Chronic Effects of Different Rest Intervals Between Sets on Dynamic and Isometric Muscle Strength and Muscle Activity in Trained Older Women

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Objective: This study investigated the chronic effects of different rest intervals (RIs) between sets on dynamic and isometric muscle strength and muscle activity.

Design: We used a repeated-measures design (pretraining and posttraining) with independent groups (different RI). Twenty-one resistance-trained older women (66.4 ± 4.4 years) were randomly assigned to either a 1-minute RI group (G-1 min; n = 10) or 3-minute RI group (G-3 min; n = 11). Both groups completed 3 supervised sessions per week during 8 weeks. In each session, participants performed 3 sets of 15 repetitions of leg press exercise, with a load that elicited muscle failure in the third set. Fifteen maximum repetitions, maximal voluntary contraction, peak rate of force development, and integrated electromyography activity of the vastus lateralis and vastus medialis muscles were assessed pretraining and posttraining.

Results: There was a significant increase in load of 15 maximum repetitions posttraining for G-3 min only (3.6%; $P < 0.05$). However, posttraining results showed no significant differences between G-1 min and G-3 min groups for all dependent variables ($P > 0.05$).

Conclusions: The findings suggest that different RIs between sets did not influence dynamic and isometric muscle strength and muscle activity in resistance-trained older women.

Key Words: Aging, Electromyography, Exercise, Lower Limb, Recovery, Resistance Training

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The aging process is accompanied by neural, structural, and functional alterations of the neuromuscular system.[1,2] Progressive decreases in muscle mass, strength, and power have been associated with reductions in the capacity to perform activities of daily living, loss of independence in older adults, and, consequently, mortality.[3,4] Moreover, evidence has shown that reductions in muscle quality (i.e., muscle strength production per unit of activated muscle mass) of lower limbs are more pronounced when compared with upper limbs,[5] suggesting that it is extremely important to preserve muscle mass and strength of the lower limbs during the aging process.

Progressive resistance training is an excellent strategy to promote increases in dynamic and isometric muscle strength and contribute to the process of muscle hypertrophy.[6] The magnitude of these alterations is associated with the manipulation of different acute variables, that is, intensity, volume, frequency, movement velocity, exercise order, and duration of the rest interval (RI) between sets and exercises.[7]

Several studies have demonstrated in young adults that the use of longer RIs between sets (i.e., 3–5 minutes) promotes higher total volume of training compared with shorter RI (i.e., 0.5–1 minute) and consequently greater gains in dynamic maximal muscle strength.[8,9] In contrast, other studies have shown no difference between longer and shorter RIs on dynamic maximal muscle strength when the total training volume was similar.[10,11] Altogether, these results suggest that longer RI between sets promotes higher gains in dynamic muscle strength via an increased total volume of training.

Regarding isometric muscle strength, previous studies suggest that different RIs between sets do not influence maximal voluntary contraction (MVC) in young adults.[12,13] To the best of our knowledge, no studies have verified the effects of different RIs on MVC in older adults. During a rapid MVC measurement, it is possible to determine the rate of force development (RFD), which is defined as the capacity to produce muscle force rapidly.[1,14] Rate of force development determines the magnitude of acceleration in the initial phase of a movement and ultimately influences the velocity of the movement.[14] In a recent review, Maffiuletti et al.[15] highlighted that the RFD has important functional significance and is useful in designing interventions to improve physical function and reduce injury and fall risk in older people and patient populations. Based on electromyography (EMG) recordings, evidence

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suggests that muscle activation in the initial phase of an explosive contraction is one the most important mechanisms that determines the values of RFD in vivo.[14] Given the importance of the RFD for older people and the potential mechanisms that may explain alterations in this variable, there is an obvious need to verify the effects of different RIs on RFD and EMG in older people.

According to the American College of Sports Medicine,[6] RIs of 1 and 3 minutes between sets are recommended for improvements in muscle strength and hypertrophy in older adults. To the best of our knowledge, only 1 longitudinal study has examined the effects of different intervals on muscle strength using untrained older men.[16] Contrary to results in young adults, this study revealed that resistance training using a shorter RI (i.e., 1 minute) results in greater gains in maximal muscle strength compared with longer RIs (i.e., 4 minutes) when the training volume is equalized. Although there is no general consensus on the matter, many authors have suggested that shorter intervals promote greater increases in anabolic hormone and consequently in muscle mass and strength.[17,18] Nonetheless, it is important to highlight that acute anabolic hormone elevations are attenuated throughout the course of a training period,[10,11] which may limit possible adaptations via hormonal mechanisms in trained people. Indeed, recent research did not show differences between long and short RIs on acute growth hormone concentrations in resistance-trained older women, suggesting that short intervals may not promote long-term increases in mass and muscle strength in this population via hormonal mechanisms.[19]

Numerous acute studies have indicated that longer RI promotes an increase in total training volume as compared with shorter RI in resistance-trained older women.[20–22] Given that a higher volume of training appears to be more efficient to promote increases in lower-body mass and muscle strength than a lower volume in older people,[23] it is possible that the use of longer RI would promote greater increases in dynamic and isometric muscle strength in resistance-trained older women via an increase in total volume of training. In this regard, the purpose of this study was to assess the chronic effects of a resistance training program using RIs of 1 and 3 minutes between sets on dynamic and isometric muscle strength and muscle activity of the lower limbs.

