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Review

Effects of exercise programs on phase angle in older adults: A systematic review and meta-analysis

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ABSTRACT

The purpose of this study was to calculate the effects of exercise programs on phase angle (PhA) in older people. A systematic review was undertaken in multiple electronic databases in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses statement guidelines for the purposes of selecting randomized controlled trials that measured the effects of the exercise programs on PhA in older adults on 31 March 2022. We carried out a random-effect meta-analysis for the effects of exercise programs on PhA. Additionally, we analysed the differences between subgroups in terms of weekly frequency, number of sets and repetitions, and duration of interventions.

Studies were methodological assessed through the PEDro scale where one had excellent, ten had good, and three had poor methodological quality. For the purposes of the study, fourteen studies met the criteria for inclusion. However, four studies did not have enough information to be included in the quantitative analysis. The remaining ten articles revealed moderate effects on PhA in favour of intervention groups (p=0.009, SMD=0.72 [0.46–0.99], I^2=54%). The meta-analysis also showed that interventions lasting twelve weeks are more successful in generating positive effects on PhA as opposed to eight weeks (SMD's=0.79 *vs.* 0.64, respectively). These results indicate that resistance training (RT) is an effective and safe to improve PhA in the older people, especially through RT programs lasting from eight to twelve weeks. A novel finding of this study was that RT is the most used type of exercise by authors when assessing the PhA in older adults.

1. Introduction

In the last 50 years, the number of people over age 65 has tripled, and in 2050 this number is expected to represent 25% of the world's population (Bouaziz et al., 2017; Lang et al., 2013; Lutz et al., 1997). Aging is considered a risk factor contributing to the development of chronic diseases, frailty, dementia and several physical and mental implications, namely loss of functional capacity (Merchant et al., 2021). In this sense, global aging brings new challenges to economic, social, and health systems. Moreover, the global aging and the increasing life expectancy is accompanied by the deterioration of health (Sauver et al., 2015). Hence, researchers and clinicians should focus on providing solid evidence of how active and healthy aging should be considered a priority in health-related policies (Rodrigues et al., 2022).

Increasing age contributes to bone mineral density and lean mass decrease, while body fat mass increases and is distributed in the abdominal region (Kuk et al., 2009; St-Onge & Gallagher, 2010). Several lifestyle factors contribute to these age-associated changes in body fat distribution, namely daily diet, reduced physical activities, less skeletal muscle mass and reduced strength (Gambert & Pinkstaff, 2006). The assessment of body composition in older people is crucial in order to have an overview of health and nutritional status (Campa et al., 2021;

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Dos Santos et al., 2020a) which is related to physical status (Campa et al., 2018; Dos Santos et al., 2020b; Martins et al., 2021; Oliveira et al., 2022).

Exercise programs are a key component of healthy aging and one of the factors associated with a better body composition (García-Hermoso et al., 2020). Body composition modifications typically involve reductions in body fluids, increases in fat mass, and loss of muscle mass (Santanasto et al., 2016). An increase in adiposity, particularly in the abdominal area, or a reduction in intracellular fluid can contribute to the onset of chronic diseases (Santanasto et al., 2016) and to the accumulation of cellular senescence induced by destructive stimuli from inside and outside the cell (Li et al., 2021).

In recent years, the bioelectrical impedance analysis (BIA) has been considered by several authors when assessing body composition across different populations, namely older adults (Asklöf et al., 2018; Baumgartner et al., 1988; Diouf et al., 2018; Kyle, 2004; Oliveira et al., 2022; Sardinha, 2018). This method is considered effective, practical and easy to operate, given that it is portable, non-invasive, user-friendly, without exposing the technicians to radiation (Heymsfield et al., 2005; Yamada et al., 2013, 2014). The BIA assesses the whole-body and appendicular segment through the impedance which can be separated in two components: bioelectrical resistance (R) and reactance (Xc) (Baumgartner et al., 1988; Kyle, 2004; Lukaski & Raymond-Pope, 2021). In this sense, it is important to distinguish these components. Bioelectrical resistance reflects the conductivity of ionic solutions and body water while the reactance reflects the delay in the flow of that electric current, which reflects the ability of cell membranes and tissues to store some of this electric current by causing a phase shift (Norman et al., 2012). The scientific relevance of this assertion results from the fact that it is possible to calculate the value of the phase angle (PhA) using these two parameters (i.e., $\text{PhA} = [\text{arctangent } (Xc/R) \times 180°/\pi]$) (Bosy-Westphal et al., 2006). Consequently, the phase difference between voltage and electric current affecting the ability of cell membranes and tissues to store part of the electric current is expressed as PhA (Uemura et al., 2019).

The PhA could be an indicator of cellular health, such as cellular membrane integrity (Kyle, 2004), permeability (Campa, Toselli, et al., 2021), inflammation (Moreto et al., 2017; Tomeleri et al., 2018) and soft tissue hydration (Francisco et al., 2020), where higher values indicate better cell function and greater cell membrane integrity (Cruz-Jentoft et al., 2019; Mattiello et al., 2020; Yamada et al., 2021). Nowadays, there is lot of evidence highlighting that the PhA may be used as an excellent prognostic marker to predict functional capacity (Martins et al., 2021; Matias et al., 2020; Oliveira et al., 2022), sarcopenia (Dos Reis et al., 2019; Kilic et al., 2017; Rosas-Carrasco et al., 2021), quality of life (Kang et al., 2022; Norman et al., 2015; Sánchez-Lara et al., 2012), mortality risk (Norman et al., 2015; Thibault et al., 2016; Wilhelm-Leen et al., 2014), prospective falls (Uemura et al., 2019), disease prognosis (Beberashvili et al., 2014) and nutritional risk (Kyle et al., 2012).

Additionally, several studies (Uemura et al., 2019; Wada et al., 2020; Yamada et al., 2019a; Yamada et al., 2017; Yoshida et al., 2018) reported a strong association between PhA and muscle strength, such as grip strength, knee extensor strength, maximal torque of plantar flexion and dorsiflexion in middle-aged or older populations. In a recent study, Yamada et al. (2021) stated that patients with lower PhA have not only low muscle strength and power but also have low level of multi-dimensional physical fitness, including aerobic capacity (endurance) and complex gait ability. Another recent study showed positive associations between PhA and resistance of lower and upper limbs, aerobic capacity, agility and balance in older women (Oliveira et al., 2022). Therefore, it is suggested that decreased cell membrane integrity and function might cause physical impairment (e.g., muscle strength and power) and may increase the risk of falls in the older population.

According to Sardinha (2018) physical exercise could induce molecular, cellular, and tissue changes in an acute way and potentially impact chronic adaptations. In this sense, we argue that PhA is an appropriate metric for assessing the structural effects of exercise interventions and to evaluate hydration status and cell functioning, notably in older populations. Campa et al. (2021) supported this argument and stated that the PhA evaluation represents an interesting topic for future research. Recently, Oliveira et al. (2022) reinforced the previous statements and suggested the use of PhA as an additional assessment to control physical fitness modifications associated with the aging process in older women.

Cross-sectional studies have shown that PhA can be affected by physical activity (Dittmar, 2003; Koury et al., 2014; Mala et al., 2015; Torres et al., 2008). In a recent systematic review, Martins et al. (2021) reported that the main effects of exercise programs on PhA in cancer patients were caused by long-term programs (chronic effects), however the authors recommended that further systematic reviews should be conducted with other populations.

To the best of our knowledge, there is currently no systematic review and meta-analysis that reported the effects of the exercise programs on PhA in older people. Aiming to better adjust the characteristics and types of the exercise programs, it is important to assess which components of a multimodal exercise intervention are most effective for improving PhA in older people. Therefore, the purposes of the present systematic review and meta-analysis were: (1) to calculate the effects of the exercise programs on PhA in older people; (2) to describe the characteristics of those exercise programs; and (3) to provide recommendations for future studies. Our hypothesis is that it is possible to verify moderate to large effects on the PhA values in older population after interventions with exercise programs applied to older population.

2. Material and methods

This systematic review was written following the items of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Page et al., 2021). This review with meta-analysis was also registered at the International Prospective Register of Systematic Reviews (PROSPERO), registered under number CRD4202230127.

2.1. Search strategy and data sources

The following electronic databases were used to search for relevant publications on 31 March 2022: PubMed, Web of Science (WoS), Psychology and Behavioral Sciences Collection (EBSCO), and Science Direct. In order to include the most recent studies in the review, we set citations alarms in all these databases.

The data search was performed by using the U. S. National Library of Medicine's Medical Subject Headings (MeSH) terms and English language terms related to PhA and the older people. The following word combinations were used in the above-mentioned databases in accordance with a previous systematic review regarding PhA in cancer patients (Martins et al., 2021): ("phase angle" OR "bioimpedance" OR "electrical-impedance") AND ("exercise" OR "physical activity" OR "training" OR "exercise program" OR "intervention") AND ("elderly" OR "older people"). It was possible to perform 30 different searches in each database mentioned (120 in total) through these word combinations. Additionally, the reference lists of the studies retrieved were manually searched to identify potentially eligible studies not captured by the electronic searches, and we found no further studies.

