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Review

# Exercise training in older adults, what effects on muscle force control? A systematic review of randomized clinical trials

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ABSTRACT

*Aim:* To determine the magnitude of the effects of different exercise training (ET) modalities on variables of muscle force control in older adults.
*Methods:* Relevant articles were searched in PubMed, Web of Science, Science Direct and Scopus, using the keywords: Aged AND “Exercise Movement Techniques” AND (“Complexity of torque” OR “Complexity of force” OR “Variability of torque” OR “Variability of force” OR “Force Steadiness” OR “Force fluctuations”). To be included in the full analysis, the studies had to be randomized controlled trials in which older adults were submitted to ET programs and muscle force control assessment.
*Results:* The searches resulted in 702 articles from which 6 met all the inclusion criteria. The trials involved 171 healthy and functionally limited older adults (71.64 ± 1.53 years). Studies included resistance, steadiness and functional training programs. Training sessions were 2–3 time per week, lasted 6–16 months with intensities determined as percentage of the one repetition maximum loads. There is a heterogeneity regarding experimental set-up and data analysis parameters between studies. The findings show an improved muscle force control in older adults after ET. Such response is better evidenced by the assessment of the coefficient of variation (CV) of the force signals. There is moderate evidence that resistance training programs are effective to decrease CV of knee extensor force signals at lower force targets.
*Conclusions:* The findings from this review suggest that ET programs are effective to improve muscle force control in older adults.

## 1. Introduction

The process of aging is accompanied by structural changes in the neuromuscular system including reduced number of motor units (Dalton, McNeil, Doherty, & Rice, 2008), altered fiber type distribution (Lexell, 1995) and reduced muscle cross-sectional area (Kent-Braun & Ng, 1999). Often, such changes are investigated through parameters of maximal performance such as the maximal force (Caserotti, Aagaard, Buttrup Larsen, & Puggaard, 2008; Thompson et al., 2014). However, muscle maximal force measurement yields a narrow comprehension of the age-related changes within the neuromuscular system. For instance, it fails to provide information about the neurophysiologically mediated mechanisms underlying the decline in motor task accuracy and functional capacities with advancing age. Indeed, although increasing maximal force is an important issue in older adults, the literature shows that the gains of maximal force in response to exercise training (ET) programs are often not related to improvement in functional capacities (Chandler, Duncan, Kochersberger, & Studenski, 1998; Izquierdo, Aguado, Gonzalez, López, & Häkkinen, 1999; Ringsberg, Gerdhem, Johansson, & Obrant, 1999). Rather, it has been demonstrated that the age-related declines in functional capacities are more closely a matter of an impaired ability to control muscle force than a reduced capacity to generate maximal force (Shepard, Schultz, Alexander, Gu, & Boismier, 1993).

The force exerted by a muscle during a voluntary contraction is regulated by several neuromuscular mechanisms (e.g. mechanical summation of motor unit forces, pattern of output from the motoneuron pool) (Enoka et al., 2003). Consequently, the muscle force is not constant, but rather it fluctuates about an average value (Dietz, Bischofberger, Wita, & Freund, 1976; Galganski, Fuglevand, & Enoka, 1993; Löscher & Gallasch, 1993; Slifkin & Newell, 1999). The analysis of such fluctuations during standardized tasks (i.e. submaximal isometric, shortening and lengthening contractions) become a widely used method to assess the ability to control muscle force (Laidlaw, Bilodeau,

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& Enoka, 2000; Lodha, Naik, Coombes, & Cauraugh, 2010; Vaillancourt, Slifkin, & Newell, 2002). Routinely, studies investigate the muscle force control by assessing the variability of the force output through statistical metrics in absolute (within-subject standard deviation; SD) and relative (coefficient of variation; CV) terms (Contessa, Adam, & De Luca, 2009). Higher values mean higher variability of force that is a poor muscle force control. However, because of the interactions between the components of the neuromuscular system, the force output fluctuates according to an irregular, non-linear and chaotic (complex) behavior (Vaillancourt & Newell, 2003) whose temporal structure can't be analyzed through classic statistical metrics. Thereby, besides simple measures of the variability of force, it has been proposed to analyze the series of force output using methods derived from non-linear dynamics, based on chaos theory such as approximate entropy (ApEn) (Pincus, 1991) and sample entropy (SampEn) (Richman & Moorman, 2000). Higher values mean greater complexity that is a better muscle force control. While the measures of the variability of force only quantify the ability to control muscle force through the magnitude of fluctuations in force output, the measures of the complexity of force provide an insight into the dimensions of feedback control loops governing force output and the underlying state of the neuromotor system (Mayer-Kress, Deutsch, & Newell, 2003), which cannot be inferred from statistical metrics.

It is established that aging is characterized by a declined muscle force control evidenced by a heightened variability and decreased complexity of force (Arjunan, Kumar, & Bastos, 2012; Arjunan & Kumar, 2013). Such age-related loss of muscle force control has been shown to contribute to the wide related reduced ability of the older adults to execute precise motor tasks common to daily living, including handwriting, object manipulation and cooking (Flanagan & Wing, 1993; Johansson, 2002) as well as self-lifting and postural balance. Exercise programs have been investigated in order to be used as therapeutic strategy in the management of age-related decline of motor task accuracy and muscle force control (Barry & Carson, 2004). However, the effectiveness of ET programs on muscle force control remains uncertain since the available evidence relate contrasting findings depending on studies characteristics (i.e. subjects clinical status, assessed muscles, experimental set-up, data analysis parameters and ET modalities). This seems to be an important issue since providing evidence about the effectiveness of ET programs to improve muscle force control could be helpfull for prescribing the most suitable exercise modality in the management of age-related declines of motor task accuracy and muscle force control.

This study aimed to determine the magnitude of the effects of different ET modalities on variables of muscle force control in older adults, through a systematic review of literature. In addition, this study aimed to evaluate, through the GRADE approach, the quality of the evidence of the published clinical trials investigating the effectiveness of ET programs on the muscle force control of older adults.

## 2. Methods

This systematic review is registered in PROSPERO, an international database of prospectively registered systematic reviews in health and social care.

### 2.1. Search strategy and identification of trials

Searches were conducted in 4 electronic databases; PubMed, Web of Science, Science Direct and Scopus, the following keywords and Medical Subject Headings were used in the search: *Aged AND "Exercise Movement Techniques" AND ("Complexity of torque" OR "Complexity of force" OR "Variability of torque" OR "Variability of force" OR "Force Steadiness" OR "Force fluctuations")*. There were no restrictions concerning the publication date but the results were limited to English and Portuguese language.

One author performed the searches and the results were forwarded from each electronic database to the StArt tool (version 2.3.4.2), a Systematic Review tool support that allows the centralization of the databank results, automatic identification of redundant trials and easiest management of trials selection and extraction process (Hernandes, Zamboni, Fabbri, & Thommazo, 2012). Then, two authors independently assessed the title and the abstract of each article through the StArt tool, excluding irrelevant trials in accordance with the inclusion criteria. Afterwards, a full-text review and a methodologic appraisal were performed. After each selection step; title, abstract and full-text evaluation successively, both authors checked the agreement of their databank of accepted trials. A discussion involving the third reviewer was conducted in the event of disagreement.