METHODS

Participants

The sample size calculation indicated that at least 16 participants were required, using an a priori analyses, based on an α level of 0.05, power $(1 - \beta)$ of 0.95, correlation among repeated measures of 0.85, and effect size (ES) of 0.27 (increase of 6.3% in dynamic muscle strength), which was shown in a prior study performed with resistance-trained older people.[24] Twenty-four older women with resistance training experience (3.8 ± 2.9 years) were assigned to 1-minute (G-1 min) or 3-minute (G-3 min) RI training groups. Because of personal reasons unrelated to the intervention, 3 participants dropped out of the study. Thus, 10 participants in G-1 min (age, 66.5 ± 4.7 years; body mass, 68.1 ± 10.3 kg; height, 157.7 ± 4.6 cm) and 11 participants in G-3 min (age, 66.3 ± 4.3 years; body mass, 70.1 ± 12.7 kg; height, 157.3 ± 5.6 cm) completed the study. All participants attended a fully supervised dynamic resistance training program during six months prior to the study, with the following characteristics: (*a*) 3 days per week on nonconsecutive days, (*b*) 8 exercises including leg press, (*c*) 3 sets were performed with 50% to 70% of 15 maximum repetitions (RMs), and (*d*) 2-minute RI between sets. In order to attend to the general principles of progression, training intensity was increased up to approximately 90% of 15 RMs in the present study. Inclusion criteria were age 60 years or older and having no contraindications involving the cardiovascular system, muscles, joints, or bones of the lower limbs, as well as no neurological limitations to the practice of resistance training. Participants were excluded if they completed less than 80% of the sessions of the training program of the study. All participants were informed about the procedures and risks of the study and signed an informed consent form. The study was approved by the ethics committee of the local university (protocol no. 7090), according to the Declaration of Helsinki.

Experimental Design

An 8-week randomized parallel-group design was used to compare the effects of RIs between sets on dynamic and isometric muscle strength and muscle activity of the lower limbs. Two sessions of practice were conducted to familiarize the participants with test procedures. Forty-eight to 72 hours after the familiarization, MVC, peak RFD (PRFD), and the optimum loads with which the participants could perform 15 RMs were assessed for the leg press exercise. The RI between dynamic and isometric muscle strength exercises was 3 to 5 minutes. It has been suggested that 1-minute RI is sufficient to allow adequate recovery in isometric tests.[25] During the isometric tests, EMG activity of the vastus lateralis (VL) and vastus medialis (VM) of the dominant leg was recorded. Participants were randomly assigned to G-1 min or G-3 min according to the loads of the 15 RMs. Randomization was performed using a manual random number. The RIs between sets were chosen because they are established recommendations for older adults.[6] With the exception of the RI between sets, both groups performed the same resistance training program (i.e., exercises, frequency, sets, and repetition zones). Forty-eight to 72 hours after the last training session, the posttraining assessments were performed using the same pretraining procedures. All training sessions and tests were performed at the same period of the day (from 7:00 AM to 9:00 AM). The participants were instructed to maintain their food intake and hydration and to not perform any intense physical activity other than the training throughout the study period.

Dynamic Muscle Strength

The 15-RM test was assessed using a horizontal leg press with adjustable weight stacks (Righetto Fitness Equipment, Campinas, São Paulo, Brazil). Knee and hip angles were adjusted to 90 and 110 degrees, respectively. The load reference for 15 RMs was determined over the first 2 days and retested on the third day. A maximum of 3 trials per session was performed, with an RI of 10 minutes between trials. At the onset of each session, participants performed a warm-up, with 10 repetitions at 50% of 15 RMs proposed in the test trial. After 30 seconds, all participants were instructed to perform the greatest possible number of repetitions, until voluntary exhaustion, with loads that had been predetermined by the researchers. The participants were encouraged verbally to exert maximum effort. No pauses were allowed during the repetitions, and only the repetitions performed with a full range of motion were counted.

