the exposure of both limbs to similar hormonal concentrations. One possible explanation for distinct hypertrophic responses between trained and untrained limbs would be that the morphological adaptations associated with resistance training in the content and affinity of anabolic hormones receptors (e.g., testosterone) occur only in the trained limb (23). On the other hand, muscle strength gains in the contralateral limb would reflect an increase in motor neuron activation, and probably are not related to morphological adaptations. However, previous studies investigating cross-training effects report increases or no changes in neuromuscular activation of the untrained limb (19). It has been reported that changes in neuromuscular activation of the untrained limb could be related to the training mode performed (e.g., type of muscle action) and similar to gains in muscle strength (19). In addition, it has been suggested that the cross-training effect contributes approximately 7.8% to muscle strength gains of the contralateral limb (30), and this adaptation would result from neural mechanisms involving acute facilitation at the motor cortex to the untrained contralateral limb following excitation of the trained limb (11). The training protocols in the current study were performed with a minimal interval of 24h in order to minimize the potential acute, deleterious effects of unilateral training on muscular strength performance on the contralateral limb. Finally, it has been argued that when both limbs of the same individual are trained by performing different protocols, the cross training effect is minimal or non-existent (30), therefore, it could be expected that any difference in strength responses between limbs would be due to the different training protocols (11).

Practical Applications

This study showed that a NMF protocol with equal volumes as a MF protocol produced similar strength and muscle hypertrophy gains. These results suggest that performing repetitions to MF was not a determining factor for the chronic adaptations associated with resistance training, hence NFM training (with equal volume to MF) could be an alternative training method for untrained individuals. In addition, based on the vastus lateralis muscle CSA and muscular endurance individual analyses, a higher number of individuals responded better to the NMF protocol. These results could be related to the need for a longer recovery period between sessions for individuals training to MF, thus, an insufficient recovery would induce a greater action of inhibitory mechanisms impairing the adaptations promoted by this training mode.

Strength and conditioning professionals could opt for periodically performing a MF protocol to determine the maximal number repetitions that could be completed by an individual, but then distribute the volume between sets in subsequent NMF training sessions. This training strategy could result in a similar or even better muscle hypertrophy and muscular endurance adaptations compared to performing repetitions to MF in all training sessions, but with lower perceptions of effort. However, these recommendations are limited to the exercise and sample with characteristics similar to those of the current study. Finally, future research is needed to determine the impact of MF protocols on the chronic adaptations associated with resistance training.

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Figures and legends

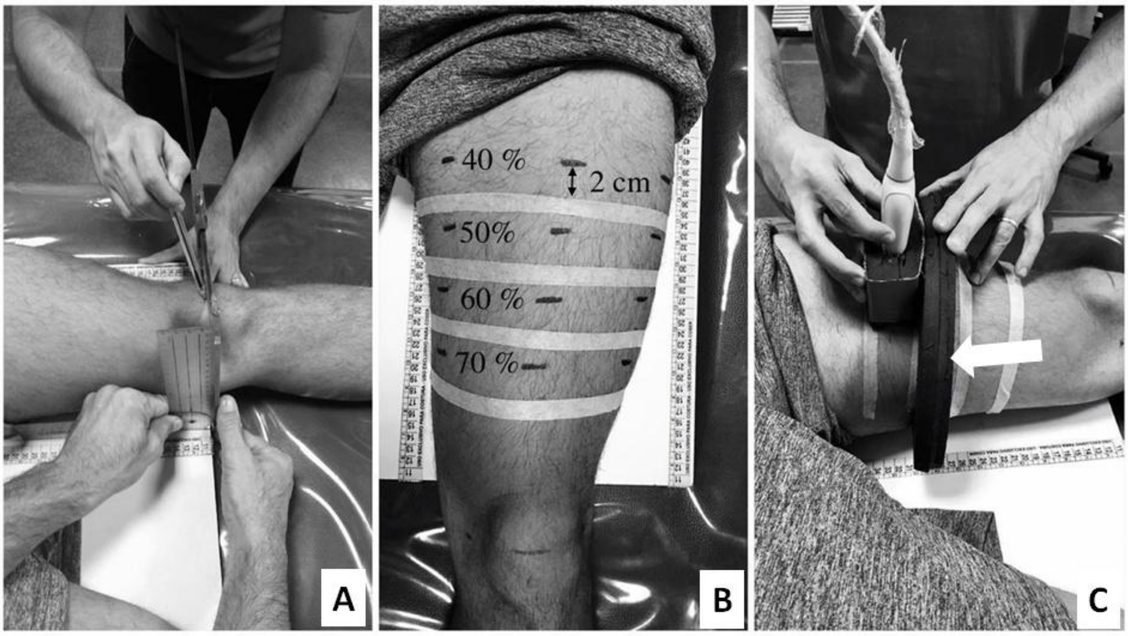

Figure 1. Thigh marking procedures (A and B) and ultrasound images acquisition (C). Probe guide (white arrow).

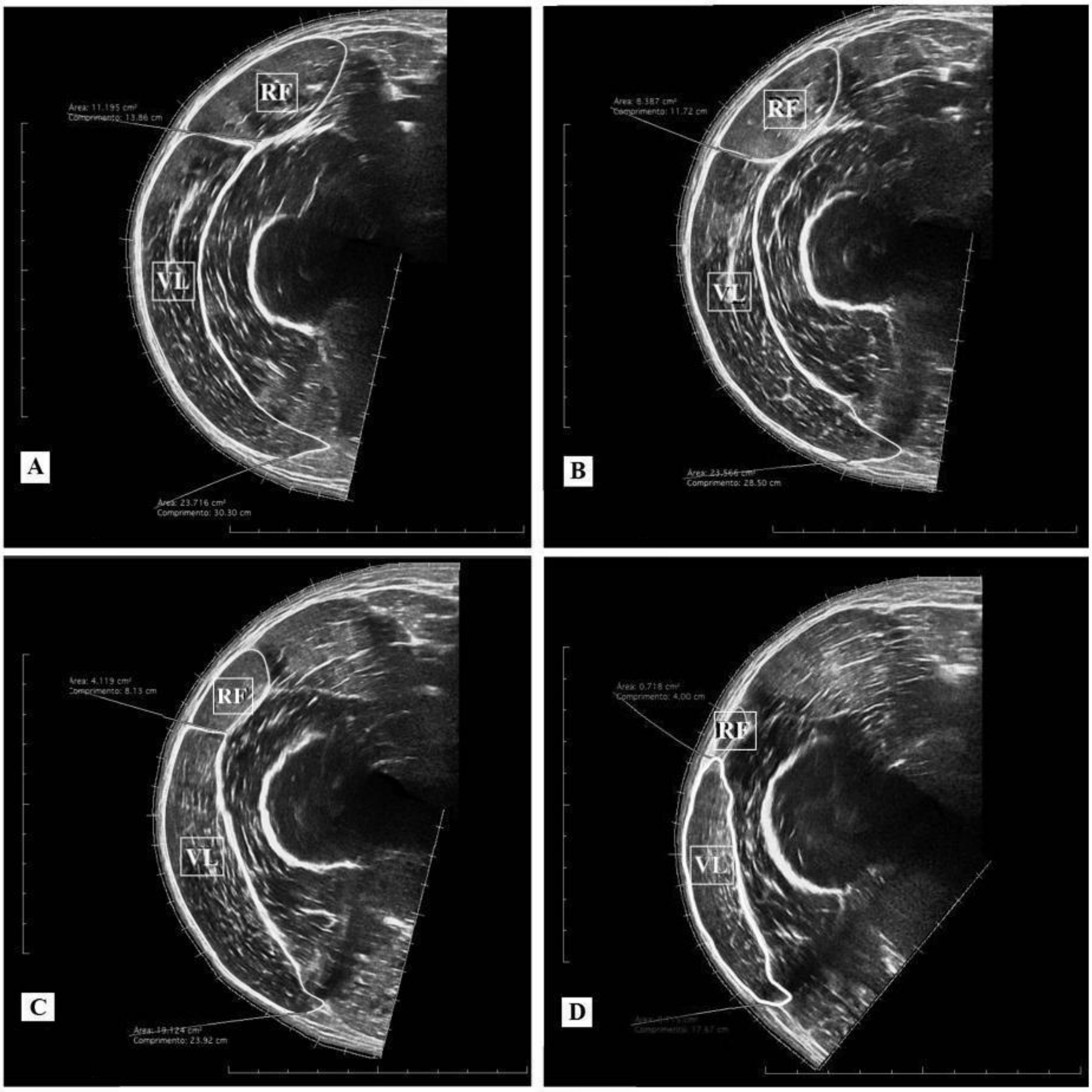

Figure 2. Ultrasound images and cross-sectional areas (CSA) at 40% (A); 50% (B), 60% (C), and 70% (D) of femur length. Rectus femoris (RF) and vastus lateralis (VL).

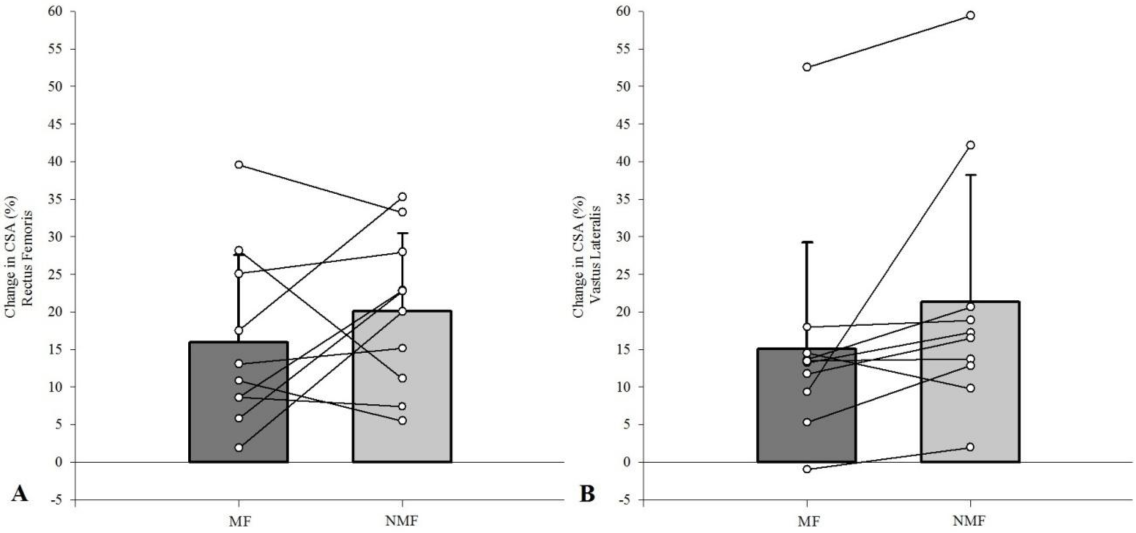

Figure 3. Changes in rectus femoris (A) and vastus lateralis (B) muscle cross-sectional areas (CSA) at post-test relative to baseline for each training protocol; mean (vertical bars); standard errors (vertical lines); individual values for each training protocol (white circle); link between individual values for each training protocol (sloping lines).

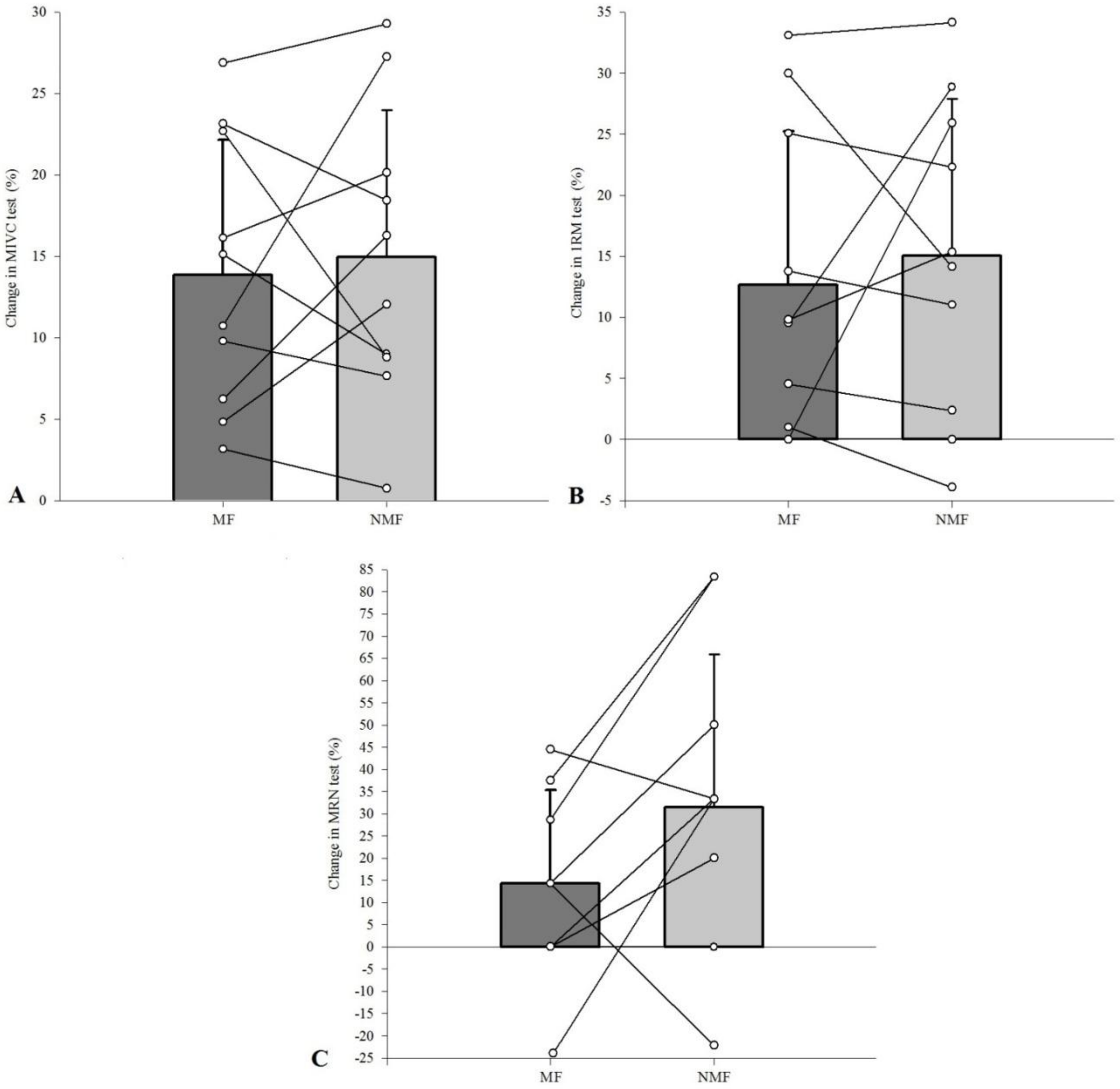

Figure 4. Changes in maximal voluntary isometric contraction (MVIC) (A), one repetition maximum (1RM) (B) and maximum number of repetition (MNR) (C) tests at post-test relative to baseline for each training protocol; mean (vertical bars); standard errors (vertical lines); individual values for each training protocol (white circle); link between individual values for each training protocol (sloping lines).

