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Effects of Resistance Training Program on Muscle Mass and Muscle Strength and the Relationship with Cognition in Older Women

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Abstract: The aim of this study was to study the effects of a resistance training programme on Maximal Dynamic Strength (MDS) and muscle morphology of the upper limbs (UL) and lower limbs (LL), as well as to analyse their association with cognition, in a population of older women. The study had a duration of 24 months and a total of 93 Chilean older women participated. The participants were divided into two groups: the Physical Activity Group (PAG, n = 45, age (X ± SD) 77.93 ± 3.54 years), and the Sedentary Group (SG, n = 48, age (X ± SD) 77.71 ± 3.41 years). The PAG carried out a muscle strength training routine twice per week. The following variables were evaluated: muscle function through maximal dynamic strength (1RM), muscle morphology through arm and calf circumference (AC and CC, respectively), and cognition (Mini Mental State Examination: MMSE). The results show that the SG recorded significant decreases (percent changes; $p < 0.05$) in the analysed variables: MMSE (−3.5%), MDS in UL (−3.3%), MDS in LL (−4.1%), AC (−4.5%), CC (−4.1%), and BMI (−3.1%). However, the PAG improved significantly in all the analysed variables except in BMI: MMSE (3.9%), MDS in UL (3.6%), MDS in LL (3.5%), AC (1.8%), and CC (2.5%). Moreover, there was a significant association ($p < 0.05$) between the changes in the muscle strength variables and the changes in cognition level. Therefore, it can be concluded that a two-year muscle strength training programme (load intensity between 30–55% 1RM) in older women improves Maximal Dynamic Strength in UL and LL, as well as muscle mass in arms and calves. Furthermore, it can be asserted that the changes in muscle strength levels could predict the changes in the levels of cognition in older women.

Keywords: aging; cognitive state; exercise; female; muscle function; physical activity; sedentary

1. Introduction

Ageing, muscle disuse and malnutrition are associated with a greater oxidative damage of the skeletal muscle and a reduction of muscle mass and strength [1]. Similarly, oxidative stress increases age-related brain deterioration [2], with a decrease of executive functions [3]. However, it has been demonstrated that a progressive, low-to-moderate-intensity, individualized, and controlled resistance training programme produces significant improvements in maximum muscle strength and cognition in older women [4]. In this sense, it has been reported that the decrease of muscle strength, regardless of muscle mass, could be considered as the core of fragility, as it can predict changes in gait speed and mobility and involves greater risk of mortality in older people [5]. Thus, for example, it has been shown that a greater calf circumference can be positively related to a lower fragility index and greater functional performance [6]. Likewise, most studies indicate that frailty syndrome triggers cognitive deterioration [7] and, therefore, it has been reported that the loss of muscle strength and the presence of cognitive deterioration, as well as the interaction between them, could affect balance in older people [8]. In this line, a recent study asserts that cognitive deterioration and muscle strength loss are associated with frailty in postmenopausal women [9]. Similarly, muscle density has been related to cognitive functioning, which depends to a greater extent on muscle strength than on muscle mass [10,11].

It has been reported that skeletal muscle contraction is an important source of neurotrophic factors, which regulate the synapses in the brain tissue [12]. However, the links between cognition and skeletal muscle are not fully understood since ageing is involved in the deterioration of both skeletal muscle and cognitive functions.

Muscle resistance training is known to produce significant improvements of muscle strength and muscle circumferences in healthy older adults [13]. Handgrip strength depends on upper limb strength; thus, women with low handgrip strength have poor quality of life in terms of mobility and activities of daily living, as well as pain or discomfort [14]; moreover, it would be associated with a greater risk of cognitive deterioration [15]. Furthermore, it has been stated that lower grasp strength has a predictive validity for the decrease of cognition, mobility, and functional state and the increase of mortality in older people [16,17]. Interestingly, a previous study has shown a decrease of muscle strength without muscle mass loss in upper and lower limbs in a group of women with Alzheimer's disease in early and mild stages; however, this has not been observed in the moderate stage of the disease [18]. It has been claimed that the functioning of the lower limbs is strongly related to multiple cognitive domains rather than to skeletal muscle mass, which is important for the detection and prevention of cognitive deterioration [19]. It has been proposed that a dual-task multimodal physical training improves frontal cognitive functions and muscle strength in the lower limbs of older people with Alzheimer's disease [20]. It is worth highlighting that, in men at risk of developing sarcopenia, previous studies have shown a decrease of fat-free mass, grasp strength and gait speed over a period of 24 months, demonstrating that the changes in the lower limbs were greater than those in the upper limbs [21]. Therefore, further longitudinal studies are needed to explore the causality between cognition and the muscle morphology and function of the upper and lower limbs.

Similarly, other findings indicate that the approaches of high-speed resistance training are effective in improving cognitive function and physical performance in older people with cognitive frailty [22]. However, further research is needed to determine the extent to which training can improve the functional capacities and the effect on cognitive performance [23], since, apparently, the lack of brain-muscle-brain communication has a negative impact on ageing, which leads to frailty, sarcopenia, fatigue, depression, and cognitive frailty [24].

Therefore, the aim of this study was to analyse the effects of a two-year resistance training programme on the muscle morphology and maximal dynamic strength of the upper (UL) and lower limbs (LL) and to determine whether the increase (or improvement) of muscle strength and mass is associated with improvements in cognitive function, in a population of older women.

