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ORIGINAL ARTICLE

Comparison of Neuromotor and Progressive Resistance Exercise Training to Improve Mobility and Fitness in Community-Dwelling Older Women

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Abstract

Purpose Neuromotor exercise, which stimulates motor fitness components (balance, agility, coordination), has been less investigated than other forms of exercise such as resistance or aerobic training to counteract the age-related impairment in mobility. The aim of the study was to verify whether neuromotor exercise was as effective as resistance training in improving mobility and related fitness components in healthy older women.

Methods Thirty-five women (mean age 69.6 ± 3.2 years) were assigned to a neuromotor (NMT) or a progressive resistance training (PRT) group, both exercising 1 h, twice weekly for 12 weeks. The NMT group exercised static and dynamic balance, agility, speed, reaction time and coordination, while the PRT performed prevalently machine based, strengthening exercises. All participants were tested before and after the intervention for walking speed under different conditions, chair rise time, cardiorespiratory fitness, muscular strength and power. A 2 × 2 MANOVA and subsequent ANOVAs were performed to ascertain the effects of the two trainings.

Results Similar improvements were observed for mobility ($P = 0.000$, $\eta_p^2 = 0.73$) and for fitness ($P = 0.000$, $\eta_p^2 = 0.96$) in both groups.

Conclusions The present results suggest that in healthy older women improvements in mobility may be obtained through both strength and neuromotor exercise. The present results contribute to further our knowledge on the effects of neuromotor exercise for older people and add relevant information on exercise interventions targeting mobility in the elderly.

Keywords Neuromotor exercise · Mobility · Walking speed · Cardiorespiratory · Muscle power · Muscle strength

Introduction

Mobility indicates the ability of the individual to move independently and safely for different purposes to very short distances in the immediate living surroundings or to more distant destinations. Moving independently requires the ability to adapt to the surrounding environment through the coordinated involvement of musculoskeletal, cardiopulmonary, nervous and cognitive systems [7, 10, 14, 38, 50]. It is therefore a key factor to lead an active lifestyle and experience good quality of life at all ages [22, 52]. Aging is well known to gradually reduce mobility due to the decline in physical capacities and in sensory and cognitive functions [2]. Diminished mobility is associated with disability and even mortality [4, 24] particularly in older and sedentary individuals [12, 22]. Moreover, the prevalence of mobility difficulty seems higher in women than in men [12].

Physical activity and exercise are widely recognised to reverse, at least partially, the age-related mobility changes and interventions applying different types of physical exercise have been used over the years. Most of the published research has addressed physical fitness with strengthening, flexibility and aerobic exercises as main objectives [2]. In contrast, motor fitness, which includes agility, balance, coordination, power, reaction time and speed [5, 9], has been

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investigated less [21]. Motor fitness exercises, also described by the ACSM as neuromotor exercises [21], pose specific attention to stimulate skills using perception and central processing to perform the task accurately [47] and are crucial for effective mobility [6, 19, 18]. In this respect, the recent application of exercise stressing the timing and coordination of movement has shown promising results for mobility improvement in older individuals [6, 35].

Given the above, it seems important to investigate the effects of neuromotor exercise to help identify the optimal exercise for mobility. This is particularly important for women who, living longer than men and comprising most of the aging population, practice less physical activity and have lower levels of physical fitness at all ages [26, 27]. As they are at greater risk of developing disability at older ages [12], they represent a target population for physical intervention aiming at maintaining or improving mobility.

The aim of the present study was to verify the efficacy of 12 weeks of neuromotor training (NMT) compared to progressive resistance training (PRT) in improving measures of mobility and physical fitness in healthy community dwelling older women. Similar effects were expected on mobility in both groups while greater improvement in physical fitness were expected in the PRT group.