Isometric Muscle Strength

The MVC and PRFD were determined using a custom-built bilateral leg-press device with a force transducer (model 2000 NTM; EMG System, São José dos Campos, São Paulo, Brazil). All participants were seated with the knee and hip positioned at 90 and 110 degrees, respectively. Two submaximal isometric contractions were performed as a specific warm-up. Thereafter, participants were verbally encouraged to exert maximum isometric contractions as fast as possible during 5 seconds. Three attempts were performed by each participant, with an RI of 3 minutes between each attempt. All participants received visual feedback via the computer screen.

Signal acquisition from the force transducer and muscle activation was obtained using an analogical signal amplifier (model CS 800 AF; EMG System), at a frequency of 2000 Hz per channel and amplified at a gain of 1000× (sampling bandwidth 20–500 Hz). The signal was stored and analyzed off-line at a later time using a fourth-order, zero-lag Butterworth low-pass filter at a cutoff frequency of 15 Hz. The onset of the strength production was defined as 7.5 N above baseline.[14] The MVC was defined as the highest value registered within the 1-second window (500–1500 milliseconds) after the onset of muscular contraction.[26] The PRFD was determined by the steepest slope of the curve, calculated within regular windows of 20 milliseconds (Δforce / Δtime), for the first 200 milliseconds after the onset of muscular strength production.

Muscle Activation

Raw muscle activation signal was acquired simultaneously with the MVC according to the International Society of Electrophysiology and Kinesiology,[27] using an 8-channel electromyograph (model CS 800 AF; EMG System) with a bandpass filter using cutoff frequencies of 20 to 500 Hz, gain of 1000×, and a common mode rejection ratio greater than 120 dB. The raw muscle activation was converted to digital signals using an A/D 12-bit converting plate, with a sampling frequency of 2000 Hz for each channel and an input range of 5 mV.[28] Muscle activation was recorded using bipolar surface electrodes (diameter, 10 mm; center-to-center distance, 20 mm), which were positioned on the anatomical points following standards proposed by the SENIAM (Surface Electromyography for the Non-Invasive Assessment of Muscles).[29] Surface electrodes were positioned over the agonist VM and VL of the right leg, on the muscular belly in parallel with the orientation of the muscle fibers. The reference electrode was positioned on the wrist joint (i.e., styloid process radius and ulna). In order to reduce skin impedance, the electrode area was shaved and cleaned with abrasive and alcohol. The electrode positions were marked on a transparent paper to ensure the same recording sites pretraining and posttraining. The EMG signal was digitally filtered using a high-pass, fourth-order, zero-lag Butterworth filter with a 5-Hz cutoff frequency, followed by a moving root-mean-square filter with a time constant of 50 milliseconds.[14] The integrated EMG (iEMG) activity was defined as the area under the curve of the rectified EMG signal, that is, the mathematical integral of the raw EMG signal.[14] The onset of iEMG was initiated 70 milliseconds before the individual onset of the contraction to account for the presence of electromechanical delay.[14] The iEMG activity for the peak force was determined within the 1-second window (500–1500 milliseconds) after the onset of the muscular contraction.[26]

Resistance Training Program

The resistance training program consisted of 3 sessions per week, on nonconsecutive days, during 8 weeks. All participants were instructed to perform 3 sets of 15 repetitions, with a load that elicited failure in the third set. The load of the training was adjusted when the number of repetitions performed in the third set was either above or below the repetitions established. Total volume (sets × repetitions × load) of each week (i.e., 3 sessions) and during 8 weeks (i.e., 24 sessions) was recorded. To provide an overall conditioning stimulus, other exercises were performed after the leg press exercise (i.e., fly, triceps curl, lat pull-down, biceps curl, shoulder press or shoulder shrug, calf raise, and abdominal exercises). The participants were instructed to complete each repetition in approximately 1 second in the concentric phase and in 1 second in the eccentric phase. The duration of the set, from the onset of the first repetition until voluntary exhaustion, was recorded manually with a digital timer (model 8904; Herweg, Timbó, Santa Catarina, Brazil). The average time for each repetition was calculated by dividing the duration of each set by the number of repetitions. All tests and training sessions were closely supervised by the researchers of the study.

Statistical Analyses

The Shapiro-Wilk test was used to verify normal data distribution, and homogeneity of variance was tested by the Levene test. Data are reported as means and SDs. The training-related effects on 15 RMs, MVC, PRFD, and iEMG activity of the VL and VM were assessed using a 2-way analysis of variance (ANOVA) (groups [G-1 min and G-3 min] and time [pretraining and posttraining]) with repeated measures as the time factor. Total volume of each week was analyzed by using a 2-way ANOVA (groups [G-1 min and G-3 min] and time [first to eighth weeks]) with repeated measures as the time factor. The Scheffé post hoc test was used to locate group differences when a significant F ratio was shown by the 2-way ANOVA. Total training volume (Σ 8 weeks) between groups (G-1 min and G-3 min) was compared using unpaired Student *t* test. Effect sizes were calculated to analyze the magnitude of the differences by Cohen *d*.[30] Intraclass correlation coefficient (ICC) was used to test the reliability of the 15-RM assessments (number of repetitions multiplied by load). The level of significance adopted for all analyses was $P < 0.05$. Statistical procedures were performed using the Statistica program, version 7.0. The sample size was calculated using the G POWER software (version 3.1.9.2).