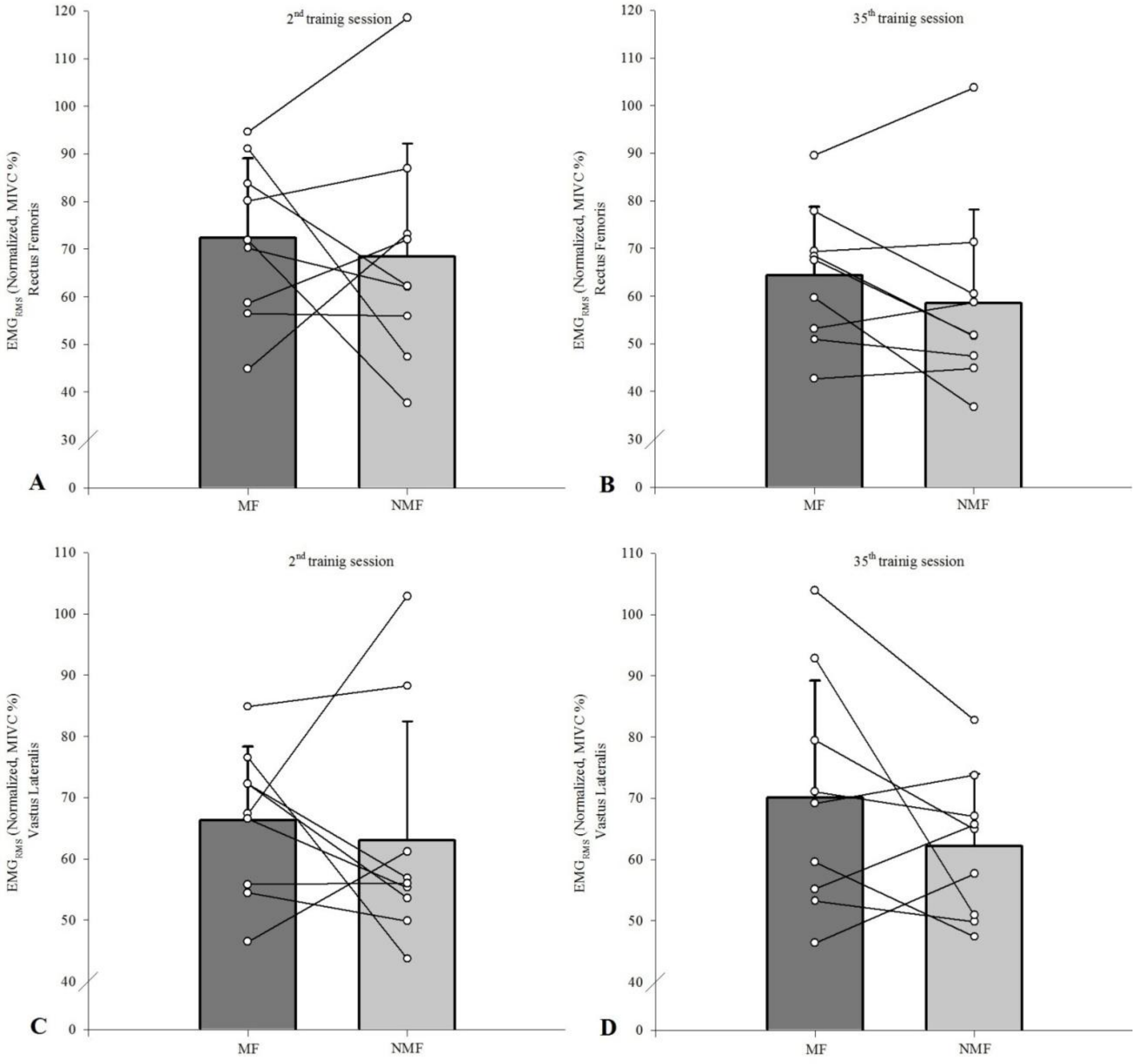

Figure 5. Normalized EMG$_{RMS}$ of the rectus femoris (A and B) and vastus lateralis (C and D) muscles for 2nd and 35th training sessions; mean (vertical bars); standard errors (vertical lines); individual values for each training protocol (white circle); link between individual values for each training protocol (sloping lines). EMG$_{RMS}$ = root mean square of the electromyographic signal.

3 ESTUDO 2

3.1 Informações do artigo 2

Título: Resistance training with different repetition duration to failure: Effect on hypertrophy, strength and muscle activation

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Resumo: This study investigated the effects of two 14-week resistance training protocols with different repetition duration (RD) performed to muscle failure (MF) on gains in strength and muscle hypertrophy as well as on normalized electromyography (EMG) amplitude and force-angle relationships. The left and right legs of ten untrained males were assigned to either one of the two protocols (2-s or 6-s RD) incorporating unilateral knee extension exercise. Both protocols were performed with 3-4 sets, 50-60% of the one-repetition maximum (1RM), and 3 min rest. Rectus femoris and vastus lateralis muscles cross-sectional areas (CSA), maximal voluntary isometric contraction (MVIC) at 30° and 90° of knee flexion and 1RM performance were assessed before and after training period. In addition, normalized EMG and force-angle relationships were assessed in the 6th and 39th experimental sessions. The main results show that the 6-s RD protocol induced larger gains in MVIC in the 30° of knee angle measurement than the 2-s RD protocol. Increases in MVIC in the 90° of knee angle and 1RM were indifferent between the 2-s and 6-s RD protocols. For the rectus femoris muscle growth, inconclusive changes were found across the ten subjects. In contrast, the 2-s RD protocol may have resulted in superior vastus lateralis muscle hypertrophy. Moreover, different normalized EMG and force-angle values were detected between protocols over most of angles analyzed. Thus, performing longer RD could be a more appropriate strategy to provide greater gains in maximal muscle strength at shortened knee positions, although shorter RD would induce superior muscle hypertrophy.

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Carta de submissão: Apêndice I

3.2 Artigo 2

1 INTRODUCTION

Repetition duration (RD) is an important feature of a resistance training program [1] influencing the strength gains and hypertrophy (i.e. quadriceps femoris muscles) [2]. Nevertheless, the systematic effect of the RD on resistance training is not yet fully understood [3,4]. It has been reported that measurements on isokinetic devices showed poor training and sports specificity (e.g. reduced ecological validity) and the lack of equalization of resistance training protocols would be some of the limitations presented by studies that investigated the influence of RD [4]. Moreover, the absence of registration and/or poor control over the RD, especially during protocols to muscle failure (MF), may hamper its meaning for the effectiveness isoinertial exercises [4]. Hence, RD control and comparability between training protocols must be considered to be mandatory for a proper understanding of the RD effect in a resistance training program.

A meta-analysis on the RD effect on muscle hypertrophy (including only studies with protocols performed to MF) concluded that similar muscle hypertrophy responses may be observed when performing RD between 0.5-s and 8-s [5]. This result suggests that a wide RD range may be employed in order to produce muscle hypertrophy. However, in addition to RD, the meta-analysis also included studies with variations in the load intensity [6], and studies were only one of the protocols was performed until MF [2]. Consequently, the results of the meta-analysis cannot be attributed to the manipulation of RD only. Previous studies have suggested that muscle strength and hypertrophy are predominantly influenced by the load intensity [(e.g. percentage of one repetition maximum - %1RM)] [7] and by the RD [2,4]. Therefore, given that different variables combined may simultaneously influence the chronic responses induced by strength training [1], the effect of RD only within a resistance training to MF while controlled for the load intensity remains unknown.

Other aspect to be considered in studies on the impact of RD on muscle hypertrophy relates to the use of different assessment instruments (e.g. biopsy, magnetic resonance imaging or ultrasound) and assessment locations on the muscle (e.g. 50% of the muscle femur length). Cross-sectional area (CSA) is a well-known estimate of the muscle volume. However, single point measurements somewhere along the muscle length may not adequately represent the entire muscle hypertrophic response [8]. Thus, a CSA analysis including several assessment locations along the muscle length may possibly provide a more accurate depiction of the muscle hypertrophic [8] and, therefore, a more accurate analysis of hypertrophy gains after resistance training programs as well.

Protocols performed with different RDs enforce different mechanical characteristics (e.g. different forces generated throughout the same range of motion - ROM), with higher force values for shorter RD [2,9]. As a consequence, different neuromuscular and morphological adaptations may be induced through resistance training with different RDs [4,10]. Results from Sampson and Groeller [11] showed that a resistance training protocol performed with faster movements (shorter RD) produced similar muscle hypertrophy when compared to a protocol with slower movements (longer RD). This study also was showed that despite the ability to perform higher number of repetitions during protocols with shorter RD compared to protocols performed with longer RD [12], only the protocol with longer RD was performed to MF (6 RM), causing a higher training volume in relation to the other protocols (4 repetitions not to MF). Given that the faster movements were not executed with the maximum number of repetitions, the results by Sampson and Groeller [11] remain inconclusive about the RD effect during resistance training to MF. In addition, given that the protocols with faster movements were performed with a time under tension (TUT) up to three times shorter than the protocol with slower movement, the similar hypertrophy observed between protocols reinforce the argument about the impact of mechanical tension (force applied by external resistance to the musculature) to induce adaptations. In this sense, the higher training volume and TUT performed during the slower protocol was probably a balance factor in relation to the greater magnitude of mechanical tension observed during protocols with shorter RD (verified by higher peak force values) [9], inducing to similar hypertrophy.

In addition, it has been shown that protocols with shorter RD performed to MF presented higher degrees of neuromuscular activation compared to protocols performed with longer RD [12]. An increase in the neuromuscular activation is associated either with a higher motor unit recruitment or an increase in the firing frequency of the motor units [13]. Both factors would contribute to chronic adaptations associated with resistance training [14]. Therefore, considering that the magnitude of the mechanical tension and neuromuscular activation would be determinant factors of neuromuscular adaptations [15], protocols with shorter RD performed to MF (consequently higher number of repetitions) should theoretically provide superior responses of muscular hypertrophy when compared to protocols performed with longer RD.

Protocols incorporating different RDs and repetition numbers evolve to provide different mechanical [9] and neurophysiological responses [9,16]. Therefore, gains in muscle strength may have different causes. However, the review by Davies et al. [3] verified only a trend for larger gains in muscular strength (measured by 1RM performance) for protocols with shorter RDs and moderate intensities (60-79% 1RM) compared to longer RDs. Unfortunately, protocols with exercises leading to MF were not considered in this review. Moreover, the 1RM test does not provide information on maximum force values in different joint angles. In particular, the 1RM test fails to provide information about maximal force values in specific sections of the ROM where a mechanical disadvantage may possibly occur to explain the different adaptations to RT [17]. As a consequence, maximum voluntary isometric contractions (MVIC) should be analyzed across a range of different joint angles to properly understand about the effects of different RDs [18].

In the past, studies showed that different RDs evolved to different force-angle relationships across the ROM. This was particularly true for the beginning and the end of the muscle actions [2,9]. Protocols with shorter RDs require faster movements. Therefore, they lead to larger peak forces at the beginning of the concentric action (e.g., lengthened position during knee extension) compared to protocols with longer RDs [9]. At the end of the ROM (e.g., shortened position during knee extension), a decrease in force is observed when faster movements are performed.

In contrast, protocols with longer RDs come along with less variation in the force response throughout the ROM, while larger force values appear at the end of the concentric actions [2,9]. All in all, varied strategies to apply force throughout the concentric action incorporating different RDs may promote different increases in maximal isometric strength at specific points across the ROM. As a consequence, it was the aim of this study to compare the effects of two protocols with different RDs performed to MF on measures of maximal strength (1RM and MVIC) and muscle hypertrophy (CSA). A secondary aim was to compare the effects of these RD strategies on features of the neuromuscular activation and force-angle relationships during both protocols execution. Based on our previous arguments, we hypothesized that larger increases in the 1RM and the CSA would be induced by a protocol with shorter RDs. In addition, the MVIC gains were expected to be different in specific areas across the ROM. In particular, larger forces were expected for faster training protocol at 90^{o} of knee flexion (stretched position) and for slower protocol at 30^{o} of knee flexion (shortened position).

2 MATERIALS AND METHODS

2.1 Study design

In the present study, a repeated measures design was adopted. Volunteers performed two resistance training protocols with two RDs (2-s or 6-s RD protocol) for 14 weeks. The left and the right legs were randomly assigned and balanced for limb dominance to either one of the protocols. Pre and post-test measures included: CSA, MVIC and 1RM tests. To assess the lower limb dominance voluntaries were asked to answer the following question: “If you would shoot a ball on a target, which leg would you use to shoot the ball?”

In session 1, limb dominance was determined, volunteers were familiarized with all the procedures, and training protocols were assigned to each limb. In the next session, ultrasound images were recorded to determine rectus femoris and vastus lateralis muscles CSA. The strength tests (MVIC and 1RM) were conducted in sessions 3 and 4 separated by at least 48h. Next, subjects trained from session 5 to 39 for a total of 14 weeks and five training sessions per week. The training sessions were separated by at least 24 h. For each week, subjects trained their left or right either on days 1, 3, and 5, or on days 2 and 4 in an alternating way. Through this training schedule, a minimum of 48 h inter session rest was provided for each leg. In sessions 6 and 39 (for each protocol), the rectus femoris and vastus lateralis neuromuscular activation were assessed through surface electromyography (EMG) while participants performed their respective training protocols. In session 40, separated between 72 and 120h from the last training session, the post-test ultrasound measurements were conducted similar to session 2. Finally, in session 41, the MVIC and 1RM post-tests were executed for both lower limbs.

2.2 Participants and Ethics

The sample size calculation was performed by using the software G.Power for Windows version 3.1.9.2 (Düsseldorf, Germany) and by following the guidelines proposed by Beck [19], with a priori statistical power (1 - ß) of 0,8, effect size of 0.68 and 5% significance level. Ten males aged between 18 and 30 years (mean ± SD: age = 23.1 ± 4.63 years; body height = 1.72 ± 0.07 m; body mass = 68.4 ± 9.46 kg; body fat percentage = 14.03 ± 6.56%) participated in this study. The inclusion criteria for participation were: (1) no resistance training during the last six months; (2) no functional limitations that could influence the 1RM test or the training protocols; and (3) no use of pharmacological substances or ergogenics supplements, and no other modes of resistance exercise during the study period. Subjects were informed about the study aims, procedures, and risks prior to signing an informed consent form. The local ethics committee of the university approved this study which complied with the Declaration of Helsinki. Additionally, each subject was instructed not to engage in any physical activity immediately before the testing sessions and to maintain the same diet before each session.

2.3 Testing procedures and Experimental Sessions

2.3.1 Experimental Session 1(anthropometric measurements)

After receiving information about the goals and the purpose of study and giving written consent, the volunteers answered the Physical Activity Readiness Questionnaire (PAR-Q). Next, they were submitted to an anamnesis examining possible limitations related to the study participation. In addition, body height, mass, and fat percentage (skinfold thickness) measurements were conducted. As a next step, volunteers were positioned on a seated knee extension machine (Master, Minas Gerais, Brazil) while maintaining a hip angle of 110º (angle between the backrest and the equipment seat). For measurement purposes, the lateral epicondyle of the femur was aligned with the rotational axis of the device and the pad of the device placed approximately 3 cm above the medial malleolus. These positions were registered for future replication in the subsequent tests and training sessions. All tests sessions were held at the same time of the day for each volunteer.

2.3.2 Experimental Sessions 2 and 40 (CSA - ultrasound measurements)

During these sessions, ultrasound images were recorded for the CSA analysis of the rectus femoris and vastus lateralis muscles. The acquisition procedure for the CSA images was conducted as described by Noorkoiv et al. [20]. Initially, volunteers remained lying in a dorsal decubitus position on a stretcher for 15 minutes. During this period, the anterior regions of both thighs were marked to identify the reference points for the ultrasound image acquisition. Next, the major trochanters and lateral epicondyles of the femurs were identified, and femur length was measured (Figure 1A). From the proximal end of thigh, 40, 50, 60, and 70% of femur length were identified and marked on volunteer’s skin by using a tape measure and a pachymeter positioned parallel to the intercondylar line. Then, a line with a microporous adhesive tape was attached 2cm from each percentage point on the thigh (Figure 1B) to delimitate the probe guide area for the ultrasound image acquisition (Figure 1C). Finally, the distances between the intercondylar line and each percentage point on the thighs were recorded for post-test replication. The procedures used to acquire images in the pre-test were the same for the post-test session (40th session). The latter was started no earlier than 72-120 h following the last training session.

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An ultrasound device (MindRay DC-7, Shenzhen, China) was used in an extended-field-of-view mode with a 4 cm linear transducer. The equipment was configured with 10 MHz frequency, an acquisition rate of 21 frames/s, a depth for the image capture ranging from 7.7 and 9.7 cm, and a gain between 50 and 64 dB. The settings were adjusted for each subject to produce the clearest images of the analyzed muscles. The same experienced examiner (~ 120h of training and 600 images acquired before of the study) conducted the acquisition of two images for each of the given femur percentage lengths (40, 50, 60, and 70%). For the acquisition procedure, the probe was placed transversely in parallel to intercondylar line using a coupled guide on the subject's thigh (probe guide) (Figure 1C). This procedure was performed with constant speed (controlled by metronome) and lasted between 12 and 15 s depending on the subject's thigh circumference. Sixteen images per subject were obtained for the rectus femoris and vastus lateralis muscle CSA analysis (8 pre-test + 8 post-test). Following the acquisition procedure, CSAs of each muscle scan were manually demarcated by a blinded examiner using specific software (OsiriX MD 6.0, Bernex, Switzerland) (Figure 2). For the data analysis, the rectus femoris and vastus lateralis muscle CSA mean values were calculated using two images acquired at each percentage of the femur length. Finally, based on the 40, 50, 60, and 70% length measurements, the sum of four CSAs of each analyzed muscle was calculated generating a summary CSA value per muscle to avoid a possible misinterpretation based on one measurement site only [20]. This value was used in the statistical data analysis.