Materials and Methods

Participants

Following ethical approval by the local university (identification code n. LS-09-79), 35 women aged between 65 and 75 (mean age 69.6 ± 3.2 years; height 163.7 ± 6.8 cm; body mass 67.9 ± 6.6 kg; BMI 25.6 ± 3.2 kg/m^2) were initially recruited through local community centres. A priori power analysis for ANOVA repeated measure, within-between interaction with $1-\beta$ error probability = 0.80; α error probability = 0.05 resulted in a sample size of 34 participants [13]. Inclusion criteria were as follows: (a) living independently; (b) not taking part in regular physical exercise more than once weekly; (c) being "clinically stable" as established via a medical history questionnaire [23] including any pathological conditions that could potentially influence study outcomes. Following consent procedures, participants were assigned to either a neuromotor training (NMT; $n = 19$) or a progressive resistance (PRT; $n = 16$) training both exercising twice weekly for 1 h for 12 weeks, under the supervision of experienced and qualified personnel.

Neuromotor Training

Based on previous experience [17], the NMT exercise was composed of 10 min of general warm-up, 25 min of conditioning and 15 min of floor exercises, all with the accompaniment of music. The warm up was performed by walking in different directions (front, back, side) and progressively stretching all major joints i.e., shoulders, elbow, wrists, spine, hips, knees and ankles. The conditioning section included exercises for fine and gross motor coordination such as hand–eye or foot–eye coordination, static/dynamic balance, and agility, as well as exercises for spatial orientation, reaction ability and strength differentiation. These were implemented by requiring for example walking movements (a) of different dimensions (e.g., long, short, wide, narrow, big, small, close, far, high); (b) on path of different shape (e.g., line, round); (c) with different contact of the foot to the floor (toes, heels); (d) with quick motor reactions to different stimuli (e.g., visual, auditory or tactile); (e) with different strength requirement (e.g., walking/light jogging stepping over hurdles placed at different distances with repetitions at different speed). Moreover, hand held equipment such as foam balls, medicine balls, bean bags, sticks and dumbbells were used during the classes to provide an external load or focii of attention.

The floor part of the session included exercises strengthening the major muscle groups (i.e., abdomen, back, upper and lower limbs and stretching) and relaxation exercises.

Progressive Resistance Training

Progressive resistance training was developed following traditional exercise recommendations for older adults [15]. The target intensity of 80% of 1RM was reached progressively starting from familiarization without loading, to loading at 40–60% of 1RM for the first 2 weeks, and to loading at 80% 1RM thereafter for the entire training period. If participants could not keep the intensity at the load corresponding to the calculated 80% of 1RM, they were instructed to keep intensity at 15–17 of the rate of perceived exertion (RPE) as this has been reported to correspond to about 80% of 1RM [15]. To maintain constant training intensity after the initial 2 weeks, the 1RM test was repeated every 4 weeks.

A typical session included 10 min of warm up while walking and performing upper and lower limbs movements of flexion, extension and rotation. In the remaining time participants performed, in a circuit, three sets of eight repetitions of twelve strength exercises, alternating muscle groups and machines with free weights/floor exercises. These included machine exercises for knee extension, knee flexion, lateral pull-down, chest press and front rowing; free weights/floor exercises for biceps, triceps and deltoids, lower limbs (i.e., squats, stepping), abdominals and back extension.

Testings

Participants were thoroughly familiarized with all testing procedures. They were tested on two separate days to avoid fatigue.

Walking speed was measured on a 10 m indoor course. Participants walked "as fast as possible without running" for 15 m with measuring gates (Smartspeed, Fusion Sport, Coopers Plains, Australia) being placed 3 m after the start and 2 m before the finishing line to allow for acceleration and to avoid slowing down before the end of the course. Walking was performed in different conditions: (a) basic, (b) stepping over two hurdles (45 cm wide and 15 and 45 cm height) placed in succession on the mid line of the track at 2 and 4 m distance from the 1st timing gate, (c) picking up two hand weights of 250 g each placed at 2 m and 4 m from the 1st timing gate at about 50 cm distance from the mid line of the track, d) on reduced width of 15 cm. Each walk was performed twice. Times were recorded to the nearest millisecond, the best time was transformed into m/s.

