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# TREINAMENTO DE FORÇA DE BAIXA INTENSIDADE REALIZADO ATÉ A FALHA MUSCULAR OU PRÓXIMO À FALHA NÃO PROMOVE GANHOS ADICIONAIS DE FORÇA, HIPERTROFIA MUSCULAR E FUNCIONALIDADE DE IDOSOS

**São Carlos**
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Dissertação apresentada à banca examinadora como requisito para obtenção do título de mestre pelo Programa Interinstitucional de Pós-Graduação em Ciências Fisiológicas da Universidade Federal de São Carlos.

Orientação: Prof. Dr. Cleiton Augusto Libardi.

São Carlos

2019

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*"Ninguém baterá tão forte quanto a vida. Porém, não se trata de quão forte pode bater, se trata de quão forte pode ser atingido e continuar seguindo em frente. É assim que a vitória é conquistada."*

**Rocky Balboa**

# RESUMO

**Introdução:** O objetivo do presente estudo foi comparar os efeitos de protocolos de treinamento de força (TF) de baixa intensidade realizados até a falha muscular (FAI), até a interrupção voluntária (VOL) e de baixo volume (FIX) com repetições fixas na força e hipertrofia muscular e na funcionalidade de idosos. **Métodos:** Quarenta e um idosos (60-77 anos) foram randomizados em três grupos de TF: FAI, VOL e FIX. Os três grupos completaram 12 semanas de TF à 40% de uma repetição máxima (1-RM). Os protocolos de treinamento eram compostos por três séries na cadeira extensora, leg press e mesa flexora, realizados duas vezes na semana, onde FAI realizava repetições até a falha concêntrica, VOL realizava repetições até a interrupção voluntária e FIX realizava 10 repetições por série. A força foi avaliada através do teste de 1-RM, área de secção transversa (CSA) por ultrassonografia e funcionalidade foi avaliada pelos testes de levantar da cadeira (CS), velocidade de marcha habitual (HGS) e máxima (MGS), *timed up-and-go* (TUG) e seis minutos de caminhada (6MWT). Todas as avaliações foram realizadas antes e depois do período de treinamento. **Resultados:** Os resultados mostraram aumentos similares nos valores de 1-RM ($P$ < 0.0001) para todos os grupos do Pre para o Post. Não foram observados aumentos significantes na CSA. Além disso, todos os grupos mostraram aumentos similares para CS e HGS e não houveram mudanças significantes para os testes de MGS, TUG e 6MWT para nenhum grupo. **Conclusão:** Protocolos de baixa intensidade não precisam ser realizados até à falha muscular, ou próximos à falha para promoverem ganhos significativos em força e em alguns dos parâmetros funcionais em idosos em estágios iniciais de treinamento.



**Palavras-chave:** Falha concêntrica—baixa intensidade—exercício

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# APRESENTAÇÃO

Essa dissertação é composta por um manuscrito original intitulado "*Low-load resistance training performed to muscle failure or near muscle failure do not promote additional gains on strength, muscle hypertrophy and functionality of older adults*", o qual está formatado de acordo com as normas do "*The Journals of Phisiology: Medical Sciences*" *(Impact factor: 4.902)*.

**LOW-LOAD RESISTANCE TRAINING PERFORMED TO MUSCLE FAILURE OR NEAR MUSCLE FAILURE DO NOT PROMOTE ADDITIONAL GAINS IN MUSCLE STRENGTH, HYPERTROPHY AND FUNCTIONALITY OF OLDER ADULTS**

## ABSTRACT

**Background:** The present study compared the effects of low-load resistance training (RT) protocols performed to failure (FAI), to voluntary interruption (VOL) or lower-volume fixed repetitions (FIX) on muscle strength, hypertrophy and functionality in older adults**. Methods:** Forty-one older adults (60-77 years) were randomized into three RT groups: FAI, VOL and FIX. The three groups completed 12 weeks of RT at 40% of the one-repetition maximum (1-RM). Training protocols involved three sets in knee extension, leg press and leg curl, performed twice a week, in which in FAI protocol repetitions were performed to muscle failure, in VOL, repetitions were performed to voluntary interruption and FIX performed 10 repetitions per set. Muscle strength was measured through 1-RM, cross-sectional area (CSA) by ultrasonography and functionality through chair stand (CS), habitual and maximal gait speed (HGS and MGS, respectively), timed up-and-go (TUG) and 6-minute walking test (6MWT). All the assessments were performed pre- and post-training. **Results:** The results showed similar increases from Pre to Post in 1-RM values for all groups ($P < 0.0001$). There were no significant increases in CSA. Additionally, all groups demonstrated significant and similar increases in CS and HGS and there were no significant changes in MGS, TUG and 6MWT for any group. **Conclusions:** Low-load protocols do not require to be performed to muscle failure or near failure to promote significant improvements in strength and some of the functional parameters in initial stages of training in older adults.