Further, after the selection process, reference lists from the selected articles were checked to retrieve articles that met the inclusion criteria but were not found during the initial searches in the electronic databases (Fabbri et al., 2016). This latter process was repeated until no article fulfilling the inclusion criteria was found. In order to find relevant recent studies, additional searches on the 4 initial electronic databases were repeated with the same keywords and Medical Subject Headings. This process was done until the end of the preparation of the manuscript.

### 2.2. Eligibility criteria for study selection

The studies included in this systematic review met the following criteria.

#### 2.2.1. Study design

Only randomized clinical trials were included.

#### 2.2.2. Participants

It has been adopted the definition of older adults as person over 65 years old (Quadagno, 2002). Then, only samples with a mean age of at least 65 years were included. The mean age, sample size and clinical status were recorded.

#### 2.2.3. Type of intervention

Subjects participated in a ET program with single or multiple components. The intensity, duration, frequency, type and length of exercise in each article were recorded.

#### 2.2.4. Outcome measures

Studies reporting outcomes related to muscle force control (i.e. force variability and/or complexity) assessed by analyzing force signals recorded during submaximal isometric contractions. The experimental set-up and parameters of the investigated variables were recorded.

### 2.3. Methodologic quality assessment

Each paper was critically appraised by 2 reviewers for methodologic quality by using the Physiotherapy Evidence Database (PEDro) scale (0–10) (de Morton, 2009; Maher, Sherrington, Herbert, Moseley, & Elkins, 2003). Higher PEDro scores indicated better quality. The literature suggests that high-quality studies should achieve a total score higher than 50% of the possible maximum (Coury, Moreira, & Dias, 2009; Verhagen et al., 1998). Thus, for this review, trials with a PEDro score higher than or equal to 5.0 were classified as high methodological quality studies.

### 2.4. Data extraction

Two authors independently extracted following relevant data from included studies: participants' data (sample size, mean age, studied groups and clinical status), ET program parameters (intensity, duration, frequency, type and length of exercise), experimental set-up and parameters of the investigated variables. The differences were discussed with the third author. The result sections of each article were studied and all relevant results related to the training intervention effects on the main outcomes were extracted and interpreted.

### 2.5. Data synthesis and analysis

The heterogeneity of the included clinical trials (regarding the parameters of ET programs, experimental setup and data analysis) hindered to perform a meta-analysis. The magnitude of the effect of each ET program on the investigated variables was assessed throught the effect size (ES). Standardised mean difference (Hedges & Olkin, 2014) was calculated for each comparison group separately, considering the values before and after intervention. These were further classified as small (< 0.20), moderate (around 0.50) or large (> 0.80), according to Cohen's criteria (Cohen, 1988).

The quality of evidence for the outcomes standard deviation (SD) and coefficient of variation (CV) was determined through the GRADE approach. The GRADE approach classifies the level of evidence as high, moderate, low, or very low analysing the following domains that can affect the quality of the evidence of the outcomes of a clinical trial: trial design limitations due to risk of bias, inconsistency of results, indirectness, imprecision of results and publication bias. A review of each factor followed the subsequent classification: not serious (score is not rated down), serious (score is rated down by one level) and very serious (score is rated down by two levels), according to the interference biases detected in these items. The details of this method have been reported previously (Atkins et al., 2004; Furlan, Pennick, Bombardier, van Tulder, & Editorial Board, 2009; Richards et al., 2013).

## 3. Results

### 3.1. Trial selection

The searches in electronic databases resulted in 702 clinical trials, of which 64 were duplicated and 227 excluded by title checking, remaining 411 articles. From these, 406 were rejected after the abstracts evaluation, remaining 5 selected articles. After checking the references of these, 201 articles were found. 200 of these latter were excluded after evaluation, resulting in 1 new selected article. After checking the references of this article, 25 articles were found. From these, 22 were rejected and 3 duplicated, remaining no article. Summarily, the initial searches and the references checking resulted in 6 articles. Details of the selection process are presented in Fig. 1.

### 3.2. Characteristics of included studies (Table 1)

#### 3.2.1. Participants

The studies involved 171 older adults with mean age of 71.64 ± 1.53 years old. Most of the subjects were female (62.38%), and two studies did not report participants gender (Hortobögyi, Tunnel, Moody, Beam, & DeVita, 2001; Tracy & Enoka, 2006). One study involved functionally limited older adults (Manini, Clark, Tracy, Burke, & Ploutz-Snyder, 2005) while in others studies, participants were healthy older adults. In all trials, participants were divided in training and control groups. The findings of Hortobágyi et al. included older adults and young subjects (Hortobágyi et al., 2001), although, only older adults' results have been analyzed in this review.

#### 3.2.2. Interventions

The most of the trials included resistance training (Hortobágyi et al., 2001; Kobayashi, Koyama, Enoka, & Suzuki, 2014; Laidlaw, Kornatz, Keen, Suzuki, & Enoka, 1999; Manini et al., 2005; Tracy & Enoka, 2006; Tracy, Byrnes, & Enoka, 2004). The other ET programs were steadiness (Tracy et al., 2004) and functional (Manini et al., 2005) training programs. Resistance training programs targeted on the knee extensor, elbow, wrist and hand muscles. Depending on the trials, training sessions were 2–3 time per week, for 6–16 weeks with training intensities determined as percentage of the one repetition maximum (1-RM) loads. Across studies, participants performed 2–7 sets of 8–12 repetitions through direct loads or specifics training devices: beginning movement load machine (Kobayashi et al., 2014) and weight-stack machine (Tracy & Enoka, 2006).

#### 3.2.3. Experimental set-up

The force control was assessed for the knee extensor muscle (Hortobágyi et al., 2001; Kobayashi et al., 2014; Manini et al., 2005; Tracy & Enoka, 2006; Tracy et al., 2004), elbow flexors muscle (Kobayashi et al., 2014) and dorsal interosseus (Laidlaw et al., 1999). After determining the individual isometric maximum voluntary contraction (MVC), participants were required to sustain contractions at different target forces calculated as percentage of the MVC, except Hortobagyi et al, who defined a fixed target force (25 N) for all subjects (Hortobágyi et al., 2001). In the trials which investigated the force control of the knee extensor muscle, participants were positioned on an isokinetic dynamometer with the knee angle varying between 65° and 95° of knee flexion (full extension = 180°) depending on studies. Participants were required to sustain submaximal contractions at target forces between 2% and 65% of their MVC during 5–15 seconds. The contractions were performed in random order and each contraction was followed by a 60-second rest period. In the trial which investigated the force control of hand muscles, the target forces were between 2.5%, 5%, 10% and 20% of MVC and participants were required to exert isometric contractions during 30 s on load cells connected to strain-gauge amplifiers. Participants rested for 60–90 s between consecutive contractions (Laidlaw et al., 1999). Only one study investigated the force control of elbow flexors muscle (Kobayashi et al., 2014). In this study, the elbow joint of the right arm was flexed to 90° (full extension angle: 180°). The participants were required to sustain submaximal contractions at 10%, 30% and 65% of their MVC during 10–12 seconds in random order with at least 60 s of rest between trials (Kobayashi et al., 2014).

