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Pilates and Proprioceptive Neuromuscular Facilitation Methods Induce Similar Strength Gains but Different Neuromuscular Adaptations in Elderly Women

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ABSTRACT

Background/Study Context: The aging process is associated with a decline in muscle mass, strength, and conditioning. Two training methods that may be useful to improve muscle function are Pilates and proprioceptive neuromuscular facilitation (PNF). Thus, the present study aimed to compare the influence of training programs using Pilates and PNF methods with elderly women.

Methods: Sixty healthy elderly women were randomly divided into three groups: Pilates group, PNF group, and control group. Pilates and PNF groups underwent 1-month training programs with Pilates and PNF methods, respectively. The control group received no intervention during the 1 month. The maximal isometric force levels from knee extension and flexion, as well as the electromyography (EMG) signals from quadriceps and biceps femoris, were recorded before and after the 1-month intervention period.

Results: A two-way analysis of variance revealed that the Pilates and PNF methods induced similar strength gains from knee flexors and extensors, but Pilates exhibited greater low-gamma drive (i.e., oscillations in 30–60 Hz) in the EMG power spectrum after the training period.

Conclusions: These results support use of both Pilates and PNF methods to enhance lower limb muscle strength in older groups, which is very important for gait, postural stability, and performance of daily life activities.

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The aging process is associated with decline in muscle mass, strength, and conditioning, thereby affecting the ability to carry out many daily activities. Exercises combining strength and resistance could be used to control or reverse these muscle impairments (Aagaard, Suetta, Caserotti, Magnusson, & Kjaer, 2010; Cadore et al., 2011, 2005; Izquierdo et al., 2003, 2004; Wood et al., 2001). In this context, two training methods may be useful for the elderly people, Pilates and proprioceptive neuromuscular facilitation (PNF), owing to their benefits to muscle strength and conditioning.

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Pilates is a training method that combines stretching and strengthening exercises, improving mind-body awareness (Bernardo, 2007), whereas the PNF method uses a proprioceptive stimulus, through techniques such as stretch-relax and contract-relax, to improve the muscle stretch and/or strength (Adler, Beckers, & Buck, 2008). These methods have been widely prescribed for elderly people because they employ elastic or manual resistance, with low impact for skeletal and muscular systems. Because the adhesion to exercise programs from this population depends on factors such as the intensity and safety, these training methods seem to be appropriate for fragile populations such as elderly people.

Previous studies with older adults have shown significant strength gains with weight training (Albino et al., 2012; Cadore et al., 2010; Cavani, Mier, Musto, & Tummers, 2002), and positive results also have been observed after training periods with Pilates (Amorim, Sousa, & Santos, 2011; Dorado, Calbet, Lopez-Gordillo, Alayon, & Sanchis-Moysi, 2012; Irez, Ozdemir, Evin, Irez, & Korkusuz, 2011) and PNF (Nelson, Chambers, McGown, & Penrose, 1986; Kofotolis & Kellis, 2007; Pereira & Gonçalves, 2012) methods. Despite this, to the authors' knowledge, there are no previous studies comparing both the strength and motor control adaptations to Pilates and PNF methods.

Pilates and PNF methods aim to provide muscular strength gains through exercises with mild to moderate resistance, but with a great proprioceptive (i.e., a great sensorial input from joints to the central nervous system) component, which can optimize strength gains by neural adaptations. The main neural adaptations to resistance training methods consist of an increase in motor unit recruitment capacity, as well as an increase in the firing frequency of these motor units. These characteristics are directly influenced by descending cortical command. The most common method used to evaluate neural adaptations to strength training is analysis of the electromyographic (EMG) signal.