The ability to rise from sitting was assessed as the time required to rise from sitting for five times as fast as possible from a standard 43 cm height chair with participants folding arms across their chest. Recordings were made using a stopwatch starting at the initiation of the movement and stopping when subjects stood upright for the 5th time [25].

Cardiorespiratory fitness was assessed using a sub-maximal, 1-min incremental cycling test up to 85% of predicted maximal HR calculated as 220−age. VO_2, VCO_2, VE, and HR were continuously recorded using a breath-by-breath open-circuit gas analyser (Quark B2, Cosmed, Italy). The ventilatory threshold (VT), adopted as indicator of aerobic fitness, was visually identified by two experienced physiologists using both the ventilatory equivalents [8] and the V-slope methods [3]. Briefly, with the equivalent method VT was identified as the point where VE/VO_2 increased whilst VE/VCO_2 remained constant. With the V-slope method VT was detected by plotting CO_2 production (VCO_2) vs. O_2 uptake (VO_2) as the point where a departure from linearity of VCO_2 was observed.

Maximal knee extension and flexion torques (Nm) were measured on the dominant limb during a maximal voluntary contraction using an isokinetic dynamometer set at an angular velocity of 60°/s (Biodex System 3 Pro, Biodex Medica System Inc., NY, USA). Subjects performed from a starting position approximately 90° at the knee, with four consecutive maximal flexions and extensions of the limb. Peak torque of the best flexion and extension was calculated.

Isometric hand grip strength of the dominant hand was measured with the participant standing and relaxing their arm along their body (Baseline Hydraulic Hand Dynamometer Fabrication Enterprise Inc., Irvington, NY, USA). Two trials were performed with 1-min rest in between and the highest score was used for statistical analysis.

Peak power of the lower limbs was assessed with a countermovement jump performed on a force platform (AMTI's BP400600-2000, Advanced Mechanical Technology, Inc. MA, USA) following widely used procedures [11]. From an upright posture, with feet shoulder width apart and hands on hips, participants flexed their knees as fast as possible to a knee angle of about 90°, before forcefully extending to perform a vertical jump. Peak power, normalized for body mass (PPkg = W/kg), was calculated as previously described [11]. To explore the different contributions to PP generation, the two power determinants, force at PP and velocity at PP, were also calculated.

Statistical Analysis

After checking data for normality of distribution and outliers, descriptive statistics were calculated on all variables. Two groups of dependent variables were formed based on their correlation level: mobility and physical fitness to which repeated measures 2 × 2 MANOVA and subsequent ANOVAs were applied with time as within factor and training as between factor to evaluate the effects of the two trainings separately for the two groups of variables. IBM SPSS version 24 was used for all analysis. Moreover, to verify if changes in mobility were linked to changes in physical fitness, Pearson's correlation coefficients were calculated between the differences pre and post (Δ) values of mobility and fitness.

A significance level of $P < 0.05$ was used in all statistical analysis. For ANOVA results, cut off values of η_p^2 of effect size small, medium and large were 0.01, 0.06 and 0.14, respectively. Data were expressed as mean and SD unless otherwise stated.

Results

Participants' compliance with the training programmes was 85% for both groups. The exclusion for low attendance was set at a threshold of missing more than 25% of the total number of classes. Four participants were lost at follow up (3 NMT and 1 PRT), three had to be excluded for low attendance (2 NMT, 1 PRT), three, despite agreeing to take part, never started the programme (PRT), and one, although completed the first assessment, never started the programme (PRT). The final sample was composed of 24 participants (NMT = 14; PRT = 10).

Independent t tests revealed no significant differences between the groups at baseline in any measurements.

