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Influence of strength training intensity on subsequent recovery in elderly

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ABSTRACT

Understanding the influence of strength training intensity on subsequent recovery in elderly is important to avoid reductions in physical function during the days following training. Twenty-two elderly were randomized in two groups: G70 (65.9 ± 4.8 years, $n = 11$) and G95 (66.9 ± 5.1, n = 11). Baseline tests included maximum voluntary isometric contraction (peak torque and rate of torque development - RTD), countermovement jump, and functional capacity (timed up and go, stairs ascent and descent). Then, both groups performed a single strength training session with intensities of 70% (G70) or 95% (G95) of five repetition maximum. The same tests were repeated immediately, 24 h, 48 h, and 72 h after the session. Peak torque was lower than baseline immediately after for both groups and at 24 h for G95. Compared with G70, G95 had lower peak torque at 24 h and 48 h. Countermovement jump, timed up and go, stairs ascent, and RTD at 0–50 ms only differed from baseline immediately after for both groups. RTD at 0–200 ms was lower than baseline immediately after and 24 h after the session for both groups. In conclusion, reduced physical function immediately after strength training can last for 1–2 days in elderly depending on the type of physical function and intensity of training. Higher intensity resulted in greater impairment. Exercise prescription in elderly should take this into account, e.g., by gradually increasing intensity during the first months of strength training. These results have relevance for elderly who have to be fit for work or other activities in the days following strength training.

1. Introduction

Since the 1970s there has been a steady rise in the proportion of elderly people in most parts of the world (OECD, 2016). This has important socioeconomic consequences as the number of economically inactive people continues to rise. One of the consequences is that people in many parts of the world are expected to stay at the labor market until a higher age (Eläketurvakeskus, 2017). However, the inherent decline in muscle function (i.e., maximum strength, power, explosive force, and functional capacity) with aging may impede this ambition (Byrne et al., 2016; Izquierdo et al., 1999; Manini and Clark, 2012; McKinnon et al., 2017). The decrease in physical capacity with age may make it more difficult to meet the work demands, and effective methods for maintaining muscle strength with aging are therefore important.

Strength training is a widely used method for improving and maintaining muscle strength, power, and hypertrophy among all age groups. In the older population, strength training is efficient to attenuate and even reverse the deleterious effects of aging in the neural and muscular function, as evidenced through physiological and biomechanical adaptations such as increases in neural drive (Unhjem et al., 2015), voluntary activation (Arnold and Bautmans, 2014), motor unit firing rate (Kamen and Knight, 2004), and muscle hypertrophy (Lixandrão et al., 2016). These adaptations can result in gains of muscle power as well as maximum and explosive strength, which provides improvements of stabilization during standing, locomotion, or in response to mechanical perturbation (Izquierdo et al., 1999; Pijnappels et al., 2008), in functional capacity of daily living activities performance, reducing risk of falls (Bento et al., 2010; Byrne et al., 2016; Moura et al., 2017), and maintenance of work ability among workers with hard physical labor (Jakobsen et al., 2015; Sundstrup et al., 2014).

Despite the numerous beneficial long-term adaptations, the acute response to high-intensity strength training can be viewed as “damaging” from a muscle cellular point of view. The mechanical overload produced by successive concentric and especially eccentric actions during unaccustomed strength training damages contractile proteins, intermediate filaments, and connective tissue surrounding the muscle

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fibers (Lau et al., 2013). This initiates an inflammatory process and causes delayed onset muscle soreness, increasing muscle stiffness and swelling (Clarkson and Hubal, 2002), and concomitant reductions in maximum voluntary contraction force (Dedrick and Clarkson, 1990), explosive force (Peñailillo et al., 2015), power (Byrne et al., 2004), and flexibility (Nogueira et al., 2014). Elderly people experience greater muscle damage (Manfredi et al., 1991) and need longer time for recovery (Dedrick and Clarkson, 1990) compared with younger people. Considering that many elderly people already have reduced physical function relatively to younger people, this can have important consequences for daily living activities and work ability. Thus, recommendations for elderly initiating strength training programs should consider not only long-term but also acute effects of different training regimens.

Studies investigating muscle damage in elderly have mainly used eccentric muscle actions, causing a great impairment on the neuromuscular properties (Dedrick and Clarkson, 1990; Lavender and Nosaka, 2006; Nogueira et al., 2014). By contrast, traditional strength training intensity is determined by concentric strength (i.e., one repetition maximum – 1-RM), which is relatively lower compared with eccentric strength (Weir et al., 1995). In this way, muscle damage following traditional strength training may be different from eccentric induced muscle damage. Studies in elderly inducing muscle damage using high-volume strength training (Roth et al., 1999, 2000) and an eccentric cycle ergometer (Manfredi et al., 1991) have investigated muscular structural changes, but not physical function and strength. Ferri et al. (2006) investigated muscle damage in the calf muscles of elderly performing unaccustomed strength training consisting of 10 sets with 10 repetitions at 70% of 1-RM, but did not investigate impairment in functional capacity. Different combinations of strength training variables (i.e., intensity, volume, rest intervals, and frequency), training level, targeted muscles (Brentano et al., 2016; Ferri et al., 2006; Nogueira et al., 2014; Roth et al., 1999, 2000) affect the muscle damage response. Training intensity is one of the key variables being manipulated. A recent strength training study comparing low and high intensities (20 vs 80% of 1-RM) found similar muscle hypertrophic effects in elderly, but the high intensity resulted in greater strength gains (Van Roie et al., 2013). Training intensities ranging from 60 to 85% of 1-RM are generally known to be effective for increasing muscle mass and strength (Mayer et al., 2011). From a safety point of view, the lower end of the intensity spectrum may be preferable to avoid overload injuries in unaccustomed elderly initiating strength training. Nevertheless, it is unclear how low/moderate intensity (60–69% of 1-RM) and high intensity (> 80% of 1-RM) (Peterson et al., 2010) differ from each other regarding acute muscle damage and functional responses after a single session of strength training.