**Key words:** concentric failure - low-intensity - exercise.

**INTRODUCTION**

The ageing process is associated to decreases in muscle strength and mass (Doherty, 2003), as well as in the rate of torque development (RTD) (Libardi et al., 2016). Such reductions may lead to functional impairments, increasing the risk of falling and interfering in activities of daily living (ACSM, 2009).

A widely recommended strategy to mitigate the ageing-related alterations in muscle morphology and function is the regular practice of resistance training (RT) (ACSM, 2009). It is known that RT may maximize gains in muscle strength and hypertrophy even using low-load protocols (e.g., < 50% of one-repetition maximum [1-RM]), as long as the exercise is performed to muscle failure (Mitchell et al., 2012; Van Roie et al., 2013; Nobrega et al., 2018). However, exercising to the point of muscle failure may acutely exacerbate blood pressure raises (Libardi et al., 2017), and also increase the possibility of overtraining and the occurrence of musculoskeletal injuries when performed for long periods (Stone et al., 1996; Nobrega and Libardi, 2016). In fact, according to the American College of Sports Medicine recommendation for older adults, RT must be carried out until a substantial fatigue is installed, and should be interrupted prior to muscle failure (ACSM, 2009). In this sense, our group demonstrated that muscle strength gains and hypertrophy produced by low-load RT protocols performed to voluntary interruption (i.e., when the participant voluntarily interrupts a set of exercise after reaching a considerable fatigue, before muscle failure) are similar to failure protocols, even producing lower muscle fatigue and number of repetitions (Nobrega et al., 2018). However, the effects of the voluntary interruption in older adults are still unknown.

Although voluntary interruption seems to be an interesting strategy to avoid the aforementioned intercurrences in older adults, it may produce a significant training volume, as the number of repetitions is comparable to protocols to muscle failure (Nobrega et al., 2018), which may not be aligned to the recommendations to older adults in early stages of RT (Garber et al., 2011). Interestingly, RT using low-load and a fixed low number of repetitions (i.e., distant to the point of muscle failure) may represent an attractive strategy for previously untrained older individuals. It has been demonstrated that even being interrupted relatively far from the point of muscle failure may improve the performance of the activities of daily living, even without maximizing the gains in muscle strength and hypertrophy (ACSM, 2009; Reid et al., 2015). However, it remains unclear if the adaptations promoted by a low-load and a lower and fixed number of repetitions could be comparable to low-load RT protocols performed to muscle failure or voluntary interruption.

Thus, the aim of our study was to compare the effects of low-load RT protocols performed to muscle failure (FAI) and voluntary interruption (VOL) with a RT protocol using low-load and fixed low number of repetitions (FIX) on muscle strength, hypertrophy and functionality of older adults. Our hypothesis is that FIX will be capable of promoting similar improvements in functionality even inducing lower gains in muscle strength and hypertrophy than FAI and VOL protocols.

## METHODS

### Participants

Forty-one older adults (Men: n = 18, 67 ± 6 years, 169 ± 6.5 cm, 78.7 ± 9.3 kg and Women: n = 23, 64 ± 3 years, 157 ± 5.1 cm, 67 ± 9.2 kg) were recruited for this study. After to receive the study information, all the participants have signed an informed consent and underwent the stress electrocardiogram test to verify if there was any non-reported abnormality – which was conducted by a physician. To match our inclusion criteria participants should be absent from any RT activity in the last 6 months and were oriented to not perform any strenuous activities during the trial. Exclusion criteria involved cardiovascular diseases (e.g., blood vessel diseases, coronary artery disease, arrhythmias), use of pacemaker, diabetes and any disease that could restrict the practice of RT (Nelson et al., 2007). There were three dropouts during the study, one for health issues and other two for personal reasons. Thus, thirty-eight participants have completed all the training sessions and assessments. All procedures executed in our study were approved and were in accordance with the institutional ethical committee (082446/2017) and with the Declaration of Helsinki.

**Experimental design**

Initially, participants underwent cross-section area (CSA) of vastus lateralis by ultrasound. Twenty-four hours later, the RTD was assessed through a ballistic test in an isokinetic dynamometer and an array of functional tests. After seventy-two hours, all the functional tests were repeated. Seventy-two hours later, all the participants were familiarized with the 1-RM test in three exercises, respecting the following order: knee extension (KE), leg press (LP) and leg curl (LC). The 1-RM tests were performed every seventy-two hours until the values differed less than 5% from the previous test, to prevent from the learning effect. Thereafter, the subjects were randomized in a balanced way, through the 1-RM and CSA baseline data, into one of the three experimental protocols: Low-load RT performed to failure (FAI, n = 13), low-load RT carried out until volitional interruption (VOL, n = 12) and low-load RT performed with fixed repetitions (FIX, n = 13). To ensure that the participants assimilated the instructions provided for each of the training protocols, a familiarization session was carried out prior to the beginning of the training period. Following, seventy-two hours later, the participants started training twice a week, for 12 weeks. At the week 6, seventy-two hour after the twelfth session, another 1-RM test was performed to adjust the training loads. After 12 weeks (24 sessions), all the assessments were performed after seventy-two hour from the last session, respecting the same order and time intervals.