Descending drives from the motor cortex may be identified from EMG signals because muscle fiber action potentials are generated as a result of the neuromuscular transmission (Brown, 2000), and recent studies (Negro & Farina, 2011a, 2011b; Stegeman, Van De Ven, Van Elswijk, Oostenveld, & Kleine, 2010) strongly suggest that the central nervous system can directly transmit oscillations to the control signals to muscles. Then, the common input to a spinal motoneuron pool may be studied through EMG signal analysis (Neto, Baweja, & Christou, 2010; Neto & Christou, 2010; Pereira, Freire, Cavalcanti, Luz, & Neto, 2012; Pereira, Schettino, Machado, Silva, & Neto, 2010).

Therefore, the aim of this study was to compare the influence of a training period with Pilates and PNF methods on strength gains and motor control adaptations during voluntary contractions, applied to a group of elderly women.

METHODS

Participants

A total of 150 community-dwelling older women, included in a local social project, were invited to take part in the trial. Ninety volunteers were interested, but after applying inclusion and exclusion criteria (see below), only 63 volunteers were enrolled, thus composing the study sample.

Sixty-three healthy elderly women (60–80 years) (age: 69.2 ± 6.14 years; height: 151.4 ± 6.41 cm; weight: 58.6 ± 8.44 kg), who are sedentary (evaluated using the International Physical Activity Questionaire [IPAQ]), volunteered to take part in the study. Subjects were excluded from the study if they presented any orthopedic, neurological, cardiac, vestibular, visual, or psychiatric impairment that would not allow them to perform all the tasks in the study. Written informed consent was obtained from all subjects, the university ethics committee gave approval for the study (no. 644.367), and the study was registered in Clinical Trials (NCT02274909).

The volunteers were randomly divided into three groups: Pilates group, who underwent a 1-month (three times per week) training program with Pilates method; PNF group, who underwent a 1-month (three times per week) training program with PNF method; and a control group, who received no intervention during a 1-month period, concomitantly to the training groups. Subjects from Pilates and PNF groups who missed two consecutive sessions were excluded (Figure 1).

Study Protocol

For those subjects undergoing training, the average duration of sessions was 50 minutes. Both training programs were progressive, with resistance, difficulty, and the number of repetitions increasing gradually.

The exercise protocol of the Pilates method consisted of muscle stretching of the upper limbs, trunk, and lower limbs before the exercises. Then, exercises involving range of motion and strength of upper limbs, trunk, and lower limbs were performed, always associated with breathing in different positions and with increasing repetitions and resistance along the weeks of training. Swiss ball, theraband, and magic circle were used as acessories to increase the resistance and difficulty of exercises.

The exercises from the PNF method were performed with stretching, associated with hold-relax technique, for upper and lower limbs. Then, subjects carried out exercises with the upper limbs, in a bilaterally symmetrical pattern, and with the lower limbs, in the

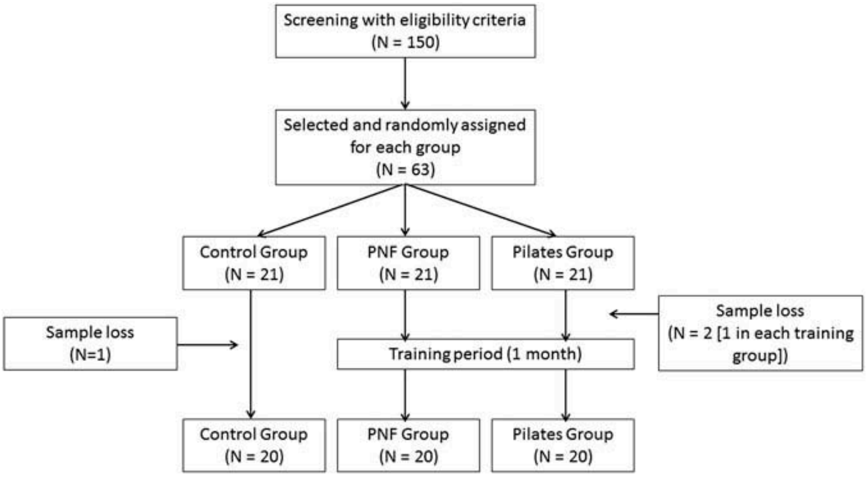

Figure 1. A flowchart showing the study design.

asymmetric bilateral pattern. Additionally, scapular and pelvic girdle exercises were done with a symmetrical and reciprocal combination.