Because the acute damaging response of unaccustomed strength training may negatively affect function and work ability in elderly people, thoroughly investigating acute changes in strength, power, function, and recovery time is vital for being able to provide optimal recommendations. Therefore, the purpose of this study is to compare the effects of different intensities of strength training programs to concentric failure in the lower limb muscles power, maximum and explosive force, functional capacity impairment, and recovery time in elderly.

2. Methods

2.1. Subjects

Subjects were recruited from our laboratory's participant database of previous strength training experiments. To be included, volunteers should be at least 60 years and able to complete the training session and all the tests. Exclusion criteria were current participation in structured traditional strength training and/or other exercises that involve strength or eccentric components (such as sports, high intensity running or cycling) in the last three months prior to the study, lower limb musculoskeletal and/or neuromuscular disease or chronic pain, unstable cardiovascular disease, and being unable to perform the exercises to concentric failure. In this way we could ensure that the training intensities would be as high as intended.

Twenty-five healthy elderly volunteered to participate in the present study and after three were excluded, 22 were eligible for the experiment. The reasons for excluding the three subjects were: unavailability to perform all the tests ($n = 1$) and lower limb discomfort (none with diagnosed disease – $n = 2$). Subjects were randomized in two groups: Moderate intensity group (G70, $n = 11$, ♀ = 4 and ♂ = 7; 65.9 ± 4.8 years; 75.1 ± 11.9 kg, and 32.2 ± 6.7% body fat) and high intensity group (G95, n = 11, ♀ = 3 and ♂ = 8; 66.9 ± 5.1 years; 73.5 ± 16.3 kg, and 31.3 ± 7.1% body fat). Subjects were requested to avoid any exercise, to not take anti-inflammatory drugs or dietary supplements and to not change their lifestyle during the experimental period. All volunteers gave written informed consent, and the study was approved by the local Human Research Ethics Committee (approval number: 1.657.414) and in accordance with the Helsinki declaration.

2.2. Study design

This study consisted of nine laboratory visits (i.e., 2 weeks). During the first visit, subjects were informed about study design and procedures. Subsequently, subjects were randomized in two groups; G70 and G95 (i.e. simple randomization). During the second visit, subjects reported to the laboratory for body composition assessment. During the next three visits, each separated by 48 (± 1) hours, subjects were familiarized, tested and retested in the following tests: (1) maximum voluntary isometric contraction (MVIC), (2) countermovement jump, (3) functional capacity, and (4) five-repetitions maximum (5-RM) for baseline values. During the sixth visit, each subject completed a single strength training session of either G70 or G95, depending on the randomized allocation. After 10 min following the 5-RM tests, each subject performed MVIC, countermovement jump, and functional capacity tests. Subjects repeated MVIC, countermovement jump, and functional capacity tests in the subsequent days (i.e., 24 ± 1, 48 ± 1, and 72 ± 1 h). All tests were performed by the same experienced evaluators.

2.3. Body composition

Subjects body composition were assessed by a trained evaluator with a dual-energy X-ray absorptiometry (DXA) (Lunar Prodigy Advance, GE Medical System Lunar, Madison, WI, USA), that were daily and weekly calibrated as recommended by the manufacturer. Height was measured using a standing stadiometer (Alturexata, Minas Gerais, Brazil) and body mass by a digital scale (Welmy W200, São Paulo, Brazil), with 0.1 cm and 0.1 kg resolution, respectively.

2.4. Maximum voluntary isometric contraction

Subjects performed a general warm-up of 5 min using cycle ergometer. Thereafter, subjects were firmly secured by inelastic straps about the trunk, hips, thighs, and ankle followed by a pre-conditioning to the dynamometer with 10 submaximal repetitions of concentric knee extension and flexion (120°·s^{-1}) and three isometric attempts from submaximal to near-maximal efforts (60 s of rest between them). MVIC contractions were performed for the knee extensors at a static knee joint angle of 70° and hip angle of 85° (0° = knee full extension and hip in neutral position) using a daily calibrated isokinetic dynamometer (Biodex System 4, Biodex Medical Systems, Shirley, NY, USA). Hereafter, each subject performed three to four maximal trials sustained for approximately 5 s. Participants were instructed to produce force "as fast and as hard as possible" (allowing 120 s of rest between the trials). A fourth trial was performed if the third trial exceeded previous attempts with > 5%. Baseline values were obtained by subtracting weight of the shank from the initial signal. Peak torque was defined as the highest torque value obtained in the MVIC attempts. The highest isometric peak torque was chosen for further analysis.