**Maximal dynamic muscle strength (1-RM)**

Maximal dynamic strength was assessed through bilateral 1-RM tests, performed in three exercises at the same day and the following order: KE, LP and LC. In accordance with Brown and Weir (2001) protocol, participants warmed up for 5 minutes in a cycle ergometer between 20 and 25 $km \cdot h^{-1}$. For specific warming up, participants performed 8 repetitions at 50% of the estimated 1-RM and 3 repetitions at 70% of the estimated 1-RM, sets were separated by 2 minutes of rest. The 1-RM test was composed by 5 attempts in each of the three exercises, with 3 minutes of rest 3 minutes between attempts and exercises. The results were presented for pre- and post-training as the sum of the 1-RM values for all the three exercises together. The Coefficient of Variation (CV) and the Typical Error (TE) between tests were 1.7% and 1.0 kg in KE, 1.5% and 3.5 kg in LP and 2.2% and 0.8 kg in LC, respectively.

**Muscle cross-sectional area (CSA)**

Muscle CSA of *vastus lateralis* was measured through a B-mode ultrasonography imaging with a 7.5 MHz linear-array probe (Mysono U6 EX; Samsung, São Paulo, Brazil) as described in Lixandrao et al. (2014). The participants were asked to avoid physical activity for at least seventy-two hours prior to the assessment. To begin, participants were instructed to lay down for 15 minutes to allow fluid distribution. The images were collected at the midpoint of the right thigh established after palpation and measurement of the distance between the greater trochanter and the inferior border of the lateral epicondyle. At this point, legs were transversally marked every 2-cm from the medial to the lateral aspect of the *vastus lateralis,* to guide probe displacement. Surface gel was used to provide acoustic coupling. Avoiding dermal deforming, sequential images were acquired aligning the top border of the probe with each of the marks following a middle-to-lateral orientation. After the digitalization of the images, the images were sequentially reconstructed in PowerPoint 2013 (Microsoft, Redmond, Washington, USA) and analyzed through the ImageJ software. The CV and TE between two repeated measurements with an interval of seventy-two hours were 1.27% and 0.19 $cm^2$, respectively.

**Rate of torque development (RTD)**

The RFD were evaluated through a ballistic protocol, as described in Libardi et al. (2016). The settings of the isokinetic dynamometer (Biodex System 3; Biodex Medical Systems, Shirley, New York, USA) were determined according to the company's technical specifications. Prior to the beginning of the test, a general warm up was performed at a cycle ergometer for 5 minutes at 60 rotations per minute and 25 watts. Following, each participant was positioned vertically on the dynamometer's chair, the body was firmly stabilized by two straps transversally displaced over their shoulders, one at the waist and one over the tested thigh. The center of rotation of the participant's knee was aligned to the center of rotation of the dynamometer. The test was performed isometrically at 60º in relation to the horizontal plan. The distance of the accessory of the dynamometer was comfortably adjusted to the ankle of the participant, positioned over the medial and lateral malleoli. After the individualized positioning, specific warm up composed by 10 submaximal repetitions, 2-second long, split by 20-seconds of rest. After the specific warm up, 3 minutes of rest were allowed prior to the test and between all the 4 repetitions, also lasting 2-seconds each. The participants were instructed to produce the maximum torque as fast as possible, maintain for 2-seconds, and relax as fast as possible. The curve was displayed at the dynamometer's screen in real time to provide instantaneous feedback about the curve pattern. The curve of torque production should follow a "rectangular pattern" (i.e., the torque should increase as fast as possible, the maximal torque should be maintained, and torque decay should also follow a rapid pattern). Every attempt that differed of the mentioned pattern was discarded. Strong verbal encouragement was provided in all the attempts. The chair adjustments were recorded to be repeated at the end of the 12 weeks. The data was analyzed through MATLAB 7.0 software and RTD was calculated from the following formula: $\Delta T \cdot \mathbf{\Delta t^{-1}}$.

## Functional performance

*Chair stand (CS)*

Participants started the test seated on a 43-cm-height chair with their back against the chair and feet on a force platform (AccuGait, AMTI, Boston, USA). Subjects were instructed to keep their arms crossed over their chest touching the contralateral shoulder and, as fast as they could, to stand up in a completely straight position and sit down for five consecutive times (McCarthy et al., 2004). The total time to complete task was obtained from vertical force time-series obtained through the Balance Clinic software (AMTI, Boston, USA) and analyzed using a custom-written MATLAB 7.0 (Math Works Inc., Natick, Massachusetts, USA) code. The CV and TE between tests were 3.84% and 0.45s, respectively.

*Habitual gait speed (HGS) and maximal gait speed (MGS)*

Participants were instructed to walk through a 15m distance two consecutive times in two different gait speeds: habitual and maximal, both timed by a photocell (Speed Test Fit, *Cefise Biotecnologia Esportiva*, Sao Paulo, Brazil). The first and the last 2.5-m were discarded as it was used as acceleration and deacceleration periods, respectively. Results were composed by the mean of the 2 attempts in each of the gait speeds, as described in Pasma et al. (2014). The CV and TE between HGS tests were 2.16% and 0.03m.s$^{-1}$, respectively and between MGS were 3.53% and 0.07m.s$^{-1}$, respectively.