2.2. Eligibility criteria

The PICOS model was used to design and conduct this systematic review (Methley et al., 2014), as follows: P (patients) – adults, from both sexes, regardless of the state of health; I (intervention) – participants in the intervention group (IG) that performed any exercise program (e.g., strength training, RT, aerobic training, suspension training or others); C (comparison) – Comparing the results between the groups or/and within each group under study, however there must be at least two groups under study; O (outcome) – PhA assessed from electric bioimpedance analysis (mono or multifrequency) at a frequency of 50 kHz, as primary or second outcome under study, irrespectively of the position adopted during the assessment; S (study) – non or randomized control trials.

Studies were excluded if: (1) they included participants with age < 60 years old and/or if they included cancer patients – once this population was recently included in other systematic review (Martins et al., 2021); (2) the participants did not perform any exercise program; (3) did not compare the results under the conditions mentioned above; (4) examined the effects of others types of intervention (i.e., nutritional intervention); (5) did not include or report results regarding PhA; (6) written in another language than English; and (7) other article types than original (e.g., reviews, letters to editors, cross-sectional studies, proposals for protocols, editorials, book chapters and conference abstracts).

2.3. Data extraction

All articles identified through the search strategy underwent an evaluation of the titles and abstracts, in duplicate, by two assigned researchers. Those that did not meet the inclusion criteria were excluded. Abstracts that did not provide sufficient information regarding the inclusion and exclusion criteria were selected for full-text evaluation. In a second phase, the same two assigned researchers independently evaluated all selected full-text articles and conducted a second selection following the inclusion and exclusion criteria. In a meeting with a third researcher present, disagreements between reviewers were solved by consensus.

Data extraction from the full text of the selected articles was conducted by both assigned researchers independently, using a list of intended data: (i) first author; (ii) year of publication; (iii) aim(s) of the study; (iv) country where the study was performed; (v) BIA device used; (vi) health status of the participants under study; (vii) sample (i.e., number of females, males and mean age); (viii) weight (kg); (ix) body mass index (BMI) (kg/m^2); (x) intervention details (e.g., exercises performed; intervention and session duration, weekly frequency, intensity and volume); (xi) control group characteristics; and (xii) main results regarding PhA.

2.4. Methodological quality assessment

The methodological study quality was performed using the Physiotherapy Evidence Database (PEDro) scale (Maher et al., 2003). This is a valid and reliable instrument to assess eligibility, group allocation, blinding of allocation, and comparison between groups at baseline and its outcomes. This scale includes eleven questions with yes or no answers (yes= 1; no= 0), providing a total score that ranges between zero (poor methodological quality) and ten (excellent methodological quality) (the first item is not included in the rating).

Scores were obtained from the PEDro database and therefore determined independently, avoiding any potential bias of the authors. When a study was not available on the PEDro database, two authors alone (A.D.M. and R.O.) rated the risk of bias. Disagreements between authors were solved by consensus in a meeting with the last author present (J.P.B.).

2.5. Level of evidence

Based on the physiotherapy evidence database scale and to assess the interventions' evidence, the criteria of the a previous study (van Tulder et al., 2003) was applied. Therefore, the selected studies were grouped by levels of evidence, according to their methodological quality. A study with a physiotherapy evidence database score of six or more is considered level 1 (high methodological quality) (6–8: good; 9–10: excellent) and a score of five or less is considered level 2 (low methodological quality) (4–5: moderate; <4: poor). The study with poor methodological quality (score <4) was not included in the quantitative analysis in accordance with a previous systematic review with meta-analysis (Mattiello et al., 2020).

Due to the clinical and statistical heterogeneity of the results, a qualitative review was performed, conducting a best-evidence synthesis (Kollen et al., 2009; Vaughan-Graham et al., 2015). This classification indicates that if the number of studies displaying the same level of evidence for the same outcome measure or equivalent is lower than 50% of the total number of studies found, no evidence can be concluded from the methods used in those studies.

2.6. Statistical analysis

Firstly, when the effect sizes (ES) were not reported, we calculated the ES's applying the following equation: ES = post-training mean minus pre-training mean divided by pooled standard deviation of pre-training and post-training (Cohen, 1992). Then, the following Cohen's convention was used: 0–0.19 = trivial; 0.20 –0.49 = small; 0.50–0.79 = moderate; 0.80 and higher = large ES (Cohen, 1988, 1992). When results (mean and standard deviation) on PhA were incomplete, the corresponding author the study was contacted.

Subsequently, the studies included in the quantitative analysis (n= 10) were analysed using the random effects model (Borenstein et al., 2010). A forest plot was generated for the PhA measure. The heterogeneity of the included studies was assessed by calculating the following statistics: (i) Tau^2, (ii) Chi^2, and (iii) I^2. We used the following classification to evaluate the I^2 (i.e., described inconsistency between trials): lower than 50% represents low heterogeneity; 50–74% represents substantial heterogeneity; and 75% and higher represents considerable heterogeneity (Deeks et al., 2019). At the same time, to calculate the effect of the interventions on PhA for the quantitative analysis, we used the standardized mean differences (SMDs) (i.e., SMD$_s$ = ([mean post-value intervention group minus mean post-value control group]/ pooled variance) (Cohen, 1988), according to the following thresholds: 0–0.19 = negligible effect; 0.20–0.49 = small effect; 0.50–0.79 = moderate effect; and 0.80 and higher = large effect (Martins et al., 2022)

All statistical analyses were performed through the Cochrane Review Manager (RevMan) [Computer program]. Version 5.4.1, The Cochrane Collaboration, 2020 (Deeks & Higgins, 2016).

3. Results

3.1. Studies included

After searching process, we found 6711 studies from the selected databases. Subsequently, the duplicates (4335 references) were removed either automatically or manually. Afterwards, the remaining 2376 articles were examined for their relevance based on titles and abstracts, resulting in the removal of a further 2193 studies. Upon completion of the screening procedure, we had 183 articles selected for eligibility, which were read and analyzed in depth. Finally, after reading full texts, a further 169 studies were excluded due to not meeting the eligibility criteria (Fig. 1). Therefore, the present systematic review identified fourteen studies that met the criteria for inclusion and were assessed for quality using the PEDro scale. However, four of the fourteen studies did not have enough information to be included in the quantitative analysis.

3.2. Methodological quality

The methodological assessment of the fourteen studies included in this systematic review can be found on Table 1. Those studies obtained a score between three (Yi et al., 2019) and nine (Nabuco et al., 2019) with a mean value of six [level 1] in terms of methodological quality based on the PEDro scale. Eleven of the reviewed studies presented high methodological quality [level 1] (Campa et al., 2018; Campa et al., 2021; Cunha et al., 2018; Dos Santos et al., 2020a; Nabuco et al., 2019; Osco et al., 2021; Ribeiro et al., 2017, 2018; Souza et al., 2017; Tomeleri et al., 2018; Yamada et al., 2019b), and three revealed low methodological quality [level 2] (Ribeiro et al., 2020; Skelton et al., 1995; Yi et al., 2019). Furthermore, the results of the PEDro scale showed that all studies reported the inclusion and exclusion criteria, only one study did not randomly allocated the participants into groups (Yi et al., 2019), five studies allocated the participants into groups in a concealed way (Campa et al., 2021; Nabuco et al., 2019; Osco et al., 2021; Souza et al., 2017; Tomeleri et al., 2018), and only one study did not perform the baseline comparability (Yi et al., 2019).