RESULTS

No adverse events occurred during the resistance training program, and the adherence of the participants was 100% for the G-1 min and 97.9% for the G-3 min. The ICCs for the 15-RM assessments for the pretraining and posttraining were 0.90 (95% confidence interval [CI], 0.76–0.96) and 0.94 (95% CI, 0.86–0.97), respectively. Typical error of measurement for the 15 RMs in our laboratory is 0.97 repetition.[22] The ICCs for repeated measurements of the MVC and PRFD in our laboratory are 0.94 (95% CI, 0.85–0.97) and 0.84 (95% CI, 0.63–0.93), respectively.[31]

Table 1 shows the values of dynamic and isometric muscle strength measured pretraining and posttraining in both groups. A significant main time effect was shown for loads of 15 RMs for the G-3 min ($P < 0.05$, ES = 0.44) but not for G-1 min. No significant group × time interactions were shown for 15 RMs, MVC, or PRFD ($P > 0.05$).

The iEMG activities of VL and VM are shown in Figure 1. No significant group × time interactions were shown for iEMG activity of the VM ($P > 0.05$, ES = 0.08) or VL ($P > 0.05$, ES = 0.30).

Figure 2 shows the total volume of training during each week and during the entire 8 weeks. A significant main time effect was shown for total volume each week ($F_{1,20}$ = 18.8, $P < 0.05$, ES = 0.49). Compared with the first week, significant increases ($P < 0.05$) were shown for G-1 min (third, fifth, sixth, seventh, and eighth) and G-3 min (second, third, fourth, fifth, and sixth). However, there was no significant group × time interaction for the total volume of each week ($F_{1,20}$ = 2.76, $P > 0.05$, ES = 0.12). In addition, there were no significant differences between G-1 min and G-3 min for the total volume of resistance training during the 8 weeks of training ($P > 0.05$).

TABLE 1. Dynamic and isometric muscle strength of lower limbs measured pretraining and posttraining for different RI groups in trained older women

	G-1 min	G-3 min	Effects	F	P
15 RMs, kg					
Pre	94.8 ± 18.6	92.4 ± 14.4	Group	0.07	0.79
Post	97.2 ± 18.7	95.7 ± 15.2[a]	Time	15.1	0.01
Δ%	2.5	3.6	Group × time	0.42	0.52
MVC, N					
Pre	937.0 ± 155.5	810.5 ± 129.2	Group	3.46	0.08
Post	977.6 ± 233.1	852.1 ± 132.7	Time	2.45	0.13
Δ%	4.3	5.1	Group × time	0.01	0.98
PRFD, $N \cdot s^{-1}$					
Pre	3930.7 ± 958.4	3920.9 ± 775.1	Group	0.01	0.98
Post	3807.9 ± 1026.3	3801.6 ± 695.5	Time	1.16	0.29
Δ%	−3.1	−3.0	Group × time	0.01	0.98

All values are presented in mean ± SDs.

[a]Significant difference compared with pretraining ($P < 0.05$).

G-1 min, 1-minute RI group (n = 10); G-3 min, 3-minute RI group (n = 11); Δ%, percent change in relation to pretraining.

DISCUSSION

The purpose of this study was to assess the influence of RIs between sets of 1 and 3 minutes during 8 weeks of training on dynamic and isometric muscle strength and muscle activity in the leg press exercise. Only the use of RI of 3 minutes provided a significant increase in 15 RMs posttraining. The findings of this study do not allow elucidation as to why only the RI of 3 minutes promoted significant increases in 15 RMs. However, it is important to highlight that G-3 min resulted in higher absolute training loads than G-1 min in weeks 3, 5, 6, 7, and 8 (+0.9%, +4.4%, +2.4%, +8.9%, +3.1%, +7.8%, and +2.3%), although differences between groups did not reach statistical significance. Moreover, absolute training load for G-3 min was higher compared with G-1 min during 8 weeks of resistance training (+2.3%, nonsignificant). Contrary to our hypotheses, no differences were shown between groups for 15 RMs, MVC, PRFD, and iEMG of the VL and VM. Furthermore, no differences were shown between the volume of weekly training or the total volume of training between groups during 8 weeks of resistance training.