*Timed up-and-go (TUG)*

The participants started the test seated with their back against chair (43-cm-height), arms positioned over the lateral armrests and feet over a force platform until the starting command. After the command, participants should, as fast as they could, stand up using the armrests, walk over a 3-m distance, return, sit down with their back against the seat (Miotto et al., 1999). Time was measured and analyzed as described for the CS test. The CV and TE between tests were 3.69% and 0.31s, respectively.

*Six-minute walking test (6MWT)*

Participants were encouraged verbally to walk for 6 minutes as fast as they could. The test was performed over a flat surface, without obstacles, along a 28-m square-shaped circuit delimited previously. Then, at the end of the 6 minutes, participants were instructed to keep walking in a slower pace to cool down, and the final distance traveled after 6 minutes was recorded and used as the 6MWT value (Steffen et al., 2002). The CV and TE between tests were 3.3% and 19.6m, respectively.

**Resistance training protocols**

All the groups performed a lower-limb RT protocol twice a week in three exercises: KE, LP and LC. The same exercising order was respected for all groups in all training sessions. Loads were set up at approximately 40% 1-RM measured at the maximal dynamic muscle strength test as previously explained. For FAI, 3 sets to concentric failure (i.e., the moment in which the full range of motion could not be reached) were performed. For VOL, 3 sets to the volitional failure (i.e., when the participant voluntarily interrupts a set of exercise after reaching a considerable fatigue, before muscle failure) were performed (Nobrega et al., 2018). The FIX protocol consisted on 3 sets of 10 repetitions. The rest between sets was 90 seconds for all the training protocols. Furthermore, to provide a whole-body training to the participants, all groups performed a standardized upper-limb protocol, split in two RT protocols: A) chest press machine, lateral raises, and cable pushdowns; B) Lat pulldown, bicep curl and sit-ups. The volume was established at three sets of 8 to 12 maximal repetitions for the weight exercises and sit-ups were performed to failure. The load was decreased in case the participants performed less than 8 repetitions and increased in case more than 12 repetitions were performed. The same resting time was allowed for superior protocol.

**Number of repetitions (Nrep), total training volume (TTV) and decrease in the number of repetitions (Drep)**

Nrep was recorded for all 24 sessions as sets × repetitions. The area under curve was calculated through the Nrep performed by each participant, in all 24 training sessions. We calculated the TTV as sets × repetitions × loads, and results were showed, for Nrep and TTV as the sum of the three exercises for lower limbs accumulated after all the 24 training sessions. Additionally, to provide an indirect measurement of fatigue, we calculated the Drep in the VOL and FAI protocols through the difference from the third to the first set (Drep = 3rd set - 1st set) (Nobrega et al., 2018).

**Statistical analyses**

After a visual inspection, the normality of data was evaluated through Shapiro-Wilk test. A one-way analysis of variance (ANOVA) was applied to compare baseline values, TTV, Nrep AUC and Drep between protocols. Following, a mixed model analysis was used for each dependent variable (1-RM, CSA, RTD and functional performance [CS, HGS, MGS, TUG and 6MWT]) analysis assuming protocol (FAI, VOL and FIX) and time (Pre and Post) as fixed factors and participants as random factors for the variable dependent. In case of significant $F$, Tukey adjustment was applied for multiple comparisons. The effect size (ES) were calculated for all dependent variables using the changes from pre- to post-training, and classified as small (< 0.20), moderate (0.2 – 0.79) and large (> 0.8 large) (Cohen, 1988). The assumed significance was $P < 0.05$. Statistical analysis was carried out through SAS 9.3 software (SAS institute Inc., Cary, NC).

## RESULTS

### Baseline values

There were no significant differences in the baseline values for all dependent variables (1-RM, CSA, RTD and functional performance [CS, HGS, MGS, TUG and 6MWT]; $P > 0.05$).

### Number of repetitions, total training volume and decrease in the number of repetitions

The one-way ANOVA showed differences between-groups for Nrep, TTV and Drep. FAI group showed significantly greater Nrep compared to VOL and FIX groups ($P < 0.0001$). Additionally, VOL Nrep was significantly greater than FIX ($P < 0.0001$) (Figure 1). TTV was significantly greater ($P < 0.0001$) for FAI (391595 ± 166267 kg) and VOL (274774 ± 118209 kg) groups compared to FIX (98915 ± 29430 kg). There was no difference between FAI and VOL ($P > 0.05$). Drep was greater for FAI (-5 ± 2 repetitions; -18%) and VOL (-3 ± 2 repetitions; -12.1%) groups compared to FIX ($P < 0.0001$). Additionally, Drep was greater for FAI compared to VOL ($P < 0.0001$).

**** FIGURE 1 NEAR HERE ****

### Maximal dynamic strength (1-RM)

For 1-RM (Table 1), only a main time effect was observed, with no group or interaction group vs. time effects ($P < 0.0001$; ES: FAI = 0.57 [moderate], VOL = 0.79 [moderate], FIX = 0.69

[moderate]).