Following 3 months of training, significant improvements in most of the measured parameters were observed with no differences between groups (no interaction effect). For mobility, MANOVA showed a significant main effect of time (Wilks $\lambda = 0.27$; $F(5,16) = 8.55$; $P = 0.000$; $\eta_p^2 = 0.73$) and subsequent ANOVAs revealed the effects on maximal walking speed ($F(1,20) = 5.97$; $P = 0.024$; $\eta_p^2 = 0.23$), maximal walking speed stepping over hurdles ($F(1,20) = 19.44$; $P < 0.001$; $\eta_p^2 = 0.49$), maximal walking speed picking up ($F(1,20) = 20.59$; $P < 0.001$; $\eta_p^2 = 0.51$) and chair rise time ($F(1,20) = 20.59$; $P < 0.001$; $\eta_p^2 = 0.51$) (Table 1).

For physical fitness MANOVA demonstrated a main effect of Time (Wilks $\lambda = 0.042$; $F(6,16) = 60.49$; $P = 0.000$; $\eta_p^2 = 0.96$) (Table 1). Subsequent ANOVAs showed the effect for all variables except handgrip strength: ventilatory threshold ($F(1,21) = 7.13$; $P = 0.014$; $\eta_p^2 = 0.25$), knee extensors torque ($F(1.21) = 4.6$; $P = 0.044$; $\eta_p^2 = 0.18$) and knee flexors torque ($F(1,21) = 9.15$; $P = 0.006$; $\eta_p^2 = 0.30$) PPkg ($F(1,21) = 39.08$; $P < 0.001$; $\eta_p^2 = 0.65$) (Table 2; Figs. 1, 2). The analysis of determinants of peak power, velocity and force, showed a significant increase, in the whole sample, in both velocity ($F(1,21) = 43.1$; $P < 0.001$; $\eta_p^2 = 0.67$; Fig. 2a) and force ($F(1,21) = 4.64$; $P < 0.043$; $\eta_p^2 = 0.18$; Fig. 2b, c).

No significant correlations were observed between the Δ values of mobility and fitness.

Discussion

In the present study, a neuromotor training programme, comprising exercises for balance, agility and coordination, was as effective as progressive resistance training to improve different aspects of mobility and related physical fitness components in healthy older women. Mobility is described as the ability to autonomously move and adapt to the environment [40], with walking as its crucial manifestation [33], and rising from sitting as a "precursor" of walking as in many cases it is necessary to rise from sitting before starting to walk [32]. The performance of such tasks requires the combination of physical and motor fitness [7, 10, 14, 38]. While physical fitness and its components are well identified, defined and investigated, the same is not true for motor fitness and related exercises so that it is not possible to develop definitive guideline for prescription [21, 39]. Difficulty in the development of guidelines for neuromotor exercise is likely due to the lack of consistent terminology. Comparison among studies is more difficult than for exercises such as aerobic or PRT, which have clearly defined characteristics and objectives and more easily quantifiable overload. In the present study, the term neuromotor exercise was used in accordance with the ACSM [21] and participants in the NMT group performed exercises for balance, agility, gait, coordination and proprioception.

The present results contribute to further our knowledge on the effects of neuromotor exercise for older people and add relevant information on exercise interventions targeting mobility in the elderly.

Table 1 Mobility data pre and post intervention (neuromotor training, NMT $n = 14$; progressive resistance training, PRT $n = 10$)

	NMT		PRT		All	
	PRE	POST	PRE	POST	PRE	POST
Maximal WS (m/s)	1.91 ± 0.23	1.95 ± 0.22	1.83 ± 0.17	1.96 ± 0.14	1.88 ± 0.21	1.95 ± 0.19*
Maximal WS hurdles (m/s)	1.56 ± 0.19	1.64 ± 0.22	1.55 ± 0.18	1.63 ± 0.17	1.55 ± 0.18	1.63 ± 0.20***
Maximal WS picking up (m/s)	1.25 ± 0.15	1.25 ± 0.18	1.28 ± 0.15	1.35 ± 0.14	1.32 ± 0.14	1.29 ± 0.17***
Maximal WS 15 cm (m/s)	1.80 ± 0.20	1.75 ± 0.21	1.66 ± 0.23	1.78 ± 0.23	1.70 ± 0.26	1.75 ± 0.26
Chair rise (s)	9.19 ± 1.98	7.48 ± 0.74	8.94 ± 2.33	7.58 ± 2.00	9.0 ± 2.10	7.53 ± 1.42***