Some chronic studies with young adults have shown that longer RIs lead to greater increases in muscle strength via a higher total volume of training.[8,9] De Salles et al.,[8] for example, showed that 16 weeks of resistance training (3 sets with intensity ranging from 4 to 10 RMs) performed with RI, between sets, of 3 and 5 minutes promotes higher increases in 1 RM of the leg press exercise when compared with RI of 1 minute. In contrast, studies that investigated the effects of different RIs, with an equalized total volume of training, did not show differences in dynamic and isometric muscle strength gains.[10–12] For instance, Buresh et al.[10] showed that 13 weeks of resistance training (2 sets of 8–12 repetitions with a load that elicited failure in the third set) using RI of 1 and 2.5 minutes did not result in significant differences in 5 RMs in the squat exercise. Ahtiainen et al.[12] similarly showed no significant differences in gains between RIs of 2 and 5 minutes on MVC during leg extension exercise (increases of 2.0% and 5.8%). Altogether, these findings suggest that longer RI between sets promotes higher gains in muscle strength via a higher total volume of training. In this regard, the similar results shown in the present study between groups in dynamic and isometric muscle strength of lower limbs may be due to the training design. The volume-equalized design adopted during the training sessions (i.e., load that elicited failure only in the last set) may explain the similar total volume between groups.

A limited amount of chronic studies have examined the effects of different RIs between sets in older people. To our knowledge, only Villanueva et al.[16] compared the effects of RIs of 1 and 4 minutes on 1 RM in untrained older men. After 4 weeks of a preparatory training, both groups performed 8 weeks of resistance training with total volume equated (3 days per week, 2–3 sets, 4–6 repetitions without muscular failure). The shorter RI demonstrated significantly greater increases in 1 RM compared with longer RI in a bilateral leg press (31.3% and 21.3%, respectively). The authors attributed these findings, in part, to an increase in metabolic stress (e.g.,

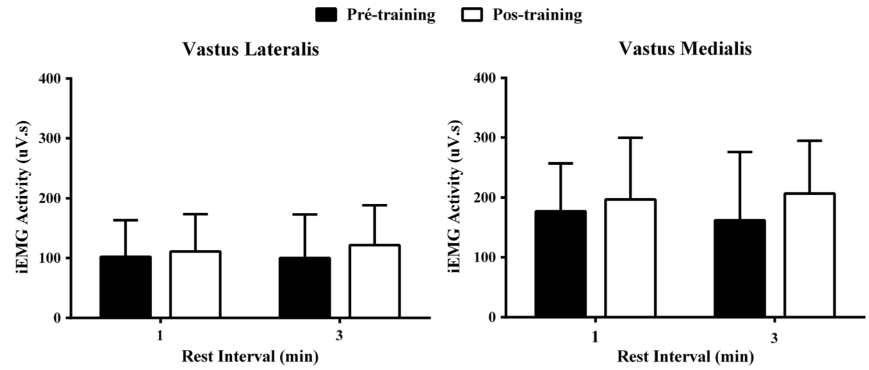

FIGURE 1. Integrated EMG activity of the VL and VM pretraining and posttraining for the different RI groups in trained older women (n = 21). All values are presented as mean ± SD.

accumulation of hydrogen ions, inorganic phosphate, and lactate).[32] The use of shorter RI does not allow sufficient recuperation to reestablish homeostasis, resulting in the accumulation of these metabolites in muscle and, consequently, elevation of anabolic hormones.[33] Although some studies have demonstrated a positive relationship between acute postexercise anabolic hormones and muscular adaptations,[34,35] the precise mechanisms of these responses have yet to be fully elucidated. Some evidence suggests that acute hormonal responses are attenuated throughout the course of the training period,[10,12] limiting possible adaptations via hormonal mechanisms. In addition, recent research has shown no differences between longer and shorter RIs on acute growth hormone concentrations in resistance-trained older women,[19] which may explain the similar responses between groups in the present study.

Meta-analytic data have shown that greater gains in muscle strength occur in untrained compared with resistance-trained individuals.[36] Taaffe et al.,[37] for example, analyzed the time course of muscle strength during 52 weeks' resistance training performed 3 days per week at high intensity (80% of 1 RM for 7 repetitions) or low intensity (40% of 1 RM for 14 repetitions) in older people not engaged in resistance training. Resistance training programs exhibited high adaptations in muscle strength during the first weeks, but these gains decreased after 12 weeks of resistance training. In line with this, the small alterations in 15 RMs, MVC, and PRFD shown in the present study may be associated with the resistance training experience of the participants (i.e., 3.8 ± 2.9 years). Considering that interrupting the practice of resistance training promotes reductions in muscle strength and functional components,[38] the maintenance of muscle strength shown in the present study has an important significance in the rehabilitation of lower limbs in trained older women.