Isometric Force Acquisition

For all groups, maximal isometric forces were recorded from knee extensors and flexors of dominant limb, before and after the 1-month intervention period. The recordings were done with the hip and knee joint angle set at 90° and maximal effort was sustained for 10 seconds. The isometric force data were obtained using a load cell with a range of 0 to 200 kg (EMG System, São Jose dos Campos, São Paulo, Brazil) synchronized to the EMG data acquisition.

EMG Measurement

Surface EMG signals were obtained using an eight-channel module (model EMG800C; EMG System) with a total amplifier gain of 2000, a common mode rejection ratio of 120 dB, sampled at 2000 Hz, and bandpass filtered (20–500 Hz). A 12-bit converter digitalized the analog signals with a sampling frequency of anti-aliasing 2.0 kHz for each channel. Preamplified (×100) bipolar superficial electrodes of Ag/AgCl (Meditrace 100; Chicopee, MA) were used with interelectrode (center-to-center) distance of 20 mm. After shaving and cleaning the skin with alcohol, the determination of the muscles and anatomical landmarks were done via palpation and the electrodes were placed over the belly of the quadriceps (electrodes placed at 50% on the line from the anterior spina iliaca superior to the superior part of the patella) and biceps (electrodes placed at 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia) femoris following the recommendation of SENIAM (Surface ElectroMyoGraphy for Non-Invasive Assessment of Muscles) project (Hermens, Frerik, Disselhorst-Klug, & Rau, 2000). Throughout the text, the terms knee flexors and knee extensors were used to refer to quadriceps and biceps femoris muscles, respectively. The load cell recordings were sampled at 2000 Hz and synchronized to the EMG recordings.

Data Analysis

Force and EMG signal analyses followed the procedures from Pereira et al. (2012), as described below.

Fluctuations in Motor Output

Force signals were bandpassed filtered between 0.05 and 10 Hz (Butterworth, order 4) and detrended before motor output variability measures were calculated. We quantified within-trial variability as the standard deviation of the detrended filtered force (*SD* of force) and as the coefficient of variation of force (CV of force: [*SD* of force/mean force] × 100).

Wavelet Analysis From Force Signal

The force and EMG frequency-domain analyses were done using Morlet wavelet transform. Wavelet and cross-wavelet spectra were generated using MATLAB functions developed by several research groups (Grinsted, Moore, & Jevrejeva, 2004; Neto et al., 2010; Torrence & Compo, 1998). For the force frequency structure analysis, we quantified the normalized wavelet scale-averaged power spectrum (NWPS), which is the squared-weighted modulus of the wavelet transform normalized by the sum of the squared-weighted modulus over all scales for each instant to time (for more details, see Pereira et al. [2012]).

The normalized wavelet scale-averaged power spectrum shows the relative importance through time of the frequency content of a signal with intensities ranging from 0% to 100%. Using the normalized wavelet spectra, we quantified the normalized power of four different frequency bands of the force signals (0–1, 1–3, 3–7, and 7–10 Hz). Normalized power of a certain frequency band was defined as the total power averaged in time within the band. These frequency bands were chosen considering their possible association to different force control mechanisms (Christou, 2005; Pereira et al., 2012; Vaillancourt & Newell, 2003).

Wavelet Analysis From EMG Signal

We used the wavelet transform of both signals and calculated the normalized cross-wavelet scale-averaged power spectrum (NXWPS), as porposed by Neto et al. (2010).