Significant differences are reported (*$P < 0.05$; ***$P < 0.001$; *WS* walking speed)

Table 2 Physical fitness data pre and post intervention (neuromotor training, NMT $n = 14$; progressive resistance training, PRT $n = 10$)

	NMT		PRT		All	
	PRE	POST	PRE	POST	PRE	POST
Body mass (kg)	70.1 ± 6.2	70.2 ± 6.1	64.8 ± 6.3	65.6 ± 6.5	67.9 ± 6.6	68.3 ± 6.5
Hand-grip (kg)	26.9 ± 4.4	27.8 ± 3.3	26.6 ± 4.2	28.0 ± 3.9	27.3 ± 3.9	26.8 ± 4.4
VO_2 at VT (mL/kg/min)	13.72 ± 2.13	14.76 ± 2.29	14.98 ± 2.37	15.96 ± 2.83	14.25 ± 2.27	15.26 ± 2.54*

Significant differences are reported (*$P < 0.05$)

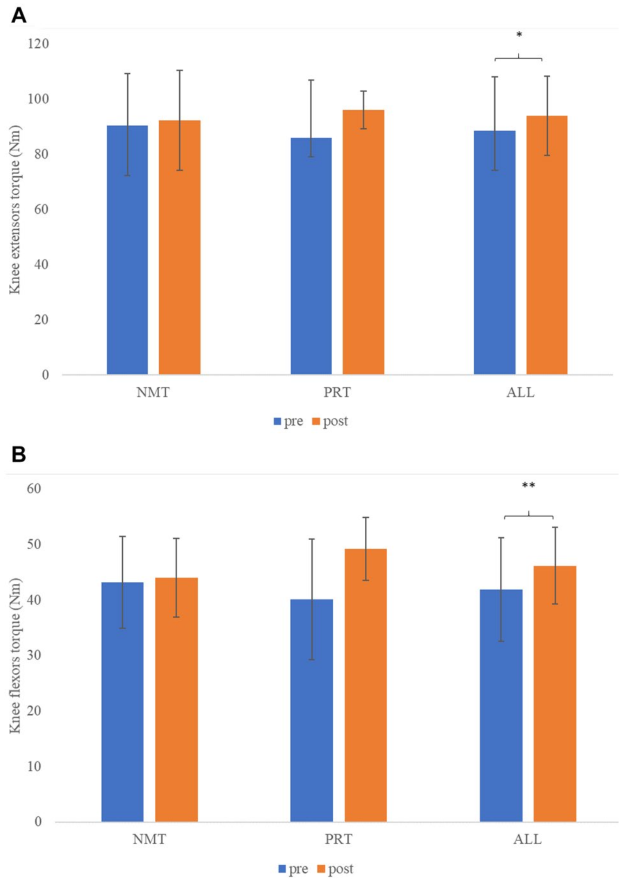

Fig. 1 Mean and SD values of knee extensors (**a**) and flexors (**b**) for the two groups and the whole sample. Significant main effects are reported (*$P < 0.05$; **$P < 0.01$). No interaction effects were observed (*NMT* neuromotor training group, *PRT* progressive resistance training group)