It is well recognized that alterations in muscle strength are associated with morphological and neural adaptations.[39] According to Moritani and DeVries,[40] increases in muscle strength are widely associated with neural factors during the early stages of a resistance training program, although this comportment appears to reduce with longer periods of resistance training. In the present study, iEMG values for the VL and VM showed no significant change posttraining for G-1 min (−2.0% and −8.4%, respectively) or G-3 min (+9.7% and +5.1%, respectively), which may also be linked to the training status of the participants. Given that muscle activation is an important mechanism to determine the RFD in vivo,[14] these findings may explain the lack of change in PRFD. It is important to highlight that the measurement and interpretation of iEMG are not without their limitations to detect chronic alterations; such issues may be related to relocation of electrodes and changes in muscle morphology.[39]

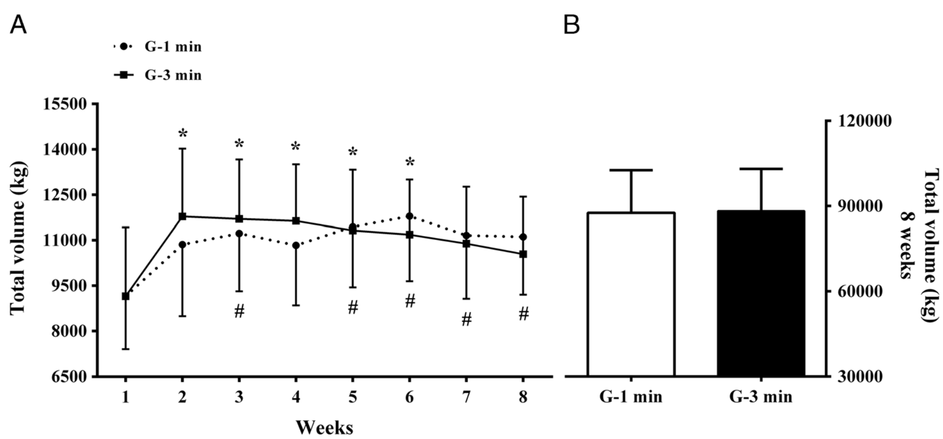

FIGURE 2. Total volume (sets × repetitions × load) of each week (A) and during 8 weeks (B) for 1-minute (G-1 min; n = 10) and 3-minute (G-3 min; n = 11) RI groups in trained older women. All values are presented as mean ± SD. [a]Significant difference compared with the first week for the G-3 min ($P < 0.05$). [b]Significant difference compared with the first week for the G-1 min ($P < 0.05$).

This study is not without its limitations. First, the sample was composed only of older women with resistance training experience. This prevents us from generalizing the results to older untrained women and men, who may present greater muscular adaptations to resistance training.[36,41] Second, we did not perform any morphological assessments, limiting us to estimate changes in muscle mass. Third, the functional capacity of the individuals was also not assessed, which may have important implications in the activities of daily life of the participants. Fourth, the use of multiple exercises in the resistance training design may have promoted muscular adaptations in different muscle groups; however, these modifications were not directly determined. Miranda et al.,[42] for example, showed that when multiple exercises are performed in the same session, the number of repetitions in subsequent exercises is reduced and results in a total lower volume. Nonetheless, to avoid the effects of multiple exercises on number of repetitions, the leg press exercise was conducted at the beginning of all training sessions in the present study. Finally, increases in muscle activation and reductions in antagonist coactivation are neuromuscular mechanisms that are involved in muscle strength alterations. In the present study, antagonist coactivation was not directly assessed, limiting us to speculate regarding any possible modifications. However, a recent meta-analysis from Arnold and Bautmans[43] showed no reductions in antagonist coactivation during knee extension (weighted mean difference = 1.1%, $P = 0.69$, for the randomized controlled trials; and weighted mean difference = 1.8%, $P = 0.51$, for the noncontrolled trials) in older people, suggesting that these changes likely did not occur in the present study.

The maintenance and/or increase in the different manifestations of muscle strength are important in the rehabilitation and independence of older people. The prescription of leg press exercise is an excellent strategy to increase efficiency and effectiveness in rehabilitation of muscle strength of the lower limbs, which is important for numerous tasks such as rising from a chair, climbing stairs, and preventing falls in older adults. Based on the results from the present study, it appears that the manipulation of longer and shorter RIs between sets during training causes slight absolute alterations in dynamic and isometric muscle strength and muscle activity in resistance-trained older women. In this scenario, shorter RIs can be considered an alternative to reduce the time spent during the training and obtain the same results in resistance-trained older women. In addition, it is possible that different RIs may have greater impacts in the rehabilitation of older untrained women or men, who may have a higher ceiling for muscular adaptations. Jambassi Filho et al.,[21] for example, have shown that training sessions composed of 3 sets of leg press exercise with an absolute load of 15 RMs using RI of 3 minutes resulted in a higher total volume (+20.4%) than training using an RI of 1 minute in older untrained women, thus suggesting that a longer RI between sets may be important in the rehabilitation of older adults untrained via an increase in the total volume of training.

