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ORIGINAL ARTICLE

Functional capacity improves in-line with neuromuscular performance after 12 weeks of non-linear periodization strength training in the elderly

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Abstract

Background While it is accepted that resistance training can improve functional capacity in older individuals, the neuromuscular source of this improvement has yet to be identified.

Aim This study investigated the link between improved neuromuscular performance and functional capacity after a 12-week resistance training period in untrained healthy older individuals.

Methods Fifteen older men and women (60–71 years) adhered to a 4-week control period, followed by 12 weeks of non-linear resistance training for the lower limbs. Maximum dynamic leg press strength (1-RM), maximum isometric knee extension torque and rate of torque development (RTD) were evaluated at − 4, 0, 4, 8, and 12 weeks, and muscle activity was assessed at 0, 4, 8, and 12 weeks. Functional capacity tests (chair rise, stair ascent and descent, and timed up and go) were performed at − 4, 0, and 12 weeks.

Results No changes occurred during the control period, but the group increased their 1-RM strength (from 142 ± 53 to 198 ± 43 kg, $p = 0.001$), which was accompanied by an increase in vastus lateralis activation ($p = 0.008$) during the intervention. Increase was observed at all RTD time intervals at week 8 ($p < 0.05$). Significant improvements in all the functional capacity tests were observed at week 12 ($p < 0.05$).

Discussion Despite the expected increase in strength, RTD, muscle activity, and functional capacity, there was no significant relationship between the changes in neuromuscular performance and functional capacity. While resistance training elicits various positive improvements in healthy older individuals, actual strength gain did not influence the gain in functional capacity.

Conclusion The present study highlights the exact cause that improved the functional capabilities during resistance training are currently unknown.

Keywords Strength training · Rate of torque development · Aging · Timed up and go · Chair rise

Introduction

Aging is associated with decrease in neuromuscular performance (i.e., maximum and explosive strength) due to adverse morphological changes (i.e., decrease in muscle size and an increase in muscle fat infiltration) and a lower ability to activate the muscles (i.e., low agonist activation and/or high antagonist co-activation) [1]. Due to these age-related declines, older people become more fragile and less independent to perform activities of daily living [2]. This could eventually lead to increased risk of fall or fracture [3, 4].

Resistance training is widely used with the intention of preventing and reversing losses in maximum and explosive strength, muscle mass, and muscle activity in older

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individuals [5–7]. Maximum strength has been assessed during dynamic (i.e., one repetition maximum load) and isometric (peak force or torque) contraction, while explosive strength can be assessed during the early phase of isometric contraction by the rate of torque development (RTD). Since both maximum and explosive strength has been linked to the ability to perform functional capacity tests [8, 9], it is not surprising that resistance training has also been shown to improve functional capacity, such as walking speed, stair climbing, and the ability to stand up from a chair [7, 10, 11]. Particularly, a low RTD, which is influenced by neuromuscular and morphological factors [12], has been suggested as a key factor for poor functional capacity and increased risk of fall [13].

Despite having evidence of the importance of strength on functional capacity from cross-sectional studies [14–16], there is a surprising lack of studies showing a direct relationship between short-term training-induced increase in strength and increase in functional capacity. This is especially surprising given the number of training studies that have been performed in this field. To the authors' knowledge, only one study, i.e., Santos et al. [17] has shown a statistically significant relationship between the training-induced gain in maximum strength and 10-m walking speed test. Consequently, it is currently undetermined whether increased strength even plays a role in improved functional capacity, and if so, what element of strength (e.g., maximal or explosive) is most influential for older people [11, 14, 18].

One possible confounding factor is that the literature is composed of many different forms of resistance training programs. Within resistance training periodization models, linear and non-linear periodization [19] have recently received scientific attention. While linear periodization improves a specific element of neuromuscular performance in each block of training, non-linear periodization, introduced by Poliquin [20], is thought to promote faster and broader adaptations in neuromuscular performance due to the frequent variations in intensity and volume, such as from session-to-session.

Therefore, there is a paucity of evidence to show a direct relationship between the training-induced improvements in different elements of strength and functional capacity, despite strength being shown (in cross-sectional studies) to be an important component of functional capacity. Second, short-term non-linear periodization resistance training may promote simultaneous improvement in maximum strength and explosive strength in older individuals, and is, therefore, an attractive model that can be used to study the effect of neuromuscular adaptations on functional capacity. Hence, the primary aim of the present study is to examine the effects of non-linear periodization resistance training on neuromuscular performance and functional capacity. Furthermore, a secondary aim was to determine the possible relationships between the training-induced improvements in healthy older individuals. It was hypothesized that neuromuscular improvement would be related to improved functional capacity in the present study [17].