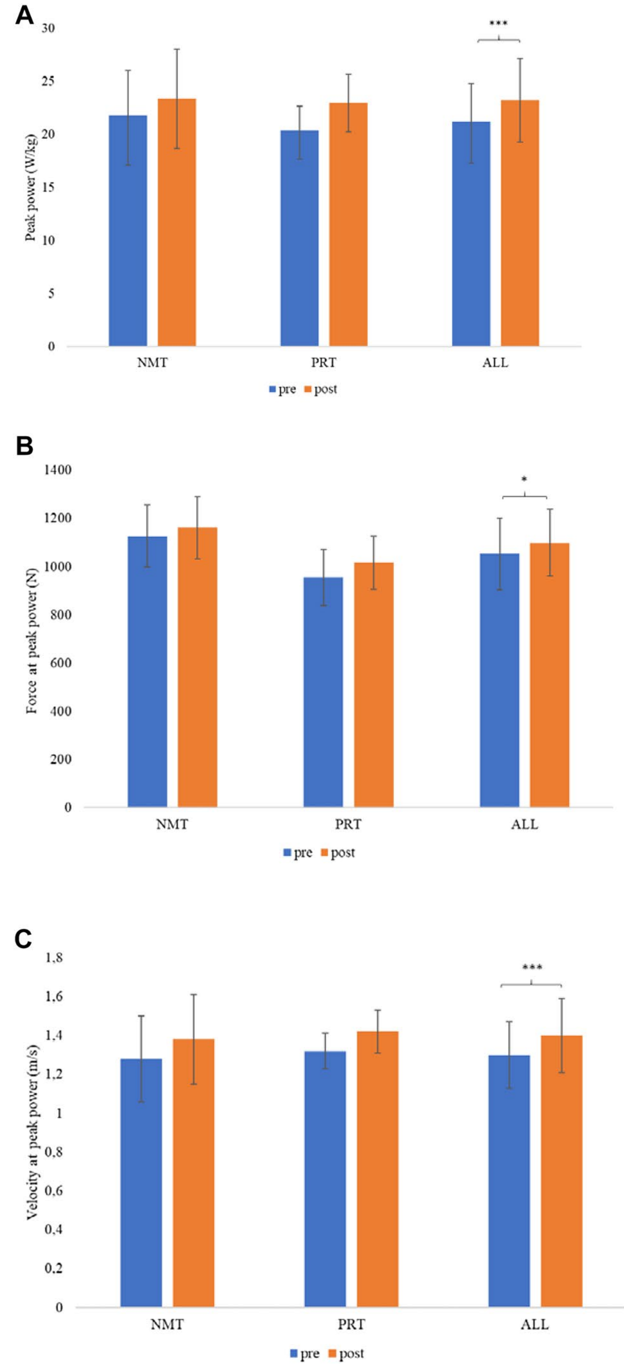

Fig. 2 Mean and SD values of peak power (**a**) and its determinants force (**b**) and velocity (**c**) for the two groups and the whole sample. Significant main effects are reported (***$P < 0.001$; *$P < 0.05$). No interaction effects were observed (*NMT* neuromotor training group, *PRT* progressive resistance training group)

Interventions for mobility enhancement have generally included exercise to increase capacities such as strength and cardiovascular with mixed results [42]. Lack of effectiveness may be explained by the fact that effective mobility is the result of the integrated efficiency of different systems: the central and peripheral nervous system, the perceptual system, and the musculoskeletal and cardiorespiratory systems [14]. The optimal exercise regime for mobility, therefore, should include, as far as possible, activities stimulating all systems [45]. As previously reported, older individuals combining high lower limbs strength capacity with good proprioception perform better on mobility tasks [19]. The present results, in line with such findings, suggest that in healthy older women, improvements in mobility may be obtained through both stimuli of physical and neuromotor type.

Research with older individuals, which has applied exercise for motor fitness and has resulted beneficial for mobility, has included both static or dynamic types of coordination and motor learning exercise, such as the adaptation of Tai-chi for frail individuals, mainly performed sitting and aiming at hand–eye-coordination [29, 30, 37, 51], or more dynamically with mobility exercises with music [35, 34, 44]. A further approach applies the motor learning model which aims to stimulate the brain to learn the timing and sequence of movements through the repetition of a single movement until is automated [6]. The presently applied neuromotor training is comparable to the motor learning model in as much it emphasises perception of movements and their repetition, with the difference that actions were repeated with small variations as per the variability of practice principle [41] with the accompaniment of music [17, 31]. Moreover, the NMT exercise may fit the dynamic action model of movement control [41], which proposes that the characteristics of the individual, the environment and the task interact regulating movement.