The torque signal was recorded at a sampling frequency of 2000 Hz with a resolution of 14-bits (MioTec Biomedical, Porto Alegre, Brazil). All subsequent analyses were performed using the scaled, filtered, and gravity-corrected torque signal. Signal processing included filtering with a recursive fourth order Butterworth low-pass filter and a cutoff frequency of 9 Hz. The slope of the torque–time curve (i.e., Δtorque/Δtime) was used to calculate the rate of torque development (RTD) in different periods (0–50 and 0–200 ms). RTD 0–50 ms is mainly determined by neural mechanisms and intrinsic contractile properties and RTD 0–200 ms by maximum voluntary force (Andersen and Aagaard, 2006; Folland et al., 2014). The onset of muscle contraction was defined as the time point where the torque exceeded the baseline by 7.5 N·m (Aagaard et al., 2002). All torque data were stored on a personal computer and processed off-line using MATLAB® R2015b (MathWorks, Natick, Massachusetts, USA).

2.5. Countermovement jump

Countermovement jump height was assessed with a Quattro Jump force platform (Kistler, Quattro Jump 9290AD, Winterthur, Switzerland). The test was performed with a maximum knee flexion angle of 70° (0° = full extension). Each subject performed three attempts. If the third attempt exceeded the previous by > 5%, subjects performed two additional trials. The average of three jumps height was chosen due to its validity to monitor neuromuscular status (Claudino et al., 2017).

2.6. Five-repetitions maximum

Subjects performed 5-RM tests (bilateral) using a horizontal leg press and a seated leg curl (Righetto®, Freestyle, São Paulo, Brazil), respectively. Knee joint range of motion was standardized from ~90° to ~5° of flexion during the leg press and from ~100° to ~5° during the seated leg curl (0° = full extension), measured by a goniometer. Using the same equipment and settings, the same evaluator conducted the familiarization, pre- and post-tests. To ensure that the true 5-RM were reached, subjects were encouraged to perform a sixth repetition after the fifth. Thus, if four or less repetitions were performed, the weight was reduced for the next trial, and if six repetitions were performed, weight was increased. The 5-RM test was considered successful when the subjects performed exactly five repetitions. Each subject performed 1–3 trials with a rest period of 5 min, before the leg press and subsequently for the seated leg curl.

2.7. Functional capacity

Functional capacity was assessed with the following tests: 1) timed up and go, 2) stair ascent, and 3) stair descent. All the tests were filmed with a camera (GoPro Hero 4 Silver; GoPro Inc. California, USA) with a sample rate of 100 Hz and analyzed by an evaluator blinded to training group. Timed up and go, stair ascent and stair descent tests were performed and analyzed as suggested by da Silva et al. (2017). The ascent time was separated from descent time. Each subject performed two attempts of each test and the fastest time was used for further analyses.

2.8. Perceived exertion scale

The Omni-Res perceived exertion scale (0 = extremely easy and 10 = extremely hard) for strength training was used to determine the perception of effort expressed after each set during the strength training session (Naclerio et al., 2011). Subjects were familiarized with the scale before the training session.

2.9. Strength training session

An experienced researcher supervised each session of strength training. Before the training session, subjects performed a warm-up using a cycle ergometer for 5 min and doing 12 repetitions at 50% of 5-RM in the leg press and in the seated leg curl. After 2 min rest, the training session began with leg press, followed by the seated leg curl. The training intensity for the G70 and G95 were 70% and 95% of 5-RM, equivalent of 60% and 85% of 1-RM, respectively (Brzycki, 1993). Three sets for each exercise were performed. Subjects were requested to complete as many repetitions as possible on each set. Rest interval between sets and exercises were 120 s for both groups. Lifting tempo was between 1 and 2 s for concentric and eccentric actions, which naturally became lower near concentric failure as fatigue increased. Strong verbal encouragement was given during each set for all subjects, especially during the final repetitions, ensuring that concentric failure was achieved.

2.10. Statistical analyses

The intraclass correlation coefficient and coefficient of variation for each test of the present study were calculated using the tests and retest values to verify the test-retest reliability (Hopkins, 2000). Knee extensor peak torque, RTD early (0–50 ms) and late (0–200 ms) phases, countermovement jump, timed up and go, stair ascent, and stair descent baseline results was set as 100%. The percentage of the subsequent tests results (post, 24 h, 48 h, and 72 h) were calculated relative to baseline. Means and standard deviations were calculated for the baseline values and training variables. Independent samples student t-test was used to compare baseline values of peak torque, RTD (0–50 ms), RTD (0–200 ms), 5-RM, timed up and go, stair ascent, and stair descent, as well as training session load and total relative work differences between groups. Perceived exertion scale differences between sets and groups were calculated with a non-parametric test (Friedman).