2. Materials and Methods

2.1. Design

This was a two-year, experimental, non-probabilistic, longitudinal study.

2.2. Participants

The recruitment of participants (Figure 1) was conducted from a potential population of older women (n = 214) from the neighbourhood residents' committees of the southwestern area of the Santiago Metropolitan Region (Chile). An initial sample was obtained (n = 163), which was randomised into two groups. The final sample (n = 93) was constituted by the following groups: Physical Activity Group (PAG, n = 45, age (X ± SD) 77.93 ± 3.54 years) and Sedentary Group (SG, n = 48, age (X ± SD) 77.71 ± 3.41 years) (Table 1).

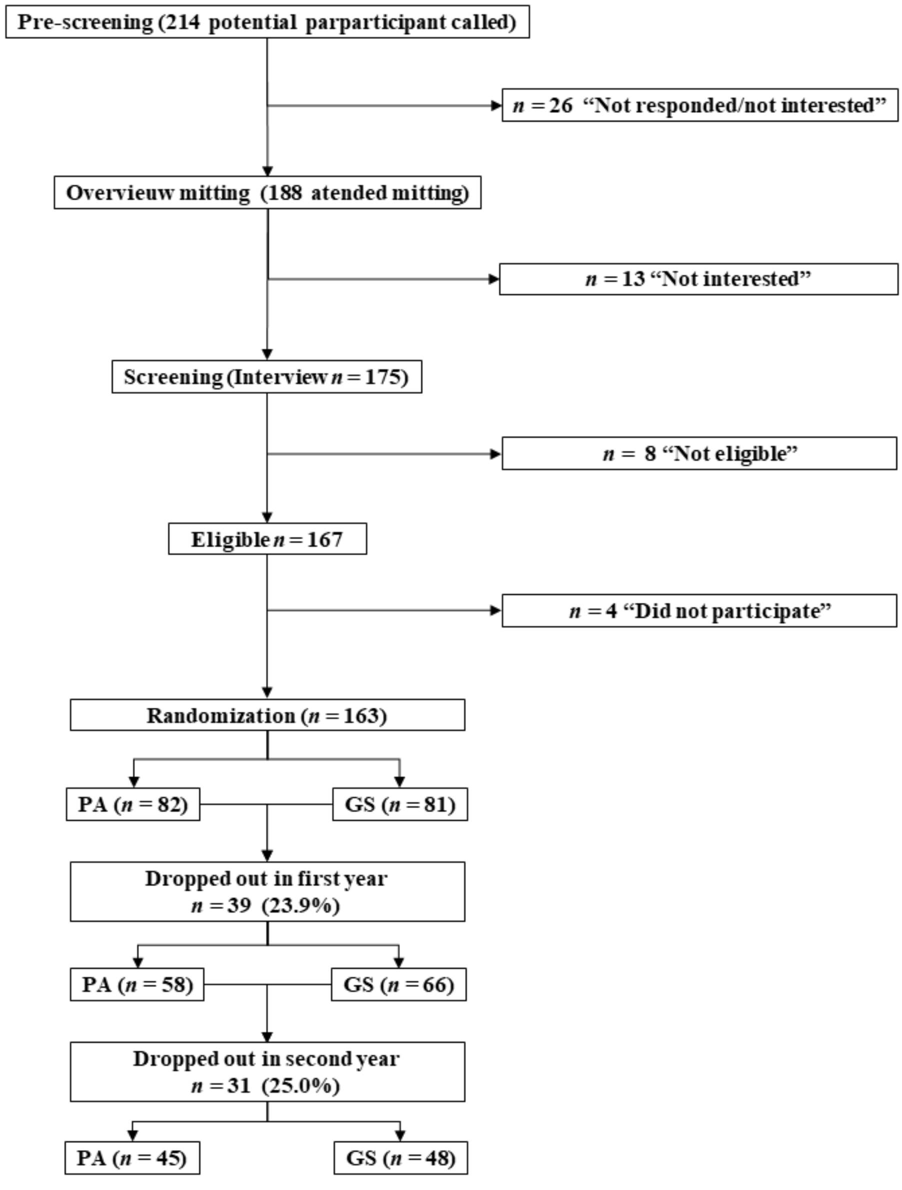

Figure 1. Sequence for recruitment screening. PAG (Physical Activity Group) and SG (Sedentary Group).

The women of both groups had an education level that allowed them to read and write without help. All participants were retired at the time of the intervention. Both groups declared that they carried out not additional physical or sport activity other than the activities of daily living. The intervention period began in January 2018 and was terminated in December 2019. The inclusion criteria were the following: (i) women aged ≤83 and ≥63 years; (ii) medical authorisation to perform physical moderate-intensity resistance exercise; (iii) members of the neighbourhood residents' committees of the southwestern area of the Santiago Metropolitan Region (Chile); (iv) women who were involved in any systematic exercise programme and/or physical activity within 5 years prior to the beginning of the study; (v) full primary education; (vi) no previous diagnosis of cognitive deterioration or muscle mass loss; (vii) signed informed consent.

Table 1. Participants' baseline characteristics.