By observing descriptive statistics (Table 1; Figs. 1, 2), it can be speculated that the two applied trainings acted through different mechanisms. Strength enhancing exercise may have enhanced mobility by optimizing muscle strength. The neuromotor exercise, as previously suggested for similar motor fitness exercise [48], may have induced mobility enhancement by stimulating motor skills through tasks requiring processing information with higher involvement of sight, hearing, vestibular and proprioceptive systems, and through the observed increase in the velocity of muscle strength generation. It is known that the first phases of learning or retraining a motor task are less efficient and demanding more attention. In those that follow when the task becomes automated, there is less need of control and cognitive involvement [16], allowing a more effective movement. The neuromotor exercise might have helped such process. The lack of correlation between the Δ values of fitness and mobility supports the idea that factors which were not measured in the present study may have contributed to the observed improvements (e.g., motor fitness, cognition, self-confidence).

The other point of interest of the present study relates to the improvements observed in the other fitness parameters, which may have also contributed to a more efficient mobility (Tables 1, 2; Figs. 1, 2). In fact, while PRT was specifically designed to improve strength, the NMT exercise did not follow a strict application of the overload principle for any of the assessed physical and motor fitness capacities. Surprisingly, both exercises significantly increased aerobic fitness measured as VT. This parameter is an indicator of the individual's submaximal work capacity performance and particularly for older individuals, who are hardly required to perform at maximal capacity during daily activities, VT may represent a more relevant indicator of physical fitness than VO_{2max} [1]. It is not easy to speculate the mechanism behind such improvement; it could be that both exercises induced a general increase in movement mastery, which may have induced an increase in exercise efficiency [36, 42]. Moreover, it could not be excluded that the 10 min warm up of both exercises, mainly performed by walking, could have contributed to the observed improvement. It is in fact known that in older individuals VT corresponds to the intensity of daily living activities including walking [43].

Regarding improvements in lower limb strength, although statistical analysis indicates that both knee extensors and flexors only have a main effect, as showing in Fig. 1a, b, it seems that the PRT group improved more than the NMT. Possibly due to the small number of subjects, an interaction effect did not appear. Both groups improved power of the lower limbs and particularly velocity at peak power. The present results are in line with previous application of a similar form of dynamic exercise, which proved effective in enhancing lower limb peak power [46], but not strength. This result supports the notion that lower limb power, which has been described as an important determinant of mobility in aging [2], can be safely improved using body weight-based exercises and by increasing the speed of movement without external or with light overload [49]. On the other hand, grip strength did not show any significant change possibly because, as known, older people use their upper limbs more regularly with daily activities [28]. Losses in strength in the upper limbs are less evident than in the lower limbs, which consequently may have a greater room for improvements [20].

The present study has several limitations that need to be addressed. Although the assessment of fitness and mobility included a comprehensive battery for most of the functions relevant for mobility, motor fitness was not directly tested. The adopted mobility tasks require dynamic balance, speed and agility, coordination, but are not specific tests for such capacities. Explanation of mechanisms behind the observed improvements are therefore only speculative. Similarly, possibly due to the small number of participants, it was not possible to observe relationships between gains in physical fitness and mobility, although all fitness measures were highly correlated with mobility measures at baseline (data not shown).

Moreover, while strength training followed well-established exercise recommendations, the neuromotor exercise had no guidelines for intensity, duration and repetitions to follow. Future research should be designed to specifically investigate the dose–response issue for neuromotor exercise, and applying tests for motor fitness (i.e., proprioception, reaction time, muscle strength differentiation) relevant for mobility in older individuals.

In conclusion, both strength and neuromotor exercise were effective in improving aspects of mobility and physical and motor fitness in older women. While improvements in the strength group were more likely linked to gains in muscular efficiency, for the neuromotor group these were possibly due to a mixture of improvements in muscular and motor fitness (i.e., velocity in strength production). It is likely that optimal exercise for mobility improvements and enhancement in older individual may require the combination of exercises for physical fitness (strength, power, flexibility and cardiovascular) and for motor fitness (balance, coordination, agility, speed and reaction time).

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