Additionally, only one study blinded the participants and the technicians responsible for the program's sessions (Nabuco et al., 2019), six studies blinded the assessors who measured at least one key outcome (Cunha et al., 2018; Ribeiro et al., 2017, 2018, 2020; Souza et al., 2017; Yamada et al., 2019b), two studies did not perform an adequate follow-up (Ribeiro et al., 2020; Yamada et al., 2019b), seven studies performed an intention-to-treat analysis (Campa et al., 2018; Cunha et al., 2018; Dos Santos et al., 2020a; Nabuco et al., 2019; Ribeiro et al., 2017; Tomeleri et al., 2018; Yamada et al., 2019b), all studies reported a between-group statistical comparisons and point measures and measures of variability for at least one key outcome (Campa et al., 2018;

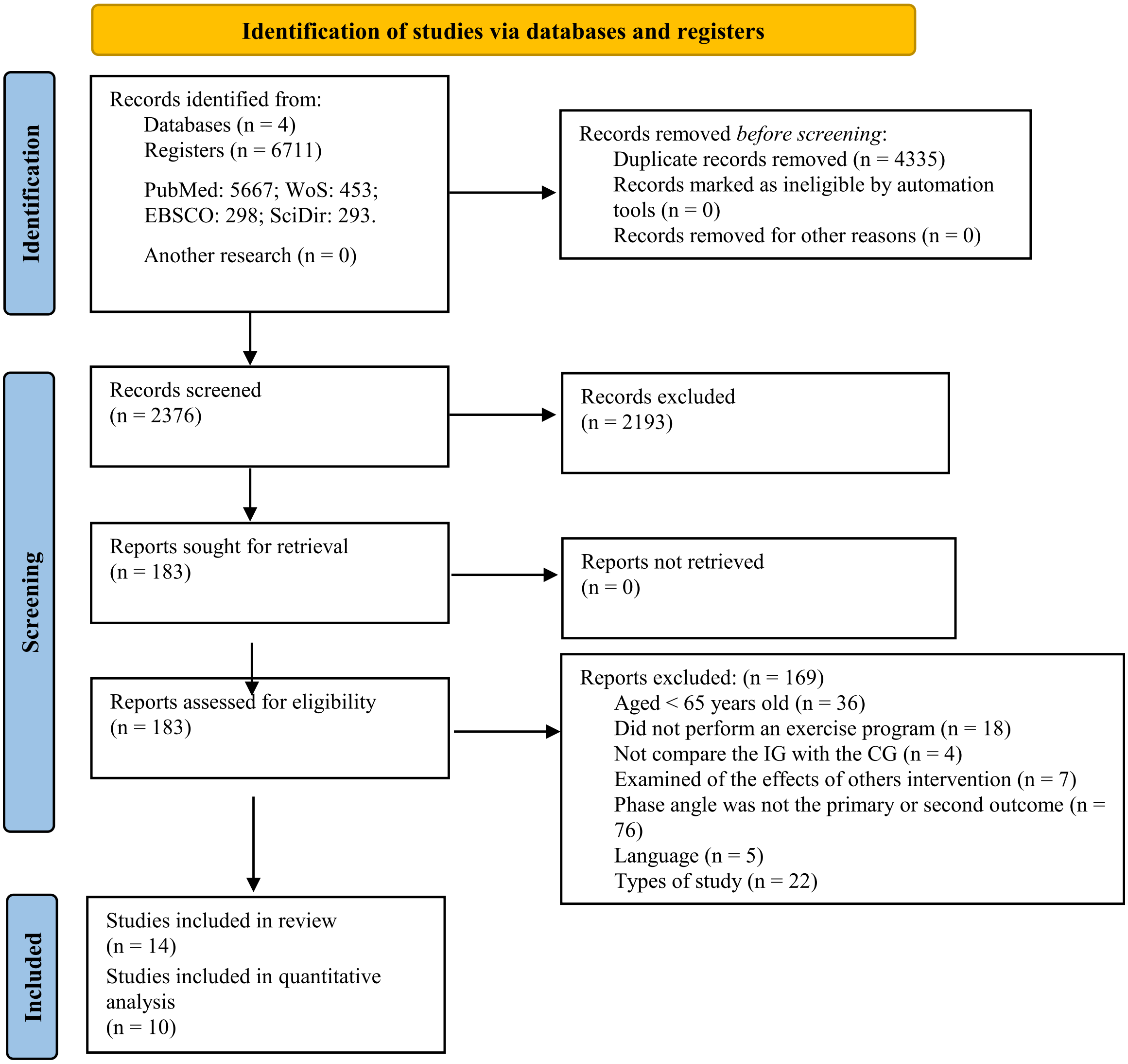


Fig. 1. Flow chart of study design by PRISMA 2020.

Campa et al., 2021; Cunha et al., 2018; Dos Santos et al., 2020a; Nabuco et al., 2019; Osco et al., 2021; Ribeiro et al., 2017, 2018, 2020; Skelton et al., 1995; Souza et al., 2017; Tomeleri et al., 2018; Yamada et al., 2019b; Yi et al., 2019).

3.3. *Studies characteristics*

Table 2 shows the characteristics of the fourteen studies included in this review. A total of 667 participants participated in these studies, and 441 of those participants entered into an exercise program (i.e., allocated in IG). It should be noted that 590 participants were female and only 77 were male. In this regard, eleven studies (Campa et al., 2018; Cunha et al., 2018; Dos Santos et al., 2020a; Nabuco et al., 2019; Osco et al., 2021; Ribeiro et al., 2017, 2018, 2020; Skelton et al., 1995; Souza et al., 2017; Tomeleri et al., 2018) included solely females in the analysis and only one study was conducted solely with men (Campa et al., 2021). The sample size of the intervention groups ranged from 12 (Campa et al., 2021) to 31 (Yi et al., 2019) participants with the mean age ranging from 67 (Campa et al., 2018; Nabuco et al., 2019) to 84.7 years old (Yamada et al., 2019b).

Regarding the origin of the studies, most studies were conducted in Brazil (Cunha et al., 2018; Dos Santos et al., 2020a; Nabuco et al., 2019; Osco et al., 2021; Ribeiro et al., 2017, 2018, 2020; Souza et al., 2017; Tomeleri et al., 2018), two were performed in Italy (Campa et al., 2018, 2021), one was performed in South Korea (Yi et al., 2019), one Japan (Yamada et al., 2019b), and one in England (Skelton et al., 1995). The most frequently used equipment to quantify the PhA value was the Xitron Hydra, model 4200 (Cunha et al., 2018; Dos Santos et al., 2020a; Nabuco et al., 2019; Ribeiro et al., 2017, 2018, 2020; Souza et al., 2017; Tomeleri et al., 2018).

3.4. *Intervention's characteristics*

Table 3 shows the description of the interventions performed in the included studies. Only one study did not perform a resistance training (RT) exercise program (Yi et al., 2019). Thirteen of those RT programs were performed using a Total-body Resistance exercise, usually known as TRX (Campa et al., 2018, 2021), a combination of elastic band and body weight (Campa, Schoenfeld, et al., 2021; Skelton et al., 1995; Yamada et al., 2019b), a combination of free weights and machines (Cunha et al., 2018; Nabuco et al., 2019; Ribeiro et al., 2017, 2018, 2020; Souza et al., 2017; Tomeleri et al., 2018), and a training on machines only (Osco et al., 2021). The running time of these exercise programs ranged from eight (Dos Santos et al., 2020a; Ribeiro et al., 2017, 2020) to twelve weeks (Campa et al., 2018, Campa et al., 2021; Cunha et al., 2018; Nabuco et al., 2019; Osco et al., 2021; Ribeiro et al., 2018; Skelton et al., 1995; Souza et al., 2017; Tomeleri et al., 2018; Yamada et al., 2019b).

The single training sessions had a duration range between 30 (Yamada et al., 2019b) to 120 min (Yi et al., 2019), and a total duration per week that ranged from 60 (Yamada et al., 2019b) to 225 min (Osco et al., 2021) (mean 150 min/week), with five studies not reporting the sessions duration (Cunha et al., 2018; Dos Santos et al., 2020a; Nabuco et al., 2019; Ribeiro et al., 2017; Souza et al., 2017).

The number of training sessions ranged from one (Yi et al., 2019) to three sessions per week (Campa, Schoenfeld, et al., 2021; Cunha et al., 2018; Dos Santos et al., 2020a; Nabuco et al., 2019; Osco et al., 2021; Ribeiro et al., 2017, 2020; Skelton et al., 1995; Souza et al., 2017; Tomeleri et al., 2018) with a total number of sessions ranging from 11 (Yi et al., 2019) to 33 training sessions per intervention (Campa et al., 2021; Cunha et al., 2018; Nabuco et al., 2019; Osco et al., 2021; Ribeiro et al., 2017, 2018; Skelton et al., 1995; Souza et al., 2017; Tomeleri et al., 2018) with a mean of 30 training sessions.

The intensity of the sessions was quantified mostly through repetition maximum (RM) (Cunha et al., 2018; Dos Santos et al., 2020a; Osco et al., 2021; Ribeiro et al., 2017, 2018; Souza et al., 2017; Tomeleri et al., 2018) and through the 6-20 arbitrary units (AU) of the rated perceived exertion, usually known as RPE (Borg, 1982) (Campa et al., 2021; Yi et al., 2019). The number of sets performed varied from one (Cunha et al., 2018; Ribeiro et al., 2018) to four per exercise (Campa et al., 2018), and it is also important to note that only one study used a non-fixed number of sets (Osco et al., 2021). Regarding the number of repetitions used per set of exercise, only three studies (Campa et al., 2018, 2021; Yamada et al., 2019b) used the same number of repetitions in all sets, while most of the interventions varied the number of repetitions throughout the execution of each exercise, either increasing (Cunha et al., 2018; Nabuco et al., 2019; Ribeiro et al., 2017, 2018, 2020; Skelton et al., 1995; Souza et al., 2017; Tomeleri et al., 2018) or decreasing in number (Dos Santos et al., 2020a; Osco et al., 2021; Ribeiro et al., 2017).