The normalized cross-wavelet scale-averaged power spectrum (hereafter referred to as the normalized cross-wavelet spectrum) considers the relative importance from 0% to 100% of the commonalities in the variance of the two signals in different frequencies through time. Thus, the normalized cross-spectrum can be used to compare the strength through time of common oscillations within the same pair of EMG signals and among different pairs of EMG signals. Using the normalized cross-wavelet spectrum, we quantified the mean normalized power of six different frequency bands of the EMG signals (5–13, 13–30, 30–60, 60–100, 100–150, and 150–200 Hz).

For statistical analysis, the three frequency bands below 100 Hz, 13–30 Hz (beta drive), 30–60 Hz (low-gamma drive), and 60–100 Hz (high-gamma drive), are important because, among other things, they have been previously associated with specific cortical drives (Brown, 2000) and associated with changes in voluntary effort (Marzullo et al., 2010; Neto et al., 2010) and fatigue (Pereira et al., 2010). It is expected that there would be an increase in beta and, especially, low-gamma band after a physical training period (Neto et al., 2010), since the magnitude of low-gamma drive of EMG power spectrum exhibits a close relationship with the cortical descending command to muscles influenced by somatosensory input (Gray, 1994; Wang, 2010; Neto, Lindheim, Marzullo, Baweja, & Christou, 2012; Pereira et al., 2012). The interference EMG signals were used for wavelet analysis, as proposed by experimental (Christou & Neto, 2010; Halliday & Farmer, 2010; Pereira et al., 2012, 2010) and EMG simulation (Farina, Merletti, & Enoka, 2004; Johnston, Formicone, Hamm, & Santello, 2010; Neto & Christou, 2010; Stegeman et al., 2010) studies.

Statistics

A one-way analysis of variance was used to compare the EMG signal, muscle force, and force variability and force spectrum among groups at the pretraining moment. As there were no significant differences among groups at the pretraining moment, a two-way analysis of variance (3 groups × 2 times of measurement) was used to infer the effect of applied training methods on the EMG signal, muscle force, and force variability and force spectrum. Analysis of varaince (ANOVA) procedures were followed by appropriate Bonferroni corrections, and significant results were followed by post hoc comparisons with Dunnett's test. A significance level of $p \leq .05$ was used to identify statistical significance, and the analyses were performed with the SPSS 21.0 statistical package (IBM, Armonk, NY, USA). Data are reported as means ± *SE* (standard errors).

RESULTS

One-way analysis of variance indicated no differences among groups for all variables (i.e., isometric force, force fluctuation, and force and EMG spectral features) at pretraining moment ($p > .05$).

Isometric muscle force from knee extensors (KE) and flexors (KF) showed significant main effect for groups ($F_{2,56} = 6.77$, $p = .002$ from KE; $F_{2,56} = 3.72$, $p = .03$ from KF), for measure ($F_{1,56} = 23.08$, $p < .0001$ from KE; $F_{1,56} = 21.23$, $p < .0001$ from KF), and a significant Group × Measure interaction ($F_{2,56} = 19.97$, $p < .0001$ from KE; $F_{2,56} = 6.65$, $p = .003$ from KF) (see Figure 2).

Force Fluctuations

Differently from isometric muscle force, force variability, studied through CV of force from knee extensors and flexors, did not exhibited significant main effect for groups ($F_{2,56} = 2.21$, $p = .119$ from KE; $F_{2,56} = 1.91$, $p = .158$ from KF), for measure ($F_{1,56} = 3.07$, $p = .085$ from KE; $F_{1,56} = 2.20$, $p = .161$ from KF), and a significant Group × Measure interaction ($F_{2,56} = 1.30$, $p = .281$ from KE; $F_{2,56} = 0.768$, $p = .469$ from KF) (see Figure 3).