A repeated measures ANOVA was used to analyze main effects as well as the group (G95, G70) × time (sets 1, 2, and 3) interaction, and also, the group (G95, G70) × time (baseline, post, 24 h, 48 h, and 72 h) interaction for the percentage values of peak torque, RTD (0–50 ms), RTD (0–200 ms), timed up and go, stair ascent, and stair descent. When significant F-values were identified, Sidak post-hoc test was performed to identify pairwise differences. Effect sizes were calculated according to Cohen (1988). Effect sizes of 0.20, 0.50 and 0.80 are considered small, moderate and large, respectively. The SPSS 18.0 (IBM, Inc., Chicago, IL) software was used for statistical analyses. An alpha level of 5% was used in all statistical analyses.

3. Results

There were no baseline differences between groups for any of the physical performance, age, and body composition variables. Peak torque for G70 and G95 were 184 ± 41 and 189 ± 54 N·m, respectively ($p = 0.830$), RTD (0–50 ms) were 833 ± 320 and 820 ± 376 N·m·s^{-1}, respectively ($p = 0.938$), RTD (0–200 ms) were 581 ± 187 and 622 ± 227 N·m·s^{-1}, respectively ($p = 0.657$), countermovement jump height were 26.3 ± 7.2 and 26.5 ± 7.4 cm, respectively ($p = 0.948$), timed up and go time were 5.5 ± 0.5 and 5.5 ± 0.9 s, respectively ($p = 0.952$), stair ascent were 3.5 ± 0.4 and 3.3 ± 0.5 s, respectively ($p = 0.376$), and stair descent were 3.3 ± 0.4 and 3.2 ± 0.8 s, respectively ($p = 0.647$). Training load, number of repetitions performed, and perceived exertion scale of sets 1, 2, and 3, and the total relative work for G70 and G95 during the training session are presented in Table 1.

Table 1
G70 and G95 performance in horizontal leg press and seated leg curl exercises in the strength training session. Training load, repetitions performance and perceived exertion for sets 1, 2, and 3, and relative total work.

	Horizontal leg press		Seated leg curl	
	G70	G95	G70	G95
Training load (kg)	70.6 ± 16.8	87.7 ± 29.5	52.4 ± 13.9[c]	68.1 ± 19.1
Reps Set 1	18.0 ± 4.9[c]	6.5 ± 1.2	19.5 ± 6.2[c]	9.6 ± 3.0
Reps Set 2	13.6 ± 6.5[c,a]	5.4 ± 1.8	15.1 ± 5.3[ca]	7.9 ± 3.2[a]
Reps Set 3	11.8 ± 6.3[c,b,a]	3.8 ± 1.8[b,a]	13.1 ± 4.9[c,b,a]	6.3 ± 3.5[b,a]
PES Set 1	9.2 ± 0.9	9.6 ± 0.5	8.8 ± 1.4	9.1 ± 0.5
PES Set 2	9.6 ± 0.7[a]	9.6 ± 0.5	9.1 ± 1.0	9.5 ± 0.5
PES Set 3	9.6 ± 0.7[a]	10.0 ± 0.0[b,a]	9.2 ± 1.3	9.4 ± 0.7
Relative total work (%)	3042 ± 1173[c]	1572 ± 610	3335 ± 1122[c]	2144 ± 851

Reps = repetitions; PES = perceived exertion scale; Relative total work = % of 5-RM × (Reps set1 + set2 + set3).

[a] Different from set 1.

[b] Different from set 2.

[c] Difference between groups; ($p < 0.05$).

A group (G70 and G95) x time (baseline, post, 24 h, 48 h, and 72 h) interaction was observed for knee extensor peak torque ($F = 3.882$; $p = 0.020$). G70 values for 24 h and 48 h after the training session were higher than G95 ($p = 0.005$ and $p = 0.004$, respectively). Post results for G70 and G95 were lower than baseline ($p = 0.005$ and $p < 0.001$, respectively), 24 h ($p < 0.001$ and $p = 0.02$, respectively), 48 h ($p < 0.001$ and $p = 0.013$, respectively), and 72 h ($p < 0.001$ and $p = 0.005$, respectively). In addition, G95 results in the 24 h was lower than baseline ($p = 0.002$) (Fig.1A). The effect size of post, 24 h, 48 h, and 72 h compared to baseline were −0.91, −0.04, 0.13, and 0.11 for G70 and − 0.56, −0.22, −0.17, and − 0.03 for G95.

A time effect was observed for RTD (0–50 and 0–200 ms - $p < 0.001$), without differences between groups. RTD (0–50 ms) at the post was lower than baseline ($p < 0.001$), 24 h ($p = 0.003$), 48 h ($p = 0.035$), and 72 h ($p = 0.001$) (Fig.1B). In the same way, RTD (0–200 ms) at the post was lower than baseline ($p = 0.001$), 48 h ($p = 0.029$), and 72 h ($p = 0.002$). However, at the 24 h was lower than baseline ($p = 0.003$) and 72 h ($p = 0.036$) (Fig.1C). The RTD (0–50 ms) effect size of post, 24 h, 48 h, and 72 h compared to baseline were − 0.97, −0.41, −0.54, and − 0.38 for G70 and − 0.65, −0.45, −0.30, and − 0.26 for G95. The RTD (0–200 ms) effect size of post, 24 h, 48 h, and 72 h compared to baseline were −0.81, −0.34, −0.29, and −0.11 for G70 and −0.56, −0.41, −0.32, and −0.23 for G95.