The levels of adherence in the exercise programs ranged from 75% (Yamada et al., 2019b) to more than 95% (Skelton et al., 1995), however

Table 1
Analysis of the risk of bias of the studies included in this review.

First Author (Year)	PEDro Scale											Total score	Methodological quality
	1	2	3	4	5	6	7	8	9	10	11		
Campa (2021)	Y	1	1	1	0	0	0	1	0	1	1	6	**Good**
Osco (2021) §	Y	1	1	1	0	0	0	1	0	1	1	6	**Good**
Dos Santos et al., 2020a §	Y	1	0	1	0	0	0	1	1	1	1	6	**Good**
Ribeiro (2020)	Y	1	0	1	0	0	1	0	0	1	1	5	**Moderate**
Yi (2019)	Y	0	0	0	0	0	0	1	0	1	1	3	**Poor**
Yamada et al. (2019b)	Y	1	0	1	0	0	1	0	1	1	1	6	**Good**
Nabuco (2019) §	Y	1	1	1	1	1	0	1	1	1	1	9	**Excellent**
Cunha (2018) §	Y	1	0	1	0	0	1	1	1	1	1	7	**Good**
Ribeiro (2018)	Y	1	0	1	0	0	1	1	0	1	1	6	**Good**
Tomeleri (2018) §	Y	1	1	1	0	0	0	1	1	1	1	7	**Good**
Campa (2018)	Y	1	0	1	0	0	0	1	1	1	1	6	**Good**
Souza (2017)	Y	1	1	1	0	0	1	1	0	1	1	7	**Good**
Ribeiro (2017)	Y	1	0	1	0	0	1	1	1	1	1	7	**Good**
Skelton (1995)	Y	1	0	1	0	0	0	1	0	1	1	5	**Moderate**

Abbreviations: 1, Eligibility; 2, Random allocation; 3, Concealed allocation; 4, Baseline comparability; 5, Blind subjects; 6, Blind therapists; 7, Blind assessors; 8, Adequate follow-up; 9, Intention-to-treat analysis; 10, Between-group comparisons; 11, Point estimates and variability; Y, yes; N, No; §, Scored by reviewers.
Note: Eligibility criteria item does not contribute to total score.

Table 2
Characteristics of the fourteen included studies.

First Author (Year)	Country	BIA Device	Health status	Intervention Group [a]					Control Group [a]			
				Cod	SampleN/F/M	Age (yr)	Weight (kg)	BMI (kg/m^2)	Sample N/F/M	Age (yr)	Weight (kg)	BMI (kg/m^2)
Campa (2021)	Italy	BIA 101 Anniversary, Akern, Florence, Italy.	Physically independent, not having a chronic disabling disease or amputations.	A B	12/0/12 13/0/13	NR NR			11/0/11	NR		
Osco (2021)	Brazil	BIA Vitality, Harrisville, USA.	Physically independent, not having chronic disabling and metabolic diseases.	A B	19/19/0 18/18/0	69.7 ±8.2 70.1 ±6.7	NR NR	28.8 ±6.3 29.1 ±6.7	NA			
Dos Santos et al., 2020a	Brazil	Xitron Hydra, model 4200, Xitron Technologies, San Diego, USA.	Physically independent, free from cardiac or orthopedic dysfunction, and not receiving hormonal replacement therapy.	Narrow Wide	19/19/0 18/18/0	NR NR			18/18/0	NR		
Ribeiro (2020)	Brazil	Xitron Hydra, model 4200, Xitron Technologies, San Diego, USA.	Physically independent, with BMI$>$25 kg/m^2 and not receiving hormonal replacement therapy.	A	18/18/0	69.0 ±6.7	72.3 ±10.3	30.7 ±4.6	15/15/0	67.1 ±4.1	70.7 ±10.1	29.1 ±3.3
Yi (2019)	South Korea	InBody S10, InBody, Korea.	Physically independent, not diagnosed with dementia.	BP WP	29/22/7 31/28/3	78.5 ±6.9 72.9 ±6.2	58.4 ±9.7 56.5 ±8.6	23.8 ±2.9 24.4 ±3.3	28/20/8	74.4 ±4.9	60.8 ±8.1	25.3 ±3.2
Yamada et al. (2019b)	Japan	MC-780A, Tanita, Tokyo, Japan.	Physically independent, with sarcopenia and dynapenia.	A	28/18/10	84.7 ±5.1	52.3 ±9.6	22.6 ±3.0	28/15/13	83.9 ±5.7	49.7 ±8.9	21.2 ±2.9
Nabuco (2019)	Brazil	Xitron Hydra, model 4200, Xitron Technologies, San Diego, USA.	Physically independent, free from cardiac or orthopedic dysfunction, not receiving hormonal replacement and/or thyroid therapy.	A	23/23/0	66.5 ±7.1	62.2 ±10.4	23.8 ±3.7	NA[b]			
Cunha (2018)	Brazil	Xitron Hydra, model 4200, Xitron Technologies, San Diego, USA.	Physically independent, free from cardiac or orthopedic dysfunction, not receiving hormonal replacement and/or thyroid therapy.	G1S G3S	20/20/0 20/20/0	69.7 ±6.0 68.2 ±4.3	69.8 ±15.2 62.6 ±12.4	28.2 ±5.0 26.7 ±4.8	22/22/0	68.0 ±4.5	63.4 ±11.8	25.9 ±4.0
Ribeiro (2018)	Brazil	Xitron Hydra, model 4200, Xitron Technologies, San Diego, USA.	Physically independent, not hypertensive or on medication for hypertension, and not receiving hormonal replacement therapy.	G2X G3X	17/17/0 22/22/0	69.0 ±5.1 69.1 ±5.8	68.6 ±15.1 69.3 ±15.6	28.6 ±5.4 28.1 ±5.2	NA			
Tomeleri (2018)	Brazil	Xitron Hydra, model 4200, Xitron Technologies, San Diego, USA.	Physically independent, free from cardiac or orthopedic dysfunction, and not receiving hormonal replacement therapy.	A	26/26/0	70.6 ±5.4	65.3 ±11.5	26.8 ±4.3	25/25/0	68.8 ±4.4	65.8 ±11.9	26.9 ±4.5
Campa (2018)	Italy	BIA 101 Anniversary, Akern, Florence, Italy.	Physically independent, non-hypertensive patients and not receiving hormonal replacement therapy.	A	15/15/0	66.5 ±4.3	72.7 ±12.1	28.8 ±4.6	15/15/0	65.6 ±5.2	77.1 ±7.1	32.4 ±5.6
Souza (2017)	Brazil	Xitron Hydra, model 4200, Xitron Technologies, San Diego, USA.	Physically independent, free from cardiac or orthopedic dysfunction and not receiving hormonal replacement therapy.	A	22/22/0	67.1 ±4.5	64.0 ±12.2	26.6 ±4.7	19/19/0	67.3 ±4.3	64.2 ±12.7	26.8 ±5.1
Ribeiro (2017)	Brazil	Xitron Hydra, model 4200, Xitron Technologies, San Diego, USA.	Physically independent, free from cardiac or orthopedic dysfunction and not receiving hormonal replacement therapy.	A B	25/25/0 26/26/0	69.7 ±6.6 68.9 ±5.8	66.7 ±13.1 66.8 ±12.3	28.0 ±5.2 27.3 ±4.6	25/25/0	66.8 ±4.2	64.3 ±12.7	26.3 ±4.6
Skelton (1995)	England	BIA 109, RJL Body Impedance Analyser.	Physically independent, no history of cardiovascular, cerebrovascular, respiratory, systemic, muscular, or uncontrolled metabolic disease.	A	20/20/0	79.5	54.1 ±9.1	NR	20/20/0	79.5	61.5 ±11.4	NR

Abbreviations: N, number; F, Female; M, Male; BIA, bioelectrical impedance analysis; BMI, body mass index; yr, years; kg, kilograms; NR, not reported; NA, not applicable; USA, United States of America; BP, breathing meditation program; WP, walking program. a, data present in mean and standard deviation; b, the other groups under study were not analyse due to exclusion criterion number 4.

Table 3
Description of the interventions performed in the included studies.