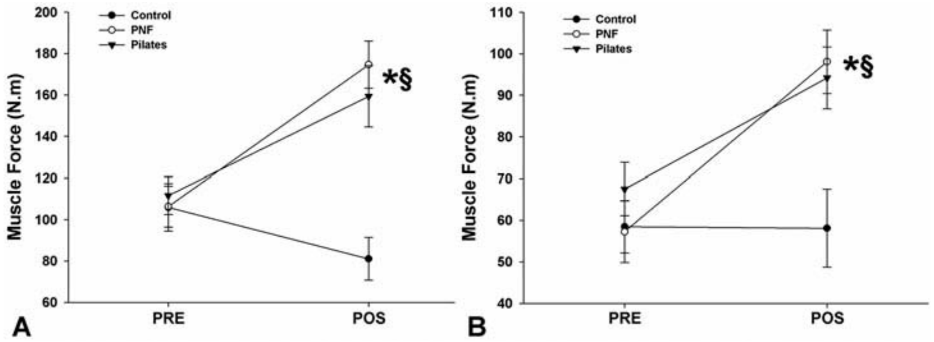

Figure 2. Isometric force from knee extensor (*A*) and knee flexor (*B*) muscle groups prior (PRE) and after (POS) the intervention period. *Significantly different from measure PRE ($p < .05$). §Significantly different from group control at measure POS ($p < .05$).

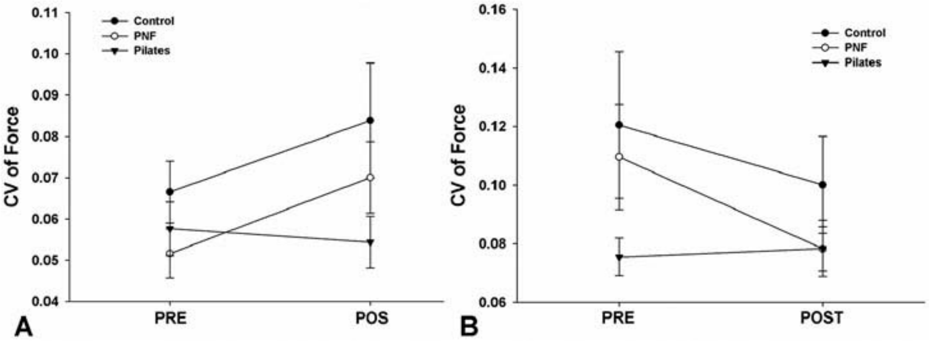

Figure 3. Coefficient of variation (CV) of force from knee extensor (*A*) and knee flexor (*B*) muscle groups prior (PRE) and after (POS) the intervention period.

Force Spectral Features

The analysis of the normalized power spectrum of force data showed a significant main effect only for knee extensors at the 7–10 band ($F_{2,56} = 3.44$, $p = .04$). It was also observed significant Group × Measure interaction for knee extensors at 0–1 ($F_{2,56} = 3.72$, $p = .03$) and 7–10 ($F_{2,56} = 3.57$, $p = .03$) bands (see Table 1). Differently from the spectral analysis of force from knee extensors, knee flexors did not exhibited significant main effect or interactions (see Table 1). The post hoc analysis showed that the group submitted to the PNF method exhibited a greater 0–1 Hz and a lesser 3–7 Hz band after the intervention period.

EMG Spectral Features

The analysis of normalized power spectrum of EMG signal demonstrated a significant main effect for group ($F_{1,56} = 3.49$, $p = .05$) and significant Group × Measure interaction ($F_{2,56} = 2.79$, $p = .05$) only for the knee extensor (i.e., quadriceps) at the low-gamma band (see Table 2). The post hoc analysis showed that the group submitted to the Pilates method exhibited a greater low-gamma band after the intervention period.

DISCUSSION

The goal of this study was to compare the influence of training programs with Pilates and PNF methods given to elderly women on the strength gains and motor control during voluntary contractions. The major finding of our study was that 1-month training programs with Pilates and PNF methods induce similar strength gains from knee flexors and extensors but different neuromuscular adaptations in elderly women.