A time effect was observed for countermovement jump height ($p = 0.002$) without differences between groups. In the post, values were lower than baseline ($p = 0.001$), 24 h ($p = 0.021$), 48 h ($p = 0.008$), and 72 h ($p = 0.041$) (Fig.1D). The effect size of post, 24 h, 48 h, and 72 h compared to baseline were −0.37, −0.08, 0.17, and −0.14 for G70 and −0.49, −0.23, −0.04, and −0.12 for G95.

For functional capacity tests, a time effect was observed for timed up and go ($p = 0.036$) and stair ascent ($p = 0.012$), without differences between groups. There was no change for stair descent ($p = 0.241$) during all the experimental period (Fig.2C). Timed up and go values in the post were higher than baseline ($p = 0.015$) (Fig. 2A). Stair ascent values in the post were higher than 24 h ($p = 0.023$), 48 h ($p = 0.033$), and 72 h ($p = 0.004$) (Fig.2B). For TUG the effect size of post, 24 h, 48 h, and 72 h compared to baseline were 0.13, 0.13, 0.35, and −0.09 for G70 and 0.44, 0.09, 0.19, and 0.20 for G95. For stair ascent the effect size of post, 24 h, 48 h, and 72 h compared to baseline were 0.54, 0.05, −0.15, and −0.45 for G70 and 0.24, 0.13, −0.02, and −0.02 for G95. For stair descent the effect size of post, 24 h, 48 h, and 72 h compared to baseline were 0.50, 0.11, −0.05, and −0.10 for G70 and 0.03, 0.09, 0,06, and −0.03 for G95.

The variation of individual responsiveness between subjects of G70

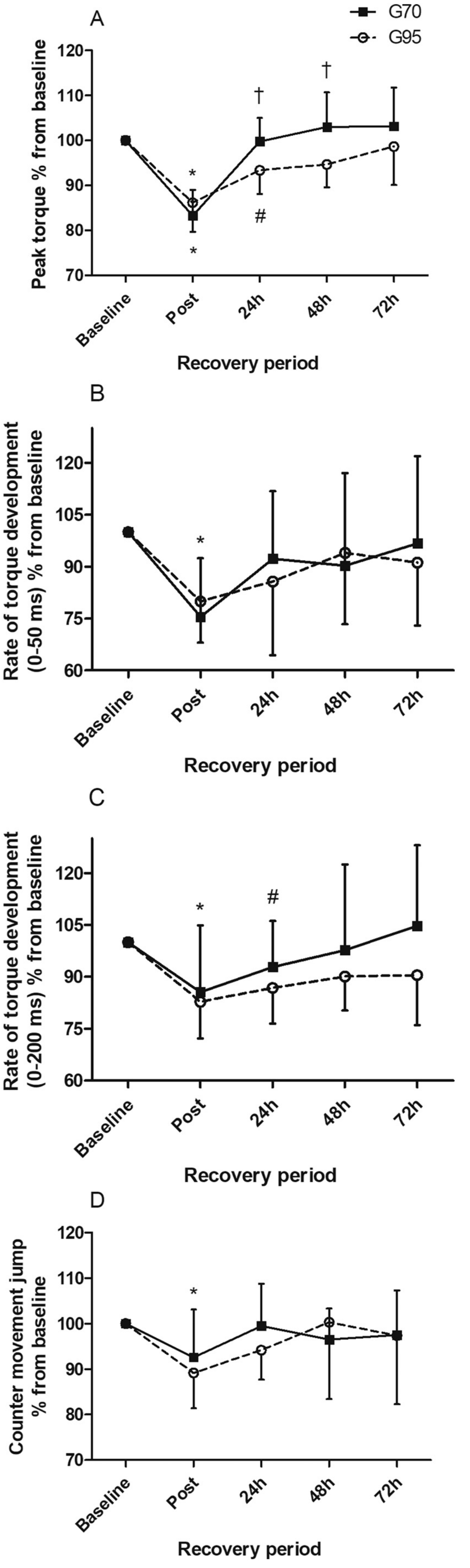

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Fig. 1. The means ± standard deviation for: A) peak torque percentage during a maximum voluntary isometric contraction for groups G70 and G95, before (baseline), right after (post) and 24 h, 48 h, and 72 h after the training session. † Difference between groups in the same recovery period moment; * Lower than baseline, 24 h, 48 h, and 72 h in both groups; and # Lower than baseline in G95. ($p < 0.05$). B/C) rate of torque development percentage (B: 0–50 ms and C: 0–200 ms) for groups G70 and G95, before (baseline), right after (post) and 24 h, 48 h, and 72 h after the training session. For both groups, * Lower than baseline, 24 h, 48 h, and 72 h; and # Lower than baseline and 72 h; ($p < 0.05$). D) counter movement jump height percentage for groups G70 and G95, before (baseline), right after (post) and 24 h, 48 h, and 72 h after the training session. For both groups, * Lower than baseline, 24 h, 48 h, and 72 h ($p < 0.05$).

and G95 for MVIC, countermovement jump, RTD (0–50 ms and 0–200 ms), and functional capacity tests are presented in Fig.3.