Variables	Control Group (n = 48)		Experimental Group (n = 45)	
	Mean ± SD	95% (CI)	Mean ± SD	95% (CI)
Age (years)	77.71 ± 3.41	(76.72 to 78.70)	77.93 ± 3.54	(76.87 to 79.00)
Body mass (kg)	62.07 ± 6.19	(60.27 to 63.86)	61.45 ± 6.38	(59.53 to 63.36)
Stature (cm)	1.58 ± 0.06	(1.56 to 1.59)	1.57 ± 0.06	(1.55 to 1.59)
Primary school completed	100%		100%	
High school completed	74.4%		80.1%	

The exclusion criteria were the following: (i) patients with depression under pharmaceutical treatment; (ii) patients with pathological conditions incompatible with physical exercise; (iii) malnutrition or cardiovascular, joint, muscular, or bone diseases; (iv) illiterates; (v) attendance to less than 80% of the sessions of the training programme; (vi) severe pathologies during the study period. The study complied with the guidelines of the Declaration of Helsinki, which was approved by the World Medical Association.

2.3. Procedure

The estimations of 1RM strength test were conducted according to the following phases (Table 2).

Phase 1: Week 1. During the week prior to the initial estimation of 1RM (pre-test), two sessions of technical adaptations and diagnostic assessments were carried out, which consisted in submaximal strength exercises in two days, with a gap of 48 h between them. On the first day, the participants performed 2 sets of 6–8 repetitions on "90° Seated Chest Press" and 5–7 repetitions on "45° Leg Press" (Figure 2). Through the OMNI scale, according to Morishita et al. (2019) [25], the load intensity was adjusted between 30 and 55% of the estimated 1RM. The participants rested for 3–4 min between sets.

Phase 2: Week 0. Pre-test. In the following week, the initial tests for the estimation of the individual's 1RM were conducted. These began with a general warm-up based on general joint mobility (5′) and a specific warm-up, which consisted in 3 sets of 10, 12, and 15 repetitions with very light loads (20–30% 1RM, OMNI scale), in each of the exercises used for the muscle strength tests. Subsequently, the participants performed two attempts with the same submaximal loads to failure, with a 5-min rest between attempts. The loads used were based on the estimations recorded in Phase 1, i.e., the technical adaptation and diagnostic phase. The sets in which the repetitions were 8–10RM were considered, taking the largest number of repetitions, to estimate the theoretical 1RM.

Phase 3. Weeks 1–101 (Months 1–24). Period of intervention based on muscle strength resistance training (Figure 2). During this period, the protocol of Phase 2 was repeated five times.

Phase 4. Week 102 (Month 25). Post-test. The protocol of Phase 2 was repeated.

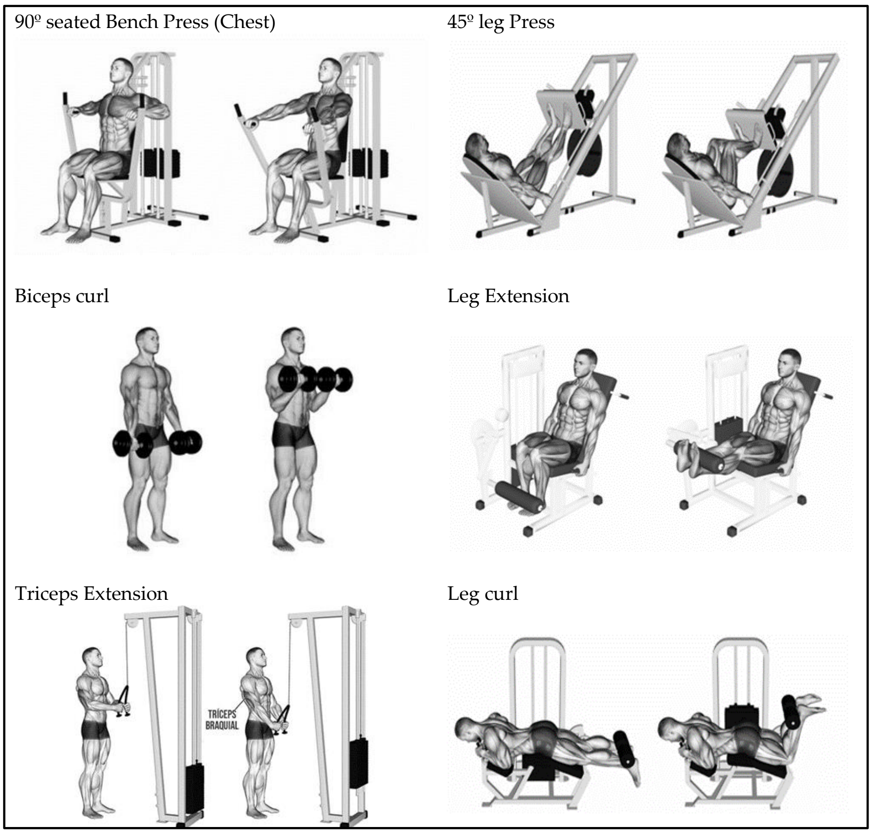

Figure 2. Training and testing exercises.

Table 3 shows the characteristics of the resistance training programme. This programme was complemented with multi-joint exercises that were carried out twice per week in 90-min sessions. Each session began with a warm-up that consisted of 15 min of cardiorespiratory activation through low-intensity aerobic exercise (walking) and joint mobility exercises for the shoulders, hips, and knees. At the end of each session, for approximately 10 min, the participants performed back-to-calm exercises of joint flexibility and amplitude for the main muscle groups and joint chains. Every 4 weeks, the tests for the estimation of the theoretical 1RM were repeated in order to adjust the training stimuli to the individual adaptations and ensure the precision of the training load intensity applied throughout the entire intervention period.