**Muscle cross-sectional area (CSA)**

There were no main group, time or interaction group vs. time effects in muscle CSA (*P* > 0.05; ES: FAI = 0.15 [small], VOL = 0.08 [small], FIX = 0.11 [small]) (Table 1).

**Rate of torque development (RTD)**

There were no main group, time or interaction group vs. time effects in RTD (*P* > 0.05; ES: FAI = 0.01 [small], VOL = 0.31 [moderate], FIX = 0.35 [moderate]) (Table 1).

**** TABLE 1 NEAR HERE ****

**Functional performance**

There was a main time effect in CS (*P* = 0.001; ES: FAI = 0.52 [moderate], VOL = 0.88 [large], FIX = 0.32 [moderate]) and HGS (*P* = 0.036; ES: FAI = 0.12 [small], VOL = 0.43 [moderate], FIX = 0.55 [moderate]), with no main group and interaction group vs. time effects. Conversely, there were no main group, time or interaction group vs. time effects in for MGS (*P* > 0.05; ES: FAI = 0.16 [small], VOL = 0.17 [small], FIX = 0.31 [moderate]). Likewise, there were no main group, time or interaction group vs. time effects for TUG, although there was a trend for interaction group vs. time (*P* = 0.055; ES: FAI = 0.35 [moderate], VOL = 0.81 [large], FIX = 0.03 [small]). Finally, there were no main group, time or interaction group vs. time effects in 6MWT (*P* > 0.05; ES: FAI = 0.04 [small], VOL = 0.10 [small], FIX = 0.03 [small]) (Table 2).

**** TABLE 2 NEAR HERE ****

## DISCUSSION

Our findings showed that low-load RT protocols may promote significant improvements in muscle strength and functionality of healthy non-trained older adults, even without reaching muscle failure or near failure. Additionally, increases in CSA may not be determinant for improvements in functionality.

Regarding muscle CSA, there were no significant differences intra- or inter-groups. Our results contrast with studies that showed muscle hypertrophy through RT intervention (Fiatarone et al., 1990; Fiatarone et al., 1994; Wallerstein et al., 2012; Bechshoft et al., 2017) and agree with others that shown minor or no muscle hypertrophy (Grimby et al., 1992; Hakkinen et al., 2001; Bamman et al., 2003; Reid et al., 2015). The variability of the hypertrophic gains in older adults have been demonstrated previously, although the reasons are not well-known (Ahtiainen et al., 2016).

Concerning muscle strength, our study demonstrated similar results for all groups, despite the difference in TTV and Nrep between groups. These results are in accordance with other studies that did not showed a dose-response between TTV and Nrep and strength gains for older adults in early stages of RT (Radaelli et al., 2014; Borde et al., 2015). Once neither group showed a significant increase in muscle CSA, the muscle strength gains presented herein can be attributed to neural adaptations, which has been suggested to be the main responsible to initial RT-related gains in muscle strength (Moritani and deVries 1980; Hakkinen et al., 1998; Seynnes et al., 2007; Damas et al., 2016; Del Vecchio et al., 2019). In this regard, it has been demonstrated that low-load FAI and VOL protocols promote similar muscle activation during the exercising sets (Nobrega et al., 2018). In fact, it has been assumed based on electromyography data that after a certain number of low-load repetitions, MUs cease firing and possibly recruits other MUs to keep muscle contraction (Fallentin et al., 1993; Fuglevand et al., 1993). Although FIX protocol had an indication to be far from the point of muscle failure, it is possible that the accumulation of sets throughout a same training session may have promoted a recruitment of higher threshold motor units. Thus, it is possible to speculate that the motor unit recruitment stimulated by low-load and lower volume protocols are sufficient to promote important strength gains in early stages of training in older adults, as previously demonstrated (Jiang et al., 2016).

For RTD, no significant changes were observed after RT period. The results may be explained by the principle of specificity, once non-specific isometric and ballistic protocols were used to evaluate RTD, which is different of the type of contraction traditionally performed in RT protocols (i.e., dynamic contraction with moderate velocity) (Baechle, 2008; Schoenfeld et al., 2017). Thus, it is possible that the RT protocols in the present study, were not satisfactory to induce specific neural patterns of power training in a greater extent, such as RTD in older adults (Aagaard et al., 2002; Fielding et al., 2002; Wallerstein et al., 2012; Tiggemann, et al., 2016).