#### 3.2.4. Data analysis

The force control of the knee extensor muscle was assessed by analyzing the steadiest 1–8 seconds windows from the central region of the force signals. The sampling frequency varied between 200–1000 Hz depending of studies. Therefore, the total data points assessed were 1600 (Kobayashi et al., 2014; Tracy & Enoka, 2006; Tracy et al., 2004) and 8000 (Manini et al., 2005). Hortobagyi et al, assessed separately 1000 and 5000 data points (Hortobágyi et al., 2001). The studies investigated the knee extensor variability through both SD and CV of the force signals, except Hortobagyi et al who preferred only the latter variable (Hortobágyi et al., 2001). Besides the CV of the force signals, Kobayashi et al also assessed the knee extensor variability by analyzing in the frequency domain of the force signals with fast Fourier transform (FFT) analysis (Kobayashi et al., 2014). The force control of the dorsal interosseus muscles was investigated by analyzing the 20 s steadiest windows from the central region of the force signals, however, the sampling frequency has not been reported, therefore, the total data points analyzed was unknown (Laidlaw et al., 1999). Authors investigated the force variability through both SD and CV of the force signals. Kobayashi et al. assessed the force variability of elbow flexors muscle by computing the CV and analyzing the frequency domain of the force signals with FFT analysis. The authors analyzed the steadiest 8 s windows from the central region of the force signals. The sampling frequency was 200 Hz, thus, the total data points assessed were 1600 (Kobayashi et al., 2014).

### 3.3. Quality assessment

PEDro average score was 6.5, ranged from 6 to 7.The most critical

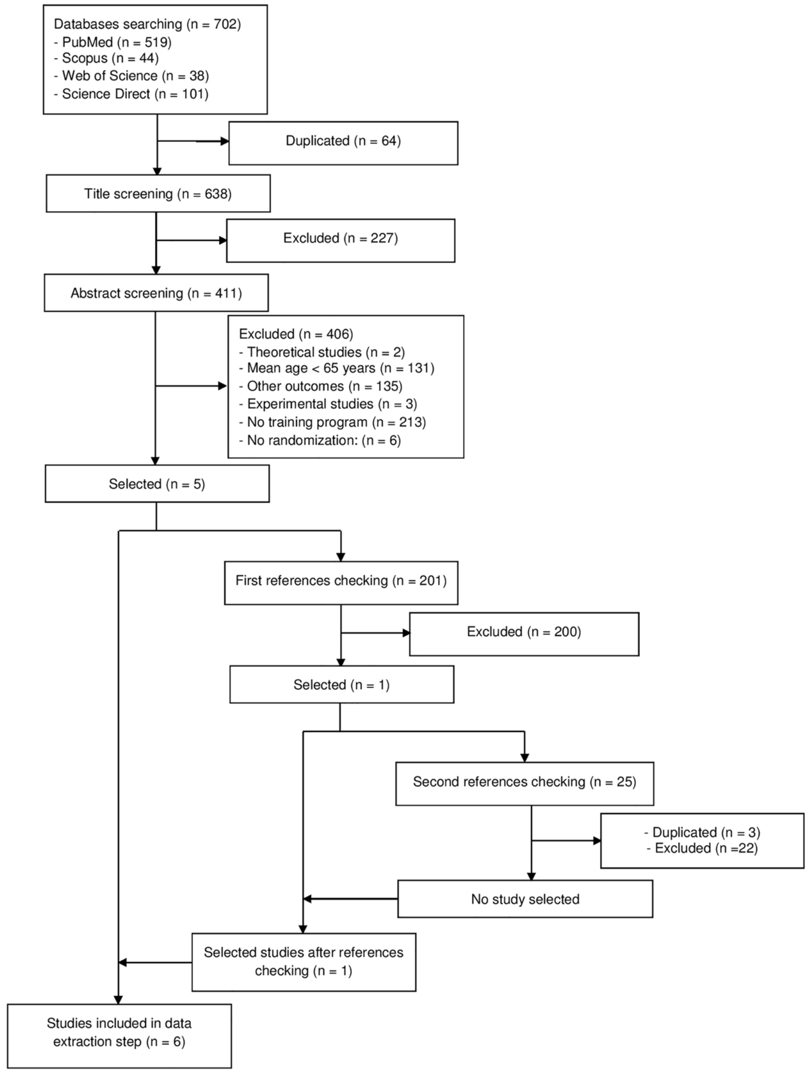


**Fig. 1.** Flowchart for the search strategy and reasons for exclusion.

criteria to be satisfied were secret allocation and participants, therapist and assessor blinding (Table 2).

### 3.4. Effects of exercise

The magnitude of the effect of each ET program on the muscle MVC and force control is presented on the Table 3. Briefly, although some trials failed to show a significant increase of the MVC after training, the findings showed that the ET programs have large effects on the MVC of older adults regardless the participants clinical status, assessed muscles, experimental set-up and the exercise modalities. Across studies, depending on the force targets and ET programs, the SD of the force signals increased (Tracy et al., 2004) or decreased (Laidlaw et al., 1999; Tracy et al., 2004) significantly. Mostly, the studies reported that the exercise-related changes in the SD were non-significant (Hortobágyi et al., 2001; Laidlaw et al., 1999; Manini et al., 2005; Tracy & Enoka, 2006). The calculated effect sizes depended on the force targets and exercise modalities. Resistance training programs showed both negatively (Laidlaw et al., 1999; Manini et al., 2005) and positively (Hortobágyi et al., 2001; Tracy et al., 2004) small to large effects on the changes of the SD of the force signals. Functional (Manini et al., 2005) and steadiness (Tracy et al., 2004) training mainly showed positively small to large effects on the changes of the SD of the force signals. Studies reported significant decreases of the CV of the force signals after training (Kobayashi et al., 2014; Laidlaw et al., 1999; Tracy et al., 2004), although in one trial such exercise-related changes of CV were non-significant (Manini et al., 2005). Nevertheless, the calculated effect sizes showed that regardless participants clinical status, assessed muscles, experimental set-up and the exercise modalities, ET programs have mainly negatively small to large effects in the decreases of the CV of the force signals.

Previously to assess the quality of evidence for the outcomes, the trials included in the systematic review were divided according to the assessed muscles (knee extensor and dorsal interosseus muscles). Subsequently, since the outcomes (SD and CV) are related to force targets, the GRADE approach don't included one study in which a fixed force target (25 N) was established for all participants instead of being determinated by calculating a percentage of the individual MVC (Hortobágyi et al., 2001). Furthermore, one study without untrained control group was not included in the GRADE approach (Manini et al., 2005). Therefore, the 4 remaining trials were included in the assessment of the quality of evidence for the outcomes (Kobayashi et al., 2014; Laidlaw et al., 1999; Tracy & Enoka, 2006; Tracy et al., 2004). In the remaining studies, distinctions were made according to the force targets and comparison groups.