Methods

Subjects

Seventeen older men and women (age range 60–72 years, eleven women and six men) naive to resistance training volunteered to participate in the study. Each participant was carefully informed of the study design and potential risks before the study, after which they provided written consent. After screening by the medical doctor, all the participants were indicated as healthy. The study was approved by the local Human Research Ethics Committee. During the intervention, one man and one woman withdrew from the study, both reporting discomfort from muscle soreness. All the other participants completed all the 24 training sessions ($n = 15$, baseline characteristics presented in Table 1). The participants regularly participated in low-intensity exercises, such as walking, jogging, and swimming approximately twice a week for at least 2 years.

Table 1 Characteristics of the subjects

	Whole group ($n = 15$)		Women ($n = 10$)		Men ($n = 5$)	
	Mean	SD	Mean	SD	Mean	SD
Age (years)	63.9	3.0	64.8	3.1	62.2	1.8
Height (m)	1.63	0.09	1.58	0.06	1.71	0.05
Pre-body mass (kg)	70.4	10.9	70	11.9	71.4	9.7
Post-body mass (kg)	70.1	10.2	69	10.6	72	10.3
Pre-body fat (%BF)	36.5	12.8	44.2	6.8	21.3	6.2
Post-body fat (%BF)	35.8	12.8	43.6	6.4	20.2	5.1
Pre-lean body mass	44.2	9.3	38.4	3.8	55.8	3.8
Post-lean body mass	44.8	10.3	38.5	4.6	57.3	5.5

Experimental approach to the problem

The experimental period consisted of 17 weeks with 1 week of familiarization test period (5 weeks before week 0; week −5), a control period of 4 weeks, and during this time, no strength training occurred (i.e., week −4 and 0), followed by 12 weeks of a non-linear periodization supervised strength training period (i.e., week 0–12). The control period allowed determination of test–retest reliability of the methods, as well as possible measurement error and controlled for possible learning effects. Maximum dynamic leg press strength (1-RM), maximum isometric unilateral knee extension peak torque (PT_{MAX}), and RTD were measured on five different occasions every 4 weeks (−4, 0, 4, 8, and 12 weeks) with accompanying electromyogram (EMG) activity assessed on four occasions (0, 4, 8, and 12 weeks). Functional capacity tests were measured three times (−4, 0, and 12 weeks). Correlation analyses were performed comparing training-induced changes in (all) neuromuscular variables with training-induced changes in (all) functional capacity tests.

Anthropometry

Body mass and height were obtained with an electronic scale (Sohenle®, Nassau, Germany) and a manual wall-mounted stadiometer (Sanny®, São Paulo, Brasil), with 0.1 kg and 0.1 cm resolution, respectively. Abdomen, iliac, and hip circumferences were measured using an anthropometric tape (Sanny®, São Paulo, Brazil) with 1 mm resolution. Afterwards, body composition was estimated using the Siri equation [21] for the women and Tran and Weltman [22] equations for the men.

Dynamic maximum strength

Participants performed a general warm-up of 3–5 min of cycling at 50 W (Ergo-Fit, Ergo Cycle 167, Pirmasens, Germany). Thereafter, they performed a specific warm-up set of eight repetitions at approximately 50% of the estimated 1-RM followed by another set of three repetitions at 70% of the estimated 1-RM on a 45° leg press device. The protocol consisted of 1–5 sets of two repetitions, with progressive loads increasing after every successful attempt. The 1-RM was determined when the individual performed only one complete repetition [23]. To standardize the range of motion, all the participants needed to fully extend their knees (0° = full extension) when taking the load, lower the load until the knees touched an individually positioned wooden rod (representing a flexed knee angle of 90° measured by goniometer), and return to the fully extended position. This method was used in all the testing and training sessions with the 45° leg press device to ensure the same range of motion was used throughout the study. A 2-year experienced evaluator instructed the participants to exert their maximal force and to not let them hold their knees/thighs during training/tests. Absolute strength was expressed as load in kg (for 1-RM) and normalized relative to body mass (as kg:BM) (intraclass correlation coefficient (ICC) 1-RM = 0.95 and coefficient of variation (CV) = 4.1%).

Isometric maximum strength

After 15 min of rest following the 1-RM test, PT_{MAX}, and RTD of the right leg were measured using a calibrated isokinetic dynamometer (Biodex system 4, Biodex Medical Systems, Shirley, USA). Participants sat, so that the hip and knee were at 85° and 70°, respectively (0° = hip neutral position and full extension of knee) and were firmly secured by inelastic straps about the trunk, hips, thighs, and ankle. The test began by performing ten concentric isokinetic knee extension/flexion repetitions at 120° s^{-1}. Thereafter, each participant performed 3–4 maximal isometric voluntary contractions (2 min recovery between the trials was given). The participants were instructed to exert their maximal force "as hard and fast as possible" for 5 s. A fourth trial was performed, if the third trial was more than 5% better than the previous trials. Torque signal was recorded at a sampling frequency of 2000 Hz with a resolution of 14-bits using a Miograph system (MioTec Biomedical, Porto Alegre, Brazil). All the subsequent analyses were performed on 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. PT_{MAX} was defined as the highest value of torque (N m) recorded during the entire performance. Peak torque was also normalized to body mass and was expressed as N m:BM (PT_{MAX} ICC = 0.95 and CV = 3.6%).