Table 2. Temporalization.

Phase 1	**Phase 2**	**Phase 3 (101 Weeks): Intervention Period**											**Phase 4**
Week −1	**Week 0**	**Weeks 1–17**		**Weeks 18–34**		**Weeks 35–51**		**Weeks 52–68**		**Weeks 63–85**		**Weeks 86–101**	**Week 102**
Learning	Pre-Test	Training 16 weeks	Control Test 1 1 week	Training 16 weeks	Control Test 2 1 week	Training 16 weeks	Control Test 3 1 week	Training 16 weeks	Control Test 4 1 week	Training 16 weeks	Control Test 5 1 week	Training 16 weeks	Post-test

Table 3. Timetable resistance training program.

Weeks	**0**	**1–17**		**18–34**		**35–51**		**52–68**		**63–85**		**86–101**	**102**
Intensity		**1RM § 30–40%**		**1RM 35–40%**		**1RM 40–45%**		**1RM 40–45%**		**1RM 45–50%**		**1RM 50–55%**	
Bench press	Pre-test ¥	1–2 set; 6–8 rep * 30–60 s	Control test 1 ¥	2–3 set; 6–8 rep * 30–60 s	Control test 2 ¥	2–4 set; 5–7 rep * 1–2 min	Control test 3 ¥	3–4 set; 4–6 rep * 2–3 min	Control test 4 ¥	2–3 set; 3–5 rep * 3–4 min	Control test 5 ¥	2–3 set; 2–4 rep * 3–4 min	Post-test ¥
Biceps curl		1–2 set; 6–8 rep * 30–60 s		2–3 set; 6–8 rep * 30–60 s		2–4 set; 5–7 rep * 1–2 min		3–4 set; 4–6 rep * 2–3 min		2–3 set; 3–5 rep * 3–4 min		2–3 set; 2–4 rep * 3–4 min	
Triceps extension		1–2 set; 6–8 rep * 30–60 s		2–3 set; 6–8 rep * 30–60 s		2–4 set; 4–6 rep * 1–2 min		3–4 set; 4–6 rep * 2–3 min		2–3 set; 3–5 rep * 3–4 min		2–3 set; 2–4 rep * 3–4 min	
Leg press		1–2 set; 5–7 rep * 30–60 s		2–3 set; 5–7 rep * 30–60 s		2–4 set; 4–6 rep * 1–2 min		3–4 set; 3–5 rep * 2–3 min		2–3 set; 2–4 rep * 3–4 min		2–3 set; 2–3 rep * 3–4 min	
Leg extension		1–2 set; 5–7 rep * 30–60 s		2–3 set; 5–7 rep * 30–60 s		2–4 set; 4–6 rep * 1–2 min		3–4 set; 3–5 rep * 2–3 min		2–3 set; 2–4 rep * 3–4 min		2–3 set; 2–3 rep * 3–4 min	
Leg curl		1–2 set; 4–6 rep * 30–60 s		2–3 set; 4–5 rep * 30–60 s		2–4 set; 3–4 rep * 1–2 min		3–4 set; 2–4 rep * 2–3 min		2–3 set; 2–3 rep * 3–4 min		2–3 set; 1–2 rep * 3–4 min	

* Rest time between sets. ¥ 90° Seated Chest Press, 45° Leg Press. In Pre-test and Post-test, also MMSE, Arm Circumference, Calf Circumference, and § 1-Repetition Maximum.

2.4. Variables

Cognitive state was evaluated through the Mini Mental State Examination (MMSE) [26]. The Mini-Mental State Examination (MMSE) is a short assessment instrument used to grade cognitive mental status, it assesses orientation to time and place, attention, memory, and ability to follow commands. The MMSE provides a quick and reliable quantitative assessment of an individual's cognitive state [27]. The Spanish version had been previously validated in a sample of Chilean older adults [28] and used in populations of older Hispanic people [29]. In the present study, due to the homogeneity in the education level of the participants, we applied a total score of 30 points and a cut-off point of $\leq$24 for the diagnosis of pathological suspicion or MCI [30–32].

Calf circumference (CC) was measured with the participants in the standard anatomical position, recording the maximum calf circumference. CC is a suitable anthropometric measurement to predict components of lean body mass [33,34].

Arm circumference (AC) was measured in the right arm, raised to a horizontal position in the sagittal plane, with the forearm in supination and the elbow flexed at 45°. The maximum arm circumference was recorded. AC is considered to be an indicator that can detect the loss of muscle mass in older adults [35]. Both CC and AC are strongly correlated with lean mass, and thus can be used to evaluate malnutrition in older people [36].

The use of prediction equations to determine maximal muscle function (1RM) for older adults is a practical tool for strength training in this population. Training programmes based on estimated values of 1RM allow calculating appropriate training intensities, ensuring their safety [37]. Recent studies have shown their reliability and validity to estimate 1RM [38]. In the present study, we applied the equations developed to predict 1RM in older men and women [39]. The exercise used for the lower-limb maximum strength test was 45° Leg Press. Upper limb strength was evaluated with 90° Seated Chest Press.