- PLEASE INSERT FIGURE 2 HERE -

2.3.3 Experimental Sessions 3, 4 and 41 (strength tests)

The strength tests were conducted during the third session in order to familiarize the subjects with the procedures to be performed during the following session. After positioning the participants in the equipment, a familiarization MVIC test was conducted encompassing two attempts of 5s in duration with knee flexion angles of 30° and 90° (knee extended = 0º). MVIC tests were conducted with both legs with 2-minute rest periods between each attempt [21]. Testing order was randomized between legs. The same order was maintained during the post-test session. The highest force value registered for each attempt at knee flexion angles of 30° and 90° was used in following data analyses. During the MVIC test, a verbal command was given on which the subject exerted a maximum force against the fixed lever of the knee extensor machine. Visual feedback of the force trace was provided to the subject as well as verbal instruction from the examiners to achieve maximum strength. The load cell raw data (Tedea, Bavaria, Germany) were converted into digital data (Biovision, Wehrheim, Germany) and filtered through a 4th-order Butterworth low-pass filter with a cutoff frequency of 10 Hz.

The 1RM test familiarization was performed 10 minutes after the completion of the MVIC test. Initially, according to procedures described by Lacerda et al. [16,21], subjects performed 10 repetitions without any weight on the equipment. The 1RM was determined in concentric mode within a maximum of 6 attempts with 5-minutes rest periods in between [16,21]. In addition, a 5-minute rest period was given between the tests conducted with each of the lower limbs.

In session 4, the MVIC and 1RM tests of the familiarization session were repeated. These tests were also repeated in the 41st experimental session with a rest interval of at least 48h following the previous session 40 (ultrasound measurements). The data measured in sessions 4 and 41 were used for statistical analysis.

2.3.4 Experimental Sessions 5 to 39 (training period)

After the initial testing period, the 14-week training commenced (35 training sessions). All participants completed 100% of the training sessions. The experimental protocols consisted of 3-4 sets at 50-60% 1RM with 3-minute rest periods in between. In the 2-s RD protocol, subjects completed each repetition in 2 seconds (1 second concentric, 1 second eccentric). In the 6-s RD protocol, subjects perform each repetition in 6 seconds (3 seconds concentric, 3 seconds eccentric). The protocols complied with recommendations for resistance training and muscle hypertrophy [1]. Previously, training protocols with similar concentric and eccentric durations were already investigated in our laboratory or in others' [12,16,21]. For both protocols, all sets were executed until the subjects were unable to complete the concentric action within the required ROM (70°).

During the first two weeks, training sessions included 3 sets at 50% of 1RM. At third week (6th training session), the intensity was increased to 60% of 1RM. From week 9 (20th training session) until the end of the training period, one more set was added such that the subjects. Given that any variation of the load characteristics in addition to the RD could possible bias the training adaptations, the load configuration and progression were strictly controlled.

Every two weeks, beginning in the third week (6th training session), 1RM tests for both legs were re-assessed on a weekly basis before the first training session. A 10-minute rest period between the 1RM test and the start of the training session was provided. During these sessions, the 1RM test was conducted at the same day time as in the pre-test to standardize the circadian rhythm which may possibly influence strength performance.

2.3.5 Experimental Sessions 6 and 39 (2nd and 35th training sessions) (force and electromyography measurements)

The surface EMG procedure (Biovision, Wehrheim, Germany) followed the recommendations by Hermens et al. [22]. For the rectus femoris and vastus lateralis muscles, bipolar surface electrodes (Ag/AgCl - 3M-2223, Brazil) were aligned parallel to the muscle fiber orientation. Prior to the electrode placement above the muscle bellies, the skin areas were shaved, cleaned with alcohol using a cotton pad. The inter-electrode distance was 4cm which each electrode to be placed 2cm distant from the center of the muscle belly. The ground electrode was attached above the patella. After the electrode attachment, a silk paper was used to assess their positions as well as the patella and other relevant points on the skin. In addition, the subject’s two thighs were photographed with the electrodes positioned. These procedures were conducted in 6th session to map the electrode positions on the thigh and to verify high reproducibility in the post-test measurements (39th session).

To measure the ROM and the muscle action durations during both protocols, the angular displacement was recorded using a potentiometer (aligned with volunteer's knee-joint). For all training sessions, this device was coupled to the rotational axis of the knee extension device. The potentiometer raw data were converted into angular displacement data and filtered through a 4th-order Butterworth low-pass filter with a cutoff frequency of 10 Hz. The duration of each muscle action was comprised of the time between the maximum (100° of knee flexion) and minimum (30° of knee flexion) angular positions. Thus, the duration of the concentric action corresponded to the period between the maximum and minimum angular positions. In turn, the duration of the eccentric action corresponded to the time between the minimum and maximum angular positions. Additionally, concentric/eccentric durations and the RDs were determined throughout the angular displacement time. This potentiometer data provided online information on a laptop screen for the subjects regarding the duration and ROM data of each muscle action throughout the training sessions and tests [16,21]. Moreover, a metronome was used to help subjects maintain pre-established RDs.

All electromyographic, load cell, and potentiometer signals were synchronized and converted by an A/D board (Biovision, Wehrheim, Germany) with a sampling rate of 4,000 Hz. DasyLab software (Version. 11.0; Measurement Computing Corporation, Massachusetts, USA) was used to record and process the data. The methodological procedures to record force measurements were detailed in strength tests section. The electromyographic data acquisition was amplified (factor 500) and filtered (4nd-order Butterworth band-pass filter of 20-500 Hz) to calculate the EMG amplitude as the root mean square (EMG_{RMS}). Before commencing each experimental session (6th or 39th), subjects were asked to perform a MVIC test for 5s on the knee extension machine exercise at 60° knee flexion (controlled by the potentiometer). The highest force and EMG_{RMS} values in the MVIC test were used as a reference for the normalization of the subsequent measurements in the exercise protocols. The EMG_{RMS} during the MVIC was measured over a 1s period from 500ms before the MVIC peak force to 500 ms after [23]. The mean force and EMG_{RMS} of the concentric muscle actions for each 10° knee flexion area (100°-90°, 90°-80°, up to 40-30°) was calculated and normalized by the reference values from the normalization test. As a result, relatives force and EMG_{RMS} x knee-joint angle curves (normalized force and EMG-angle) were assessed. This procedure was performed for each protocol. For the acquisition of the force and EMG_{RMS} values during experimental sessions 6 and 39, participants performed 3 sets with 50% of the previous 1RM value in each protocol.

2.4 Statistical analyses

Statistical analysis was performed with SPSS for Windows version 20.0 (SPSS, Inc., Illinois, USA). Initially, paired sample t-tests were used to test for differences between the training groups in absolute baseline values for the main variables analyzed (CSA, 1RM and MVIC). No significant differences were detected. As baseline to post-test values increased for both training protocols, an analysis of relative data was used. As such, measures for the CSA, the 1RM, and the MVIC tests were transformed into relative values ((Pos-test - Pre-test) / Pre-test * 100). All data were expressed as mean ± *SD*. In addition, 95% confidence interval [CI] and individual values were presented for the main variables analyzed. The normal distribution and the homogeneity of variances were verified by the Shapiro-Wilk and the Levene's tests, respectively. For the estimation of effect sizes, Cohen`s d values were calculated using the equation $d = (M_{2s} - M_{6s}) / ((SD_{2s} + SD_{6s}) / 2)$ in which M_{2s} is the mean value of the 2-s RD protocol, M_{6s} is the mean value of the 6-s RD protocol, and SD expressing the respective standard deviation. These values are considered to reflect the magnitude of the differences (effect size) in each treatment with values ≤ 0.20 expressing a trivial effect; values between 0.21 and 0.49 expressing a small effect; values between 0.50 and 0.79 a moderate effect, and values ≥ 0.80 a large effect.

The differences between the training protocols in the CSA, 1RM, and the MVIC relative scores were analyzed through a paired sample t-test for each muscle separately. The intra-rater reliability was verified by the intraclass correlation coefficient ($ICC_{[3,1]}$). For the ICC calculations were conducted for both CSA measures (rectus femoris and vastus lateralis) and for both the test sessions (pre and post-test). The ICC intersession values were calculated based on familiarization and pre-test data. The individual analyses for the CSA, 1RM and MVIC tests were calculated according to Damas et al.[24]. As such, if an individual had a difference from the relative score between the 2-s and the 6-s RD protocol within 2 typical errors (2TE), difference between the protocols were considered non-existent. The typical error (TE) was calculated through the equation $TE = SDdiff / \sqrt{2}$, in which SDdiff is the standard deviation of the difference scores observed between the two measurement scores. Two pre-test CSA measurements in each lower limb were used to calculate the TE. In addition, the 1RM and MVIC were obtained from measures during the third (familiarization) and fourth (pre-test) sessions. Again, sessions and corresponding strength tests for each lower limb were separated by at least 48 h.

Normalized EMG-angle relationships for the rectus femoris and the vastus lateralis muscles were established during the 6th and 39th sessions to compare neuromuscular activation differences between the 2-s and the 6-s RD protocols. A three-way (session x protocol x knee joint angle) ANOVA with repeated measures was conducted to analyze the training effects in the normalized EMG_{RMS} for each muscle. Similar to EMG_{RMS} responses, a three-way (session x protocol x knee joint angle) ANOVA with repeated measures was used to compare force-angle relationships in the 6th and 39th sessions. When necessary, a post hoc Bonferroni honest significant difference test was used to identify the differences reported in the ANOVA’s. Furthermore, the EMG_{RMS} and force values for each protocol obtained during the normalization test from experimental sessions 6 and 39 were compared by t-test. This procedure aimed to identify possible differences in measurements in both lower limbs of the same individual. Thus, the feasibility of comparing the EMG_{RMS} and force responses of the two training protocols should be established.

In view of the control variables adopted in this study, paired sample t-tests were used to compare the RDs (training sessions), TUT and ROM between training protocols (mean values for all sets). Finally, given the number of repetitions for each protocol does not meet the precepts for a parametric analysis, Mann-Whitney-Wilcoxon test was used to compare the values in this variable for both protocols. This data is presented as median (number repetitions per set) and interquartile interval values. The level of the error probability/statistical significance was set at $p \leq 0.05$ for all statistical tests.

3 RESULTS

3.1 CSA

The intra-rater reliability values found in these sessions were 0.99 for both analyzed muscles. For the relative rectus femoris muscle CSA, no significant difference between the 2-s and the 6-s RD protocols were found (2-s RD = 25.26 ± 11.73%, CI = [17.99-32.53]; 6-s RD = 21.32 ± 13.61%, CI = [12.88-29.75]) ($t_9 = 1.11$, $p = 0.29$, $d = 0.31$) (Figure 3A). In addition, no significant difference was observed between the protocols for vastus lateralis muscle CSA (2-s RD = 19.47 ± 9.75%, CI = [13.43-25.51]; 6-s RD = 16.84 ± 9.09%, CI = [11.21-22.47]) ($t_9 = 0.85$, $p = 0.41$, $d = 0.28$) (Figure 3B).

The TE values for rectus femoris and vastus lateralis muscles CSA were 1.62% and 0.89%, respectively. The rectus femoris muscle CSA individual analyses showed that 5 individuals (50% of the sample) had larger values in the 2-s RD protocol. In contrast, for 3 individuals (30% of the sample) larger rectus femoris CSA values were detected in the 6-s RD protocol. The remaining 2 individuals (20% of the sample) showed no difference in the hypertrophic responses between the training protocols (the difference was within 2TE = 1.80%) (Figure 3A). Regarding the vastus lateralis muscle CSA, larger values for the 2-s RD protocol were detected in 5 individuals (50% of the sample), 2 individuals (20% of the sample) showed larger values for the 6-s RD protocol, and the other 3 individuals (30% of the sample) showed no difference between the training protocols in their hypertrophic adaptations (2TE = 3.62%) (Figure 3B).

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3.2 1RM

The ICC intersession value for 1RM tests was 0.98. Paired sample t-test indicated no significant differences between the 2-s and the 6-s RD protocols for the 1 RM (2-s RD = 12.45 ± 7.36%, CI

= [7.89-17.01]; 6-s RD = 13.33 ± 9.98%, CI = [7.14-19.51]) (t_9= - 0.49, p = 0.63, d = - 0.10) (Figure 4). The TE value for 1RM test was 3.46%. Our results show that only 1 individual (10% of the sample) achieved a substantial increase in the 1RM for the 2-s RD protocol and only 1 individual for the 6-s RD protocol. The remaining 8 individuals (80% of the sample) showed no difference between training protocols in 1RM (2TE = 6.92%) (Figure 4).

- PLEASE INSERT FIGURE 4 HERE -

3.3 MVIC

The ICC intersession values for MVIC test at 30^o and 90^o of knee flexion were 0.96 and 0.94, respectively. For 30^o measurements, paired t-test indicated significant differences between protocols (t_9= 2.50, p = 0.03, d = - 0.87), with the 6-s RD protocol having higher relative gains than the 2-s RD protocol (2 s = 2.13 ± 5.49%, CI = [-1.27-5.53]; 6 s = 8.07 ± 7.99%, CI = [3.12-13.02]) (Figure 5A). No differences were detected between both protocols at 90^o (t_9= 0.34, p = 0.74, d = 0.15) (2 s = 13.96 ± 7.05%, CI = [9.59-18.33]; 6 s = 15.69 ± 15.01%, CI = [6.39-24.99]) (Figure 5B).

The TE value for the 30^o measurements was 4.50%. The individual responses showed that 4 individuals (40% of the sample) had larger values in the 6-s RD protocol. The remaining 6 individuals (60% of the sample) showed no difference in the in maximal isometric strength performance between the training protocols (the difference was within 2TE = 9.00%) (Figure 5A). In addition, the TE value for the 90^o measurements was 5.74%. Concerning individual responses, larger values for the 2-s RD protocol were detected in 3 individuals (30% of the sample), 3 individuals (30% of the sample) showed larger values for the 6-s RD protocol, and the other 4 individuals (40% of the sample) showed no difference between the training protocols in their maximal isometric strength performance (2TE = 11.48%) (Figure 5B).

- PLEASE INSERT FIGURE 5 HERE -

3.4 EMG-angle relationship

The EMG_{RMS} values obtained during the normalization showed no significant difference between the 2-s RD and the 6-s RD training protocols (rectus femoris - $t_{19}= 0.70$, $p = 0.50$, $d = 0.13$) (vastus lateralis - $t_{19}= 0.77$, $p = 0.45$, $d = 0.15$). Significant differences in the rectus femoris muscle activation were observed between the 2-s RD and the 6-s RD training protocols in all knee-joint angles analyzed during 6th and 39th sessions (protocol x knee-joint angle interaction - $F_{6,54} = 66.55$; $p < 0.001$) (Figure 6AB). The same was true for the vastus lateralis muscle activation (protocol x knee joint angle interaction - $F_{6,54} = 51.00$; $p < 0.001$) (Figure 7AB). The 2-s RD protocol 2 s resulted in larger normalized EMG_{RMS} scores in six of the seven knee-joint angles analyzed (100-90^{o} to 50-40^{o}). For the 6-s RD protocol, significantly larger vastus lateralis muscle activation was found in the last knee-joint angle (40-30^{o}) only. No significant interaction was observed for the normalized EMG_{RMS} data for the interaction between time x protocol x knee joint angle for the rectus femoris ($F_{6,54} = 2.02$; $p = 0.14$) and vastus lateralis muscles ($F_{6,54} = 2.64$; $p = 0.10$). In addition, no significant interactions were detected between time x knee joint angle ($F_{6,54} = 2.64$; $p = 0.07$) and time x protocol ($F_{1,9} = 0.17$; $p = 0.69$) for rectus femoris and vastus lateralis muscles ($F_{6,54} = 0.14$; $p = 0.91$) ($F_{1,9} = 0.01$; $p = 0.91$), respectively. No significant main effect for the time factor (rectus femoris: $F_{1,9} = 0.14$; $p = 0.71$; $d = 0.03$) (vastus lateralis: $F_{1,9} = 2.43$, $p = 0.15$, $d = 0.36$) was detected. In contrast, significant main effects were found for the training protocol (rectus femoris: $F_{1,9} = 29.46$, $p< 0.001$, $d = 1.32$) (vastus lateralis: $F_{1,9} = 16.13$, $p = 0.003$, $d = 1.09$) and for knee-joint angle (rectus femoris: $F_{6,54} = 15.67$, $p< 0.001$, $d = 1.10$) (vastus lateralis: $F_{1,9} = 10.18$, $p> 0.001$, $d = 0.91$).