First Author (Year)	Training method	Intervention duration (wk)	Session duration (min)	Intervention Group							Control Group	Follow-up
				Exercises performed	Frequency (days/wk)	Intensity	Sets (n)	Reps (n)	Rest (s)	Supervised?		
Campa (2021)	RT performed using TRX.	12	60	Squat, biceps curl, chest press, low row, rotational ward, squat with Y deltoid fly, triceps pushdown.	3	13 from 6-20 RPE scale	3	12	60	Yes	Without exercise	No
	RT performed using a combination of elastic band and body weight.	12	60	Squat, alternating lunge, alternating curl, push up, plank, row, alternating lateral raise.	3	13 from 6-20 RPE scale	3	12	60	Yes		
Osco (2021)	RT performed using a machine.	12	75	Chest press, leg press, front pulldown, knee extension, arm curl, leg curl, triceps pushdown, calf raises.	3	20 RM (wk1-6) 15 RM (wk7-12)	2 (wk1-2) 3 (wk3-6) 3 (wk7-12)	15 (wk1-2) 12-15 (wk3-6) 8-12 (wk7-12)	60 (wk1-2) 90 (wk3-6) 90 (wk7-12)	Yes	NA	No
	RT performed using elastic tubes.	12	75	Knee extension and flexion, shoulder abduction, elbow flexion and extension, chest press, seated row.	3	Progressively increased to match the number of repetitions	2 (wk1-2) 3 (wk3-6) 3 (wk7-12)	15 (wk1-2) 12-15 (wk3-6) 8-12 (wk7-12)	60 (wk1-2) 90 (wk3-6) 90 (wk7-12)	Yes		
Dos Santos et al., 2020a	RT (Narrow Repetition Zone).	8	NR	Chest press, horizontal leg press, seated low-row, leg extension, barbell preacher curl, lying leg curl, triceps pushdown, seated calf raise.	3	12/10/8 RM	3	12/10/8	60–120 between sets 120–180 between exercises	Yes	Without exercise	No
	RT (Wide Repetition Zone).	8	NR	Chest press, horizontal leg press, seated low-row, leg extension, barbell preacher curl, lying leg curl, triceps pushdown, and seated calf raise.	3	15/10/5 RM	3	15/10/5	60–120 between sets 120–180 between exercises	Yes		
Ribeiro (2020)	RT performed using a combination of free weights and machines.	8	45-50	Chest press, seated row, triceps push-down, preacher curl, horizontal leg press, knee extension, knee curl, seated calf raise.	3	NR	3	8-12	60–120 between sets 120–180 between exercises	Yes	Without exercise	No
Yi (2019)	Breathing meditation program.	11	120	Several acupuncture points and walking.	1	13-14 from 6-20 RPE scale (wk1-3) 16-17 from 6-20 RPE scale (wk4-11)	NA	NA	NA	Yes	Without exercise	No
	Walking Program.	11	120	Guided-breathing meditation and walking.	1	NR				Yes		
Yamada et al. (2019b)	RT performed using a combination of elastic band and body weight.	12	30	Trunk flexion, hip flexion, hip extension, hip abduction, hip adduction, knee extension, and ankle plantar flexion.	2	NR	3	20	NR	Yes	Without exercise	No
Nabuco (2019)	RT performed using a combination of free weights and machines.	12	NR	Chest press, horizontal leg press, seated row, knee extension, preacher curl, leg curl, triceps pushdown, seated calf raise.	3	NR	3	8-12	NR	Yes	NA[a]	No

(*continued on next page*)

Table 3 (*continued*)

First Author (Year)	Training method	Intervention duration (wk)	Session duration (min)	Intervention Group							Control Group	Follow-up
				Exercises performed	Frequency (days/wk)	Intensity	Sets (n)	Reps (n)	Rest (s)	Supervised?		
Cunha (2018)	RT performed using a combination of free weights and machines.	12	NR	Chest press, horizontal leg press, seated row, knee extension, preacher curl, leg curl, triceps pushdown, seated calf raise.	3	10-15 RM	1	10-15	120–180 between exercises	Yes	Without exercise	No
		12	NR	Chest press, horizontal leg press, seated row, knee extension, preacher curl, leg curl, triceps pushdown, seated calf raise.	3	10-15 RM	3	10-15	60–120 between sets 120–180 between exercises	Yes		
Ribeiro (2018)	RT performed using a combination of free weights and machines (G2X).	12	90	Chest press, horizontal leg press, seated row, knee extension, preacher curl, leg curl, triceps pushdown, and seated calf raise.	2	10-15 RM	1	10-15	120–180 between exercises	Yes	NA	No
	RT performed using a combination of free weights and machines (G3X).	12	90	Chest press, horizontal leg press, seated row, knee extension, preacher curl, leg curl, triceps pushdown, seated calf raise.	3	10-15 RM	1	10-15	120–180 between exercises	Yes		
Tomeleri (2018)	RT performed using a combination of free weights and machines.	12	45-50	Chest press, seated row, triceps pushdown, preacher curl, horizontal leg press, knee extension, knee curl and seated calf raise.	3	10-15 RM	3	10-15	60–120 between sets 120–180 between exercises	Yes	Without exercise	No
Campa (2018)	RT performed using TRX.	12	60	Squat, rear deltoid row, biceps curl, chest press, low row, and rotational ward.	2	Manipulated by changing the inclination of the body from an upright position.	4	12	60	Yes	Without exercise	No
Souza (2017)	RT performed using a combination of free weights and machines.	12	NR	Chest press, horizontal leg press, seated row, knee extension, preacher curl, leg curl, triceps pushdown, seated calf raise.	3	10-15 RM	3	10-15	60–120 between sets 120–180 between exercises	Yes	Without exercise	No
Ribeiro (2017)	RT performed using a combination of free weights and machines (Constant Load).	8	NR	Chest press, horizontal leg press, seated row, knee extension, preacher curl, leg curl, triceps pushdown, seated calf raise.	3	8-12 RM	3	8-12	90 between sets 150 between exercises	Yes	Without exercise	No
	RT performed using a combination of free weights and machines (Pyramidal Load).	8	NR	Chest press, horizontal leg press, seated row, knee extension, preacher curl, leg curl, triceps pushdown, seated calf raise.	3	12/10/8 RM	3	12-10-8	90 between sets 150 between exercises	Yes		
Skelton (1995)	RT performed using a combination of rice bags, elastic tubing and body weight.	12	60	NR	3 (2 at home)	NR	3	4-8	NR	Yes and No	Without exercise	No

Abbreviations: n, number; min, minutes; sec, seconds; wk, week; RM, repetition maximum; RPE, rated perceived exertion; NR, not reported; NA, not applicable. a, the other groups under study were not analyse due to exclusion criterion number 4.

Table 4
Main results of the included studies.