2.5. Statistical Analysis

IBM SPSS 23® software (SPSS Inc. Chicago, IL, USA) was used for the statistical analysis. For the descriptive statistics, mean and standard error were calculated. To estimate the reliability of averages, a 95% confidence interval was calculated. Regarding the intragroup pre–post differences, Student's *t*-test for related samples or Wilcoxon test was conducted depending on the Shapiro–Wilk normality test (normality) and Levene test (homoscedasticity). The comparison between groups was performed using Student's *T*-test or Mann–Whitney U-test, depending on the normality and homoscedasticity tests. Cohen's d effect size was also calculated, considering values of $d < 0.3$ as small, $d = 0.3–0.5$ as moderate, $d = 0.5–0.7$ as large, $d = 0.7–0.9$ as very large, and $d > 0.9$ as extremely large. Moreover, a simple (bivariate) linear regression analysis was also carried out to determine the relationship between the study variables. Statistical significance was set at $p < 0.05$.

3. Results

Table 4 shows the results obtained in the Sedentary Group (SG). After the intervention period, this group presented a statistically significant decrease of maximal dynamic strength in the two muscle groups evaluated. In both cases, the effect size recorded was small. Similarly, the indicators of muscle mass showed significant reductions in both arms and legs, with a small effect size. In the same line, the BMI also showed a significant decrease. With respect to cognition, measured through the MMSE, after the two-year intervention period, the SG presented a significant deterioration of the cognitive state, with a moderate effect size.

Table 5 shows the results obtained in the group that carried out the resistance training (PAG). After the intervention period, this group presented a significant improvement of maximal dynamic strength in both muscle groups, i.e., in the Chest Press and Leg Press tests. In both cases, the effect size was small. Likewise, the indicators of muscle mass also showed statistically significant increases ($p < 0.001$) with a trivial effect size. The cognitive state, measured through the MMSE, showed a significant improvement after the 24-month strength training, with a moderate effect size. Regarding the BMI, there was practically no change after the training period. A slight increase was observed, although it was not statistically significant.

Table 4. Intragroup comparisons before (pre-test) and after (post-test) the intervention (mean, standard deviation, and confidence interval).

Sedentary Group (*n* = 48)						
Variables	Pre-Test		Post-Test		*p*-Value *	Effect Size ¥
	Mean ± SD	95% (CI)	Mean ± SD	95% (CI)		
BMI (kg/m^2)	25.09 ± 3.10	(24.19 to 25.99)	24.32 ± 3.26	(23.3 to 25.27)	<0.001	−0.24
1RM Chest Press (kg)	13.25 ± 1.76	(12.74 to 13.76)	12.8 ± 1.79	(12.2 to 13.33)	<0.001	−0.25
Arm Circ. (cm)	27.33 ± 3.62	(26.28 to 28.38)	26.10 ± 3.48	(25.09 to 27.12)	<0.001	−0.35
1RM Leg Press (kg)	44.48 ± 3.16	(43.56 to 45.40)	42.6 ± 3.46	(41.68 to 43.69)	<0.001	−0.54
Calf Circ. (cm)	29.9 ± 4.34	(28.64 to 31.16)	28.6 ± 4.29	(27.44 to 29.93)	<0.001	−0.28
MMSE (max. score 30)	23.25 ± 2.23	(22.60 to 23.90)	22.33 ± 1.75	(21.82 to 22.84)	0.003	−0.46

* *p*-value: *t*-test or Wilcoxon according to normality. ¥ Cohen's effect size (d < 0.20, trivial; d = 0.2–0.6, small; d = 0.6–1.2, moderate; d = 1.2–2, large; d = 2–4, very large and d > 4, extremely large). BMI: Body Mass Index; 1RM_Chest Press: 90° seated Press bench; Arm Circ: Arm circumference; 1RM_Leg Press: 45° Leg Press; Calf Circ: Calf circumference; MMSE: Mini Mental State Examination.

Table 5. Intragroup comparisons before (pre-test) and after (post-test) the intervention (mean, standard deviation and confidence interval).

Physical Activity Group (*n* = 45)						
Variables	Pre-Test		Post-Test		*p*-Value *	Effect Size ¥
	Mean ± SD	95% (CI)	Mean ± SD	95% (CI)		
BMI (kg/m^2)	25.16 ± 3.70	(24.04 to 26.27)	25.32 ± 3.68	(24.21 to 26.43)	0.053	0.04
1RM Chest Press (kg)	13.31 ± 1.76	(12.78 to 13.84)	13.76 ± 1.88	(13.19 to 14.32)	0.007	0.24
Arm Circ. (cm)	27.11 ± 3.24	(26.14 to 28.09)	27.62 ± 3.52	(26.56 to 28-68)	<0.001	0.15
1RM Leg Press (kg)	45.64 ± 4.35	(44.34 to 46.95)	47.18 ± 4.23	(45.91 to 48.45)	<0.001	0.36
Calf Circ. (cm)	30.09 ± 4.41	(28.76 to 31.41)	30.78 ± 4.24	(29.50 to 32.05)	<0.001	0.16
MMSE (max. score 30)	23.16 ± 1.88	(22.59 to 23.72)	23.93 ± 1.78	(23.40 to 24.47)	0.017	0.43

* *p*-value: *t*-test or Wilcoxon according to normality. ¥ Cohen's effect size (d < 0.20, trivial; d = 0.2–0.6, small; d = 0.6–1.2, moderate; d = 1.2–2, large; d = 2–4, very large and d > 4, extremely large). BMI: Body Mass Index; 1RM_Chest Press: 90° seated Press bench; Arm Circ: Arm circumference; 1RM_Leg Press: 45° Leg Press; Calf Circ: Calf circumference; MMSE: Mini Mental State Examination.