The quality of evidence for each outcome according to the GRADE approach is presented in Tables 4ab–5a b . Reasons for downgrading the quality of the body of evidence are cited in the notes below each table.

**Table 1**
Characteristics of the included studies.

| Studies | Participants (clinical status, group, Sample size, gender, age) | Intervention (training modality, intensity, frequency and duration) | Assessed muscles | Experimental set-up |
|---|---|---|---|---|
| Hortobágyi et al. (2001) | Healthy old adults (n = 30; M&F*; 72 ± 4.7 years) and young (n = 10; M&F*; 21.1 ± 1.2). | 30 sessions of strength training using bilateral supine leg press as the exercise. HI Group: 5 bouts of 4–6 repetitions with 80% of the 1-RM. LI Group: 5 bouts of 8–12 repetitions at 40% of their maximal weight. | Knee extensor muscles | Subjects were instructed to sustain contractions at 25 N during 5 s. |
| Kobayashi et al. (2014) | Healthy older adults; Training group (n = 17; M:7; F:10; 67.5 ± 5.2 years) and Control group (n = 7; M:3; F:4; 67.5 ± 5.8 years) | 8 weeks of BML training performed on BML training machines; 3 d/week; at 30% of the 1-RM in 5–7 sets of 15 repetitions. | Knee extensor muscles and elbow flexors muscle | Steady contractions at three target forces: 10%, 30%, and 65% MVCs performed in random order and sustained for 10–12 s with at least 60 s of rest between trials. |
| Manini et al. (2005) | Functionally limited older adults; RT (n = 9; M:1; F:8; 72 ± 10 years); FT (n = 8 F; 79.2 ± 7.5 years) and FRT (n = 7; M:1; F:6; 73 ± 5.5 years) | 10 weeks of RT (three lower body exercises: leg press, leg extension and leg curl), FT (rising from a chair, rising from a kneeling position and stair ascending/descending) or FRT; performed 2 days/week; each session lasted 30–45 min. RT: 2 training sets of 10RM. Once a subject was able to lift more than 10 repetitions the load was increased. If the subject was unable to lift the weight for 8 repetitions, the load was decreased. FT: 2 work sets with 10 repetitions. FRT: 1day of resistance and 1day of functional training per week. | Knee extensor muscles | Subjects were asked to exert a knee extension force to a target level during 15 s, with their dominant limb at three different intensities (10, 25 and 50% MVC) in a random order. |
| Tracy & Enoka (2006) | Healthy old adults, Training group (n = 21) and Control group (n = 9); 72 ± 4.6 years | 16 weeks of knee-extension exercise training using weight-stack machine (Icarian, Sun Valley, CA), 3 d/week at 30% of 1-RM (adjusted weekly) 3 sets of 10 repetitions of the knee-extension exercise. | Knee extensor muscles | The participants performed a knee extension as steady as possible for 10–12 seconds, at target forces of 2, 5, 10, and 50% of MVC force with the left leg. |
| Tracy et al. (2004) | Healthy old adults; Heavy-load strength training (n = 11; M:5; F:6; 73.1 ± 4.9 years), Heavy-load steadiness training (n = 6; M:4; F:2; 69.7 ± 3.7 years) and Control Group (n = 9; M:4; F:5; 74.2 ± 4.9 years). | 16 weeks of heavy-load strength training or heavy-load steadiness training, performed 3 d/week at 3 sets of 10 repetitions of a knee-extension task. Heavy-Load and Heavy-Load Steady training: 80% of 1-RM load. Updated weekly. | Knee extensor muscles | After the MVC assessment, isometric knee extension contractions were performed with the left leg at target forces of 2, 5, 10, and 50% MVC. Subjects were instructed to match the target as steadily as possible for 10–12 s. |
| Laidlaw et al. (1999) | Old adults with no known neuromuscular disorders heavy-load training group (n = 8; M:4; F:4; 68.3 ± 2.2 years); light-load training group (n = 8; M:4; F:4; 70.4 ± 2.0 years) and control group (n = 11; M:5; F:11; 72.4 ± 1.7 years) | 4 weeks of strength training program with the first dorsal interosseus muscle, 3 d/week. 6 sets of 10 repetitions. The heavy-load group: 80% of the 1-RM load, and the light-load group: 10% of the 1-RM load. The 1-RM load was measured weekly, and the training loads were set accordingly. | The first dorsal interosseus | After the MVC in the abduction direction. Target forces were set at 2.5, 5, 10, and 20% of MVC force. The subjects gradually increased the abduction force during an isometric contraction to the target force displayed on the oscilloscope and held the force steady at the target force for 30 s. The order of the trials was varied. |

M: Male; F: Female; LI: Low Intensity; HI: High Intensity; BML: Beginning Movement Load; MVC: Maximum Voluntary Contraction; RM: Repetition-Maximum; RT: Resistance Training; FT: Functional Training; FRT: Functional + Resistance Training.

**Table 2**
PEDro Scale of the Included Studies.

| Study | Specified Eligibility Criteria | Random Allocation | Secret Allocation | Similar groups at baseline | Participants Blinding | Therapist Blinding | Assessor Blinding | < 15% Dropouts | Intention-to-Treat Analysis | Between-Group Difference Reported | Point Estimate and Variability Reported | PEDro Score (0–10) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hortobágyi et al. (2001) | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 7 |
| Kobayashi et al. (2014) | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 6 |
| Manini et al. (2005) | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 6 |
| Tracy and Enoka (2006) | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 7 |
| Tracy et al. (2004) | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 7 |
| Laidlaw et al. (1999) | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 6 |
| Studies which satisfied the criteria (%) | 83.33 | 100 | 0 | 100 | 0 | 0 | 0 | 66.67 | 100 | 100 | 100 | |

Briefly, the evidence synthesis showed that there is low evidence that resistance training programs decrease SD of force signals of the knee extensor muscle. The quality of the body of evidence of resistance training contribution programs on the decrease of CV of force signals of the knee extensor muscle was low and moderate respectively for higher (30%, 50% and 65%) and lower (2%, 5% and 10% MVC) force targets. There is very low evidence that resistance training programs decrease SD and CV of force signals of the dorsal interosseus muscles in older adults.