RTD over specific time intervals (0–30, 0–50, 0–100, 0–150, 0–200, and 0–250 ms) was defined as the slope of the torque–time curve (i.e., Δtorque/Δtime) relative to the onset of contraction. Onset of contraction was defined as the instant where the torque increased 7.5 N m above the rising baseline level [13]. RTD reliability values were: 0–30 ms: 0.92 and 18.6%, 0–50 ms: 0.94 and 19.1%; 0–100 ms: 0.96 and 17.9%; 0–150 ms: 0.96 and 15.1%; 0–200 ms: 0.97 and 12.5%; 0–250 ms: 0.98 and 11.5% for ICC and CV, respectively.

Muscle activity

EMG was recorded during the leg press 1-RM test from the vastus lateralis, rectus femoris, and biceps femoris of the right leg. The reference electrode was placed on the surface of the tibia. The electrodes (Kendall Meditrace, Mansfield, USA) were placed longitudinally over the muscle belly and aligned according to the orientation of the muscle fibers in bipolar configuration and an inter-electrode distance of 22 mm. The position of all the electrodes with respect to the muscle length and anatomic landmarks was recorded and also traced onto an individual acetate sheet to ensure the same placement in each test over the experimental period [24].

EMG signals were recorded at a sampling rate of 2000 Hz with common rejection mode of 110 dB, impedance input of 1TΩ, and resolution of 14-bit using a Miograph system. EMG signals were filtered off-line using a recursive fifth order Butterworth; bandpass 20–500 Hz digital filter. The root mean square (RMS) values were used as an index of the total muscle activity for all the muscles during the 1-RM trials. The maximum RMS values were determined during the 90°–70° knee angle (i.e., from a period of 0.3 s before/after peak EMG) during concentric 1-RM leg press action. Co-activation pattern was assessed by the ratio of agonist/antagonist quadriceps muscles. For data analysis, proper mathematical routines were developed using software Matlab 7.17 (MathWorks Inc., MA, USA).

30-s Chair stand test

Participants sat on a chair (height 43 cm) with back straight and feet on a flat surface positioned about shoulder width apart, arms crossed at chest height, with hip and knee flexed at approximately 90°. At a verbal signal, the participant rose to a fully upright position and then returned to the initial seated position. Participants were encouraged to complete as many repetitions as possible within a 30-s period [25]. One evaluator using a chronometer controlled the time, as well as the number of repetitions. All the participants were tested three times with a 4-min rest between attempts, and the best attempt was recorded (ICC = 0.99 and CV = 3.4%).

Timed up and go (TUG)

The minimum time (in seconds) needed for the participant to rise from a seated position (same chair as the 30-s chair stand test), walk forward 3 m, and then return the same 3 m and resume a seated position was measured. The participants performed the test three times in both the directions with a 4-min rest between the attempts, and the fastest time from the three trials was used for further analysis [25]. The same evaluator using a chronometer controlled the time (ICC = 0.97 and CV = 6.6%).

Stair ascent and descent test

The test was performed in a linoleum-covered indoor stairs with handrails. The start position was at the bottom of eight steps (15 cm high, 27.5 cm deep). Participants were instructed to complete the task as fast as possible placing one foot on each stair and should slide their hand along the handrail for safety. Timing commenced for the stair ascent test when the participant raised their foot off the ground to climb the first step and stopped when both feet were placed on the eighth step. After 30-s of rest, participants were asked to descend the stairs. Again, timing commenced when they raised their foot off the ground for the first step and stopped when they completed the last step. All the participants were tested three times with a 4-min rest between trials, and the best time was recorded. The same evaluator controlled each trial with a chronometer (stair ascent: ICC = 0.99 and CV = 2.8%; stair descent: ICC = 0.99 and CV = 3.5%, respectively).