- PLEASE INSERT FIGURES 6 AND 7 HERE -

3.5 Force-angle relationship

The force values obtained during the normalization showed no significant difference between both training protocols analyzed ($t_{19} = 0.73$, $p = 0.47$, $d = 0.04$). Similar to EMG_{RMS}, differences were observed between the 2-s RD and the 6-s RD training protocols for the interaction between normalized force x knee-joint angle during 6nd and 39th sessions (time x protocol x knee-joint angle interaction - $F_{6,54} = 2.65$; $p = 0.02$). In 6th session, the 2-s RD protocol exhibited significantly larger normalized force values in the first four knee-joint angles analyzed (100-90^o to 70-60^o). The same was true for the first three knee-joint angles (100-90^o to 80-70^o) in the 39th experimental session. In contrast, for the 6-s RD protocol larger normalized force values were found in the last two knee-joint angles (50-40^o 40-30^o) during sessions 6 and 39. In addition, significant changes in the force x angle relationships between training sessions were detected only for the 2-s RD protocol. These changes were related to a reduction in the force values from 70-60^o until 40-30^o of knee flexion (Figure 8AB). Moreover, significant interactions were found between the time x knee joint angle ($F_{6,54} = 14.24$; $p = 0.001$) and the protocol x knee-joint angle ($F_{1,9} = 296.59$; $p < 0.001$). No significant interaction was observed for the interaction of time x protocol ($F_{1,9} = 2.48$; $p = 0.15$). Finally, no significant main effect for time ($F_{1,9} = 1.81$; $p = 0.21$; $d = 0.29$) and for protocol ($F_{1,9} = 1.55$, $p = 0.70$ $d = 0.03$), but a significant main effect for knee-joint angle ($F_{6,54} = 84.82$, $p < 0.001$,$d = 0.77$) were indentified.

- PLEASE INSERT FIGURE 8 HERE -

3.6 Control variables (RD, number of repetitions, TUT and ROM)

As expected, 6-s RD protocol showed longer average RD than 2-s RD protocol (2.04 ± 0.08 s; 5.98 ± 0.09 s, respectively; $t_{69} = 284.48$, $p < 0.001$, $d = 46.27$). In addition, larger TUT mean values were observed in the 6-s RD protocol (mean for all sets = 43.47 ± 10.92; 1st set = 52.5 ± 15.83, 2nd set = 42.58 ± 12.25, last set (3rd or 4th) = 36.98 ± 10.89) as compared to the 2-s RD protocol (mean for all sets = 30.51 ± 7.52; 1st set = 38.1 ± 10.55, 2nd set = 29.57 ± 7.98, last set (3rd or 4th) = 25.09 ± 7.17) ($t_{69} = 15.95$; $p < 0.001$; $d = 1.38$). In regard to the number of repetitions, the Mann-Whitney-Wilcoxon test showed significantly larger median values for the 2-s RD protocol (median for all sets = 14 [12-17]; 1st set = 18 [21.25-17], 2nd set = 14.5 [16.25-12.75], last set (3rd or 4th) = 12 [14-11]) as compared to the 6-s RD protocol (median for all sets = 7[6-8]; 1st set = 9 [8-10], 2nd set = 7 [6-8], last set (3rd or 4th) = 6 [5-7]) ($U_{69} = 7.29$; $p < 0.001$; $d = 2.63$]. Last not least, no significant differences were detected between the 2-s RD and the 6-

s RD protocols in the ROM average values (2-s RD: 70.77 ± 0.79°; 6-s RD: 70.99 ± 0.65°; t_{69}= 1.90, p = 0.06, d = 0.30).

4 DISCUSSION

The purpose of this study was to compare the strength and muscle hypertrophy responses induced by two protocols with different RDs performed to MF. In addition, we aimed to verify the effects of these RD strategies on knee extension force and neuromuscular activation in the rectus femoris and vastus lateralis muscles. To the best of our knowledge, no other studies have compared these chronic adaptations for resistance training with different RD to MF (matched by intensity, set and rest) analyzing average and individual data. The main results of the present study were: 1) the 2-s RD protocol showed at least larger than or similar effects in muscle hypertrophy than the 6-s protocol; 2) the 6-s RD protocol induced larger gains in MVIC at knee flexion of 30^{o} than the 2-s RD. However, both protocols induced similar increases in MVIC at for the 90^{o} of knee angle and in 1RM performance. Additionally, differences between the protocols were detected in the EMG and force-angle relationships in 6th and 39th sessions. Overall, these results partially confirm our previous hypotheses that differences in training protocols leading to MF with RDs may provide distinct EMG and force-angle relationships. Thus, RD must be considered an important variable to be associated with chronic adaptations of resistance training.

Both rectus femoris and vastus lateralis muscles had a similar increase in muscle CSA for the 2-s RD and the 6-s RD protocols after 35 training sessions with a small effect size [d = 0.31 (rectus femoris) and 0.28 (vastus lateralis)]. In agreement with the average hypertrophic response, the individual analyses demonstrated a substantial proportion of participants showed no difference between protocols (20% of the participants for rectus femoris and 30% for vastus lateralis). In contrast, 50% of the participants increased rectus femoris and vastus lateralis CSAs through the 2-s RD protocol while a smaller proportion of participants showed larger CSAs through the 6-s RD protocol (30% for rectus femoris and 20% for vastus lateralis). Therefore, individual hypertrophy responses suggest that shorter RDs with faster knee extensions appear to promote similar or even larger muscle hypertrophy when compared to longer RDs with slower knee extensions. These results may be explained by increases in the neuromuscular activation (e.g. higher recruitment of motor units and/or firing rate) [13,16], by increases in the force values during the execution of each repetition [9,11], and by differences in the training volume [25].

For the 2-s RD protocol, roughly twice the volume of the 6-s RD protocol (14 vs. 7 repetition per set, respectively) was executed and this variable has shown to be an important factor related to muscle hypertrophy [26]. In general, a higher training volume it is connected to an increase in the TUT. In turn, larger TUTs have been used to explain the superiority of the hypertrophic adaptations observed in protocols with higher training volume [26]. Additionally, studies investigating resistance protocols balanced by training volume but different in the RDs and TUTs showed larger muscle hypertrophy after training with longer RDs and TUTs [2]. In the present study, the 2-s RD protocol was executed with average TUTs approximately 25% larger than in the 6-s RD protocol (43 s vs. 30 s, respectively). In turn, the 2-s RD protocol encompassed double of the 6-s RD training volume. Thus, the larger volume of 2-s RD protocol and the longer TUT of the 6-s RD protocol might mutually counterbalance their effects on muscle hypertrophy. However, despite the importance of increased TUT, especially in the process of muscle hypertrophy, a higher motor unit recruitment may be expected through a protocol with shorter RD and higher volume [12,16]. Consequently shorter RDs in line with a higher training volume may lead to larger muscle hypertrophy [27].

The increase in the number of motor units recruited during resistance training has been pointed as a central factor to trigger muscle hypertrophy [27]. The present study demonstrated a higher neuromuscular activation for the 2-s RD as compared to the 6-s RD protocol during most of the ROM measurements conducted (100º to 40º). In contrast, the 6-s RD protocol showed higher neuromuscular activation only in the last 10º range for concentric ROM (40º to 30º). This result suggests a more extensive participation of faster motor units during most of concentric ROM for the 2-s RD. However, these differences may not have been sufficient to result in a marked increase in CSA to the 2-s RD protocol as compared to the 6-s RD. Although increased neuromuscular activation is associated with higher motor unit recruitment other factors may contribute to the changes in the EMG amplitude as well such as increased firing frequency and synchronization of motor units [13]. Therefore, care must be taken when interpreting EMG data obtained prior and after resistance training period.

Similarly to neuromuscular activation, higher force values were found during the 2-s RD protocol at the beginning of concentric ROM while higher force values were observed for 6-s RD protocol at the end of concentric ROM. Moreover, at the 39th experimental session, the 2-s RD protocol was executed with higher muscle forces (100º to 70º) during most ROM areas compared to the 6-s RD protocol (50º to 30º). These results agree with previous results showing higher muscle forces at the beginning of concentric ROM when performing faster movements [9]. It should be noted, however, that, although the RD of 2 s was only a third of the 6-s RD, the magnitude of the forces applied in the two experimental situations were similar (43% of MVIC at 39th experimental session). This result does not agree with previous studies [9]. Sampson et al. [9] compared protocols with different RDs and showed differences in force produced close to 25% at the onset of concentric action. However, their participants were instructed to perform ballistic movements or controlled movements within 4 s. With similar protocols to those in the last study, Sampson and Groeller [11] found similar gains in muscle hypertrophy in both experimental conditions after 12 weeks of training. For these authors, the higher force applied during ballistic movements would be a determinant factor for the muscle hypertrophy. Therefore, it is possible that in the present study despite the higher force demand during 2-s RD protocol at the beginning of concentric ROM, similar in force produced between both protocols was essential so that no significant differences could be detected in the CSA average data of rectus femoris and vastus lateralis. In contrast, the individual analyses showed a higher proportion of participants with greater hypertrophy after training with the 2-s RDs compared to the 6-s RDs.

In agreement with the CSA overall responses, the average maximal dynamic strength performance (1RM test) was similar between the 2-s RD and the 6-s RD protocols (small effect size, *d* = 0.15). The 1RM test individual analyses showed that 80% of the sample did not respond differently in either of the two protocols confirming the overall results. As a mixed result, higher force values were detected in the 2-s RD as compared to the 6-s RD protocol during the initial phase of the ROM in the concentric action while the 1RM gains were similar between protocols. This outcome did not confirm the superior performance when training with fast movement velocities and moderate intensities (60-79% 1RM) as was indicated in a previous meta-analysis [3]. Hence, our initial hypothesis was rejected.

In line with previous research [11], we did not find differences in 1RM performance originating from different RD protocols using the same load intensity. In contrast, other investigators had found higher 1RM gains when utilizing fast movement velocities [4,28]. The discrepancy between these results may be associated to different RD adopted in these studies. Although the movement time in the 2-s RD protocol was three times shorter than in the 6-s RD protocol, participants were not instructed to perform explosive movements which was the case in other studies [4,28]. It has been reported a greater neuromuscular activation and impulse production when performing ballistic movements [29]. Thus, this factor may have influenced the occurrence of adaptations favorable to the 1RM increase for faster protocols in the abovementioned studies [4,28], which was not observed in the present research. Importantly, in the above mentioned studies at least one of the analyzed protocols was performed to MF. Thus, differences within the levels of effort must be assumed [4,11,28]. Thus, performing repetitions to MF provide a maximum effort for all individuals during both protocols [30], which may have been a determinant factor in not having difference in 1RM gains between the two protocols investigated in the present study. Thus, training to MF could hamper the effect of RD on maximum dynamic strength performance observed in previous studies.

In addition, it has been reported that exposure to successive 1RM tests on a two week basis may bias in the 1RM individual’s performance when comparing different resistance protocols [31]. Consecutive measurements may evolve to a similar motor pattern within the 1RM tests. Hence, it appears possible that existing differences between training protocols may not be detected [32]. Accordingly, studies on RD effects showing inconclusive results for the 1RM tests may have other outcomes further to the 1RM measurement procedures [33]. Therefore, MVIC tests performed at different joint angles may be a valid alternative to investigate the effect of different training protocols on muscle strength responses. Given that protocols with different RD provide changes in force production that varies over the ROM [9], it was hypothesized that greater isometric maximal strength gains would be found in knee-joint angles with higher instantaneous force values applied.

Similar to the 1RM scores, the relative increases in the MVIC values at 90ºof knee flexion did show comparable improvements by both RD training protocols. A small effect size (*d* = 0.15) reinforces the result found by t-tests. Based on the TE values, the individual analyses showed that 40% of the sample did not respond substantially different for either of the two training protocols. In turn, 3 participants each showed substantial improvements in either the 2-s RD or the 6-s RD protocol. Conversely, larger relative gains were observed in the MVIC at 30º of knee flexion for 6-s RD protocol (large effect size; *d* = - 0.87). Moreover, the individual analyses revealed that, albeit a greater proportion of participants demonstrated similar improvement in both protocols (60% of participants) in the MVIC values while some individuals increased the MVIC score at 30º of knee flexion only for the 6-s RD protocol (40% of participants) with no one having larger improvement for the 2-s RD protocol. Based on results from previous studies [18], we hypothesized that the distinct force-angle relationship obtained during the two training protocols would influence the MVIC relative gains at different knee-joint angles. These previous studies, in general, presented larger maximum strength gains in the joint angles near the training angle/ROM used in the corresponding training. In contrast, in the present study, our subjects performed both training protocols with the same ROM (70º) varying the force generated along the angular exercise range (100º to 30º). Data from the 39th training session (Figure 8B) show that in the initial (100-90º) and final (40-30º) ranges of the concentric testing action largest differences in force production were detected between the protocols (7 vs. 13%). Additionally, the 2-s RD protocol showed higher values at the beginning and the 6-s RD protocol at the end of the testing movement. Given that type of mechanical stimulus (i.e. type of contraction) may contribute to the specific training adaptations [34] it appears possible that the higher force production in the 6-s RD protocol compared to the 2-s RD protocol at the end of concentric action might be sufficient to produce differences in isometric relative force gains at 30° but not at 90° of knee flexion. Furthermore, increases in isometric force after training have been associated with increases in neuromuscular activation [8]. The EMG-angle relationship for the 6-s RD protocol showed higher normalized EMG_{RMS} at 40-30° of knee-joint angle (end of concentric action) and so help to explain the relative force gains at 30° of knee flexion. Moreover, previous studies verified joint-angle specific strength gains close to trained angle/ROM [18] while others only showed joint-angle specific strength gains for resistance training performed in shorter muscle lengths [8], reinforcing the results obtained in the present study up to 30° of knee flexion. However, it should be emphasized that the mechanisms suggested to explain distinct strength gains at specific joint angles are still poorly understood [8,18].

A limitation of the intra-individual experimental design is a possible cross-training or cross education effect [35]. There is evidence in the literature indicating that the cross-training effect, if it occurs, would be restricted to neural parameters and muscle strength gains while morphological changes (e.g., CSA) would not be influenced by this effect [35]. In this respect, muscle strength gains in the contralateral limb should evolve from an increase in the motor neuron activation and are not related to morphological adaptations. However, previous studies investigating the crossing-effect for neuromuscular activation showed inconclusive results [36,37]. For example, Hortobágyi et al. [36] found that changes in the neuromuscular activation of the untrained limb depending on the training mode performed (e.g., type of muscle action). The neuromuscular changes were similar to the changes in the muscle strength. In addition, researchers found that the cross-training effect contributes to approximately 7.8% of the muscle strength gain of the contralateral limb [38]. Such adaptation was explained by neural mechanisms involving acute facilitation within the motor cortex of the untrained contralateral limb following excitation of the trained limb [39]. The training protocols were performed with a minimum interval of 24h in order to minimize the acute effect of unilateral training reducing the maximal strength performance in contralateral limb. Finally and most important to our study, it has been argued that, when both limbs of an individual are trained with different protocols, the cross-training effect is minimal or non-existent [38]. Hence, we expected that any difference in the strength responses between limbs would be due to training protocols and not owing to a crossing effect [39].

4.1 Conclusion

This study showed that protocols with different RD performed to MF produced similar muscle hypertrophy relative gains despite differences in the EMG- and force-angle relationships. Therefore, different training volumes and TUTs based on the different RDs appear to produce a similar stimulus to the skeletal muscle growth. However, when considering individual data, faster movements may result in larger muscle hypertrophy (mainly for vastus lateralis muscle) compared to slower movements. Thus, we argue that an increased training volume provided by performing faster movements to MF would promote greater muscle hypertrophy when compared to higher TUTs during slower movements. It is noteworthy that the highly trained individuals possibly require larger training volumes in order to achieve chronic adaptations (i.e. muscle hypertrophy) associated with resistance training as compared to untrained or moderately trained individuals [40]. Yet, although no differences in 1RM gains between protocols were found, our MVIC data provides important insight for the understanding of joint-angle specific strength responses induced by RDs. We demonstrate that high force production in the end of concentric action during the 6-s RD protocol induced higher maximal isometric strength at 30^{o} of knee flexion when compared to the 2-s RD protocol.