Strength improvements have been observed after training periods with Pilates (Dorado et al., 2012; Kim, Jung, Shim, Kwon, & Kim, 2014) and PNF (Nelson et al., 1986; Kofotolis & Kellis, 2007; Reis et al., 2013; Tanvi, Shalini, Parul, & Gaurav, 2013) methods, but the effect over the motor control adaptations to Pilates and PNF methods have not been studied.

Our results from strength gains after the Pilates and PNF training periods corroborate previous studies (Dorado et al., 2012; Irez et al., 2011; Nelson et al., 1986; Kofotolis &

Table 1. Normalized power spectra of force from 0–1, 1–3, 3–7, and 7–10 Hz of knee extensors and flexors prior (pre) and after (post) the intervention period

	Knee extensors							
	Pre				Post			
Intervention	0–1 Hz (%)	1–3 Hz (%)	3–7 Hz (%)	7–10 Hz (%)	0–1 Hz (%)	1–3 Hz (%)	3–7 Hz (%)	7–10 Hz (%)
Control	88.2 ± 2.1	8.1 ± 1.7	2.6 ± 0.6	0.7 ± 0.2	86.7 ± 2.5	9.5 ± 2.0	2.7 ± 0.5	0.6 ± 0.1
PNF	82.8 ± 2.8	10.7 ± 1.8	4.3 ± 1.0	1.3 ± 0.2	90.2 ± 2.8*	6.5 ± 2.2	1.8 ± 0.5*	0.9 ± 0.2
Pilates	84.9 ± 1.9	10 ± 1.6	2.9 ± 0.6	1.3 ± 0.3	82.1 ± 2.3	12.4 ± 1.8	3.0 ± 0.5	1.5 ± 0.4
	Knee flexors							
Intervention	0–1 Hz (%)	1–3 Hz (%)	3–7 Hz (%)	7–10 Hz (%)	0–1 Hz (%)	1–3 Hz (%)	3–7 Hz (%)	7–10 Hz (%)
Control	85.3 ± 2.7	8.8 ± 1.6	3.8 ± 0.8	1.0 ± 0.3	89.6 ± 1.5	6.1 ± 1.0	2.6 ± 0.5	0.9 ± 0.3
PNF	87.9 ± 2.7	7.5 ± 1.8	3.1 ± 1.2	0.9 ± 0.3	92.3 ± 1.0	5.3 ± 0.7	1.2 ± 0.2	0.5 ± 0.2
Pilates	86.3 ± 2.7	7.3 ± 1.4	2.0 ± 0.3	0.8 ± 0.2	87.0 ± 1.6	8.9 ± 1.4	2.5 ± 0.5	0.9 ± 0.2

*Significantly different from pre measure ($p < .05$).

Table 2. Normalized power spectra of force from 13–30, 30–60, and 60–100 Hz of the knee extensor and knee flexor muscles prior (pre) and after (post) the intervention period

	Knee extensors					
	Pre			Post		
Intervention	13–30 Hz (%)	30–60 Hz (%)	60–100 Hz (%)	13–30 Hz (%)	30–60 Hz (%)	60–100 Hz (%)
Control	6.77 ± 0.50	67.49 ± 1.88	25.63 ± 1.77	6.83 ± 0.43	67.35 ± 1.30	25.68 ± 1.39
PNF	6.11 ± 0.50	67.3 ± 0.85	26.47 ± 0.80	6.02 ± 0.83	67.4 ± 0.96	26.48 ± 0.99
Pilates	5.65 ± 0.56	68.44 ± 1.30	25.80 ± 1.52	5.52 ± 0.36	71.54 ± 1.53*	22.86 ± 1.39
	Knee flexors					
Intervention	13–30 Hz (%)	30–60 Hz (%)	60–100 Hz (%)	13–30 Hz (%)	30–60 Hz (%)	60–100 Hz (%)
Control	6.56 ± 0.67	65.16 ± 1.91	28.02 ± 1.92	5.75 ± 0.39	64.77 ± 1.49	29.14 ± 1.55
PNF	5.96 ± 0.41	61.28 ± 1.42	32.42 ± 1.62	5.25 ± 0.52	62.63 ± 1.03	31.84 ± 1.26
Pilates	5.63 ± 0.84	61.35 ± 2.03	32.65 ± 2.32	5.74 ± 0.53	65.14 ± 1.45	28.87 ± 1.59

*Significantly different from post measure ($p < .05$).