Resistance training program

The participants trained twice a week with at least 48 h between the sessions. All the training sessions were supervised by a 2-year trained instructor. Each training session included the 45° leg press, lat pull down, seated cable row, hip abductor, and lumbar extensor exercises (all the machines; Righetto, Freestyle, São Paulo, Brazil). After each 4th week of training, 45° leg press 1-RM was retested and the training load adjusted accordingly for the subsequent 4 weeks and, therefore, controlled the load used during training. All of the other exercises were performed using three sets of ten repetitions of the self-selected load. The 45° leg press training program was divided into three mesocycles utilizing the weekly non-linear periodization. Thus, training volume varied each week, so that two sessions at each load (60, 70, 80, and 90% of 1-RM) were performed every 4 weeks. Lifting tempo was instructed to be "careful and controlled". Lifting tempo was confirmed from video recording (Samsung®, HMX-U10BN/XAZ, Swon, South Korean) during the 45° leg press exercise and the approximate eccentric and concentric duration for all participants was 2 s. During the 12-week intervention, participants continued taking part in their pre-study recreational low-intensity physical activities (e.g., walking, jogging, and swimming 1–3 times/week).

Statistical analyses

Data normality was assessed through the Shapiro–Wilk test. Repeated measures ANOVA assessed the variables over five (maximum and explosive strength), four (EMG), and three (functional capacity) time points. When a significant F value for time was identified, Bonferroni post hoc tests were performed. Pearson product-moment correlation coefficient (r) was calculated to determine whether there was a relationship between; (1) baseline neuromuscular and functional capacity performance (i.e., in-line improvement) and (2) the training-induced improvements (i.e., Δ%changes vs. Δ%changes) in neuromuscular parameters and functional capacity tests performance. Also, effect size (ES) was calculated (post-test mean − pre-test mean/standard deviation of pre-test) using the scale proposed by Rhea [26] (trivial < 0.50; small 0.50–1.25; moderate 1.25–1.9; large > 2.0) to examine the magnitude of the treatment effect. All the analyses were performed using SPSS 18.0 (IBM Corp., Armonk, USA). Alpha level was set as $p < 0.05$.

Results

There were no significant changes during the control period ($p > 0.05$). A significant main effect for time was observed ($F = 99.8$, $p = 0.001$, ES = 1.54) in 1-RM performance. Continuous significant increase was observed from week 0 to week 4 ($p < 0.001$, 22 ± 12%, ES = 0.75), week 4 to week 8 ($p < 0.001$, 9 ± 8%, ES = 0.48) and from week 8 to week 12 ($p = 0.045$, 7 ± 6%, ES = 0.28, Fig. 1a) with an overall improvement of 41 ± 13% ($p < 0.001$, ES = 1.54). The observed increase in normalized strength mirrored the findings for 1-RM (e.g., at week 0–12) ($F = 57.9$, $p = 0.001$, ES = 1.54, Fig. 1b).

There were no significant changes during the control period ($p > 0.05$) or during the intervention for knee extension PT_{MAX} ($F = 1.421$, 6 ± 15%, $p = 0.239$, ES = 0.14). The values for PT_{MAX}:BM mirrored the findings for PT_{MAX} ($F = 1.092$, 4.4 ± 11%, $p = 0.369$, ES = 0.14).

There were no significant changes during the control period in knee extension RTD ($p > 0.05$). A significant main effect for time was observed during the intervention period for all the time intervals of RTD (0–30 ms: $F = 5.899$, $p < 0.001$, 55 ± 56%, ES = 0.92; 0–50 ms: $F = 4.629$, $p < 0.05$, 43 ± 49%, ES = 0.70; 0–100 ms: $F = 3.968$, $p < 0.005$, 31 ± 38%, ES = 0.52; 0–150 ms: $F = 5.998$, $p < 0.001$, 29 ± 31%, ES = 0.64; 0–200 ms: $F = 5.211$, $p < 0.001$, 24 ± 27%, ES = 0.54; and 0–250 ms: $F = 5.471$, $p < 0.001$, 20 ± 22%, ES = 0.53) being significant at week 8 compared to week 0.

During the leg press 1-RM, there was a significant main effect on time in RMS values for vastus lateralis from week 0 to week 12 ($F = 5.747$, 114 ± 121%, $p = 0.008$, ES = 1.8, Fig. 1c). No significant change for rectus femoris ($F = 0.697$, 36 ± 68%, $p = 0.572$, ES = 0.4, Fig. 1c), and biceps femoris ($F = 1.015$, 21 ± 73%, $p = 0.430$, ES = 0.1, Fig. 1c) or in co-activation ratio ($F = 1.496$, −39 ± 41%, $p = 0.276$, ES = −0.4) were observed during the intervention period.

There was no significant change during the control period ($p > 0.05$), but significant difference was observed after the 12-week intervention in all the functional capacity tests. The 30-s chair stand showed a significant increase in the number of repetitions ($F = 18.343$, 13.9 ± 2–17.0 ± 2.6 s, $p < 0.001$, ES = 1.16).