5 PERSPECTIVES

Repetition duration is considered an essential variable of resistance training [2,3,30,33], but recent studies not supporting this view on strength and muscle hypertrophy [3,5]. Nevertheless, this investigation has shown that a resistance training performed to MF with longer RD could be a more appropriate strategy to provide greater gains in maximal muscle strength at shortened knee positions, although shorter RD would induce superior muscle hypertrophy. Thus, the current results have practical applications for individuals seeking health related improvements in muscular strength and hypertrophy. Overall, it should note that the results presented here are limited to the exercise and subject characteristics similar to those of our current study. However, future researches with trained individuals are needed to clarify the impact of protocols with different RDs on the chronic adaptations associated to resistance training performed to MF.

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Figures and legends

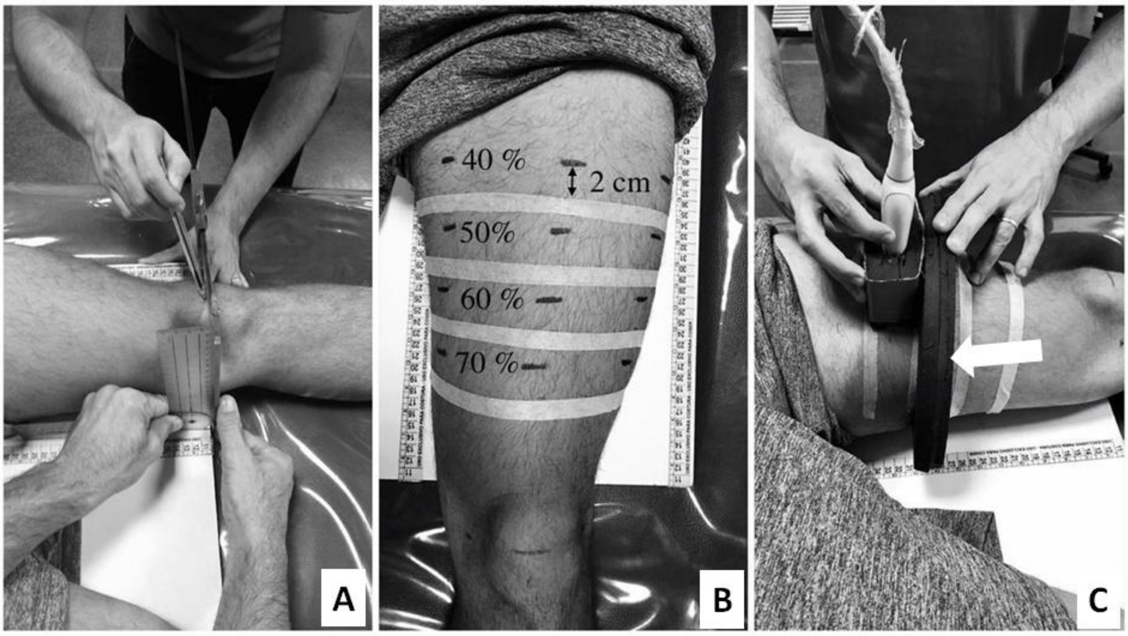

Figure 1. Thigh marking procedures (A and B) and ultrasound images acquisition (C). Probe guide (indicated by white arrow).

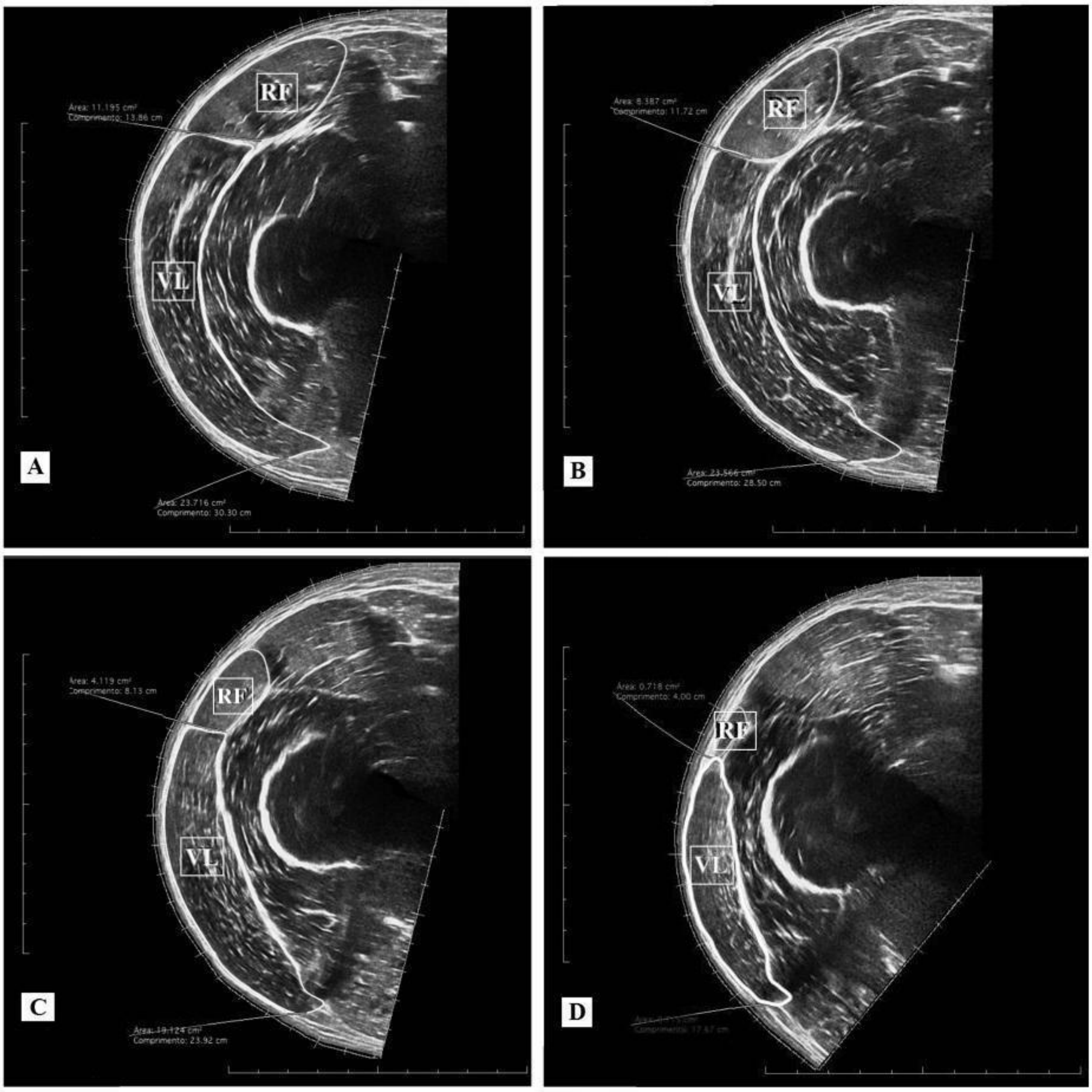

Figure 2. Ultrasound images and cross-sectional areas (CSA) at 40% (A); 50% (B), 60% (C), and 70% (D) of femur length. Rectus femoris (RF) and vastus lateralis (VL).

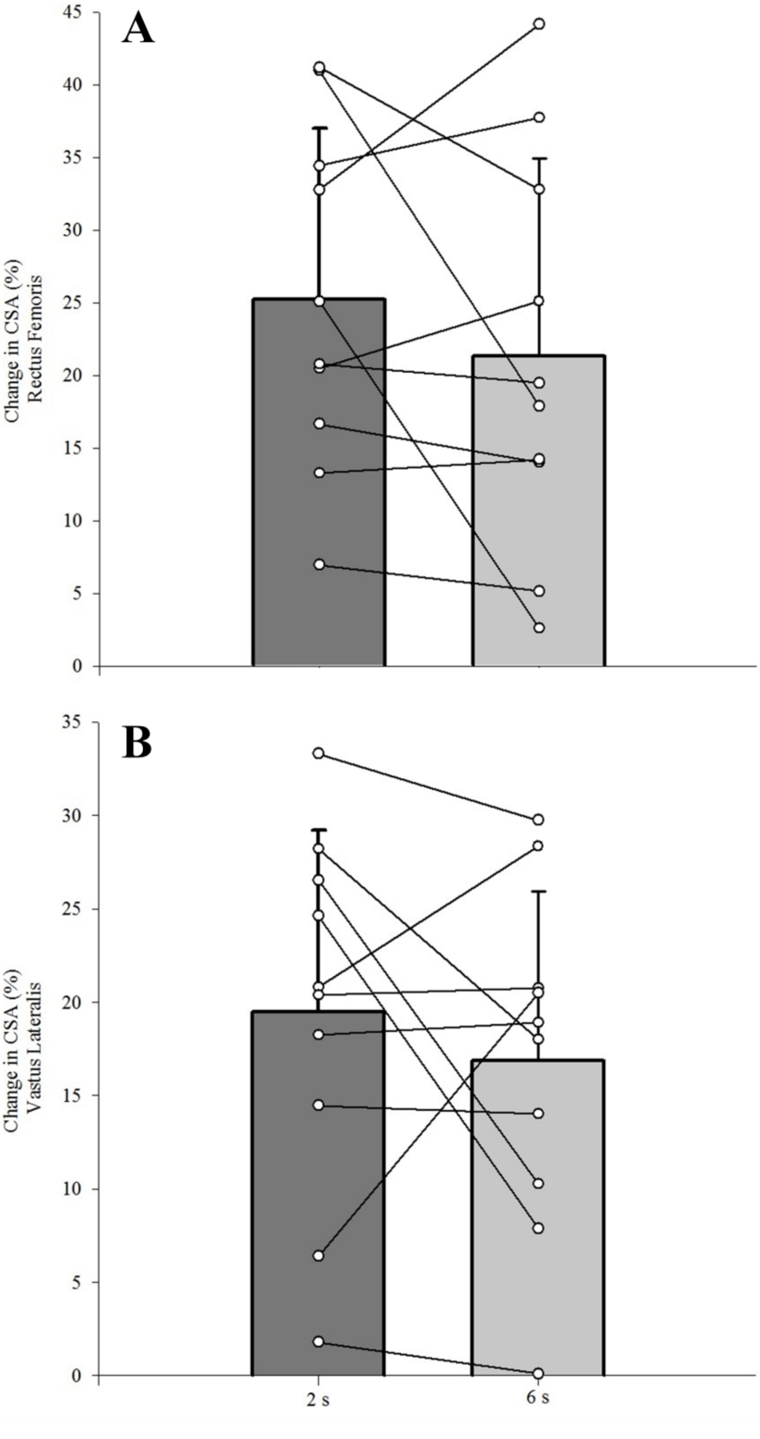

Figure 3. Changes in rectus femoris (A) and vastus lateralis (B) muscle cross-sectional areas (CSA) at post-test relative to baseline for each training protocol; mean (vertical bars); standard errors (vertical lines); individual values for each training protocol (white circles); link between individual values for each training protocol (sloping lines).

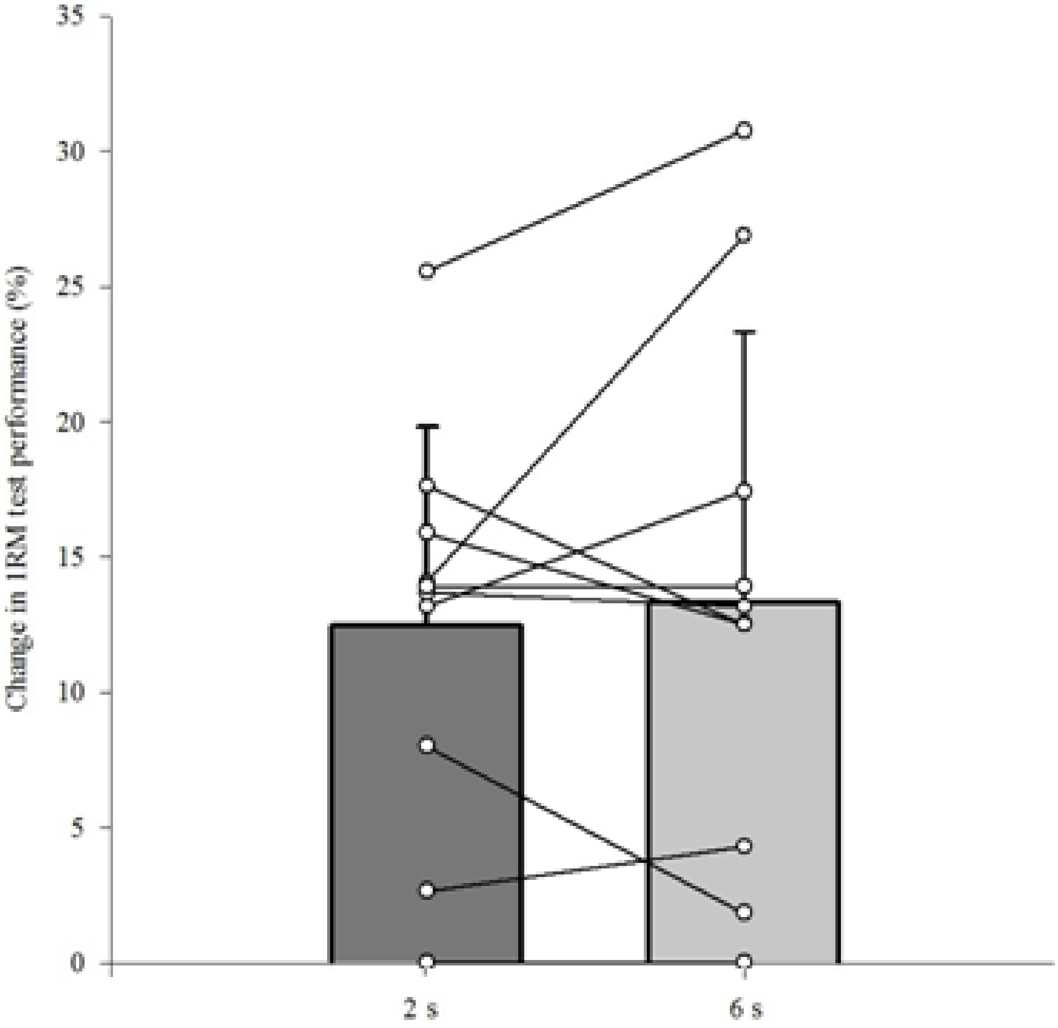

Figure 4. Changes in one repetition maximum (1RM) test at post-test relative to baseline for each training protocol; mean (vertical bars); standard errors (vertical lines); individual values for each training protocol (white circles); link between individual values for each training protocol (sloping lines).

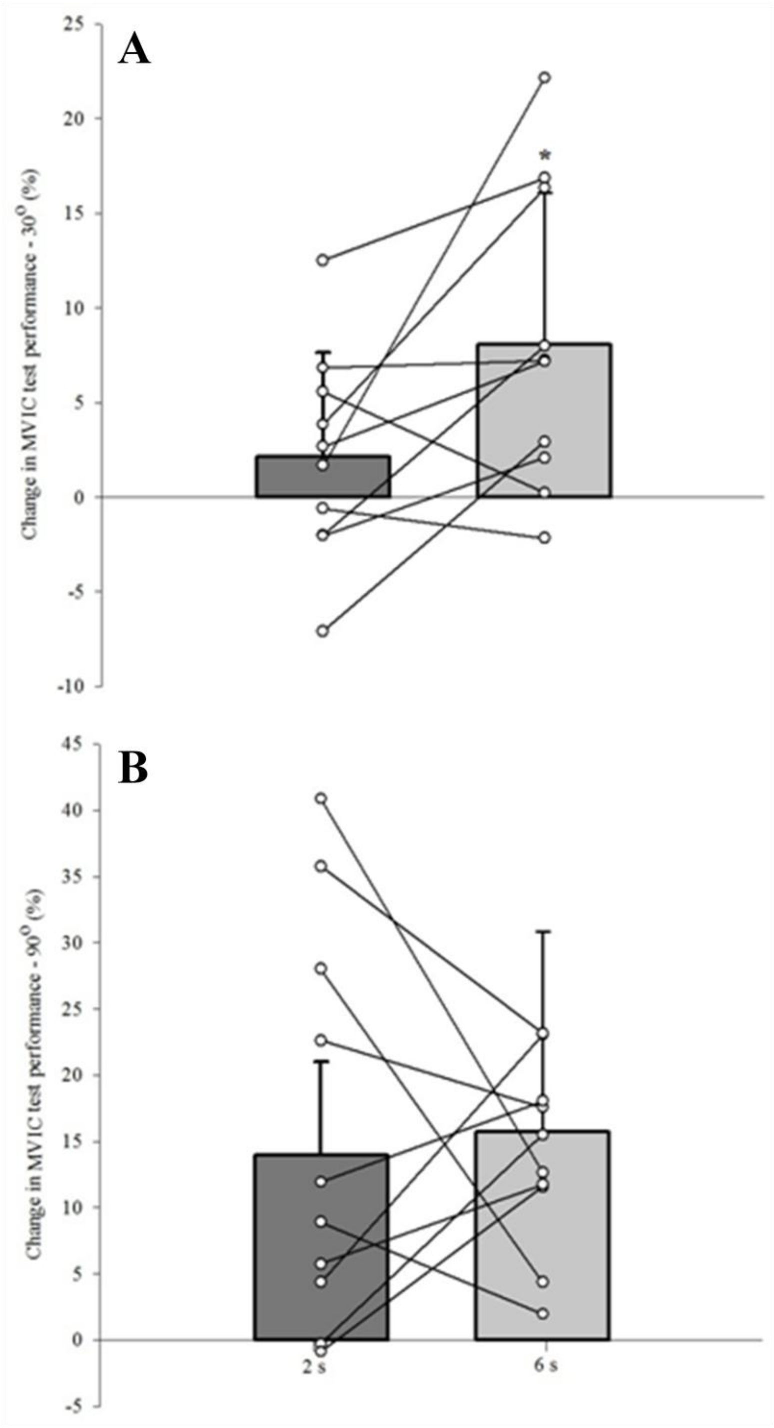

Figure 5. Changes in maximal voluntary isometric contraction (MVIC) at 30^{o} (A) and 90^{o} (B) of knee-joint angle at post-test relative to baseline for each training protocol; mean (vertical bars); standard errors (vertical lines); individual values for each training protocol (white circles); link between individual values for each training protocol (sloping lines). * 6-s RD protocol higher than 2-s RD protocol.