Age-related changes in gait speed and at the capacity of rising from a chair are commonly linked to risk of falling (Campbell et al., 1989; Rogers et al., 2003), which affect directly the capacity of performing the activities of daily living and the quality of life (Tseng et al., 1995; Mosallanezhad et al., 2014). As our results and other studies have shown, RT might play an important role in improving the capacity of performing functional activities, such as CS and HGS. Additionally, the enhancement of such parameters might be related to muscle strength improvements, and consequently, which possibly attenuates age-related losses (ACSM, 2009; Idland et al., 2014; Tiggemann, et al., 2016). In fact, as well as for muscle strength, we showed significant improvement for CS and HGS in all the groups. However, the percentage of increasing of FIX in CS was within the CV and TE, while FAI and VOL demonstrated larger improvements. It indicates that higher volume RT protocols, which possibly generate more fatigue during a RT session, may favor gains in CS. Regarding the other functional parameters, there were no significant changes for 6MWT, TUG and MGS. In agreement to our results, Van Roie et al. (2013) presented no significant improvements in 6MWT, TUG and MGS for low-load groups. Increases in 6MWT are plausible to be more related to cardiorespiratory improvements (Solway et al., 2001; Steffen et al., 2002), which was not emphasized by RT protocols. Regarding TUG and MGS, it is possible that increases in these parameters are linked to a greater capacity of acceleration and/or to perform rapid movements (Ramirez-Campillo et al., 2014). Curiously, in the TUG test, despite the non-significative results, FAI and VOL presented higher ES compared to FIX, which may indicate a slight advantage for higher volume protocols. However, it is known that older adults may present a great variability in physical functional responses to RT, which appeared in our TUG test results (from -22.5% to +25.5%) (Chmelo et al., 2015). Thus, these results require caution and further investigation is necessary to infer about the real importance of TTV and Nrep to improve this parameter in older adults.

The present study is not without limitations: 1) The relative small sample size possibly may have precluded the verification of differences between groups, causing a type II error (Sullivan and Feinn, 2012). However, this possibility was minimized through the ES analysis, which presented similar results to the mixed model analysis for the main dependent variables of the study; 2) the lack of a direct measurement of muscle fatigue to compare the differences between protocols. However, it was attenuated by the analysis of the decrease of number of repetitions during RT session; 3) the performance of three 1-RM tests in the same day, which may not have guaranteed that the training load in LP and LC was set at 40% of 1-RM. To diminish this the effect of this limitation in our results, the 1-RM tests were performed always in the same order, influencing all the RT groups in the same extent.

In conclusion, our data suggest that low-load RT protocols performed with lower Nrep and distant to the point of muscle failure promote significant improvements in muscle strength and some functional parameters for previously untrained older adults. Additionally, these gains may be comparable to the gains attained through RT protocols to muscle failure or near failure. Finally, increases in and muscle CSA may not be essential to induce improvements in muscle strength and functional performance in older adults in early stages of RT.

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**TABLES**

Table 1. Maximal dynamic strength (1-RM), muscle cross-sectional area (CSA) and rate of torque development (RTD) at baseline (Pre) and after training (Post) for RT performed to failure (FAI), to voluntary interruption (VOL) and with fixed repetitions (FIX).

| Variable | Group | Pre | Post | % |
|---|---|---|---|---|
| Maximal dynamic strength (1-RM) (kg) | FAI | 328.0 ± 107.0 | 398.0 ± 95.0* | 21.3 |
| | VOL | 339.0 ± 97.0 | 423.0 ± 116.0* | 24.8 |
| | FIX | 318.0 ± 116.0 | 393.0 ± 143.0* | 23.5 |
| Cross-sectional area (CSA) ($cm^2$) | FAI | 17.5 ± 6.0 | 18.4 ± 5.7 | 4.9 |
| | VOL | 18.0 ± 5.3 | 18.4 ± 3.7 | 1.9 |
| | FIX | 17.7 ± 4.4 | 18.1 ± 3.5 | 2.4 |
| Rate of torque development (RTD) ($N \cdot m \cdot s^{-1}$) | FAI | 565.7 ± 188.0 | 562.8 ± 205.0 | -0.5 |
| | VOL | 605.4 ± 185.0 | 656.1 ± 141.0 | 8.4 |
| | FIX | 574.0 ± 186.6 | 635.8 ± 170.1 | 10.8 |

*Significantly different from Pre (main time effect, $P < 0.05$). Values presented as mean ± SD.

Table 2. Functional tests at baseline (Pre) and after training (Post) for RT performed to failure (FAI), to voluntary interruption (VOL) and with fixed repetitions (FIX).

| Variable | Group | Pre | Post | % |
|---|---|---|---|---|
| Chair Stand (CS) (s) | FAI | 11.5 ± 2.4 | 10.5 ± 1.1* | 9.3 |
| | VOL | 12.1 ± 2.5 | 10.3 ± 1.5* | 17.8 |
| | FIX | 11.3 ± 1.1 | 11.  ± 1.1* | 3.3 |
| Habitual Gait Speed (HGS) ($m.s^{-1}$) | FAI | 1.3 ± 0.2 | 1.4 ± 0.2* | 2.5 |
| | VOL | 1.3 ± 0.1 | 1.4 ± 0.2* | 5.0 |
| | FIX | 1.3 ± 0.1 | 1.4 ± 0.1* | 5.4 |
| Maximal Gait Speed (MGS) ($m.s^{-1}$) | FAI | 2.0 ± 0.2 | 2.0 ± 0.3 | 1.5 |
| | VOL | 2.0 ± 0.3 | 2.1 ± 0.3 | 2.6 |
| | FIX | 1.9 ± 0.2 | 1.9 ± 0.2 | 3.7 |
| Timed Up-and-Go (TUG) (s) | FAI | 8.0 ± 0.9 | 7.7 ± 0.8 | 4.1 |
| | VOL | 8.2 ± 1.0 | 7.5 ± 0.7 | 9.9 |
| | FIX | 7.9  ± 0.9 | 7.9 ± 0.9 | 0.3 |
| 6-Minute Walking Test (6MWT) (m) | FAI | 617.5 ± 64.3 | 614.7 ± 71.4 | 0.2 |
| | VOL | 615.1 ± 70.8 | 622.2 ± 75.6 | -5.9 |
| | FIX | 595.3 ± 52.8 | 594.0 ± 42.6 | 0.4 |