## 4. Discussion

### *4.1. Participants*

The trials mostly assessed the effects of ET in healthy older adults' muscle force control. It has been shown that the senescence process involves changes in the neuromuscular system including the impairment of feedback mechanisms (e.g. joint-position sense, touch, kinesthesis, and proprioception) which are important in the control of muscle force (Cole, 1991; Desrosiers, Hébert, Bravo, & Dutil, 1996; Skinner, Barrack, & Cook, 1984). Consequently, aging is accompanied by a reduced ability to control or grade muscle force (Vaillancourt & Newell, 2003) with consequent impaired functional components. Nevertheless, studies also reported an impaired muscle force control in diseases such as diabetes mellitus (Suda et al., 2017), chronic stroke (Lodha et al., 2010) and Parkinson's Disease (Vaillancourt et al., 2002). Guidelines concerning these pathologies recommend specific non-pharmacological interventions (ET or rehabilitation) as part of their treatment (Ammann, Knols, Baschung, de Bie, & de Bruin, 2014; Dugan, 2016; Mak, Wong-Yu, Shen, & Chung, 2017). Accordingly, studying the contribution of these interventions in improving muscle force control of older adults with such diseases would be particularly relevant. On the other hand, determining the relationship between muscle force control and some geriatric syndromes (e.g. frailty, sarcopenia, sarcopenic obesity…) as well as investigating the contribution of ET programs in improving muscle force control in older adults with such clinical conditions could be of great relevance.

### *4.2. Interventions*

ET programs have been widely studied and recommended in addition to pharmacological and nonpharmacological therapeutic strategies in the management of the deleterious effects of the aging process (Chodzko-Zajko et al., 2009). Although regular ET triggers responses involving various physiological systems threatened by aging, evidence established that each ET modality has beneficial effects among specific physiological functions in older adults. For instance, it has been shown that resistance and aerobic exercise programs improve different aspects of older adults' muscle oxygenation depending of their clinical status (Fiogbé, de Vassimon-Barroso, & de Medeiros Takahashi, 2017). Furthermore, it has been demonstrated that aerobic (Fleg, 2012), resistance (Yamamoto et al., 2016) and fall prevention (El-Khoury, Cassou, Charles, & Dargent-Molina, 2013) training programs improve respectively aerobic capacity, muscle strength, balance, fall risk and balance in older adult. The current review is the first study aiming to provide an overview regarding trials investigating the effects of different ET modalities on the muscle force control of older adults. In the most of the included studies, participants underwent resistance training but also steadiness, and functional training programs (see Table 1 for more details about each ET modalities parameters). It should be emphasized that the greatest challenge of ET as therapeutic strategy in the management of aging is the low adherence and high dropout rates (Horne & Tierney, 2012; Picorelli, Pereira, Pereira, Felício, & Sherrington, 2014), mainly due to age-associated diseases and clinical conditions (e.g., osteoarticular, rheumatological and cardiorespiratory diseases). This hinder to carry out exercise therapies through preset

**Table 3**
Magnitude of the effect of training programs on mucle force control.

| Studies | Groups | MVC (Cohen's d) | Force targets (%) | SD (Cohen's d) | CV (Cohen's d) |
|---|---|---|---|---|---|
| Hortobágyi et al. (2001) ‡ | Low Intensity Training Group | ↑ 1.74 | 25 N (1s) | ↑ 1.63 | NA |
| | | | 25 N (5s) | ↑ 0.82 | NA |
| | High intensity Training Group | ↑ 2.78 | 25 N (1s) | 0 | NA |
| | | | 25 N (5s) | 0 | NA |
| | Combined Training Group | ↑ 2.26* | 25 N (1s) | 0 | NA |
| | | | 25 N (5s) | 0 | NA |
| | Control Group | ↑ 0.34 | 25 N (1s) | 0 | NA |
| | | | 25 N (5s) | 0 | NA |
| Kobayashi et al. (2014) | BML Training Group (Knee Results) | ↑* | 10 | NA | ↓* 2.2 |
| | | | 30 | NA | ↓* 2.16 |
| | | | 65 | NA | ↓* 2.97 |
| | Control Group (Knee Results) | ↑ | 10 | NA | ↑ 0.06 |
| | | | 30 | NA | ↓ 1.23 |
| | | | 65 | NA | ↑ 0.09 |
| | BML Training Group (Elbow Results) | ↑ | 10 | NA | ↓* 1.99 |
| | | | 30 | NA | ↓* 1.72 |
| | | | 65 | NA | ↓* 1.95 |
| | Control Group (Elbow Results) | ↑ | 10 | NA | ↑ 1.22 |
| | | | 30 | NA | ↑ 0.03 |
| | | | 65 | NA | ↑ 0.1 |
| Manini et al. (2005) | Resistance Training Group | ↑* 0.56 | 10 | ↓ 0.25 | ↓ 0.20 |
| | | | 25 | ↓ 0.00 | ↓ 0.57 |
| | | | 50 | ↓ 0.11 | ↓ 0.50 |
| | Functional Training Group | ↑* 0.83 | 10 | ↑ 0.47 | ↑ 0.28 |
| | | | 25 | ↓ 0.17 | ↓ 0.44 |
| | | | 50 | ↑ 0.21 | ↓ 0.48 |
| | Functional + Resistance Training Group | ↑* 0.46 | 10 | ↓ 0.33 | ↓ 0.30 |
| | | | 25 | ↓ 0.59 | ↓ 0.46 |
| | | | 50 | ↓ 0.22 | ↓ 0.36 |
| Tracy and Enoka (2006) | Training Group | ↑* 0.71 | 2 | = | = |
| | | | 5 | = | = |
| | | | 10 | = | = |
| | | | 50 | = | = |
| | Control Group | ↑ 0.17 | 2 | = | = |
| | | | 5 | = | = |
| Tracy et al. (2004) | Steadiness Training Group | ↑* 1.25 | 2 | ↑ 1.1 | ↑ 0.18 |
| | | | 5 | ↓* 12.88 | ↓ 1.49 |
| | | | 10 | ↑* 0.92 | ↓ 0.37 |
| | | | 50 | ↑ 0.22 | ↓* 1.16 |
| | Strength Training Group | ↑* 1.25 | 2 | ↓ 0.30 | ↓ 0.73 |
| | | | 5 | ↑* 0.82 | ↓ 0.38 |
| | | | 10 | ↑ 0.66 | ↓0.24 |
| | | | 50 | ↑ 1.17 | ↓ 0.26 |
| | Control Group | ↑ 0.17 | 2 | ↓ 0.48 | ↓ 0.37 |
| | | | 5 | ↓ 0.32 | ↓ 1.11 |
| | | | 10 | ↑ 0.86 | ↑ 0.21 |
| | | | 50 | ↓ 1.07 | ↓ 0.83 |
| Laidlaw et al. (1999) | Light Load Training Group | ↑* 2.5 | 2.5 | ↓ 1.64 | ↓* 2.5 |
| | | | 5 | ↓ 1.41 | ↓* 2.3 |
| | | | 10 | ↓ 8.59 | ↓* 5.61 |
| | | | 20 | ↓* 12.19 | ↓* 7.99 |
| | Heavy Load Training Group | ↑* 4.44 | 2.5 | ↓ 3.91 | ↓* 17.14 |
| | | | 5 | ↓ 3.1 | ↓* 5.17 |
| | | | 10 | ↓ 3.74 | ↓* 9.28 |
| | | | 20 | ↓* 8.3 | ↓* 35.07 |
| | Control Group | ↑ 1.31 | 2.5 | ↓ 0.94 | ↓ 0.88 |
| | | | 5 | ↓ 0.68 | ↓ 1.87 |
| | | | 10 | ↓ 1.49 | ↓ 6.69 |
| | | | 20 | ↓ 0.83 | ↓ 2.05 |

MVC: Maximum Voluntary Contraction, SD: Standard Deviation, CV: Coefficient of Variation ↑: Positive effect size; ↓: Negative effect size; *: Significant Difference, =: Available data did not allow the effect size calculation, although, authors related that variables remained unchanged, NA: (Not Available) variable not investigated by the study, ‡: fixed force target.

strategies, thus, requiring that ET modalities are adapted to older adults' clinical specificities. Therefore, investigating the response of older adults' muscle force control to others ET modalities (e.g. multicomponent, fall prevention, water ET…) could be particularly relevant.