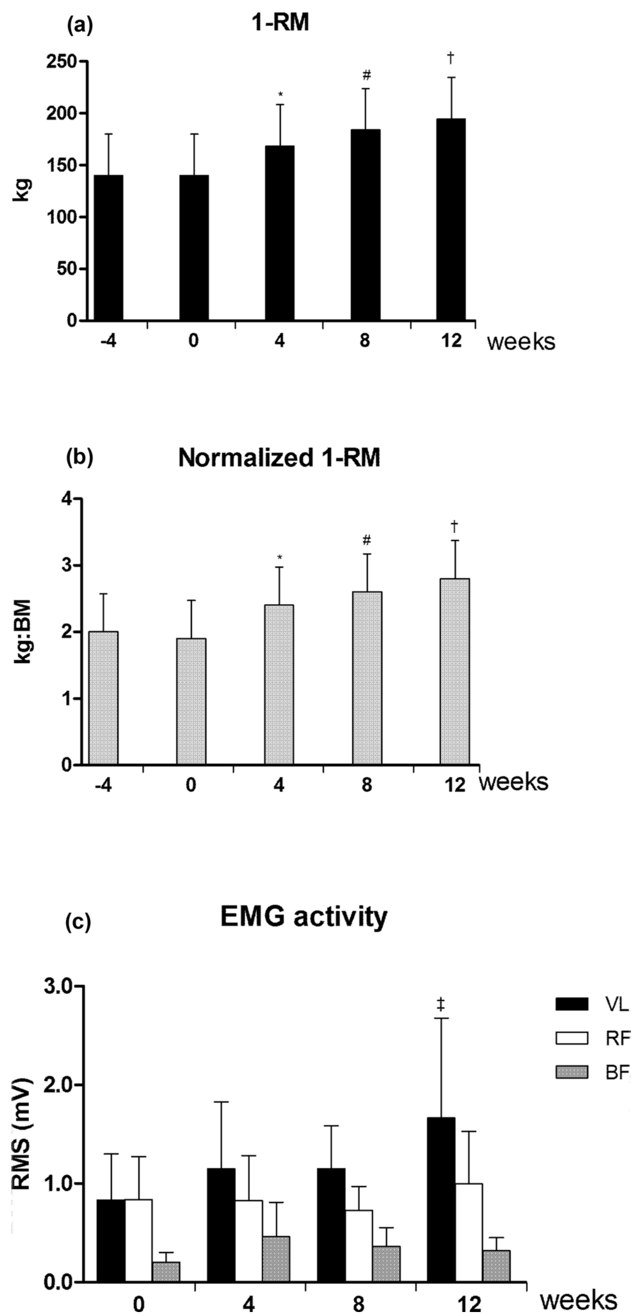

Fig. 1 Mean and standard deviation for 1-RM knee extension (**a**), normalized 1-RM (**b**), and muscle activity (**c**) during the 4-week control period and during the 12-week intervention. *Difference between week 0 and week 4, $p < 0.001$. #Significant difference between 8 week and preceding time points for absolute values, $p < 0.001$. †Significant difference between week 12 and preceding time points for absolute values, $p < 0.05$. ‡Significant difference between week 0 and week 12, $p < 0.05$

Time taken to perform the timed up and go ($F = 7.137$, 5.4 ± 0.7–4.5 ± 0.8 s, $p < 0.05$, ES = 1.51), stair ascent ($F = 29.513$, 3.8 ± 0.8–2.7 ± 0.4 s, $p < 0.001$, ES = 1.31), and stair descent ($F = 14.730$, 3.6 ± 0.9–2.6 ± 0.4 s, $p < 0.05$, ES = 0.95) tests decreased significantly.

At week 12, there were significant in-line associations between 1-RM:BM and stair descent test ($r = -0.521$, $p = 0.046$), also between timed up and go test and PT_{MAX}:BM ($r = -0.676$, $p = 0.006$) (Fig. 2a, b). Figure 2c, d demonstrates individual results in timed up and go test that were also significantly associated with all the RTD time periods (0–30 ms: $r = -0.715$, $p = 0.003$, 0–50 ms: $r = -0.709$, $p = 0.003$, 0–100 ms: $r = -0.688$, $p = 0.004$, 0–150 ms: $r = -0.694$, $p = 0.004$, 0–200 ms: $r = -0.692$, $p = 0.007$, and 0–250 ms: $r = -0.660$, $p = 0.01$).