Test-retest intraclass correlation coefficient and coefficient of variation for MVIC peak torque, RTD (0–50 ms and 0–200 ms), countermovement jump, 5-RM (leg press and seated leg curl), and functional capacity tests (timed up and go, stair ascent and stair descent) are presented in Table 2.

4. Discussion

This is the first study to examine the time-course recovery of maximal voluntary force, explosive force, power, and functional capacity after a single session of unaccustomed strength training to failure with different intensities in elderly people. The main finding of this study was an immediately decline in physical function, explosive, and maximum force parameters following a strength training session. Although both groups showed a positive recovery effect in the days following the session, G70 showed faster recovery for peak torque during MVIC and late phase RTD (0–200 ms). Thus, while either type of training can be recommended without significant impairment in physical function in the following days, a training intensity of 70% of 5-RM (~60% 1-RM) seems to be the safest choice. These results have relevance for elderly who has to be fit to work in the days following strength training.

A previous study involving young subjects indicated that the level of muscle damage in response to muscle overload is less in the knee extensors than in the elbow extensor/flexors. They described this difference to the fact that lower limb muscles frequently exposed to eccentric contractions in the activities of daily life (Chen et al., 2011). Additionally, eccentric muscle strength is better preserved than concentric strength among elderly (Roig et al., 2010). Thus, while strength training intensity is determined by concentric strength, it seems that preserved eccentric strength could attenuate muscle damage in elderly. The differences observed for maximal strength (i.e., peak torque) between G70 and G95 during the MVIC suggests that workload related to 70% of 5-RM (~60% of 1-RM) did not induce as much muscle damage as the intensity related to 95% of 5-RM (~85% of 1-RM). These results are reinforced by assessing peak torque observed for G95 after 24 h compared to the baseline value (Fig.3A).

It seems that knee extensors peak torque during a MVIC is not the best strength parameter to evaluate muscle damage compared to explosive force (Peñailillo et al., 2015). It is well-established that RTD has great importance in the response to mechanical perturbation, balance, musculoskeletal stabilization, and consequently preventing falls (Bento et al., 2010; Ema et al., 2016; Izquierdo et al., 1999). The early phase (0–50 ms) of the RTD was reduced only immediately after the training session. Because the early phase is highly dependent on neural factors and only moderately dependent on contractile properties (Folland et al., 2014), the present results suggest that neural factors (e.g., neural drive and activation in the first 0–100 ms after the onset) are reduced immediately after the training session. On the other hand, the late phase (0–200 ms) of both groups returned to baseline values only after 48 h. Previous studies have shown that RTD during late phase is highly correlated with maximum voluntary force (Andersen et al., 2005; Folland et al., 2014), and we therefore expected the recovery for peak