Kellis, 2007; Pereira & Gonçalves, 2012), where these training methods induced significant strength gains when compared with control conditions. Comparisons between these training methods have not been reported, and we showed that both methods can increase strength when compared with a control condition: no difference was observed between the studied methods. Given that the strength gains were similar between methods, it is not possible to indicate which training method was more efficient when training effects were measured at baseline and then at 1 month.

Motor output, measured through CV of force, also showed similar adaptations between training methods, but, despite the equal performance, the power spectrum of force from the knee extensors revealed a significant increase in 0–1 Hz and decrease in 3–7 Hz of force variability for the PNF method after the training period. The power spectrum of force is related to sensorial feedback and sensorimotor integration (Christou, 2005; Moritz, Christou, Meyer, & Enoka, 2005; Pereira et al., 2012), and the increase in the 0–1 Hz band may suggest an training-induced adaptation on sensorimotor integration. The principles of PNF technique may support this hypothesis, since it is focused on proprioceptive stimulus to improve the muscle stretch and/or strength (Adler et al., 2008; Davis, Ashby, McCale, McQuais, & Wine, 2005; Kotofolis et al., 2007; Burke and Culligan, 2000; Ferber, Osternig, & Gravelle, 2002).

Positive long-term and immediate effects have been observed with the Pilates method as well. Dorado et al. (2012) observed a significant increase (21%) of total volume from the rectus abdominis after 36 weeks of Pilates training in sedentary women, whereas Barbosa, Martins, Vitorino, and Barbosa (2013) observed an increased muscle activation of biceps brachii during exercise carried out with principles of Pilates method. Our results are in line with previous findings, since we showed strength improvements and neuromuscular adaptations with a short training period (i.e., 4 weeks) with Pilates method.Petrofsky et al. (2005) showed that the use of resistive devices, such as resistive bands used in our study, increases the workload substantially, increasing the muscle demands, and then the central command to the muscle. Both beta (i.e., 13–30 Hz band) and low-gamma (i.e., 30–60 Hz band) drives from EMG power spectrum have been reported as related to the descendent command (Brown, 2000; Neto et al., 2010; Neto & Christou, 2010; Pereira et al., 2010), and there is evidence of a relationship between cortical descending command to muscles influenced by somatosensory input and the magnitude of low-gamma drive of EMG power spectrum (Gray, 1994; Wang, 2010; Neto et al., 2012; Pereira et al., 2012). Then, it is possible to hypothesize that the training with Pilates methods, as we applied (i.e., with resistive devices), induces significant increases in low-gamma drive owing to the higher muscle demands involved in this practice and improvement in mind-body awareness, as proposed by Bernardo (2007), to increase the cortical descending command to muscles.

The training period seems to have been sufficient to induce different neuromuscular adaptations, but similar improvements in performance. Further studies may investigate the neuromuscular adaptations, as we have done, after a long training period with Pilates and PNF methods to elderly people.

In conclusion, 1-month training programs with Pilates and PNF methods showed significant strength gains from the knee flexors and the extensors in elderly women, with no statistical differences between methods. Despite similar strength gains, the studied methods induced different neuromuscular adaptations, which may be related to the features of each training methods.

Additionally, these results give support for the use of Pilates and PNF training methods in older age groups. In particular, the increment of lower limb muscle strength is important for gait, postural stability, and performance of daily life activities of this population. Notwithstanding, owing to their low cost, easy implementation, and good adherence by the elderly, these methods could be used with a preventive or curative perspective.

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