Although training-induced improvements (i.e., Δ%changes) were observed for 1-RM:BM, no significant changes related to the Δ%changes in functional capacity tests over the 12-week period were observed for all RTD time periods evaluated [Δ%1-RM:BM and Δ%stair ascent test ($r = -0.187$; $p = 0.503$); Δ%1-RM:BM and Δ%stair descent test ($r = 0.056$; $p = 0.841$, Fig. 3a); Δ%1-RM:BM and Δ%timed up and go ($r = 0.120$; $p = 0.688$); Δ%PT_{MAX}:BM and Δ%timed up and go ($r = -0.156$; $p = 0.579$)]. Also, individual Δ%RTD and Δ%timed up and go were not significant over anytime period (0–30 ms: $r = -0.058$, $p = 0.838$, Fig. 3b, 0–50 ms: $r = -0.097$, $p = 0.731$, 0–100 ms: $r = -0.140$, $p = 0.617$, 0–150 ms: $r = -0.121$, $p = 0.667$, 0–200 ms: $r = -0.165$, $p = 0.556$, and 0–250 ms: $r = -0.098$, $p = 0.729$).

Discussion

As expected, non-linear periodization leg press training that is done twice weekly significantly increased 1-RM, normalized 1-RM, RMS, RTD, and functional capacity in older people that were already physically active but without experience in resistance training. This is the first study to verify the effectiveness of non-linear periodization resistance training on neuromuscular performance parameters and functional capacity tests in older individuals. However, the most important result in our hypothesis is that the training-induced improvement (i.e., Δ%changes) in strength did not influence the magnitude of functional capacity improvements (i.e., Δ%changes). Consequently, while resistance training appears to be important to

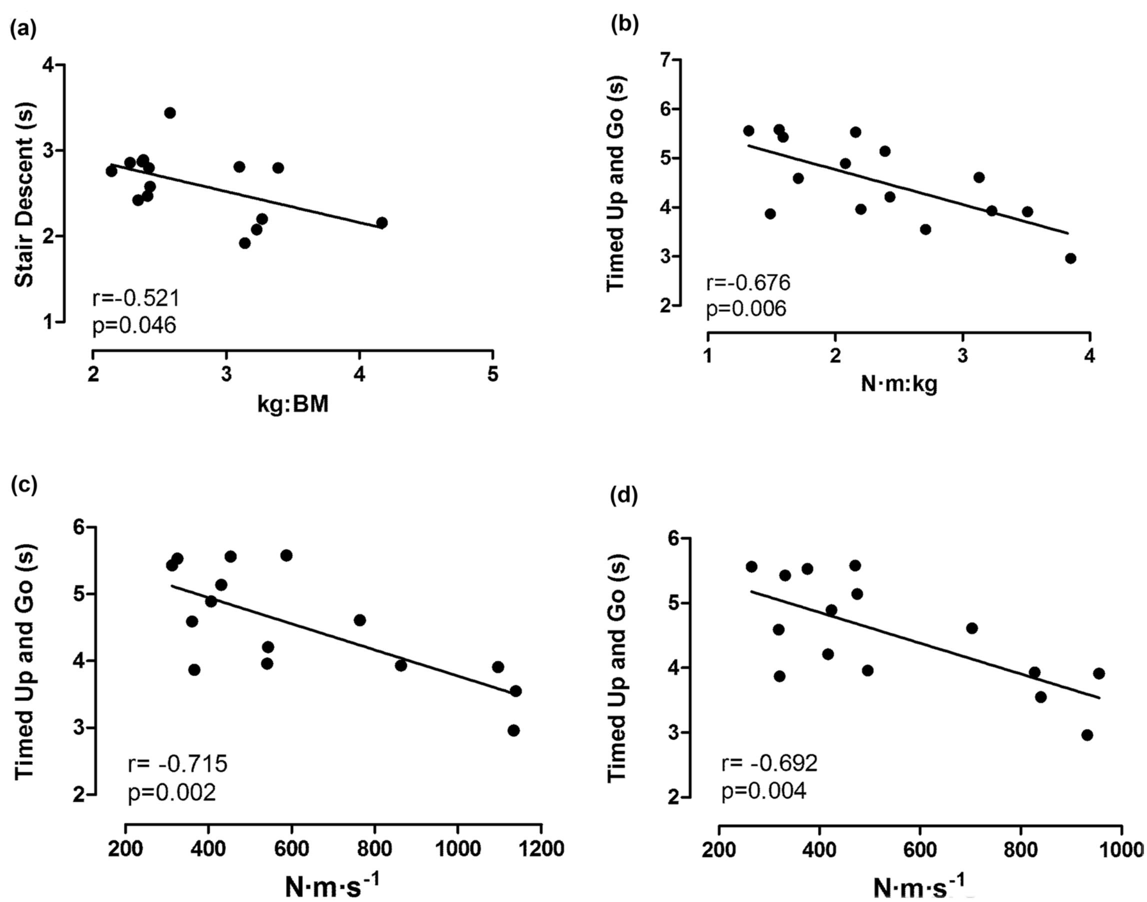

Fig. 2 Scatterplot of the relationship between **a** 1-RM:BM and stair descent and **b** PT_{MAX}:BM and timed up and go test (TUG), as well as the relationship between TUG and the absolute rate of torque development (RTD) measured at **c** 0–30, and **d** 0–200 ms at week 12