CONCLUSIONS

In summary, the findings of the present study suggest that the use of RIs of 1 and 3 minutes between sets results in similar gains in dynamic and isometric muscle strength and muscle activity in resistance-trained older women. It is important to highlight that the total volume was similar between groups during the 8-week resistance training program. Future studies are needed to analyze the effects of different RIs, between sets, on the rehabilitation of lower limb muscle strength in older untrained individuals and to examine the underlying mechanisms of RI-induced muscle adaptations.

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REFERENCES

1. Aagaard P, Suetta C, Caserotti P, et al: Role of the nervous system in sarcopenia and muscle atrophy with aging: strength training as a countermeasure. *Scand J Med Sci Sports* 2010;20:49–64
2. Mitchell WK, Williams J, Atherton P, et al: Sarcopenia, dynapenia, and the impact of advancing age on human skeletal muscle size and strength; a quantitative review. *Front Physiol* 2012;3:260
3. Aoyama M, Suzuki Y, Onishi J, et al: Physical and functional factors in activities of daily living that predict falls in community-dwelling older women. *Geriatr Gerontol Int* 2011;11:348–57
4. Alexandre Tda S, Duarte YA, Santos JL, et al: Sarcopenia according to the European Working Group on Sarcopenia in Older People (EWGSOP) versus dynapenia as a risk factor for mortality in the elderly. *J Nutr Health Aging* 2014;18:751–6
5. Lynch NA, Metter EJ, Lindle RS, et al: Muscle quality. I. Age-associated differences between arm and leg muscle groups. *J Appl Physiol (1985)* 1999;86:188–94
6. Chodzko-Zajko WJ, Proctor DN, Fiatarone Singh MA, et al: American College of Sports Medicine position stand. Exercise and physical activity for older adults. *Med Sci Sports Exerc* 2009;41:1510–30
7. Kraemer WJ, Ratamess NA: Fundamentals of resistance training: progression and exercise prescription. *Med Sci Sports Exerc* 2004;36:674–88
8. De Salles BF, Simão R, Miranda H, et al: Strength increases in upper and lower body are larger with longer inter-set rest intervals in trained men. *J Sci Med Sport* 2010;13:429–33
9. Robinson JM, Stone MH, Johnson RL, et al: Effects of different weight training exercise/rest intervals on strength, power, and high intensity exercise endurance. *J Strength Cond Res* 1995;9:216–21
10. Buresh R, Berg K, French J: The effect of resistive exercise rest interval on hormonal response, strength, and hypertrophy with training. *J Strength Cond Res* 2009;23:62–71
11. Gentil P, Bottaro M, Oliveira E, et al: Chronic effects of different between-set rest durations on muscle strength in nonresistance trained young men. *J Strength Cond Res* 2010;24:37–42
12. Ahtiainen JP, Pakarinen A, Alen M, et al: Short vs. long rest period between the sets in hypertrophic resistance training: influence on muscle strength, size, and hormonal adaptations in trained men. *J Strength Cond Res* 2005;19:572–82
13. García-López D, de Paz JA, Moneo E, et al: Effects of short vs. long rest period between sets on elbow-flexor muscular endurance during resistance training to failure. *J Strength Cond Res* 2007;21:1320–4
14. Aagaard P, Simonsen EB, Andersen JL, et al: Increased rate of force development and neural drive of human skeletal muscle following resistance training. *J Appl Physiol (1985)* 2002;93:1318–26
15. Maffiuletti NA, Aagaard P, Blazevich AJ, et al: Rate of force development: physiological and methodological considerations. *Eur J Appl Physiol* 2016;116:1091–116
16. Villanueva MG, Lane CJ, Schroeder ET: Short rest interval lengths between sets optimally enhance body composition and performance with 8 weeks of strength resistance training in older men. *Eur J Appl Physiol* 2015;115:295–308
17. Bottaro M, Martins B, Gentil P, et al: Effects of rest duration between sets of resistance training on acute hormonal responses in trained women. *J Sci Med Sport* 2009;12:73–8
18. Villanueva MG, Lane CJ, Schroeder ET: Influence of rest interval length on acute testosterone and cortisol responses to volume load-equated total body hypertrophic and strength protocols. *J Strength Cond Res* 2012;26:2755–64
19. Jambassi Filho JC, Gurjão ALD, Ceccato M, et al: Effect of different rest intervals between sets in the growth hormone concentrations in trained older women. *Rev Bras Cineantropom Desempenho Hum* 2015;17:216–25
20. Jambassi Filho JC, Gurjão ALD, Gonçalves R, et al: The effect of different recovery intervals between sets of strength training on muscular force in trained older women. *Braz J Sport Med* 2010;16:113–6
21. Jambassi Filho JC, Gurjão ALD, Ceccato M, et al: Effects of different rest intervals between sets on muscle performance in the leg press exercise in untrained elderly women. *Braz J Sport Med* 2012;18:224–8