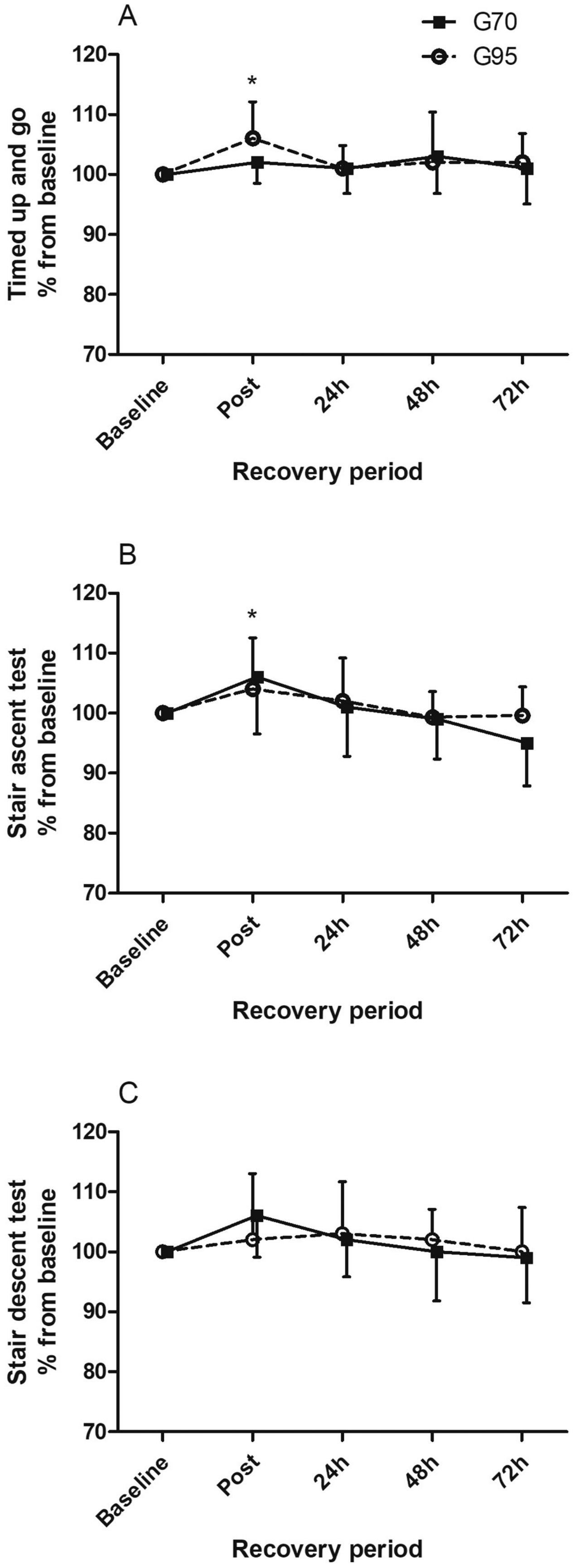

Fig. 2. The means ± standard deviation for: A) Timed up and go; B) stair ascent; and C) stair descent tests percentage for groups G70 and G95, before (baseline), right after (post) and 24 h, 48 h, and 72 h after the training session. For both groups, (A) * Higher than baseline and (B) * Higher than 24 h, 48 h, and 72 h; ($p < 0.05$).

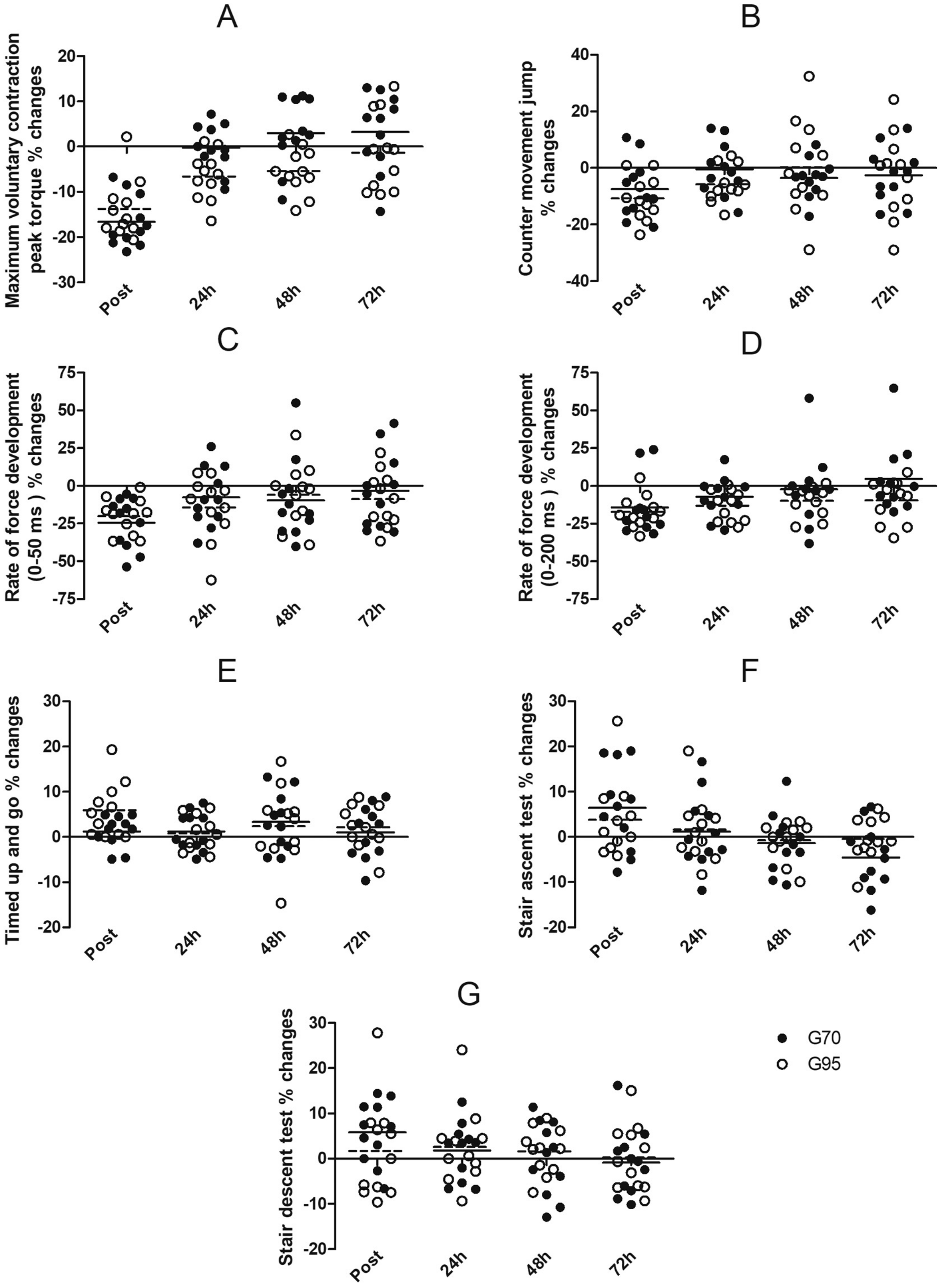

Fig. 3. Individual responsiveness as percentage changes compared to baseline for each subjects for maximum voluntary contraction (A), counter movement jump (B), rate of torque development (0–50 ms – C and 0–200 ms – D), Timed up and go (E), stair ascent (F) and stair descent (G) tests, for both groups (G70 and G95). Continuous line: G70 mean; and dashed line: G95 mean.