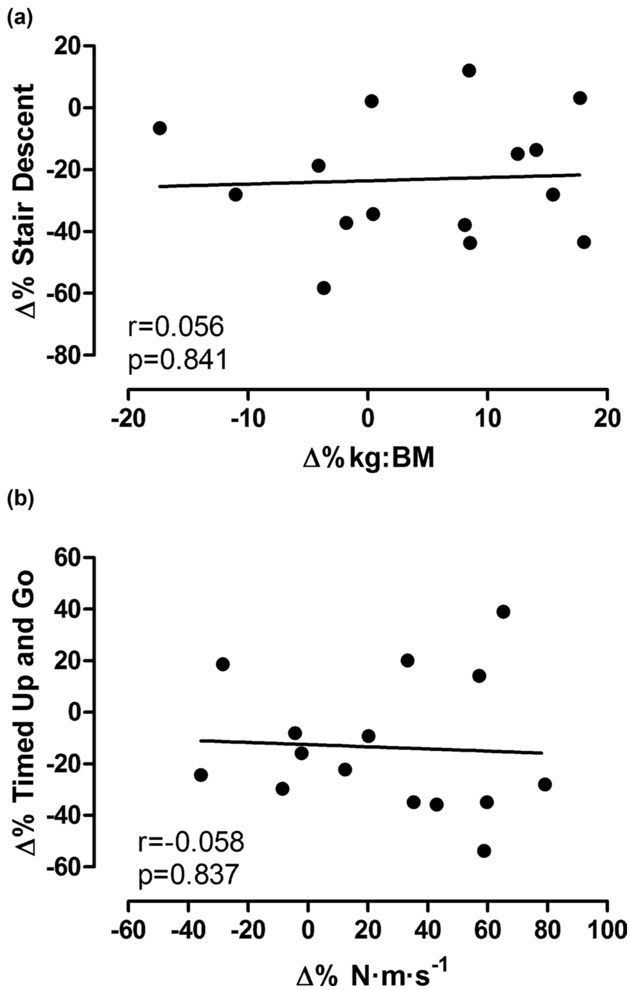

Fig. 3 Scatterplot of the relationship between relative changes in **a** 1-RM:BM and stair descent as well as **b** the absolute rate of torque development (RTD) measured at 0–30 ms and timed up and go test (TUG), and **c** 1-RM:BM and 30-s chair stand test during 12-week training

improve functional capacity, gaining a large amount of strength is not likely a prerequisite for high gain in functional capacity.

Accompanying the improvements observed in the present study for 1-RM (and normalized 1-RM), vastus lateralis activation also increased during maximum leg press tests ($p<0.05$, Fig. 1). This is a typical finding observed in elderly people, when they perform isometric maximum voluntary knee extension contractions [27], isometric maximum voluntary leg extensions [1], and dynamic maximum leg press tests [28] after an intervention period. Highlighting the importance of this adaptation is the observed significant association between the relative change in these two variables (i.e., 1-RM and vastus lateralis RMS) throughout the study ($r=0.688$, $p=0.007$). Therefore, this type of adaptation (i.e., improved muscle activation) may have been an important contributor to increased strength observed in the present study.

Although systematic adaptations to resistance training interventions occur and can be observed in the EMG (amplitude) signal, the exact mechanism underpinning this change is currently unknown. As reviewed by Farina and colleagues [29], increased EMG amplitude could be a result of increased motor unit recruitment and/or increased firing frequency, but it could also be influenced by factors within/surrounding the muscle that do not represent muscle activation (e.g., detection system, geometrical, physical, physiological fiber membrane and motor unit properties).

Despite improved maximum leg press strength in the present study, there were no changes in PT_{MAX} and PT_{MAX}:BM ($p>0.05$). This finding is likely due to a lack of specific isometric training or single-joint knee extensor training [30], since the only exercise for the knee extensors was the 45° leg press. There was, however, significant increase in RTD at various time intervals after 8 weeks of training ($p<0.05$). Although high variability in RTD is a typical characteristic of older people, as observed in the present study, it is important to note that there was no significant difference within the control period for the RTD ($p>0.05$). This finding gives confidence that a significant increase in RTD represents true improvement in rapid force production in the present study.

Improved RTD in older individuals is an important quality, since it accompanies better control of posture and an improved ability to regain balance [13, 31]. Therefore, a low RTD could lead to decreased functional capacity and independence to perform activities of daily living [32, 33]. In the present study, functional capacity was measured by tests that would involve participants sitting and getting up for 30 s, getting up and walking/turning and sitting down, as well as climbing up and down a staircase. It is important to note that, while walking has been suggested to be dependent upon triceps surae function [34], the functional capacity tests used in the present study could be considered to be largely dependent upon knee and hip extension function. Therefore, functional capacity tests closely match the leg press testing and training performed.