First Author (Year)	Aim (s)	Group Cod	Phase angle results [a]		*p* value	Group × time interaction	*Effect Size*	*Interpretation of Effect Size*
			Pre	Post				
Campa (2021)	To compare the effects of 12 weeks of suspension training versus traditional resistance exercise using a combination of bands and bodyweight on body composition, bioimpedance vector patterns, and handgrip strength in older men.	CG	6.1 ± 0.6	5.8 ± 0.4	< **0.05**	**F= 24.4 p< 0.001**	**-0.61**[b]	**Moderate**
		IG (A)	6.5 ± 0.6	6.8 ± 0.7	< **0.05**		**0.48**[b]	**Small**
		IG (B)	6.5 ± 0.7	6.8 ± 0.8	< **0.05**		**0.41**[b]	**Small**
Osco (2021)	To investigate the effects of traditional RT compared to elastic tubes training on bioimpedance vector patterns, body composition, and strength in older women.	CG	NA			NA	NA	
		IG (A)	4.8 ± 0.6	5.1 ± 0.9	< **0.05**	**F= 11.1 p= 0.002**	**0.43**[b]	**Moderate**
		IG (B)	4.6 ± 0.6	4.6 ± 0.7	> 0.05		0.0[b]	Trivial
Dos Santos et al., 2020a	To compare the effects of the crescent pyramid system performed with a wide versus a narrow repetition zone on the most informative bioimpedance parameters in older women.	CG	5.61 ± 0.9	5.25 ± 0.6	> 0.05	**p< 0.001**	-0.40[c]	Small
		IG (Narrow)	5.46 ± 0.7	5.75 ± 0.6	< **0.05**		**0.41**[c]	**Small**
		IG (Wide)	5.48 ± 0.9	6.06 ± 0.7	< **0.05**		**0.64**[c]	**Moderate**
Ribeiro (2020)	To investigate the effects of 8 weeks of RT on phase angle in obese older women.	CG	5.52 ± 0.47	5.44 ± 0.44	> 0.05	**p< 0.001**	-0.16[c]	Trivial
		IG (A)	5.59 ± 0.51	5.78 ± 0.63	< **0.05**		**0.39**[c]	**Small**
Yi (2019)	To develop forest therapy programs that can be run in urban forest areas for the elderly population to prevent cognitive decline.	CG	5.38	NR	< **0.05**	NR	**0.85**[f]	**Higher**
		IG (BP)	4.91	NR	< **0.01**		**1.30**[f]	**Higher**
		IG (WP)	5.42	NR	< **0.05**		**0.44**[f]	**Small**
Yamada et al. (2019b)	To investigate the synergistic effects of bodyweight resistance exercise and a protein supplement with vitamin D on skeletal muscle in sarcopenic or dynapenic older adults.	CG	3.23 ± 0.65	3.13 ± 1.01	> 0.05	**F= 4.47 p< 0.001**	-0.12[b]	Trivial
		IG (A)	3.15 ± 0.65	3.26 ± 1.03	> 0.05		0.13[b]	Trivial
Nabuco (2019)	To analyze the effects of a combined whey protein and RT intervention on cellular health in pre-conditioned older women.	CG	NA[d]			NA[d]	NA[d]	NA[d]
		IG (A)	5.3 ± 0.5	5.7 ± 0.5	< **0.05**	NA	**0.78**[c]	**Moderate**
Cunha (2018)	To compare the effects of RT performed with different training volumes on phase angle, body water components, and muscle quality in untrained older adult women.	CG	5.67 ± 0.60	5.36 ± 0.51	< **0.05**	**p< 0.001**	**-0.56**[c]	**Moderate**
		IG (G1S)	5.87 ± 0.59	6.12 ± 0.49	< **0.05**		**0.45**[c]	**Small**
		IG (G3S)	5.50 ± 0.58	5.90 ± 0.61	< **0.05**		**0.73**[c]	**Moderate**
Ribeiro (2018)	To compare the effects of RT performed two versus three times per week on phase angle in older women.	CG	NA			NA	NA	NA
		IG (G2X)	6.06 ± 0.87	6.40 ± 0.92	< **0.05**	p= 0.250	**0.38**[c]	**Small**
		IG (G3X)	5.82 ± 0.95	6.42 ± 0.88	< **0.05**		**0.67**[c]	**Moderate**
Tomeleri (2018)	To investigate the effects of 12 weeks of RT on Phase Angle, inflammatory and oxidative stress biomarkers.	CG	5.6 ± 0.5	5.4 ± 0.5	< **0.05**	NR	**-0.40**[e]	**Small**
		IG (A)	5.4 ± 0.6	5.8 ± 0.7	< **0.05**		**0.61**[e]	**Moderate**
Campa (2018)	To propose a suspension exercise training program, and to analyze the effect of a 12-week training program on handgrip strength and anthropometric and bioelectrical impedance parameters in older women.	CG	5.6 ± 0.4	5.5 ± 0.5	> 0.05	**p< 0.001**	-0.22[b]	Small
		IG (A)	5.6 ± 0.4	5.9 ± 0.5	< **0.05**		**0.68**[b]	**Moderate**
Souza (2017)	To analyze the effect of RT on phase angle in older women.	CG	5.62 ± 0.55	5.49 ± 0.60	> 0.05	**p< 0.001**	-0.24[c]	Small
		IG (A)	5.53 ± 0.53	5.89 ± 0.63	< **0.05**		**0.68**[c]	**Moderate**
Ribeiro (2017)	To investigate the effect of two different RT prescription methods on phase angle in older women.	CG	5.56 ± 0.50	5.48 ± 0.46	> 0.05	**p< 0.001**	−0.17[c]	Trivial
		IG (A)	5.60 ± 0.49	5.76 ± 0.59	< **0.05**		**0.30**[c]	**Small**
		IG (B)	5.41 ± 0.65	5.63 ± 0.61	< **0.05**		**0.35**[c]	**Small**
Skelton (1995)	To determine the effects of 12 weeks of progressive resistance strength training on the isometric strength, explosive power, and selected functional abilities of healthy older women.	CG	6.0 ± 0.7	6.3 ± 0.7	> 0.05	p> 0.05 F= 0.778	0.44[b]	Small
		IG (A)	5.7 ± 0.7	6.2 ± 1.1	> 0.05		0.55[b]	Moderate

Abbreviations: Significant differences are highlighted in bold. CG, control group; IG, intervention group; NR, not reported; NA, not applicable; BP, breathing meditation program; WP, walking program.

[a] Data presents in mean and standard deviation;

[b] Effect size calculated by the authors according to *Cohen (1992)*: 0–0.19 = trivial effect size; 0.20 –0.49 = small effect size; 0.50–0.79 = moderate effect size; 0.80 and higher;

[c] Effect size by *Cohen (1992):* 0–0.19 = trivial effect size; 0.20 –0.49 = small effect size; 0.50–0.79 = moderate effect size; 0.80 and higher;
[d] The other groups under study were not analyse due to exclusion criterion number 4;
[e] Effect size by *Cohen (1988):* 0–0.19 = trivial effect size; 0.20 –0.49 = small effect size; 0.50–0.79 = moderate effect size; 0.80 and higher;
[f] Effect sizes by Rosnow et al. (2000) = 0.20 –0.49 = small effect size; 0.50–0.79 = moderate effect size; 0.80 and higher.

five studies did not report this value (Campa et al., 2021; Nabuco et al., 2019; Osco et al., 2021; Tomeleri et al., 2018; Yi et al., 2019). Regarding the dropout rates of the participants, eleven studies reported the interventions efficiency indicators' (Campa et al., 2018, Campa et al., 2021; Dos Santos et al., 2020a; Nabuco et al., 2019; Ribeiro et al., 2017, 2018, 2020; Skelton et al., 1995; Souza et al., 2017; Tomeleri et al., 2018; Yi et al., 2019), with two studies (Campa et al., 2018; Nabuco et al., 2019) stating that no participants dropped out from the IG. Furthermore, ten studies presented the dropout rate from their IG with further explanations (Campa et al., 2021; Dos Santos et al., 2020a; Ribeiro et al., 2017, 2018, 2020; Skelton et al., 1995; Souza et al., 2017; Tomeleri et al., 2018; Yamada et al., 2019b; Yi et al., 2019) and one study (Osco et al., 2021) provided no explanation for that dropout.

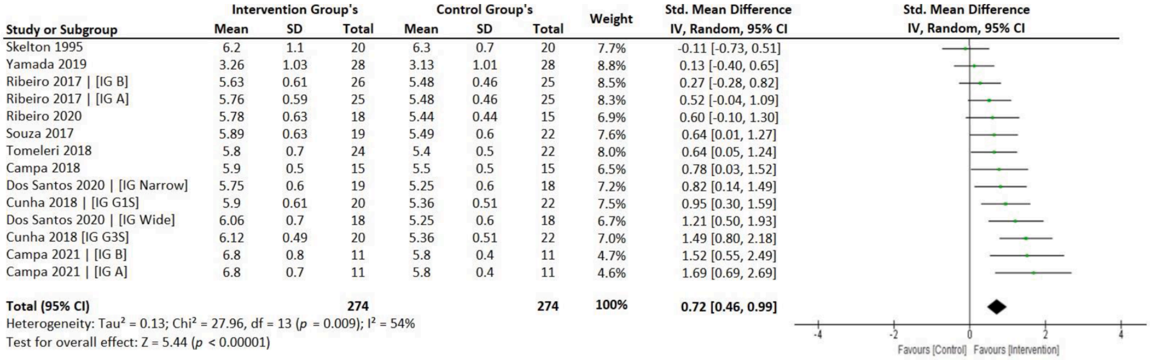
Finally, four studies did not report adverse events in both groups (Dos Santos et al., 2020a; Skelton et al., 1995; Souza et al., 2017; Yamada et al., 2019b), while the remaining studies made no reference to such events.

3.5. Results of the studies

Table 4 presents the aim, the code for each group under study, and main results for PhA of the fourteen included studies. Twelve studies showed a significant increase on PhA (Campa et al., 2018, 2021; Cunha et al., 2018; Dos Santos et al., 2020a; Nabuco et al., 2019; Osco et al., 2021; Ribeiro et al., 2017, 2018, 2020; Souza et al., 2017; Tomeleri et al., 2018; Yi et al., 2019). In terms of ES, six interventions showed a small effect [between 0.20 and 0.49] (Campa et al., 2021; Cunha et al., 2018; Dos Santos et al., 2020a; Ribeiro et al., 2017, 2018, 2020), and nine interventions revealed a moderate ES [between 0.5 and 0.79] (Campa et al., 2018; Cunha et al., 2018; Dos Santos et al., 2020a; Nabuco et al., 2019; Osco et al., 2021; Ribeiro et al., 2018; Skelton et al., 1995; Souza et al., 2017; Tomeleri et al., 2018). No intervention revealed a large ES, and only two interventions did not show a significant effect on PhA (Osco et al., 2021; Yamada et al., 2019b).