*Significantly different from Pre (main time effect, $P < 0.05$). Values presented as mean ± SD.

**FIGURE**

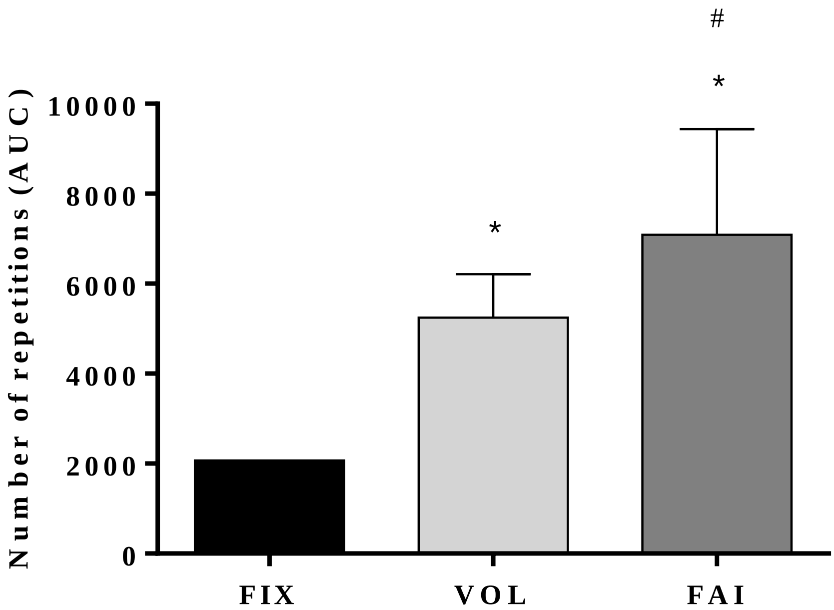


Figure 1. Nrep (AUC) for resistance training performed to failure (FAI), to voluntary interruption (VOL) and with fixed repetitions (FIX). *Significantly different from FIX (*P* < 0.0001). #Significantly different from VOL (*P* < 0.0001). Values presented as mean ± SD.

ANEXO 1

**UNIVERSIDADE FEDERAL DE SÃO CARLOS**
**CENTRO DE CIÊNCIAS BIOLÓGICAS E DA SAÚDE**
**PROGRAMA DE PÓS-GRADUAÇÃO EM CIENCIAS FISIOLÓGICAS**
**TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO**
**(Resolução 466/2012 do CNS)**

Responsável pelo projeto: João Guilherme Almeida Bergamasco
Orientador: Prof. Dr. Cleiton Augusto Libardi

**Local de desenvolvimento do projeto:**
Laboratório de Adaptações Neuromusculares ao Treinamento de Força (MUSCULAB), Departamento de Educação Física e Motricidade Humana (DEFMH), Departamento de Fisioterapia (DFisio), Universidade Federal de São Carlos (UFSCar).

**Objetivo geral do estudo:**
Você está sendo convidado a participar da pesquisa "Efeitos do treinamento de força de baixa intensidade com diferentes níveis de falha muscular na força, hipertrofia e funcionalidade de idosos" que terá aproximadamente seis meses de duração e tem como objetivo analisar e comparar os efeitos do treinamento de força de baixa intensidade com diferentes níveis de falha muscular na força, hipertrofia e funcionalidade de idosos

**Etapas e procedimentos do estudo:**
A sua participação no estudo acontecerá em 40 visitas. Na primeira visita ao laboratório, além da apresentação geral do estudo, serão verificados os critérios de inclusão e exclusão. Com agendamento prévio, na segunda visita acontecerá o eletrocardiograma (ECG) de esforço, realizado pelo médico do estudo no Departamento de Fisioterapia com o uso de uma bicicleta ergométrica e os equipamentos necessários para a realização do ECG. Com aprovação do médico, as próximas etapas seguirão. Na próxima visita, será realizado o exame de composição corporal e densidade mineral óssea, com uso do equipamento DXA. Na visita seguinte, será realizado um teste de força que avaliará a taxa de desenvolvimento de força, no equipamento Biodex. Na visita seguinte será realizada a mensuração da área de secção transversa, ou seja, massa muscular do músculo vasto lateral da coxa será realizada com uso da captura de imagens