### 4.3. Experimental set-up

The trials of the current systematic review assessed muscle force control throughout various experimental set-ups with some similar aspects. For instance, except for one study (Hortobágyi et al., 2001), after measuring the individual isometric MVC, the participants were required to exert isometric contractions at different force targets calculated as percentage of the MVC, in random order, with at least 60 s of rest between trials. In contrast, the current study highlights a heterogeneity regarding various parameters of the studies' experimental set-up. First, there was a multiplicity of devices used for the assessment of muscle force control. For instance, for the knee extensor muscle's force control, some trials used isokinetic dynamometers (Hortobágyi et al.,

**Table 4a**
Assessment of quality of evidence based on GRADE approach for studies investigating the standard deviation of the force signal of knee extensor muscle.

| Certainty assessment | | | | | | | Summary of findings | | |
|---|---|---|---|---|---|---|---|---|---|
| Outcome | Number of studies | Risk of bias | Inconsistency | Indirectness | Imprecision | Publication bias | Intervention | Comparator | Quality of evidence |
| SD of force signal at 2% MVC | 2 RCT (Tracy & Enoka, 2006; Tracy et al., 2004) | Not serious | Not serious | Not serious | Serious (−1) [b] | Strongly suspected (−1) [c] | Resistance Training | Untrained | LOW [d] ⊕⊕◯◯ |
| SD of force signal at 5% MVC | 2 RCT (Tracy & Enoka, 2006; Tracy et al., 2004) | Not serious | Serious (−1) [a] | Not serious | Serious (−1) [b] | Strongly suspected (−1) [c] | Resistance Training | Untrained | LOW [d] ⊕⊕◯◯ |
| SD of force signal at 10% MVC | 2 RCT (Tracy & Enoka, 2006; Tracy et al., 2004) | Not serious | Not serious | Not serious | Serious (−1) [b] | Strongly suspected (−1) [c] | Resistance Training | Untrained | LOW [d] ⊕⊕◯◯ |
| SD of force signal at 50% MVC | 2 RCT (Tracy & Enoka, 2006; Tracy et al., 2004) | Not serious | Not serious | Not serious | Serious (−1) [b] | Strongly suspected (−1) [c] | Resistance Training | Untrained | LOW [d] ⊕⊕◯◯ |

**NOTES**: [a]: There was heterogeneity in the results between trials, score was rated down by one level (−1); [b]: The sample sizes were not justified by sample sized calculation, score was rated down by one level (−1); [c]: studies achieved by the same research group and likely based on the same participants, score was rated down by one level (−1); [d]: GRADE working Group grades of evidence: low quality: further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate.
**ABBREVIATIONS:** SD: Standard Deviation of force signal; MVC: Maximum Voluntary Contraction; RCT: Randomized Controlled Trial.

**Table 4b**
Assessment of quality of evidence based on GRADE approach for studies investigating the coefficient of variation of the force signal of knee extensor muscle.

| Certainty assessment | | | | | | | Summary of findings | | |
|---|---|---|---|---|---|---|---|---|---|
| Outcome | Number of studies | Risk of bias | Inconsistency | Indirectness | Imprecision | Publication bias | Intervention | Comparator | Quality of evidence |
| CV of force signal at 2% MVC | 2 RCT (Tracy & Enoka, 2006; Tracy et al., 2004) | Not serious | Not serious | Not serious | Serious (−1) [c] | Strongly suspected (−1) [d] | Resistance Training | Untrained | MODERATE [e] ⊕⊕⊕◯ |
| CV of force signal at 5% MVC | 2 RCT (Tracy & Enoka, 2006; Tracy et al., 2004) | Not serious | Not serious | Not serious | Serious (−1) [c] | Strongly suspected (−1) [d] | Resistance Training | Untrained | MODERATE [e] ⊕⊕⊕◯ |
| CV of force signal at 10% MVC | 3 RCT (Kobayashi et al., 2014; Tracy & Enoka, 2006; Tracy et al., 2004) | Not serious | Not serious | Serious (−1) [b] | Serious (−1) [c] | Undetected | Resistance Training | Untrained | MODERATE [e] ⊕⊕⊕◯ |
| CV of force signal at 30% MVC | 1 RCT (Kobayashi et al., 2014) | Not serious | Serious (−1) [a] | Serious (−1) [a] | Serious (−1) [c] | Strongly suspected (−1) [a] | Resistance Training | Untrained | LOW [f] ⊕⊕◯◯ |
| CV of force signal at 50% MVC | 2 RCT (Tracy & Enoka, 2006; Tracy et al., 2004) | Not serious | Not serious | Not serious | Serious (−1) [c] | Strongly suspected (−1) [d] | Resistance Training | Untrained | LOW [f] ⊕⊕◯◯ |
| CV of force signal at 65% MVC | 1 RCT (Kobayashi et al., 2014) | Not serious | Serious (−1) [a] | Serious (−1) [a] | Serious (−1) [c] | Strongly suspected (−1) [a] | Resistance Training | Untrained | LOW [f] ⊕⊕◯◯ |

**NOTES:** [a]: Only one study for this outcome, a one-level rated down score ws assumed for this criteria (−1); [b]: There was heterogeneity in interventions between trials, score was rated down by one level (−1); [c]: The sample sizes were not justified by sample sized calculation, score was rated down by one level (−1); [d]: studies achieved by the same research group and likely based on the same participants, score was rated down by one level (−1); [e]: GRADE working Group grades of evidence: moderate quality: further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate; [f]: GRADE working Group grades of evidence: low quality: further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate.
**ABBREVIATIONS:** CV: Coefficient of Variation of force signal; MVC: Maximum Voluntary Contraction; RCT: Randomized Controlled Trial.