3.6. Meta-analysis

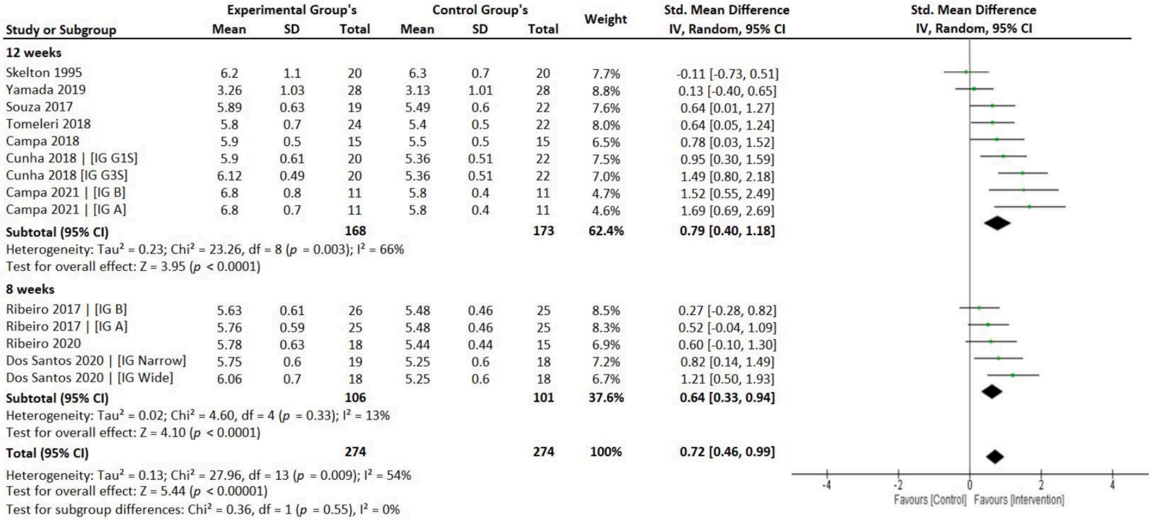
This meta-analysis included ten studies that incorporated fourteen



Study or Subgroup	Intervention Group's Mean	SD	Total	Control Group's Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Skelton 1995	6.2	1.1	20	6.3	0.7	20	7.7%	-0.11 [-0.73, 0.51]
Yamada 2019	3.26	1.03	28	3.13	1.01	28	8.8%	0.13 [-0.40, 0.65]
Ribeiro 2017 | [IG B]	5.63	0.61	26	5.48	0.46	25	8.5%	0.27 [-0.28, 0.82]
Ribeiro 2017 | [IG A]	5.76	0.59	25	5.48	0.46	25	8.3%	0.52 [-0.04, 1.09]
Ribeiro 2020	5.78	0.63	18	5.44	0.44	15	6.9%	0.60 [-0.10, 1.30]
Souza 2017	5.89	0.63	19	5.49	0.6	22	7.6%	0.64 [0.01, 1.27]
Tomeleri 2018	5.8	0.7	24	5.4	0.5	22	8.0%	0.64 [0.05, 1.24]
Campa 2018	5.9	0.5	15	5.5	0.5	15	6.5%	0.78 [0.03, 1.52]
Dos Santos 2020 | [IG Narrow]	5.75	0.6	19	5.25	0.6	18	7.2%	0.82 [0.14, 1.49]
Cunha 2018 | [IG G1S]	5.9	0.61	20	5.36	0.51	22	7.5%	0.95 [0.30, 1.59]
Dos Santos 2020 | [IG Wide]	6.06	0.7	18	5.25	0.6	18	6.7%	1.21 [0.50, 1.93]
Cunha 2018 [IG G3S]	6.12	0.49	20	5.36	0.51	22	7.0%	1.49 [0.80, 2.18]
Campa 2021 | [IG B]	6.8	0.8	11	5.8	0.4	11	4.7%	1.52 [0.55, 2.49]
Campa 2021 | [IG A]	6.8	0.7	11	5.8	0.4	11	4.6%	1.69 [0.69, 2.69]
Total (95% CI)			**274**			**274**	**100%**	**0.72 [0.46, 0.99]**

Heterogeneity: $Tau^2 = 0.13$; $Chi^2 = 27.96$, df = 13 ($p = 0.009$); $I^2 = 54\%$
Test for overall effect: Z = 5.44 ($p < 0.00001$)

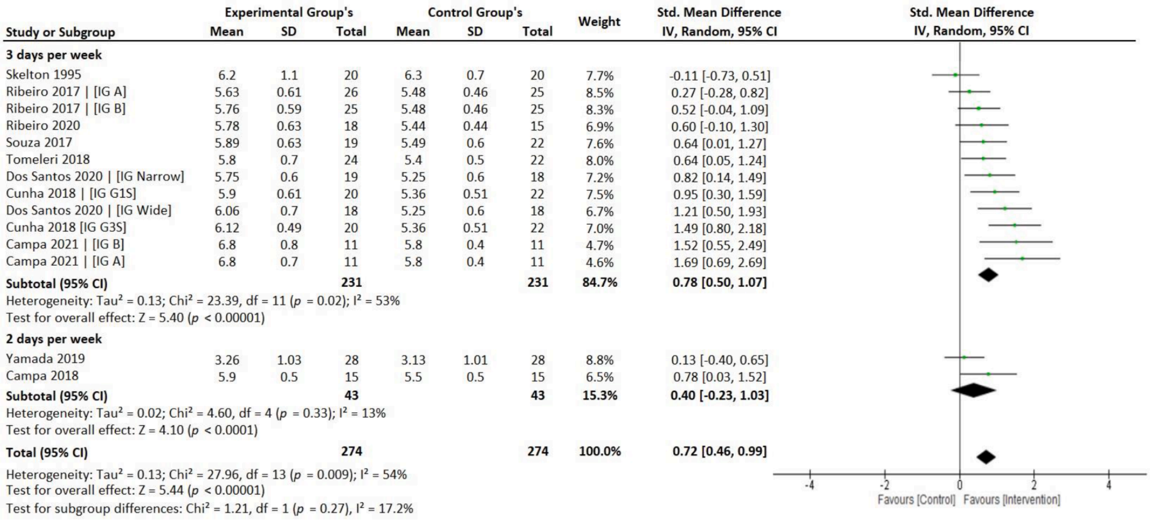
Fig. 2. Forest plot presenting standardized mean difference and 95% confidence intervals from studies reporting the effects of the exercise programs on phase angle between the intervention groups and the control groups. IV, independent variable; CI, confidence interval; SMD, standardized mean difference.



Study or Subgroup	Experimental Group's Mean	SD	Total	Control Group's Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
12 weeks								
Skelton 1995	6.2	1.1	20	6.3	0.7	20	7.7%	-0.11 [-0.73, 0.51]
Yamada 2019	3.26	1.03	28	3.13	1.01	28	8.8%	0.13 [-0.40, 0.65]
Souza 2017	5.89	0.63	19	5.49	0.6	22	7.6%	0.64 [0.01, 1.27]
Tomeleri 2018	5.8	0.7	24	5.4	0.5	22	8.0%	0.64 [0.05, 1.24]
Campa 2018	5.9	0.5	15	5.5	0.5	15	6.5%	0.78 [0.03, 1.52]
Cunha 2018 | [IG G1S]	5.9	0.61	20	5.36	0.51	22	7.5%	0.95 [0.30, 1.59]
Cunha 2018 [IG G3S]	6.12	0.49	20	5.36	0.51	22	7.0%	1.49 [0.80, 2.18]
Campa 2021 | [IG B]	6.8	0.8	11	5.8	0.4	11	4.7%	1.52 [0.55, 2.49]
Campa 2021 | [IG A]	6.8	0.7	11	5.8	0.4	11	4.6%	1.69 [0.69, 2.69]
Subtotal (95% CI)			**168**			**173**	**62.4%**	**0.79 [0.40, 1.18]**
Heterogeneity: $Tau^2 = 0.23$; $Chi^2 = 23.26$, df = 8 ($p = 0.003$); $I^2 = 66\%$								
Test for overall effect: Z = 3.95 ($p < 0.0001$)								
8 weeks								
Ribeiro 2017 | [IG B]	5.63	0.61	26	5.48	0.46	25	8.5%	0.27 [-0.28, 0.82]
Ribeiro 2017 | [IG A]	5.76	0.59	25	5.48	0.46	25	8.3%	0.52 [-0.04, 1.09]
Ribeiro 2020	5.78	0.63	18	5.44	0.44	15	6.9%	0.60 [-0.10, 1.30]
Dos Santos 2020 | [IG Narrow]	5.75	0.6	19	5.25	0.6	18	7.2%	0.82 [0.14, 1.49]
Dos Santos 2020 | [IG Wide]	6.06	0.7	18	5.25	0.6	18	6.7%	1.21 [0.50, 1.93]
Subtotal (95% CI)			**106**			**101**	**37.6%**	**0.64 [0.33, 0.94]**
Heterogeneity: $Tau^2 = 0.02$; $Chi^2 = 4.60$, df = 4 ($p = 0.33$); $I^2 = 13\%$								
Test for overall effect: Z = 4.10 ($p < 0.0001$)								
Total (95% CI)			**274**			**274**	**100%**	**0.72 [0.46, 0.99]**