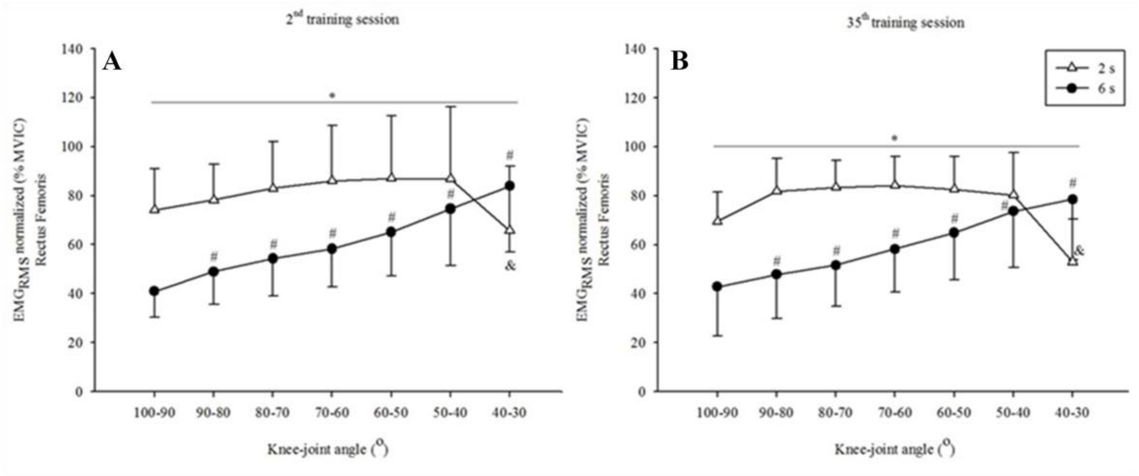

Figure 6. Rectus femoris concentric normalized EMG_{RMS} x knee-joint angle curves during 2nd (A) and 35th (B) training sessions at 2-s and 6-s RD protocols. * Significant difference between protocols. # Higher than previous joint angle (6-s RD protocol). & Lower than all previous joint angles, except for 100-90° (2-s RD protocol).

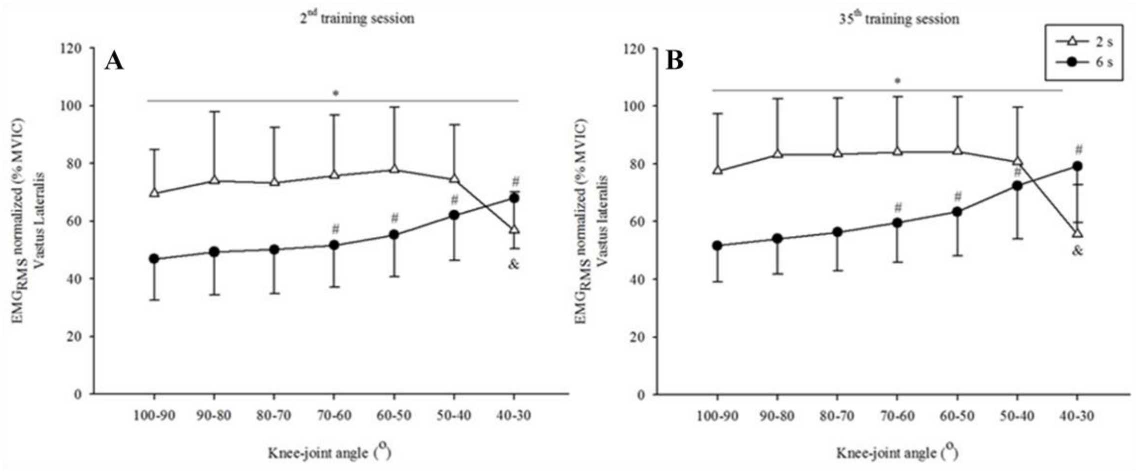

Figure 7. Vastus lateralis normalized concentric EMG_{RMS} x knee-joint angle curves during 2nd (A) and 35th (B) training sessions at 2-s and 6-s RD protocols. * Significant difference between protocols. # Higher than previous joint angle (6-s RD protocol). & Lower than all previous joint angles (2-s RD protocol).

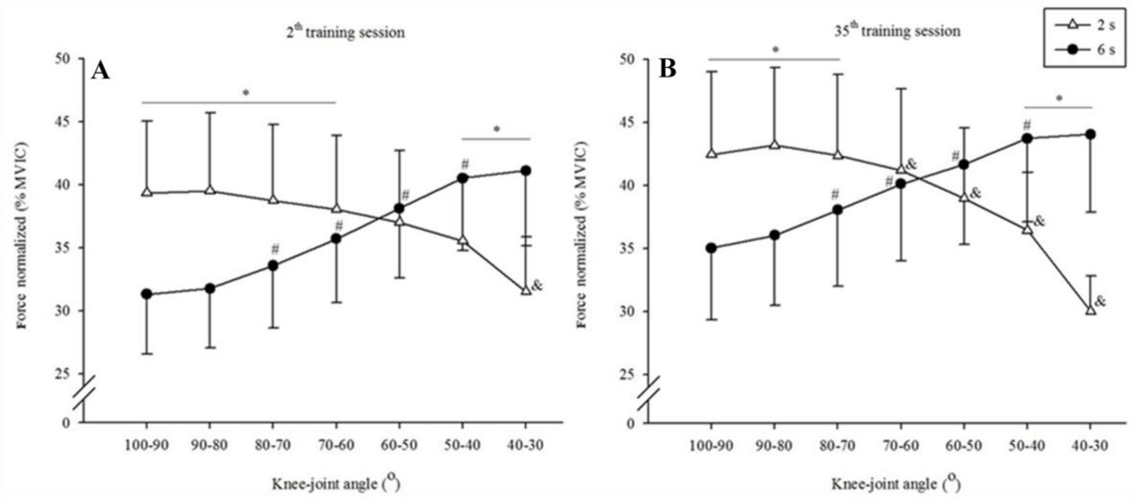

Figure 8. Concentric normalized force x knee-joint angle curves during 2nd (A) and 35th (B) training sessions at 2-s and 6-s RD protocols. * Significant difference between protocols. # Higher than previous joint angle (6-s RD protocol). & Lower than previous joint angle (2-s RD protocol).

4 SÍNTESE DOS ARTIGOS E A RELAÇÃO COM OS OBJETIVOS DA TESE

A presente tese de doutorado foi constituída de dois (2) diferentes estudos com objetivos distintos, mas investigando a temática do treinamento realizado até a falha muscular. No Estudo 1, o objetivo foi investigar o efeito do treinamento realizado até a falha muscular, sendo que foi comparado o efeito do treinamento até a falha muscular (TFM) e não-falha muscular (TNFM) no desempenho de força máxima (1RM e CIVM), de resistência de força (NMR), também na hipertrofia muscular (AST) e amplitude EMG (EMG_{RMS} normalizada) dos músculos reto femural e vasto lateral (valores médios e individuais). Os principais resultados mostraram que os protocolos de treinamento promoveram ganhos similares no desempenho de 1RM e CIVM, assim como na AST do músculo reto femural. Entretanto, a análise dos dados individuais indicou que o TNFM teria induzido a maiores aumentos no desempenho de NMR e AST do músculo vasto lateral. Além disso, as respostas de EMG_{RMS} normalizada dos músculos reto femural e vasto lateral foram similares para o TFM e TNFM durante a segunda e a última sessão de treinamento, indicando que os dois protocolos proporcionaram demandas neuromusculares semelhantes. De forma geral, é possível sugerir que o volume de treinamento seria determinante para as adaptações crônicas associadas ao treinamento de força do que a realização de repetições até a falha muscular. Contudo, é importante ressaltar que o TNFM seja realizado com um elevado nível de esforço. No presente estudo, essa questão foi verificada tendo como base os dados fornecidos pela escala de percepção de subjetiva de esforço. Durante o TNFM os valores de percepção subjetiva de esforço variaram de 15 até 18 em uma escala de 6 a 20 pontos, enquanto no TFM foram sempre igual ou maior que 19.

O objetivo do Estudo 2 da presente tese foi investigar o efeito do treinamento com diferentes durações das repetições realizados até falha muscular. Portanto, neste

Estudo foi comparado o efeito do treinamento realizado com diferentes durações das repetições (2-s e 6-s) até a falha muscular nos ganhos relativos de 1RM, CIVM (30º e 90º de flexão de joelhos) e AST (valores médios e individuais), bem como nas relações amplitude EMG-ângulo e força-ângulo. Considerando a análise dos valores médios, os protocolos 2-s e 6-s produziram respostas similares de hipertrofia muscular. Contudo, baseado na análise dos valores individuais foi demonstrado no Estudo 2 que o protocolo 2-s promoveu maior resposta hipertrofia muscular do músculo vasto lateral comparado ao protocolo 6-s, resposta não verificada para o músculo reto femural. Além disso, o protocolo 6-s proporcionou maior aumento no desempenho de CIVM a 30^{o} de flexão de joelhos do que o protocolo 2-s (resultado suportado pela análise dos valores médios e individuais). Entretanto, ambos os protocolos de treinamento induziram similares ganhos no desempenho de CIVM a 90^{o} de flexão de joelhos e 1RM. Além disso, foram verificadas diferenças nas relações amplitude EMG-ângulo e força-ângulo durante a primeira e a última sessão de treinamento. Resumindo, os resultados apresentados no Estudo 2 confirmam que a manipulação da duração da repetição promove adaptações crônicas distintas após um período de 14 semanas de treinamento de força.

5 CONSIDERAÇÕES FINAIS

5.1 Conclusões e indicações de pesquisas futuras

Portanto, tendo como base a análise dos valores médios, verificou-se no Estudo 1 que o protocolo TNFM produziu respostas similares de força máxima (1RM e CIVM) e hipertrofia muscular quando comparado ao TFM. Contudo, ao considerar a análise dos dados individuais de AST do músculo vasto lateral e desempenho de resistência de força, um maior número de indivíduos responderam melhor ao TNFM. Esses resultados sugerem que o fato de treinar com repetições até falha muscular não promoveu nenhum ganho adicional de força e hipertrofia muscular quando comparado ao TNFM. Portanto, baseado nos resultados apresentados no presente estudo, o TNFM (realizado com volume de treinamento semelhante ao TFM) pode ser considerado uma melhor estratégia de treinamento para indivíduos não treinados, por induzir adaptações crônicas similares ou até maiores do que o TFM.

Adicionalmente, os resultados apresentados no Estudo 2 revelaram que protocolos de treinamento equiparados com diferentes durações das repetições realizados até a falha muscular, produziram respostas similares de hipertrofia muscular apesar de diferenças nas relações EMG-ângulo e força-ângulo. Entretanto, quando considerados os dados individuais, pode-se concluir que o protocolo 2-s promoveu maior hipertrofia muscular do músculo vasto lateral comparado com o protocolo 6-s. Dessa forma, é possível concluir que um maior volume de treinamento proporcionado pela realização de movimentos mais rápidos até a falha muscular promoveria maior hipertrofia muscular quando comparado ao maior tempo sob tensão durante movimentos mais lentos. Além disso, embora não tenham sido verificadas diferenças significantes no desempenho de 1RM entre os protocolos 2-s e 6-s, os dados de CIVM (30º) fornecem informações sobre as respostas específicas de força por ângulo articular induzidas por diferentes durações das repetições. Os resultados apresentados no presente estudo demonstram que a elevada força exercida no final das ações concêntricas durante o protocolo 6-s pode ter sido determinante para promover um maior aumento no desempenho de CIVM a 30^o do que o protocolo 2-s.

É necessário ressaltar que, os resultados verificados neste trabalho e as conclusões apresentadas nos dois últimos parágrafos são limitados a indivíduos não treinados e a protocolos de treinamento com configurações similares aos realizados nos Estudos 1 e 2. Por exemplo, as respostas de hipertrofia são limitadas ao grupo muscular treinado no exercício extensor de joelhos, mais especificamente, aos músculos analisados (vasto lateral e reto femural). Contudo, são necessárias investigações futuras com indivíduos treinados e incluindo exercícios que contemplem outros grupos musculares para esclarecer o impacto da realização de repetições falha muscular e da manipulação da duração da repetição nas adaptações crônicas associadas ao treinamento de força.

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APÊNDICE 1 - Carta de Submissão para Revista

Cover Letter

Dear Editor In Chief,

I am submitting our manuscript entitled **"Resistance training with different repetition duration to failure: Effect on hypertrophy, strength and muscle activation"** to the Scandinavian Journal of Medicine & Science in Sports.

Our manuscript aimed to investigate the effects of two 14-week resistance training protocols each with a different repetition duration performed to muscle failure on gains in strength and muscle hypertrophy as well as on normalized electromyography (EMG) amplitude and force-angle relationships. This is the first study that controlled match intensity, set and rest between set of the resistance training protocol allowing to narrow down the variables responsible to the results. Specifically, our design allows us to show the importance of repetition duration to resistance training. Thus, we strongly believe that our manuscript will contribute to field by showing the importance of controlling repetition duration when performing resistance training until muscle failure.

"This manuscript contains material that is original and not previously published in text or on the Internet, nor is it being considered elsewhere until a decision is made as to its acceptability by Scandinavian Journal of Medicine & Science in Sports."

Best Regards

PhD. Mauro Heleno Chagas
Escola de Educação Física, Fisioterapia e Terapia Ocupacional
Universidade Federal de minas Gerais.
Av. Antônio Carlos, 6627, Belo Horizonte 31270-901
Minas Gerais, Brazil.
e-mail: mauroufmg@hotmail.com
Telephone: (+55 31) 3409-7443
Fax number: (+55 31) 3409-7443

APÊNDICE 2: Lista de tabelas de dados absolutos do Estudo 1

Tabela 1 - Somatório das áreas de secção transversa do músculo vasto lateral (cm^2) (Estudo 1)

Voluntário	Tempo	Protocolo	
		FM	NFM
1	Pré	60,45	62,55
	Pós	59,86	63,76
2	Pré	53,52	46,32
	Pós	58,50	65,85
3	Pré	43,16	35,17
	Pós	65,82	56,06
4	Pré	65,87	63,81
	Pós	74,58	74,79
5	Pré	50,62	59,42
	Pós	59,72	70,64
6	Pré	58,01	55,49
	Pós	65,90	66,95
7	Pré	59,27	53,50
	Pós	67,24	60,83
8	Pré	72,77	68,19
	Pós	83,33	74,87
9	Pré	107,26	104,31
	Pós	112,91	117,68
10	Pré	71,79	68,85
	Pós	80,21	80,19

Legenda: Pré - pré-teste; Pós - pós-teste; FM - protocolo realizado até a falha muscular; NFM - protocolo realizado sem alcançar a falha muscular.