de ultrassonografia muscular de forma indolor. Nas duas visitas seguintes, serão realizados teste e reteste de força nos equipamentos cadeira extensora, leg press e mesa flexora. Após todo o processo de avaliação inicial, os participantes serão ranqueados em quartis e distribuídos nos três grupos procedimentais: Treinamento de Força até a Falha Muscular (TF-F), Treinamento de Força com Interrupção Voluntária (TF-IV) e Treinamento de Força Distante da Falha (TF-DF). O programa de treinamento será realizado durante 12 semanas, com 2 sessões por semana que serão realizadas no Laboratório de Adaptações Neuromusculares e Treinamento de Força (MUSCULAB), localizado no Departamento de Educação Física da Universidade Federal de São Carlos. O protocolo TF-F será realizado nos equipamentos cadeira extensora, *leg press* e mesa flexora, com intensidade de 40% do valor máximo levantado pelo indivíduo nos testes de 1-RM. Serão realizadas 3 séries até a falha muscular concêntrica (estabelecida como ausência de amplitude de movimento adequada) com pausas de 1 minuto nos três exercícios. No protocolo TF-IV, os exercícios, intensidade, pausa e número de séries serão iguais aos do protocolo TF-F, no entanto, neste protocolo a interrupção do exercício será feita de maneira voluntária pelos próprios indivíduos, sem que o sujeito chegue à falha muscular. No protocolo TF-DF serão realizados os mesmos exercícios, intensidade, pausa e número de séries dos outros dois protocolos. No entanto, neste protocolo, a quantidade de repetições a serem realizadas nas 3 séries será de 10 repetições. No quarto dia após a última sessão de treinamento, serão repetidas as avaliações realizadas previamente ao início dos treinamentos, com exceção do ECG. A descrição desses procedimentos e sua segurança foi comprovada em estudos anteriores.

**Potenciais riscos e incômodos:**

Possíveis sinais de dores musculares tardias relacionadas ao treinamento de força podem ocorrer em dias posteriores às sessões de treinamento, causando desconforto na musculatura da coxa e/ou diminuição no ângulo de movimento dessa articulação com curta permanência (24 – 96h). Com a realização do treinamento, é possível que ocorram aumentos na pressão arterial, que serão supervisionadas em tempo real pelo responsável do estudo. Caso o participante apresente qualquer sintoma anormal ao relacionada ao treinamento, o exercício e a sessão de treino serão interrompidos imediatamente e os devidos cuidados serão tomados.

**Liberdade de participação:**

Sua participação é voluntária e não obrigatória. É de seu direito desistir de participar do estudo e retirar seu consentimento a qualquer momento sem que isso cause qualquer penalidade ou prejuízo com os pesquisadores e instituição realizadores do estudo.

**Responsabilidade dos pesquisadores:**

Os pesquisadores acompanharão todos os participantes em todas as visitas ao laboratório e serão responsáveis orientar os participantes em todas as etapas da pesquisa, incluindo posicionamento adequado e descrição dos procedimentos padrões durante as sessões de avaliação e de treinamento.

**Sigilo de identidade:**

As informações obtidas durante as avaliações e sessões de treinamento serão mantidas em sigilo, ou seja, não poderão ser consultadas pelo público em geral sem a devida autorização do participante da pesquisa. As informações obtidas poderão ser usadas para fins de pesquisa científica, desde que a privacidade seja sempre mantida. Possíveis dúvidas por parte do participante serão esclarecidas, bem como o acompanhamento dos resultados obtidos durante a coleta de dados.

**Custo financeiro:**

Todas as despesas com o transporte decorrentes da sua participação na pesquisa serão de sua responsabilidade, já que a Lei Federal de número 10.741, do artigo 39 assegura gratuidade ao transporte público para idosos. Porém, quaisquer ônus decorrentes de sua participação, poderão ser ressarcidos de acordo com sua necessidade.

**Dados de identificação do participante**

Nome completo: ____________________________________________________________

Data de nascimento: _________________________ RG: _____________________________

Endereço: __________________________________________________________________

Contato telefônico: ________________ E-mail: ___________________________________

**Declaro para os devidos fins que entendi os objetivos, riscos e benefícios de minha participação na pesquisa e concordo em participar. Declaro também que o pesquisador me informou que o projeto foi aprovado pelo Comitê de Ética em Pesquisa em Seres Humanos da UFSCar, Pró-Reitoria de Pós-Graduação e Pesquisa da Universidade Federal de São Carlos, localizada na Rodovia Washington Luiz, Km. 235 - Caixa Postal 676 - CEP 13.565-905 – São Carlos - SP – Brasil. Fone (16) 3351-8110. Endereço eletrônico: cephumanos@power.ufscar.br**

São Carlos, ...........de ........................................de .............

__________________________________ _____________________________________

Assinatura do participante

João Guilherme Almeida Bergamasco
(Aluno responsável pelo projeto)

__________________________________

Prof. Dr. Cleiton Augusto Libardi
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