**Table 5a**
Assessment of quality of evidence based on GRADE approach for studies investigating the standard deviation of the force signal of dorsal interosseus muscles.

| Certainty assessment | | | | | | | Summary of findings | | |
|---|---|---|---|---|---|---|---|---|---|
| Outcome | Number of studies | Risk of bias | Inconsistency | Indirectness | Imprecision | Publication bias | Intervention | Comparator | Quality of evidence |
| SD of force signal at 2.5% MVC | 1 RCT (Laidlaw et al., 1999) | Not serious | Serious (−1) [a] | Serious (−1) [a] | Serious (−1) [b] | Strongly suspected (−1) [c] | Resistance Training | Untrained | VERY LOW [d] ⊕◯◯◯ |
| SD of force signal at 5% MVC | 1 RCT (Laidlaw et al., 1999) | Not serious | Serious (−1) [a] | Serious (−1) [a] | Serious (−1) [b] | Strongly suspected (−1) [c] | Resistance Training | Untrained | VERY LOW [d] ⊕◯◯◯ |
| SD of force signal at 10% MVC | 1 RCT (Laidlaw et al., 1999) | Not serious | Serious (−1) [a] | Serious (−1) [a] | Serious (−1) [b] | Strongly suspected (−1) [c] | Resistance Training | Untrained | VERY LOW [d] ⊕◯◯◯ |
| SD of force signal at 20% MVC | 1 RCT (Laidlaw et al., 1999) | Not serious | Serious (−1) [a] | Serious (−1) [a] | Serious (−1) [b] | Strongly suspected (−1) [c] | Resistance Training | Untrained | VERY LOW [d] ⊕◯◯◯ |

**NOTES:** [a]: Only one study for this outcome, a one-level rated down score ws assumed for this criteria (−1); [b]: The sample sizes were not justified by sample sized calculation, score was rated down by one level (−1); [c]: studies achieved by the same research group and likely based on the same participants, score was rated down by one level (−1); [d]: GRADE working Group grades of evidence: very low quality: we are very uncertain about the estimate.

**ABBREVIATIONS:** SD: Standard Deviation of force signal; MVC: Maximum Voluntary Contraction; RCT: Randomized Controlled Trial.

**Table 5b**
Assessment of quality of evidence based on GRADE approach for studies investigating the coefficient of variation of the force signal of dorsal interosseus muscles.

| Certainty assessment | | | | | | | Summary of findings | | |
|---|---|---|---|---|---|---|---|---|---|
| Outcome | Number of studies | Risk of bias | Inconsistency | Indirectness | Imprecision | Publication bias | Intervention | Comparator | Quality of evidence |
| CV of force signal at 2.5% MVC | 1 RCT (Laidlaw et al., 1999) | Not serious | Serious (−1) [a] | Serious (−1) [a] | Serious (−1) [b] | Strongly suspected (−1) [c] | Resistance Training | Untrained | VERY LOW [d] ⊕◯◯◯ |
| CV of force signal at 5% MVC | 1 RCT (Laidlaw et al., 1999) | Not serious | Serious (−1) [a] | Serious (−1) [a] | Serious (−1) [b] | Strongly suspected (−1) [c] | Resistance Training | Untrained | VERY LOW [d] ⊕◯◯◯ |
| CV of force signal at 10% MVC | 1 RCT (Laidlaw et al., 1999) | Not serious | Serious (−1) [a] | Serious (−1) [a] | Serious (−1) [b] | Strongly suspected (−1) [c] | Resistance Training | Untrained | VERY LOW [d] ⊕◯◯◯ |
| CV of force signal at 20% MVC | 1 RCT (Laidlaw et al., 1999) | Not serious | Serious (−1) [a] | Serious (−1) [a] | Serious (−1) [b] | Strongly suspected (−1) [c] | Resistance Training | Untrained | VERY LOW [d] ⊕◯◯◯ |

**NOTES:** [a]: Only one study for this outcome, a one-level rated down score ws assumed for this criteria (−1); [b]: The sample sizes were not justified by sample sized calculation, score was rated down by one level (−1); [c]: studies achieved by the same research group and likely based on the same participants, score was rated down by one level (−1); [d]: GRADE working Group grades of evidence: very low quality: we are very uncertain about the estimate.

**ABBREVIATIONS:** CV: Coefficient of Variation of force signal; MVC: Maximum Voluntary Contraction; RCT: Randomized Controlled Trial.

2001; Manini et al., 2005; Tracy et al., 2004), while other studies used a load cell connected to a strain-gauge amplifier in series with a data acquisition system (Kobayashi et al., 2014; Tracy & Enoka, 2006). Afterwards, depending on studies, participants were positioned following different joints angle although assessing the same muscle. Thus, for the knee extensor muscle, Kobayashi et al. (2014) and Manini et al. (2005) positioned their participants at 95° and 60° of knee flexion (full extension = 180°) respectively. Furthermore, although the mostly of the trials calculated the force targets as percentage of the MVC, such percentage differed greatly between studies. Finally, the contractions time were also substantially different between studies assessing the same muscle. For instance, although assessing the knee extensor muscle, participants were required to sustain contractions at the target force for 5 s (Hortobágyi et al., 2001) or 15 s (Manini et al., 2005). It has been demonstrated that joints angle (Sosnoff, Voudrie, & Ebersole, 2009), force targets (Slifkin & Newell, 1999) and contractions time (Singh, Arampatzis, Duda, Heller, & Taylor, 2010) influence the muscle force control outcomes. Therefore, such heterogeneity, regarding the experimental set-up of the trials is likely a factor contributing to the contrasting findings reported in the literature.

### 4.4. Data analysis parameters

This systematic review highlights the lack of agreement about signal acquisition and processing choices leading to a multiplicity of data analysis parameters throughout studies. For instance, although all the included studies analyzed the steadiest window from the central region of the force signals, the length of such window as well as the sampling frequency vary greatly between studies. Accordingly, the total data points analyzed from the force signals differed throughout trials. Forrest, Challis, and Winter (2014) demonstrated that the choices regarding signal acquisition (e.g. sampling frequency) and processing (e.g. total data points) have a determinant impact on the value of a force complexity variable (ApEn) (Forrest et al., 2014). Although no similar investigation has been conducted with SD and CV, it could be suggested that the heterogeneity regarding the data analysis parameters would be a confounding factor for the value of the muscle force control variables. Mostly, the trials investigated the muscle force control through force variability metrics (SD and CV). Only one trial assessed the frequency domain of the force signals of knee extensors with FFT analysis (Kobayashi et al., 2014) while no trial study the force complexity variables. It is widely shown that the force complexity metrics provide an insight into the dimensions of feedback control loops governing force output and the underlying state of the neuromotor system (Mayer-Kress et al., 2003), which cannot be inferred from force variability metrics. Thus, investigating the contribution of ET programs on muscle force control through force complexity metrics in addition to force variability metrics would be particularly relevant as this would provide a better understanding of the exercise-related adaptations in older adults' neuromuscular system.

### 4.5. Effects of exercise training

The findings showed that regardless the participants' clinical status, assessed muscles, experimental set-up, and exercise modalities, the ET programs increased the MVC (with large effect sizes), in older adults. This confirms the widely evidenced improved muscle strength after ET in older adults. The neuro-physiologically mediated mechanisms involved in such response have been widely evidenced (Enoka, 1997; Moritani & DeVries, 1979; Sale, 1988). Briefly, ET triggered adaptive changes within the neuromuscular system that allow to better and fully activate motor units in specific movements and to better coordinate the activation of all relevant muscles, thus effecting a greater net force in the intended direction of movement.