Tabela 2 - Somatório das áreas de secção transversa do músculo reto femural (cm^2) (Estudo 1)

Voluntário	Tempo	Protocolo	
		FM	NFM
1	Pré	20,61	20,33
	Pós	22,38	21,84
2	Pré	8,52	11,54
	Pós	10,91	12,82
3	Pré	11,26	9,41
	Pós	14,09	12,04
4	Pré	20,61	16,45
	Pós	22,38	20,20
5	Pré	10,32	10,74
	Pós	12,13	14,53
6	Pré	18,10	17,21
	Pós	20,46	19,82
7	Pré	17,09	15,99
	Pós	18,93	16,86
8	Pré	11,58	12,69
	Pós	16,16	16,90
9	Pré	29,25	27,51
	Pós	30,94	33,77
10	Pré	13,65	14,92
	Pós	13,91	17,91

Legenda: Pré - pré-teste; Pós - pós-teste; FM - protocolo realizado até a falha muscular; NFM - protocolo realizado sem alcançar a falha muscular.

Tabela 3 - Desempenho no teste de uma repetição máxima - 1RM (kg) (Estudo 1)

Voluntário	Tempo	Protocolo	
		FM	NFM
1	Pré	17,00	16,00
	Pós	18,62	20,62
2	Pré	26,94	30,64
	Pós	29,58	35,34
3	Pré	27,00	26,48
	Pós	27,00	26,48
4	Pré	33,82	35,50
	Pós	42,30	43,42
5	Pré	37,60	32,80
	Pós	37,60	41,30
6	Pré	50,64	51,12
	Pós	51,14	49,12
7	Pré	29,74	26,42
	Pós	39,58	35,44
8	Pré	23,84	25,32
	Pós	24,92	25,92
9	Pré	28,16	30,14
	Pós	36,60	34,40
10	Pré	24,24	23,76
	Pós	27,58	26,38

Legenda: Pré - pré-teste; Pós - pós-teste; FM - protocolo realizado até a falha muscular; NFM - protocolo realizado sem alcançar a falha muscular; kg - quilograma.

Tabela 4 - Desempenho no teste de contração isométrica voluntária máxima - CIVM (N) (Estudo 1)

Voluntário	Tempo	Protocolo	
		FM	NFM
1	Pré	416,10	425,71
	Pós	478,95	463,98
2	Pré	562,33	630,42
	Pós	692,41	746,60
3	Pré	564,98	549,64
	Pós	620,20	591,63
4	Pré	773,11	675,73
	Pós	855,95	859,87
5	Pré	713,32	683,52
	Pós	757,61	794,65
6	Pré	871,26	843,22
	Pós	898,72	849,46
7	Pré	565,07	511,48
	Pós	716,91	661,22
8	Pré	597,16	553,34
	Pós	693,43	664,76
9	Pré	604,38	630,57
	Pós	741,38	686,03
10	Pré	625,16	587,64
	Pós	655,27	658,34

Legenda: Pré - pré-teste; Pós - pós-teste; FM - protocolo realizado até a falha muscular; NFM - protocolo realizado sem alcançar a falha muscular; N - Newton.

Tabela 5 - Desempenho no teste de resistência de força - NMR (número de repetições) (Estudo 1)

Voluntário	Tempo	Protocolo	
		FM	NFM
1	Pré	9	7
	Pós	9	7
2	Pré	8	7
	Pós	6	8
3	Pré	9	9
	Pós	13	12
4	Pré	5	5
	Pós	5	6
5	Pré	7	9
	Pós	7	7
6	Pré	7	8
	Pós	9	8
7	Pré	7	6
	Pós	11	9
8	Pré	8	6
	Pós	8	8
9	Pré	7	6
	Pós	8	8
10	Pré	8	6
	Pós	11	12

Legenda: Pré - pré-teste; Pós - pós-teste; FM - protocolo realizado até a falha muscular; NFM - protocolo realizado sem alcançar a falha muscular.

APÊNDICE 3: Lista de tabelas de dados absolutos do Estudo 2

Tabela 6 - Somatório das áreas de secção transversa do músculo vasto lateral (cm^2) (Estudo 2)

Voluntário	Tempo	Protocolo	
		2-s	6-s
1	Pré	74,79	64,54
	Pós	90,36	82,83
2	Pré	81,34	77,24
	Pós	93,09	88,07
3	Pré	73,83	62,63
	Pós	87,30	74,47
4	Pré	55,45	70,39
	Pós	70,16	77,62
5	Pré	45,73	41,41
	Pós	55,05	50,00
6	Pré	59,21	65,28
	Pós	60,28	65,34
7	Pré	46,59	47,47
	Pós	62,10	61,59
8	Pré	75,96	80,72
	Pós	97,39	95,25
9	Pré	48,87	65,61
	Pós	60,90	70,78
10	Pré	71,56	67,87
	Pós	76,13	81,77

Legenda: Pré - pré-teste; Pós - pós-teste; 2-s - protocolo realizado com duração da repetição de 2s até a falha muscular; 6-s - protocolo realizado com duração da repetição de 6s até a falha muscular.

Tabela 7 - Somatório das áreas de secção transversa do músculo reto femural (cm^2) (Estudo 2)

Voluntário	Tempo	Protocolo	
		2-s	6-s
1	Pré	20,54	18,80
	Pós	24,75	23,52
2	Pré	23,90	33,33
	Pós	29,90	34,20
3	Pré	14,80	14,78
	Pós	20,86	17,42
4	Pré	16,56	15,21
	Pós	19,32	17,34
5	Pré	10,14	10,02
	Pós	14,32	13,30
6	Pré	14,52	15,06
	Pós	15,52	15,83
7	Pré	16,58	14,24
	Pós	22,29	19,62
8	Pré	14,23	14,13
	Pós	18,90	20,38
9	Pré	17,85	16,96
	Pós	20,22	19,37
10	Pré	20,08	21,25
	Pós	24,25	25,38

Legenda: Pré - pré-teste; Pós - pós-teste; 2-s - protocolo realizado com duração da repetição de 2s até a falha muscular; 6-s - protocolo realizado com duração da repetição de 6s até a falha muscular.

Tabela 8 - Desempenho no teste de uma repetição máxima - 1RM (kg) (Estudo 2)

Voluntário	Tempo	Protocolo	
		2-s	6-s
1	Pré	34,72	33,26
	Pós	39,60	42,20
2	Pré	32,76	32,58
	Pós	35,38	33,18
3	Pré	46,38	43,28
	Pós	52,72	48,98
4	Pré	35,50	31,78
	Pós	35,50	31,78
5	Pré	24,30	23,30
	Pós	27,50	27,36
6	Pré	17,14	16,14
	Pós	20,16	18,16
7	Pré	20,14	20,14
	Pós	22,94	22,94
8	Pré	27,88	28,42
	Pós	28,62	29,64
9	Pré	29,60	29,60
	Pós	34,30	33,30
10	Pré	30,68	28,68
	Pós	38,52	37,50

Legenda: Pré - pré-teste; Pós - pós-teste; 2-s - protocolo realizado com duração da repetição de 2s até a falha muscular; 6-s - protocolo realizado com duração da repetição de 6s até a falha muscular; kg - quilograma.

Tabela 9 - Desempenho no teste de contração isométrica voluntária máxima a 30º de flexão de joelho - CIVM 30º (N) (Estudo 2)

Voluntário	Tempo	Protocolo	
		2-s	6-s
1	Pré	431,25	492,82
	Pós	460,67	528,46
2	Pré	385,87	426,75
	Pós	434,09	498,70
3	Pré	606,14	643,31
	Pós	602,51	629,30
4	Pré	578,94	521,32
	Pós	594,37	558,65
5	Pré	395,87	425,35
	Pós	411,05	494,83
6	Pré	292,77	298,05
	Pós	286,88	321,84
7	Pré	416,46	362,35
	Pós	423,42	442,60
8	Pré	471,71	480,92
	Pós	438,30	494,99
9	Pré	380,18	340,10
	Pós	372,40	347,12
10	Pré	433,67	454,91
	Pós	457,82	455,89

Legenda: Pré - pré-teste; Pós - pós-teste; 2-s - protocolo realizado com duração da repetição de 2s até a falha muscular; 6-s - protocolo realizado com duração da repetição de 6s até a falha muscular; N - Newton.

Tabela 10 - Desempenho no teste de contração isométrica voluntária máxima a 90º de flexão de joelho - CIVM 90º (N) (Estudo 2)

Voluntário	Tempo	Protocolo	
		2-s	6-s
1	Pré	570,97	469,96
	Pós	595,82	601,57
2	Pré	613,66	571,15
	Pós	755,18	685,98
3	Pré	760,31	765,08
	Pós	878,11	771,41
4	Pré	648,99	636,01
	Pós	724,05	630,35
5	Pré	443,32	447,51
	Pós	452,04	487,37
6	Pré	391,77	346,80
	Pós	460,58	425,17
7	Pré	335,97	327,43
	Pós	413,76	444,48
8	Pré	627,24	580,80
	Pós	700,95	614,12
9	Pré	391,73	398,85
	Pós	462,40	446,37
10	Pré	558,93	458,32
	Pós	629,68	645,56

Legenda: Pré - pré-teste; Pós - pós-teste; 2-s - protocolo realizado com duração da repetição de 2s até a falha muscular; 6-s - protocolo realizado com duração da repetição de 6s até a falha muscular; N - Newton.

APÊNDICE 4 - TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO

Venho por meio deste, convidá-lo a participar da pesquisa intitulada *"**Influência do treinamento de força realizado até a falha muscular e sua interação com diferentes durações da repetição nas respostas de hipertrofia e força muscular**",* que será realizada no Laboratório do Treinamento na Musculação da Escola de Educação Física, Fisioterapia e Terapia Ocupacional – UFMG sob responsabilidade dos pesquisadores Prof. Dr. Mauro Heleno Chagas (Orientador) e Lucas Túlio de Lacerda (Doutorando).

A pesquisa consistirá na realização de 40 sessões de treinamento na musculação, que serão executadas com uma frequência de cinco vezes na semana. Será analisado o efeito de diferentes protocolos de treinamento durante esse período, avaliando as respostas de força e ativação muscular de membros inferiores, como também o aumento da massa muscular envolvida no exercício banco extensor de joelhos. Para que seja possível realizar tais avaliações, será necessário que você seja submetido à testes de força máxima no exercício extensor de joelhos e à exames de ultrassonografia no quadríceps femoral antes da primeira e após a última semana de treinamento.

Um objetivo adicional da pesquisa é investigar as respostas neuromusculares decorrentes dos protocolos de treinamento selecionados neste estudo. Para isso, em dois dos dias de exercício, haverá a mensuração da atividade eletromiográfica do reto femoral, vasto lateral e vasto medial (músculos que compõe o quadríceps femoral) por meio de eletrodos de superfície. Será realizada a tricotomização (raspagem dos pêlos) na região da coxa para a colocação de eletrodos de superfície.

A justificativa da realização deste estudo está associada à possibilidade de entender melhor a estruturação de programas de treinamento na musculação, repercutindo na qualidade da elaboração desse tipo de treinamento tanto para pessoas que o procuram para fins esportivos quanto para a própria saúde. Sua participação colaborará para que se atinja tal objetivo. Além disso, você se beneficiará da realização de um programa de exercícios orientado por profissionais de Educação Física.

Por se tratar de uma pesquisa que realizará protocolos de treinamento de força na musculação, há risco de ocorrência de lesões musculoesqueléticas e traumatismos. Estes riscos são similares ao de uma prática convencional de exercícios de força na musculação. Considerando que tais práticas serão supervisionadas, a ocorrência de problemas se torna ainda mais reduzida. Estes eventos ocorrem em baixa frequência em condições controladas e quando realizadas por pessoas capacitadas. Caso ocorra algum trauma/lesão decorrente de realização dos protocolos de treinamento, os pesquisadores levarão o voluntário, em carro próprio, para o serviço de pronto atendimento da Universidade Federal de Minas Gerais ou acionarão o Serviço Médico de Atendimento de Urgência (SAMU).

Será garantido o anonimato dos voluntários e os dados obtidos serão utilizados exclusivamente para fins de pesquisa pelo Laboratório do Treinamento na Musculação. Os seus dados serão disponibilizados para você ao final da pesquisa. Além disso, você também poderá se recusar a participar desse estudo ou abandoná-lo a qualquer momento, sem precisar justificar-se e sem gerar qualquer constrangimento ou transtorno.

Destacamos que não está prevista qualquer forma de remuneração para participar do estudo. Além disso, todas as despesas especificamente relacionadas à pesquisa são de responsabilidade do Laboratório do Treinamento na Musculação. Por fim, os pesquisadores podem decidir sobre a exclusão de qualquer voluntário do estudo por razões científicas, sobre as quais os mesmos serão devidamente informados.

Você dispõe de total liberdade para esclarecer as questões que possam surgir durante a pesquisa. Para qualquer dúvida referente aos aspectos éticos que envolvem a sua participação nessa pesquisa, por favor, entre em contato com os pesquisadores responsáveis pelo estudo: Dr. Mauro Heleno Chagas, tel. 3409-2334 e Ms. Lucas Túlio de Lacerda, tel. 98832 0283 ou com o Comitê de Ética em Pesquisa: Av. Presidente Antônio Carlos, 6627 – Unidade Administrativa II – 2º andar, sl. 2005 cep. 31270901 - BH/MG; tel.: 34094592; email: *coep@prpq.ufmg.br*.

Após ter todas as suas dúvidas esclarecidas pelos pesquisadores responsáveis, se você concordar em participar dessa pesquisa, você deverá assinar este termo em duas vias, sendo que uma via permanecerá com você e outra será destinada aos pesquisadores responsáveis.

CONSENTIMENTO

Acredito ter sido suficientemente informado a respeito de todos os dados que li e concordo, voluntariamente, em participar do estudo *"Influência do treinamento de força realizado até a falha muscular e com diferentes durações da repetição nas respostas de hipertrofia e força muscular"*, que será realizado no Laboratório do Treinamento na Musculação da Escola de Educação Física, Fisioterapia e Terapia Ocupacional da Universidade Federal de Minas Gerais. Além disso, estou ciente de que posso me recusar a participar deste estudo e/ou abandoná-lo a qualquer momento, sem precisar me justificar e sem que isso seja motivo de qualquer tipo de constrangimento para mim.

Belo Horizonte _____ de ____________de 2018

Assinatura do voluntário: ____

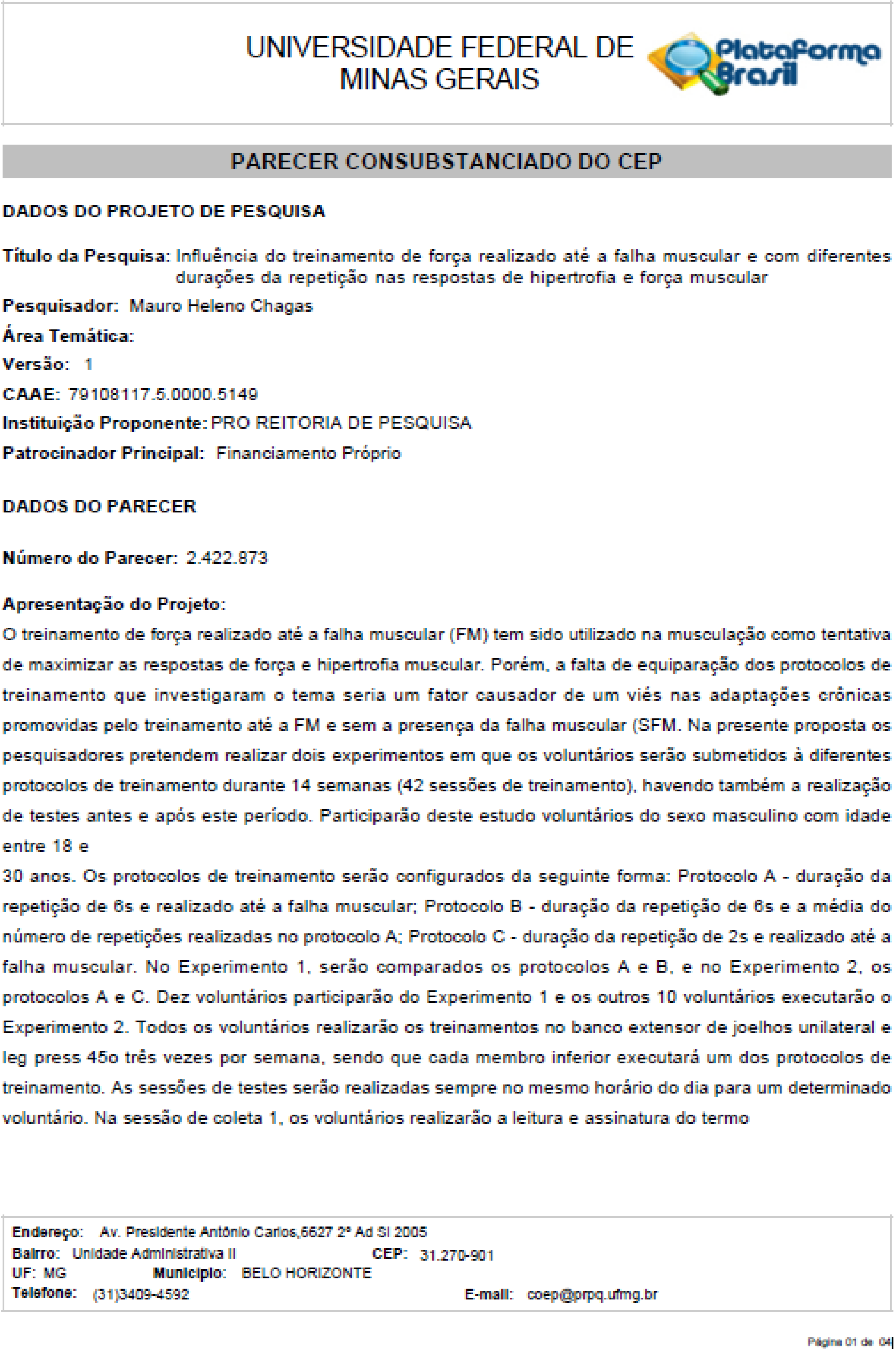
Nome do voluntário: ____

Declaro que expliquei os objetivos deste estudo para o voluntário, dentro dos limites dos meus conhecimentos científicos.