22. Filho JC, Gobbi LT, Gurjão AL, et al: Effect of different rest intervals, between sets, on muscle performance during leg press exercise, in trained older women. *J Sports Sci Med* 2013;12:138–43
23. Radaelli R, Botton CE, Wilhelm EN, et al: Time course of low- and high-volume strength training on neuromuscular adaptations and muscle quality in older women. *Age (Dordr)* 2014;36:881–92
24. Ribeiro AS, Tomeleri CM, Souza MF, et al: Effect of resistance training on C-reactive protein, blood glucose and lipid profile in older women with differing levels of RT experience. *Age (Dordr)* 2015;37:109
25. Brown LE, Weir JP: ASEP procedures recommendation I: accurate assessment of muscular strength and power. *JEPonline* 2001;4:1–21
26. Häkkinen K, Pakarinen A, Kraemer WJ, et al: Selective muscle hypertrophy, changes in EMG and force, and serum hormones during strength training in older women. *J Appl Physiol (1985)* 2001;91:569–80
27. Merletti R: Standards for reporting EMG data (ISEK/1999). *J Electromyogr Kinesiol* 1999;9:3–4
28. de Andrade AD, Silva TN, Vasconcelos H, et al: Inspiratory muscular activation during threshold therapy in elderly healthy and patients with COPD. *J Electromyogr Kinesiol* 2005;15:631–9
29. Hermens HJ, Freriks B, Disselhorst-Klug C, et al: Development of recommendations for SEMG sensors and sensor placement procedures. *J Electromyogr Kinesiol* 2000;10:361–74
30. Cohen J: *Statistical Power Analysis for the Behavioral Sciences*. Hillsdale, NJ, Erlbaum, 1988
31. Gurjão AL, Gobbi LT, Carneiro NH, et al: Effect of strength training on rate of force development in older women. *Res Q Exerc Sport* 2012;83:268–75
32. Schoenfeld BJ: Postexercise hypertrophic adaptations: a reexamination of the hormone hypothesis and its applicability to resistance training program design. *J Strength Cond Res* 2013;27:1720–30
33. Henselmans M, Schoenfeld BJ: The effect of inter-set rest intervals on resistance exercise-induced muscle hypertrophy. *Sports Med* 2014;44:1635–43
34. Hansen S, Kvorning T, Kjaer M, et al: The effect of short-term strength training on human skeletal muscle: the importance of physiologically elevated hormone levels. *Scand J Med Sci Sports* 2001;11:347–54
35. Goto K, Ishii N, Kizuka T, et al: The impact of metabolic stress on hormonal responses and muscular adaptations. *Med Sci Sports Exerc* 2005;37:955–63
36. Rhea MR, Alvar BA, Burkett LN, et al: A meta-analysis to determine the dose response for strength development. *Med Sci Sports Exerc* 2003;35:456–64
37. Taaffe DR, Pruitt L, Pyka G, et al: Comparative effects of high- and low-intensity resistance training on thigh muscle strength, fiber area, and tissue composition in elderly women. *Clin Physiol* 1996;16:381–92
38. Taaffe DR, Henwood TR, Nalls MA, et al: Alterations in muscle attenuation following detraining and retraining in resistance-trained older adults. *Gerontology* 2009;55:217–23
39. Folland JP, Williams AG: The adaptations to strength training: morphological and neurological contributions to increased strength. *Sports Med* 2007;37:145–68
40. Moritani T, deVries HA: Neural factors versus hypertrophy in the time course of muscle strength gain. *Am J Phys Med* 1979;58:115–30
41. Bamman MM, Hill VJ, Adams GR, et al: Gender differences in resistance-training-induced myofiber hypertrophy among older adults. *J Gerontol A Biol Sci Med Sci* 2003;58:108–16
42. Miranda H, Simão R, dos Santos Vigário P, et al: Exercise order interacts with rest interval during upper-body resistance exercise. *J Strength Cond Res* 2010;24:1573–77
43. Arnold P, Bautmans I: The influence of strength training on muscle activation in elderly persons: a systematic review and meta-analysis. *Exp Gerontol* 2014;58:58–68