The production and maintenance of voluntary muscle contractions are regulated by the interaction between multiple mechanisms (i.e., feedback loops, motor unit recruitment, motor unit firing rates, and attentional control) (Vaillancourt et al., 2002). Accordingly, the force or displacement produced during a voluntary muscle contraction is always subject to unintentional fluctuations. Such fluctuations, known as physiological tremor don't disturb the control of muscle activities in healthy individuals (Herbert, 2012). With advancing age, there is a degeneration of motor units (Brown, 1972; Campbell, McComas, & Petito, 1973) that involves the progressive death of α-motoneurons and the reinnervation of some of the denervated muscle fibers by surviving motor units (Oda, 1984; Stålberg & Fawcett, 1982). This reorganization triggers changes in the properties of the motor units. Since the control of muscle force depends on the integrity of the motor units' properties, these changes exaggerate tremor in older adults and consequently impair their ability to produce muscle force steadily, accurately, and temporally matched to the demands of particular movement tasks. Therefore, the ability to execute precise motor tasks common to daily living, such as handwriting, object manipulation, self-lifting and postural balance may be affected in older adults. Increasingly, there is evidence that neural adaptations associated with ET programs could contribute to slow down or even reverse the age-related loss of muscle control. Indeed, the exercise-related enhanced capacity to produce force at the level of motor units implies that fewer motoneurons need to be recruited, with a consequent reduced level of cortical activation required to produce an equivalent kinetic or kinematic outcome (Dettmers et al., 1996). Furthermore, Milner-Brown, Stein, and Lee (1975) provided specific evidence that resistance training has the potential to increase the tendency of motor units to fire synchronously (motor unit short term synchronization) as they found that the motor units of resistance-trained individuals fired with greater synchrony than those of untrained individuals (Milner-Brown et al., 1975). It has been demonstrated that such motor unit short term synchronization occurs when motoneurons receive input from axonal branches of the same presynaptic neurons, thereby increasing the probability of near-simultaneous discharge in the target motoneurons (Datta, Farmer, & Stephens, 1991; Kirkwood & Sears, 1978).

Summarily, the available evidence supports the hypothesis that ET triggered neural adaptations that contribute to improve muscle control in older adults. Unexpectedly, in the present review, the force variability variables exhibited contrasting findings in response to ET programs. While ET programs decreased the CV with negative effects size regardless the exercise modalities, assessed muscles and force targets, the response of the SD to ET varied greatly from negative to positive effects size across studies depending on force targets and exercise modalities. It should be emphasized that, negative effects size mean that the ET program contributed to decrease the studied outcome. In the context of the present study, the exercise-related decrease of the CV means an improved ability to control muscle force as response to the ET program, suggesting a beneficial adaptation of the participants' neuromuscular system to exercise. In contrast, when the muscle force control is quantified through the SD, the findings suggest both beneficial (negative effect sizes) and harmful (positive effect sizes) effects of the ET program on the older adults' neuromuscular system depending on force targets and exercise modalities. These contrasting findings are unlikely to be due to heterogeneity regarding the experimental set-up (force targets) and ET modalities since within studies, the results exhibited after ET programs differed substantially between SD and CV at several force targets. For instance, the findings of Tracy et al. (2004) showed that there was increased SD (positive effect sizes) but decreased CV (negative effect sizes) after both steadiness and strength training (See Table 3). However, such contrasting findings raise the interesting question of the difference between the calculation method of these two variables. The SD evaluate the absolute variability of the force fluctuations by merely computing the within standard deviation of the force signal whereas the CV provides a measure of the relative variability by normalizing the within standard deviation of the force signal with the mean of force output. Thus, by assessing the variability of the force signal in older adults, unlike the SD, the CV take into account the relative contribution of the individual muscle strength in the force control. It can be inferred that the differences in muscle strength between individual and studies as well as their relative influence in the force control outcomes are more minimized when analyzed through the CV of the force signal. Accordingly, the CV of the force signal likely allows more accurate values that better reflect the magnitude of fluctuations in force output.

With the exception of the CV of knee extensor force signals at lower force target (2%, 5% and 10% MVC), the findings show that the quality of the body of evidence for the contribution of resistance training programs on the muscle force control was low or very low. Thus, the findings suggest an uncertainty about the effectiveness of resistance training programs on the muscle force control assessed: i) through the SD of force signals, regardless the muscle and force targets, and ii) at higher force target (30%, 50% and 65%) for knee extensor muscle. In the other hand, there is moderate evidence that resistance training programs decrease CV of knee extensor force signals at lower force targets. This level of evidence as well as the negatively large effects size evidenced at these force targets (see Table 3) support the fact that resistance training programs improve knee extensor force variability assessed through the CV of force signals at lower force targets. One reason why resistance training programs were more effective to improve muscle force control at lowest target force may be the association between variability in motor unit discharge rate and steadiness (Barry, Pascoe, Jesunathadas, & Enoka, 2007). Since the contributions of individual motor units to the net force exerted by a muscle are greatest at low forces (Fuglevand, Winter, & Patla, 1993), relatively minor decreases in motor unit discharge variability due to resistance training would be most effective at reducing the magnitude of the force fluctuations at lowest target forces. However, it must be highlight that such level of evidence (moderate) means that further research is likely to have an important impact on the current confidence in the estimate of effect and may change such estimate.

### 4.6. Limitations

This study has some limitations. First, it should be highlighted that the heterogeneity regarding experimental set-up and data analysis parameters between studies hindered to perform a meta-analysis, but also reduced the number of studies included in the assessment of the quality of the evidence. Consequently, the reasons for downgrading the quality of the body of evidence are mainly related to the reduced number of studies. Thereby, the current levels of evidence are likely to be influenced by further researches. Afterwards, the included studies investigated only healthy and functionally limited older adults submitted to resistance, steadiness and functional training programs. Accordingly, the current findings cannot be extrapolated to older adults with other clinical conditions and undergoing other ET modalities. Furthermore, the assessment of the method quality of the trials emphasized that no study performed secret allocation and participants, therapist and assessor blinding. Thus, it would be relevant that further investigations with higher methodological quality study the effects of different ET modalities and their combinations (multicomponente training) on muscle force control in older adults with other diseases or clinical conditions.

## 5. Conclusion

This is the first study to provide evidence about the effectiveness of ET programs designed to improve muscle force control in older adults. Although the heterogeneity regarding experimental set-up and data analysis parameters between studies, the findings showed that resistance, steadiness and functional training programs improve muscle force control in healthy and functionally limited older adults. Furthermore, the quality of evidence of the published clinical trials showed that resistance training programs were more effective to improve muscle force control at lowest target force. According to the current evidences, such exercise-related improvement are more accurately reflected by the assessment of the CV of the force signal. Further investigations with higher methodological quality are needed to study the effects of different ET modalities on muscle force control of older adults with different diseases or clinical conditions.

## Conflict of interest statement

No conflicts of interest have been reported by the authors or by any individuals in control of the content of this article.

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