torque and RTD at 200 ms to be somewhat similar. Although no statistically significant differences were detected between groups, individual responsiveness values show a larger number of G95 subjects with lower values than most of G70 after 24 h and 48 h (Fig.3D).

Another strength parameter related to physical function in elderly is lower limb power. This variable is correlated with functional capacity to perform daily life activities (Byrne et al., 2016). Despite the fast recovery observed for both groups after 24 h, the most of the G95 subjects showed lower recovery than majority G70 subjects when analyzing individual responsiveness. It is important to highlight that the high variability in recovery of power (i.e., 72 h) shows that some subjects would take longer to recovery than others, independent of the training intensity (Fig.3B).

The impairments observed for all strength variables seems to play a role in the reductions of the subjects' functional capacity tests (timed up and go and stair ascent) immediately after the training session, except for stair descent. Lower impairments (reductions of < 17%) of maximum and explosive force and power observed after 24 h, 48 h, and 72 h

Table 2
Test-retest reliability.

	ICC	CV%
MVIC peak torque	0.981	4.0
Rate of torque development 0–50 ms	0.860	24.0
Rate of torque development 0–200 ms	0.912	15.9
Countermovement jump	0.936	7.4
5-RM leg press	0.992	2.7
5-RM seated leg curl	0.984	3.6
Timed up and go	0.883	4.3
Stair ascent	0.934	3.5
Stair descent	0.911	5.8

MVIC = maximum voluntary isometric contraction; 5-RM = five-repetitions maximum; ICC = intraclass correlation coefficient; CV% = coefficient of variation.

does not seem to be enough to impair in a higher magnitude the functional capacity of the elderly, independent of the training intensity. Additionally, the preservation of the eccentric strength in the elders (Roig et al., 2010) and the training intensity determined by concentric 5-RM would not be enough to impair the eccentric contraction. This may explain our results of unimpaired stair descent performance, as this test is characterized by the predominance of eccentric contractions (Reeves et al., 2008).

The present study has both strengths and limitations. Using a randomized design and the same experienced evaluator to perform all tests gives our study high internal validity. Another strength of the study is that we used a homogenous population of elderly being unaccustomed to strength training, allowing to study the acute response in this population using a variety of measurement methods. On the other hand, the effects of different strength training protocols can vary according to the training intensity, volume, exercises, age and training level or history. For example, the repeated bout effects can lead to a protective effect against muscle damage after subsequent exercise bouts. In consequence, after some training sessions, the subject would be protected against muscle damage caused by an unaccustomed training stimuli and thus experience less muscular functional impairment (Hyldahl et al., 2017). Consequently, the results from the present study cannot be extrapolated to other training methods (e.g., with sets not to concentric failure and eccentric, power or explosive type methods), other populations (e.g., previously trained, older or frail subjects) and to long-term adaptations.

As a practical application for training periodization prescription, trainers should consider at least 72 h of neuromuscular recovery after sessions to concentric failure when using high intensities such as 95% of 5-RM. When using lower intensities, such as 70% of 5-RM, a shorter period of time is needed for neuromuscular recovery. Also, trainers are recommended to consider that individuals have different recovery capacity after a strength training sessions with sets to concentric failure, so this recovery time can vary. Drawing on the same rationale, 70% of 5-RM resulted in greater relative total work (i.e. volume load) compared to 95% of 5-RM. Thus, the greater session volume and the opportunity to increase weekly training frequency (i.e., faster recovery) can result in greater weekly total volume in spite of lower intensities. As a consequence this can result in better strength (Ralston et al., 2017), hypertrophy and health responses (e.g., preservation or treatment of cardiovascular and diabetes diseases) (Figueiredo et al., 2017).

In conclusion, immediately after strength training to failure (with 70 or 95% of 5-RM intensity) elderly experience marked decreases in peak torque, explosive force (0–50 and 0–200 ms), power, and functional capacity. The acute reduction in capacity may affect daily living and working activities, balance, the capacity to respond to mechanical perturbation, and risk of falling. In the days subsequent to unaccustomed strength training, most of the subjects of the present study recovered their functional capacity, however, the balance and capacity to respond to mechanical perturbation seems to remain impaired for 24 h for the majority of subjects in G95. Additionally, some subjects still experienced impairments 72 h after the session. The individual responses should also be considered when designing strength training regimens for elderly people.

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