Next, we compare the changes recorded for each group at the beginning and the end of the intervention period. Table 6 shows the absolute values of change and Figure 3 shows the relative (percent) values of change. As can be observed, the behaviour of both groups is totally opposite in all the analysed variables. While the PAG showed an increase in maximal dynamic strength, an increase in the indicators of muscle mass, and an improvement in the cognitive state, the SG presented lower results in these parameters. These differences between groups in all the evaluated indicators were statistically significant.

Table 6. Changes after the intervention. Between-group comparisons (mean, standard deviation and confidence interval).

Variables	Change Physical Activity Group (n = 45)		Change Sedentary Group (n = 48)		p-Value *	Effect Size ¥
	Mean ± SD	95% (CI)	Mean ± SD	95% (CI)		
BMI (kg/m²)	0.165 ± 0.555	(−0.002 to 0.33)	−0.770 ± 0.97	(−1.054 to 0.487)	<0.001	−1.17
1RM Chest Press (kg)	0.444 ± 1.056	(1.127 to 0.762)	−0.438 ± 0.50	(−0.583 to −0.292)	<0.001	−1.08
Arm Circ. (cm)	0.511 ± 0.920	(0.235 to 0.788)	−1.229 ± 0.88	(−1.485 to −0.973)	<0.001	−1.93
1RM Leg Press (kg)	1.533 ± 1.236	(1.162 to 1.905)	−1.792 ± 1.03	(−2.091 to −1.492)	<0.001	−2.93
Calf Circ. (cm)	0.689 ± 1.221	(0.322 to 1.056)	−1.208 ± 0.77	(−1.432 to −0.985)	<0.001	−1.87
MMSE (max. score 30)	0.778 ± 2.099	(0.147 to 1.408)	−0.917 ± 0.91	(−1.472 to −0.362)	<0.001	−0.85

* p-value: t-test or Mann–Whitney U-test according to normality and homoscedasticity. ¥ Cohen's effect size (d < 0.20, trivial; d = 0.2–0.6, small; d = 0.6–1.2, moderate; d = 1.2–2, large; d = 2–4, very large and d > 4, extremely large). BMI: Body Mass Index; 1RM_Chest Press: 90° seated Press bench; Arm Circ: Arm circumference; 1RM_Leg Press: 45° Leg Press; Calf Circ: Calf circumference; MMSE: Mini Mental State Examination.

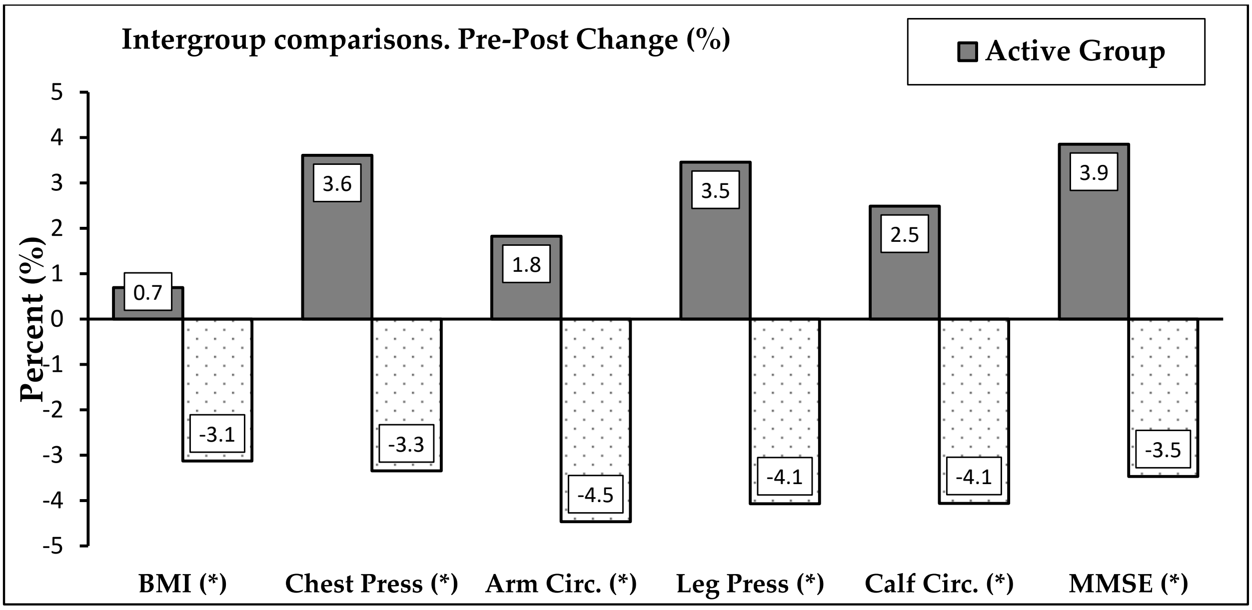

Figure 3. Between-group change percent comparisons. BMI: Body Mass Index; Chest Press: 1RM 90° Seated Press Bench Test; Arm Circ: Arm circumference; Leg Press: 1RM 45° Leg Press Test; Calf Circ: Calf circumference; MMSE: Mini Mental State Examination. (*) Significant differences in Student's t-test or Mann–Whitney U-test.