____

Lucas Túlio de Lacerda
Doutorando em Ciências do Esporte – EEFFTO/ UFMG

ANEXO 1 - Parecer Consubstanciado do Comitê de Ética



UNIVERSIDADE FEDERAL DE
MINAS GERAIS

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Influência do treinamento de força realizado até a falha muscular e com diferentes durações da repetição nas respostas de hipertrofia e força muscular

Pesquisador: Mauro Heleno Chagas

Área Temática:

Versão: 1

CAAE: 79108117.5.0000.5149

Instituição Proponente: PRO REITORIA DE PESQUISA

Patrocinador Principal: Financiamento Próprio

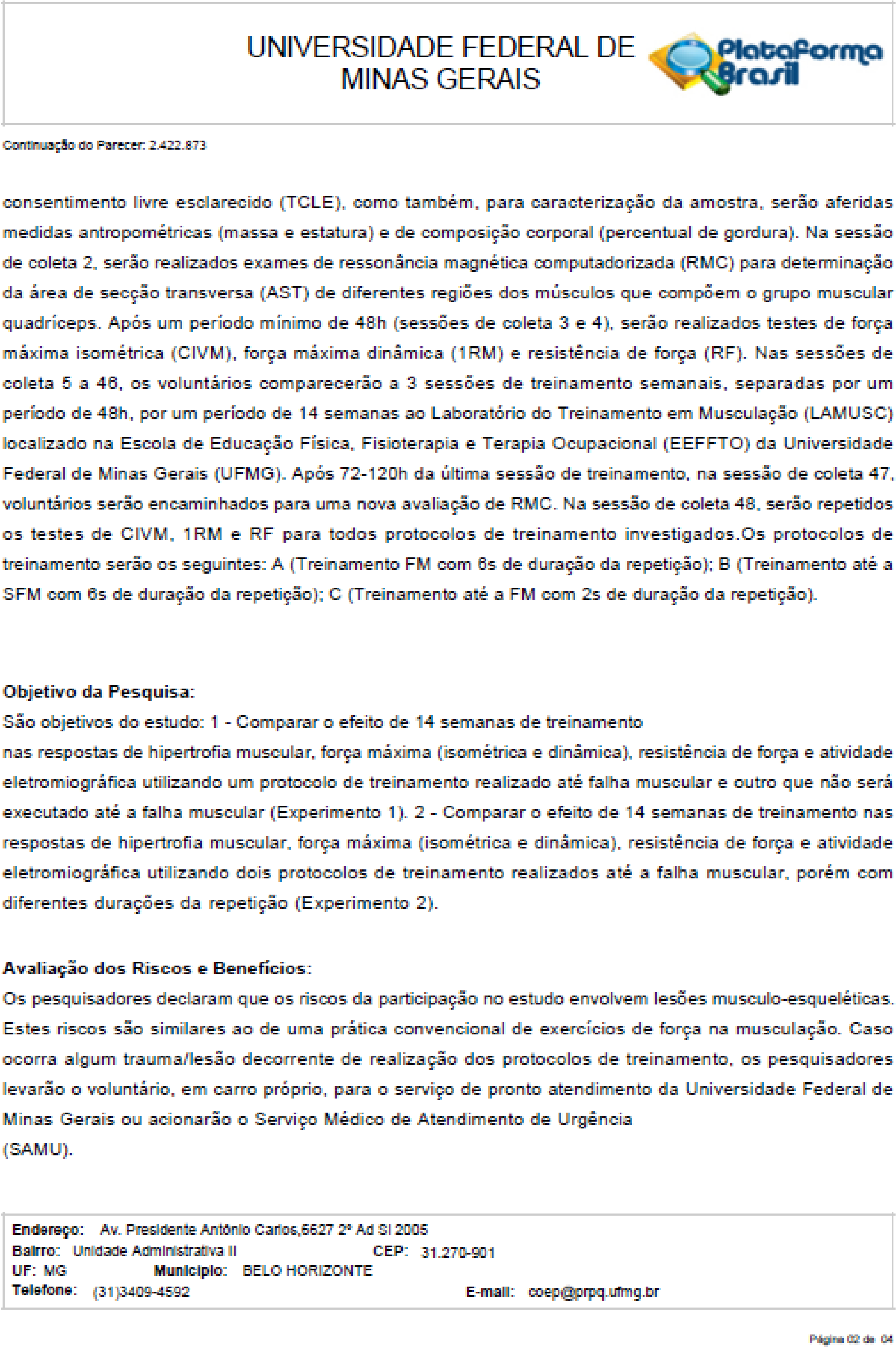
DADOS DO PARECER

Número do Parecer: 2.422.873

Apresentação do Projeto:

O treinamento de força realizado até a falha muscular (FM) tem sido utilizado na musculação como tentativa de maximizar as respostas de força e hipertrofia muscular. Porém, a falta de equiparação dos protocolos de treinamento que investigaram o tema seria um fator causador de um viés nas adaptações crônicas promovidas pelo treinamento até a FM e sem a presença da falha muscular (SFM. Na presente proposta os pesquisadores pretendem realizar dois experimentos em que os voluntários serão submetidos à diferentes protocolos de treinamento durante 14 semanas (42 sessões de treinamento), havendo também a realização de testes antes e após este período. Participarão deste estudo voluntários do sexo masculino com idade entre 18 e

30 anos. Os protocolos de treinamento serão configurados da seguinte forma: Protocolo A - duração da repetição de 6s e realizado até a falha muscular; Protocolo B - duração da repetição de 6s e a média do número de repetições realizadas no protocolo A; Protocolo C - duração da repetição de 2s e realizado até a falha muscular. No Experimento 1, serão comparados os protocolos A e B, e no Experimento 2, os protocolos A e C. Dez voluntários participarão do Experimento 1 e os outros 10 voluntários executarão o Experimento 2. Todos os voluntários realizarão os treinamentos no banco extensor de joelhos unilateral e leg press 45o três vezes por semana, sendo que cada membro inferior executará um dos protocolos de treinamento. As sessões de testes serão realizadas sempre no mesmo horário do dia para um determinado voluntário. Na sessão de coleta 1, os voluntários realizarão a leitura e assinatura do termo



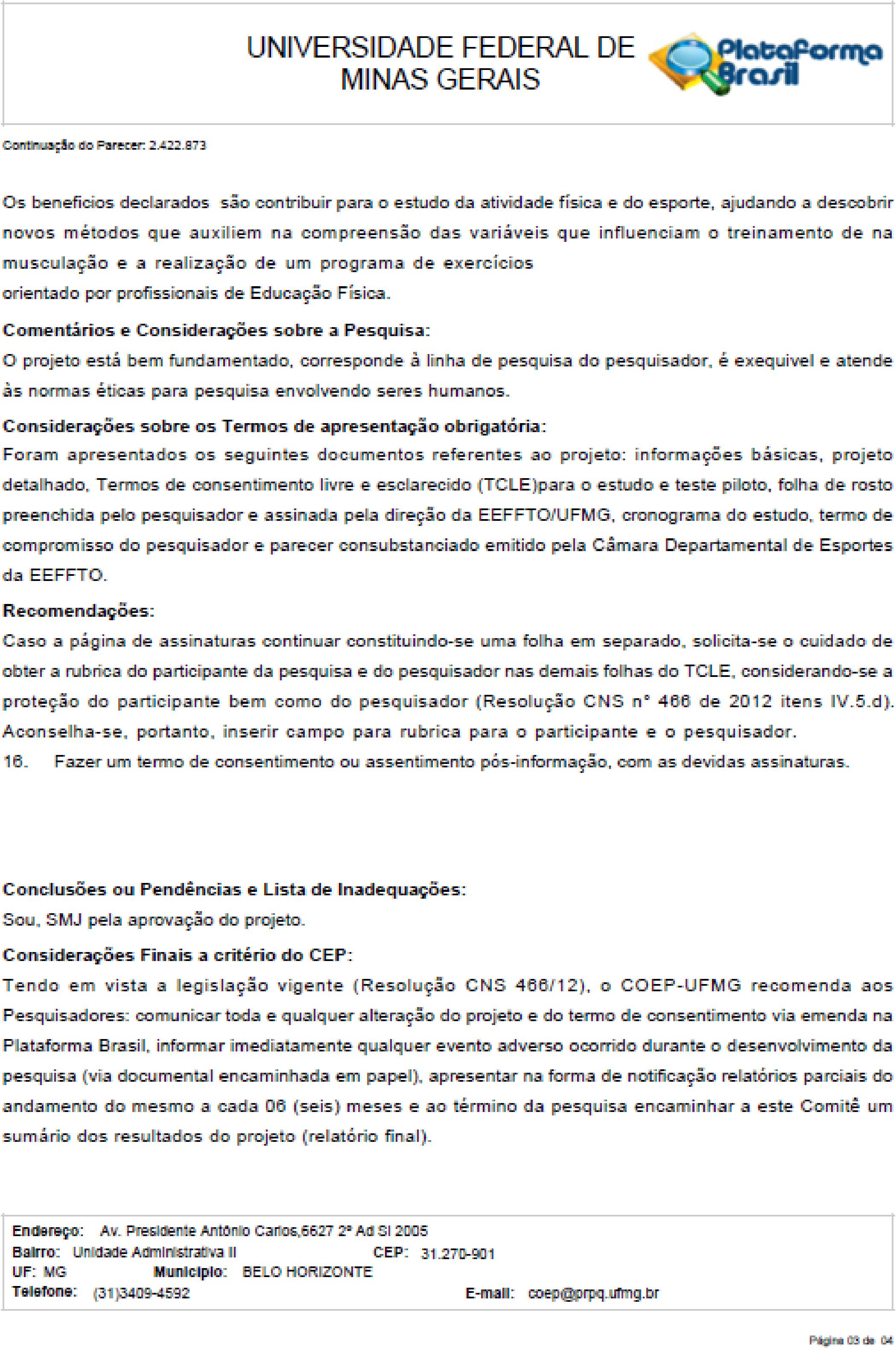
consentimento livre esclarecido (TCLE), como também, para caracterização da amostra, serão aferidas medidas antropométricas (massa e estatura) e de composição corporal (percentual de gordura). Na sessão de coleta 2, serão realizados exames de ressonância magnética computadorizada (RMC) para determinação da área de secção transversa (AST) de diferentes regiões dos músculos que compõem o grupo muscular quadríceps. Após um período mínimo de 48h (sessões de coleta 3 e 4), serão realizados testes de força máxima isométrica (CIVM), força máxima dinâmica (1RM) e resistência de força (RF). Nas sessões de coleta 5 a 46, os voluntários comparecerão a 3 sessões de treinamento semanais, separadas por um período de 48h, por um período de 14 semanas ao Laboratório do Treinamento em Musculação (LAMUSC) localizado na Escola de Educação Física, Fisioterapia e Terapia Ocupacional (EEFFTO) da Universidade Federal de Minas Gerais (UFMG). Após 72-120h da última sessão de treinamento, na sessão de coleta 47, voluntários serão encaminhados para uma nova avaliação de RMC. Na sessão de coleta 48, serão repetidos os testes de CIVM, 1RM e RF para todos protocolos de treinamento investigados.Os protocolos de treinamento serão os seguintes: A (Treinamento FM com 6s de duração da repetição); B (Treinamento até a SFM com 6s de duração da repetição); C (Treinamento até a FM com 2s de duração da repetição).

Objetivo da Pesquisa:

São objetivos do estudo: 1 - Comparar o efeito de 14 semanas de treinamento
nas respostas de hipertrofia muscular, força máxima (isométrica e dinâmica), resistência de força e atividade eletromiográfica utilizando um protocolo de treinamento realizado até falha muscular e outro que não será executado até a falha muscular (Experimento 1). 2 - Comparar o efeito de 14 semanas de treinamento nas respostas de hipertrofia muscular, força máxima (isométrica e dinâmica), resistência de força e atividade eletromiográfica utilizando dois protocolos de treinamento realizados até a falha muscular, porém com diferentes durações da repetição (Experimento 2).

Avaliação dos Riscos e Benefícios:

Os pesquisadores declaram que os riscos da participação no estudo envolvem lesões musculo-esqueléticas. Estes riscos são similares ao de uma prática convencional de exercícios de força na musculação. Caso ocorra algum trauma/lesão decorrente de realização dos protocolos de treinamento, os pesquisadores levarão o voluntário, em carro próprio, para o serviço de pronto atendimento da Universidade Federal de Minas Gerais ou acionarão o Serviço Médico de Atendimento de Urgência
(SAMU).



Os beneficios declarados são contribuir para o estudo da atividade física e do esporte, ajudando a descobrir novos métodos que auxiliem na compreensão das variáveis que influenciam o treinamento de na musculação e a realização de um programa de exercícios
orientado por profissionais de Educação Física.

Comentários e Considerações sobre a Pesquisa:

O projeto está bem fundamentado, corresponde à linha de pesquisa do pesquisador, é exequivel e atende às normas éticas para pesquisa envolvendo seres humanos.

Considerações sobre os Termos de apresentação obrigatória:

Foram apresentados os seguintes documentos referentes ao projeto: informações básicas, projeto detalhado, Termos de consentimento livre e esclarecido (TCLE)para o estudo e teste piloto, folha de rosto preenchida pelo pesquisador e assinada pela direção da EEFFTO/UFMG, cronograma do estudo, termo de compromisso do pesquisador e parecer consubstanciado emitido pela Câmara Departamental de Esportes da EEFFTO.

Recomendações:

Caso a página de assinaturas continuar constituindo-se uma folha em separado, solicita-se o cuidado de obter a rubrica do participante da pesquisa e do pesquisador nas demais folhas do TCLE, considerando-se a proteção do participante bem como do pesquisador (Resolução CNS n° 466 de 2012 itens IV.5.d). Aconselha-se, portanto, inserir campo para rubrica para o participante e o pesquisador.

16. Fazer um termo de consentimento ou assentimento pós-informação, com as devidas assinaturas.

Conclusões ou Pendências e Lista de Inadequações:

Sou, SMJ pela aprovação do projeto.

Considerações Finais a critério do CEP:

Tendo em vista a legislação vigente (Resolução CNS 466/12), o COEP-UFMG recomenda aos Pesquisadores: comunicar toda e qualquer alteração do projeto e do termo de consentimento via emenda na Plataforma Brasil, informar imediatamente qualquer evento adverso ocorrido durante o desenvolvimento da pesquisa (via documental encaminhada em papel), apresentar na forma de notificação relatórios parciais do andamento do mesmo a cada 06 (seis) meses e ao término da pesquisa encaminhar a este Comitê um sumário dos resultados do projeto (relatório final).