Significant improvement in all the functional capacity tests was observed during the present study. Resistance training-induced improvement in functional capacity has been observed previously [11, 35]. However, there are a few studies showing the benefits of low-resistance training with combining fast muscle contraction on older people's functional performance. Similar improvements in the 30-s chair stand test were observed, when comparing the present study's results with Pinto et al. [11] findings (~23 vs. ~22%, respectively) and similar improvements were observed in 1-RM performance after 4 and 6 weeks (~24 vs. ~23%, respectively). It would have also been interesting to test functional capacity after 4 weeks of training also in the present study, which may have allowed assessment whether the additional strength gain after 12 weeks (~41% overall improvement) did/did not further enhance functional capacity.

As has previously been shown [15, 16], the present study revealed a significant association between various strength measures and functional capacity performance (i.e., in-line improvements), particularly timed up and go test (Fig. 2). Nevertheless, despite the cross-sectional association between strength and functional capacity, we observed no link in the magnitude (Δ%changes) of improvement in these parameters. Our results suggest that improvement in lower-limb (i.e., hip and knee extension) maximum and explosive strength alone do not account for the improvement in functional capacity tests, such as timed up and go, stair ascent and descent, and 30-s chair stand tests. The results of the present study conflict with the results of Pinto et al. [11] and Santos et al. [17]. Although it should be stated that the former study included both the control and experimental groups into the correlation analyses without distinction, and so this data does not allow evaluation of the relationship of true training-induced gains. The only other study that we are aware of showing a statistically significant relationship ($p=0.04$) between training-induced gain in strength and functional capacity (specifically 10 m walking time) is Santos et al. [17]. Here, the relationship was moderate ($r=\sim 0.45$) and the between-subject variance was large—which was quite similar to the present study upon inspection of the figures in this article. Thus, care should be taken when interpreting the results of these studies. Consequently, there is no good evidence to suggest that there is a direct link between training-induced gain in maximum and explosive strength and improved functional capacity test performance.

Functional capacity tests can be classified as motor skills, which depend on various central and peripheral adaptations to improve [36]. Such reliance on a number of aspects of neuromuscular performance during functional capacity tests may be the one reason for the lack of direct association between improved strength and improved functional capacity. This may also be the one reason why other interventions, for example, static balance training, has shown improvement in similar functional capacity tests [37]. It is possible that different interventions lead to specific adaptations within the neuromuscular system [38] that improve particular aspects of functional capacity, and perhaps a more multi-dimensional assessment would produce greater association between neuromuscular performance improvement and functional capacity improvement.

Despite the relevance of the present findings, one possible limitation in our assessment could be that we did not measure the other factors that contribute to motor skills (e.g., visual, somatosensory, vestibular, and neurological factors) [39] or strength improvements in the other muscle groups. For example, it has been shown that strengthening the trunk muscles can lead to improvement in walking and balance tests [40]. Another potential limitation to consider is related to the small sample size and a mix of sex. Nevertheless, even with methodological efforts throughout the present study, caution also should be taken in interpreting the present results. However, from a clinical point of view, these results could help to sort out another perspective of resistance training to maintain older people's ability to function well at home in their later years. Finally, there is sufficient scientific evidence for further studies, which lead us to infer that resistance training is beneficial for functional capacity in older people. But, it is not known which specific element(s) of resistance training is the major factor causing this improvement. This poses a problem for practitioners, due to the fact that it is currently unconfirmed how to optimize resistance training programs to target improvement in functional capacity. Therefore, it would be of great importance to identify the particular aspect of resistance training, and what qualities should be trained and improved, to be able to target these deficiencies when programming resistance training.

Conclusions

Low-volume non-linear periodization resistance training was capable of increasing maximal and normalized dynamic strength, muscle activity, and RTD in a group of untrained older men and women. Moreover, increase in maximum strength and RTD was accompanied by improvement in functional capacity tests. However, no relationship between training-induced (i.e., Δ%changes) increase in strength and functional capacity was observed. Finally, for a better understanding of the direct relationship between non-linear periodization resistance training improvements in different elements of strength and functional capacity in older people, future studies with a larger sample size and involving both of the sexes should consider confirming our results.

Compliance with ethical standards

Conflict of interest On behalf of all the authors, the corresponding author states that there is no conflict of interest.

Ethical approval Ethical approval was obtained from the local Human Research Ethics Committee (CAAE: 25995714.0.0000.0121), and the protocol was written in accordance with the standards set by the Declaration of Helsinki.

Informed consent Informed consent was obtained from all individual participants included in the study.

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