Figure 4 shows the simple (bivariate) linear regression equations that relate the change in the cognitive state as a function of the changes in the levels of muscle strength and morphology. As can be observed, the improvement in muscle strength is significantly associated with the improvement in the cognitive state (Figure 4A,B). The only analysed variable whose change did not significantly predict the change in the cognition level was calf circumference.

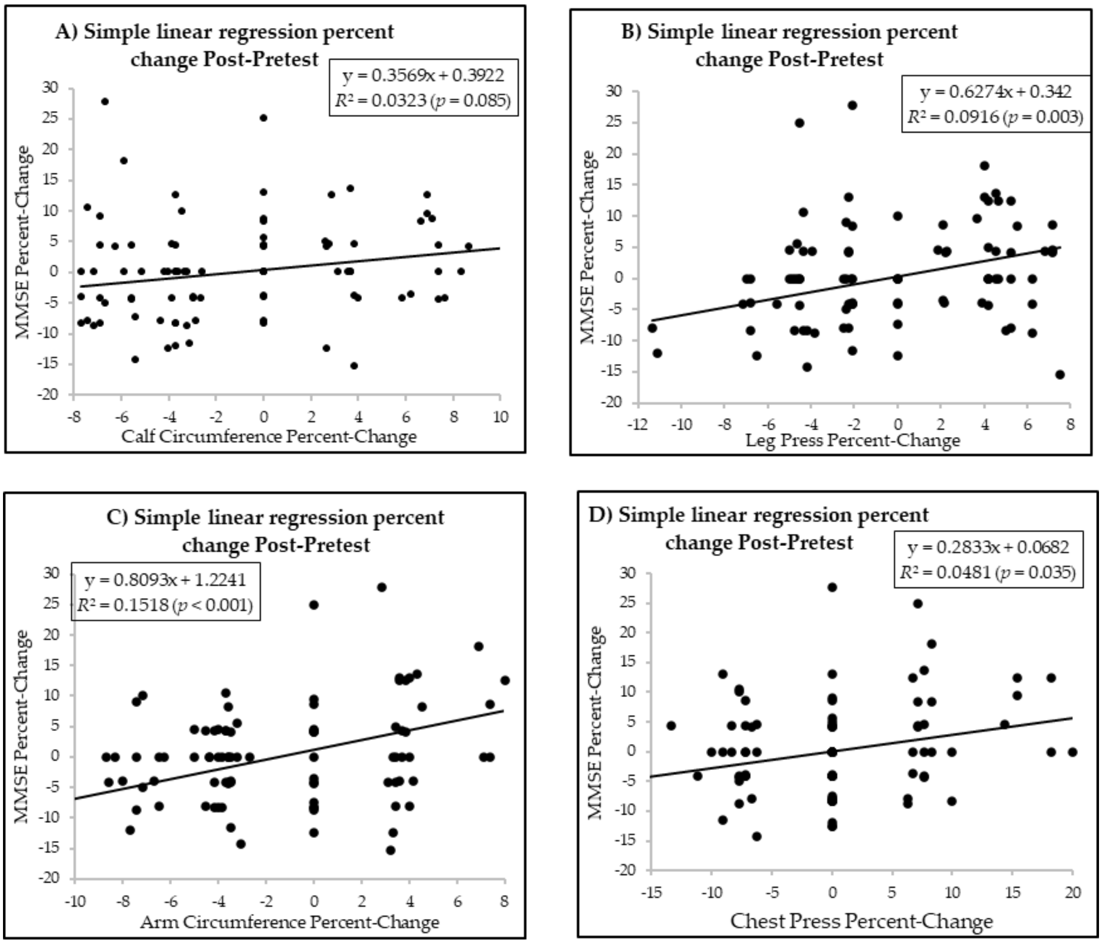

Figure 4. Post-pretest simple linear regression percent change between cognition level (MMSE) and muscle strength variables and muscle morphology variables in the total sample.

4. Discussion

The aim of this study was to analyse the effects of a two-year strength training on the maximal dynamic strength and muscle morphology of the upper (UL) and lower limbs (LL) and their possible correlation with cognitive function in a population of older women.

It is widely known that the natural process of ageing involves deleterious effects on the skeletal muscle system and that these effects are more evident in older adults [40,41]. An important finding of this study was that a period of two years is enough to observe deleterious effects of ageing on the muscle strength, muscle mass, and cognition level of sedentary older women (Table 3). All the analysed parameters showed statistically significant differences, although the effect size associated with this worsening was small in all cases, probably due to the fact that the recorded effects correspond to a period of 24 months. Two years is a long time, although not enough to detect large changes characteristic of ageing in older women, despite following a sedentary lifestyle. The loss of muscle strength and mass are not linear along time, but it depends on periodical episodes of physical exercise decline and/or muscle disuse, which could temporarily accelerate muscle loss and reduce muscle strength and power. It has been reported that muscle loss after the age of 60 years shows a ratio close to 1% per year, whereas strength loss presents a ratio of 3% per year [42], which is consistent with the results obtained in this study for the control group (Figure 3).

On the other hand, following an active lifestyle is one of the elements recommended to counteract the harmful effects of ageing [43]. Our results showed that a 24-month resistance training programme produces statistically significant improvements in the indicators of muscle strength (1RM Chest Press: p = 0.007 and 1RM Leg Press: $p < 0.001$), in the parameters of muscle morphology (Arm Circ.: $p < 0.001$ and Calf Circ.: $p < 0.001$), and in the cognition level (MMSE: p = 0.017) of participants (Table 3). Numerous studies have shown the effectiveness of muscle strength and power training [44–47]; however, precaution is also recommended in the evaluation of this population regarding the adaptation to the loads [48]. Similarly, many studies have reported improvements in the cognition level in people who carried out muscle strength training programmes [49–51].

The effect size associated with this improvement was small for maximum strength and cognition level and trivial in the case of the variables of muscle mass. This small effect size could be since the applied progression of training loads was conservative, since safeguarding the health of the participants was a priority in this study. It has been asserted that it is not necessary to apply heavy loads to attain improvements in muscle strength in older people if the training programmes are long [52,53].

All the analysed variables, except for BMI, improved significantly, which suggests that a controlled and adapted resistance training programme improves maximal dynamic strength and muscle mass in older women (Table 3).

The main finding in this study was obtained because of the comparison of the changes in the indicators of maximum muscle strength and muscle morphology between sedentary older women and older women who carried out a muscle strength training programme (Table 6 and Figure 3). After two years of intervention, the changes observed in the active group with respect to those obtained in the sedentary group showed statistically significant differences in all variables. The effect size in the variables of muscle morphology was large in both AC (1.93) and CC (1.87) (Table 6). In the muscle strength tests, the differences between groups also presented important effect sizes in both muscle groups, with 1.08 in Chest Press (moderate but very close to large), and 2.93 in Leg Press (very large) (Table 6). Similar results have been reported in a recent randomised study conducted in institutionalised older people, in which the active group performed an 8-month strength training programme, with a significant improvement of their strength with respect to the control group; the strength training was carried out with low-cost equipment [54]. In this line, a different study conducted in older women reported significant improvements in the group that performed the strength training programme with respect to the control group, who, in this case, were not completely sedentary, as they carried out a walking and physiotherapy training [55]. In long strength training programmes, the differences in strength improvements in older women who perform muscle strength training programmes are remarkable with respect to sedentary older women, even with moderate-intensity training programmes [56].

Therefore, it seems that the strength training programme carried out by the active group not only prevented the loss of muscle strength and mass characteristic of ageing in older women (as was observed in the sedentary group), but it also produced significant improvements in maximal dynamic strength and muscle mass. The behaviour of these variables was completely different between the participants who performed the strength training programme and those who followed a sedentary lifestyle (Figure 3).

In the comparison of the changes between the two groups, the data related to the cognition level showed results similar to those commented above. That is, while the active group improved, the sedentary group worsened (Figure 3), with significant differences ($p > 0.001$) and a moderate effect size (0.85). In this sense, the data obtained in this study show a considerable association between the changes in the cognition level and the changes in muscle strength and mass after the two-year intervention. Thus, Figure 4 presents the graphs and simple linear regression equations between the changes obtained in cognitive level and those recorded in maximal dynamic strength and muscle morphology in the upper and lower limbs in a period of two years. The results presented in this figure show that the changes in muscle strength, both in the lower limbs (Figure 4B; p = 0.003) and in the upper limbs (Figure 4D; p = 0.035), could predict changes in the cognitive state of older women in the same direction. That is, if muscle strength improves, then cognition improves and vice versa. A recent study reported that different muscle strength and power training programmes improved cognitive functioning globally in the active groups with respect to the control group (inactive) [50].

Despite the fact that the R^2 are statistically significant in Chest Press, Leg Press, and Arm Circumference, it should be emphasized that the explained variance is very low (Figure 4B–D). We cannot establish a cause-and-effect relationship; however, the association between the increased muscle strength/muscle mass and improved cognition can be explained by different physiological mechanisms [57]. For example, a transient increase in serum BDNF following resistance exercise in older adults could have implications for improved cognitive function in older adults. In this sense, resistance training has been correlated with increased serum levels of insulin-like growth factor1 (IGF-1) [4,58], which is an essential factor in brain neurogenesis and cognitive function [59]. Similarly, myokines are produced following skeletal muscle contractions and exert autocrine, paracrine, and endocrine effects which are sensed by the brain and may lead to changes in plasticity [60,61]. Myokine signalling mediates the muscle–brain endocrine loop, promoting relationship building between muscles and the brain, and could improve brain functions such as cognition, memory, and motor coordination [59,62].

Regarding the association between the changes in muscle morphology and those in the MMSE, statistically significant results were only obtained in arm circumference (Figure 4C: $p = 0.001$), with calf circumference showing no significant results. Thus, it seems that the evolution of the cognition level in older women could be associated with the changes in muscle strength.

The practical applications of these findings should focus on reducing the risk of falls, increasing independence and autonomy, and improving cognition in aging women. However, it is essential that resistance training programs have been adapted to older women and should follow the principles of individualization, periodization, and progression for this special population. Future lines of research could be to study the possible effects of resistance training on quality of life and include different types of exercise programs. The main limitations of the study were that the applied sampling method reduced the representativeness of the sample and a low adherence to the intervention, although it should be emphasized that the study lasted two years.

5. Conclusions

A resistance training programme on the upper and lower limbs for 24 months improves maximal dynamic strength in Leg Press and Chest Press, as well as arm and calf circumference, in older women.

The changes in the cognition level recorded through the MMSE in a period of 24 months could be associated with the changes in upper and lower limb muscle strength (Chest Press and Leg Press, respectively) and arm circumference.

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