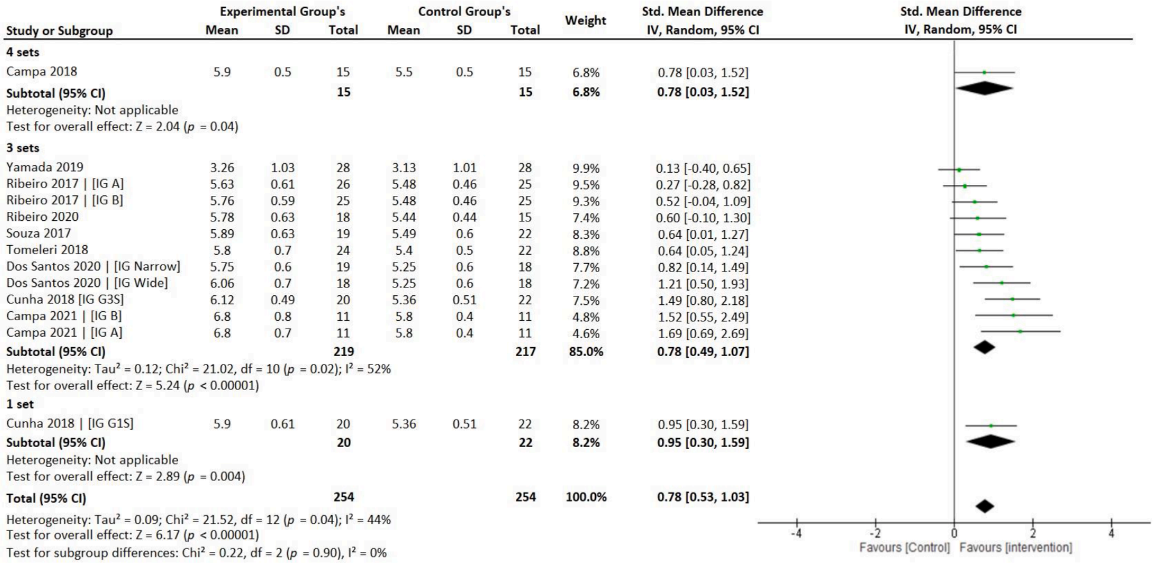
Heterogeneity: $Tau^2 = 0.13$; $Chi^2 = 27.96$, df = 13 ($p = 0.009$); $I^2 = 54\%$
Test for overall effect: Z = 5.44 ($p < 0.00001$)
Test for subgroup differences: $Chi^2 = 0.36$, df = 1 ($p = 0.55$), $I^2 = 0\%$

Fig. 3. Forest plot presenting the dose–response analysis regarding training period (12 *vs.* 8 weeks) on phase angle. IV, independent variable; CI, confidence interval; SMD, standardized mean difference.



Study or Subgroup	Experimental Group's			Control Group's			Weight	Std. Mean Difference IV, Random, 95% CI
	Mean	SD	Total	Mean	SD	Total		
3 days per week								
Skelton 1995	6.2	1.1	20	6.3	0.7	20	7.7%	-0.11 [-0.73, 0.51]
Ribeiro 2017 | [IG A]	5.63	0.61	26	5.48	0.46	25	8.5%	0.27 [-0.28, 0.82]
Ribeiro 2017 | [IG B]	5.76	0.59	25	5.48	0.46	25	8.3%	0.52 [-0.04, 1.09]
Ribeiro 2020	5.78	0.63	18	5.44	0.44	15	6.9%	0.60 [-0.10, 1.30]
Souza 2017	5.89	0.63	19	5.49	0.6	22	7.6%	0.64 [0.01, 1.27]
Tomeleri 2018	5.8	0.7	24	5.4	0.5	22	8.0%	0.64 [0.05, 1.24]
Dos Santos 2020 | [IG Narrow]	5.75	0.6	19	5.25	0.6	18	7.2%	0.82 [0.14, 1.49]
Cunha 2018 | [IG G1S]	5.9	0.61	20	5.36	0.51	22	7.5%	0.95 [0.30, 1.59]
Dos Santos 2020 | [IG Wide]	6.06	0.7	18	5.25	0.6	18	6.7%	1.21 [0.50, 1.93]
Cunha 2018 [IG G3S]	6.12	0.49	20	5.36	0.51	22	7.0%	1.49 [0.80, 2.18]
Campa 2021 | [IG B]	6.8	0.8	11	5.8	0.4	11	4.7%	1.52 [0.55, 2.49]
Campa 2021 | [IG A]	6.8	0.7	11	5.8	0.4	11	4.6%	1.69 [0.69, 2.69]
Subtotal (95% CI)			**231**			**231**	**84.7%**	**0.78 [0.50, 1.07]**
Heterogeneity: Tau² = 0.13; Chi² = 23.39, df = 11 (*p* = 0.02); I² = 53%								
Test for overall effect: Z = 5.40 (*p* < 0.00001)								
2 days per week								
Yamada 2019	3.26	1.03	28	3.13	1.01	28	8.8%	0.13 [-0.40, 0.65]
Campa 2018	5.9	0.5	15	5.5	0.5	15	6.5%	0.78 [0.03, 1.52]
Subtotal (95% CI)			**43**			**43**	**15.3%**	**0.40 [-0.23, 1.03]**
Heterogeneity: Tau² = 0.02; Chi² = 4.60, df = 4 (*p* = 0.33); I² = 13%								
Test for overall effect: Z = 4.10 (*p* < 0.0001)								
Total (95% CI)			**274**			**274**	**100.0%**	**0.72 [0.46, 0.99]**
Heterogeneity: Tau² = 0.13; Chi² = 27.96, df = 13 (*p* = 0.009); I² = 54%								
Test for overall effect: Z = 5.44 (*p* < 0.00001)								
Test for subgroup differences: Chi² = 1.21, df = 1 (*p* = 0.27), I² = 17.2%								

Fig. 4. Forest plot presenting the dose–response analysis regarding training frequency (3 *vs.* 2 times a week) on phase angle. IV, independent variable; CI, confidence interval; SMD, standardized mean difference.

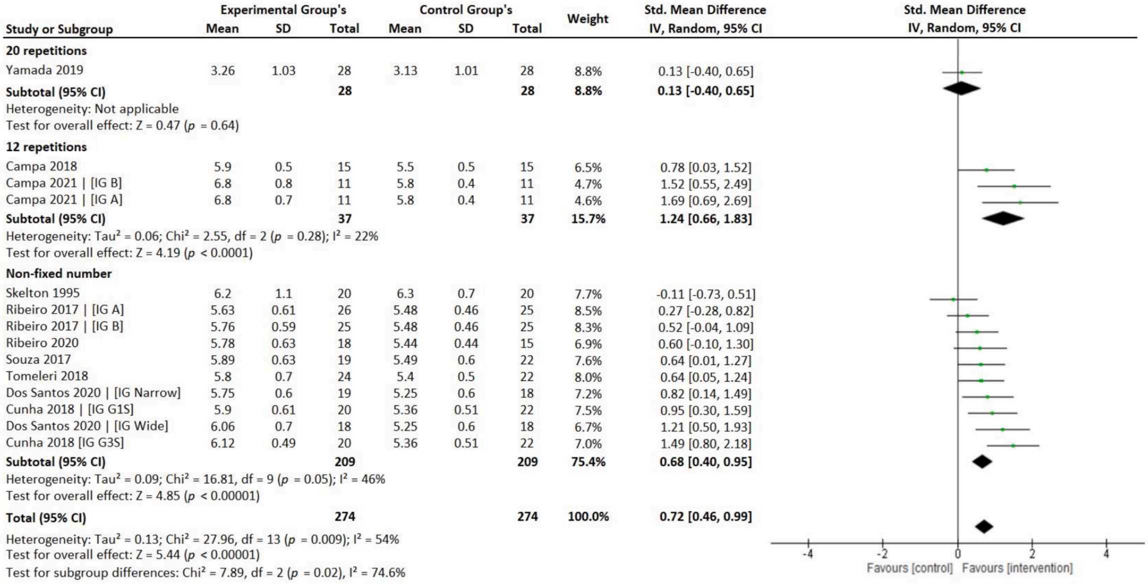


Study or Subgroup	Experimental Group's			Control Group's			Weight	Std. Mean Difference IV, Random, 95% CI
	Mean	SD	Total	Mean	SD	Total		
4 sets								
Campa 2018	5.9	0.5	15	5.5	0.5	15	6.8%	0.78 [0.03, 1.52]
Subtotal (95% CI)			**15**			**15**	**6.8%**	**0.78 [0.03, 1.52]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 2.04 (*p* = 0.04)								
3 sets								
Yamada 2019	3.26	1.03	28	3.13	1.01	28	9.9%	0.13 [-0.40, 0.65]
Ribeiro 2017 | [IG A]	5.63	0.61	26	5.48	0.46	25	9.5%	0.27 [-0.28, 0.82]
Ribeiro 2017 | [IG B]	5.76	0.59	25	5.48	0.46	25	9.3%	0.52 [-0.04, 1.09]
Ribeiro 2020	5.78	0.63	18	5.44	0.44	15	7.4%	0.60 [-0.10, 1.30]
Souza 2017	5.89	0.63	19	5.49	0.6	22	8.3%	0.64 [0.01, 1.27]
Tomeleri 2018	5.8	0.7	24	5.4	0.5	22	8.8%	0.64 [0.05, 1.24]
Dos Santos 2020 | [IG Narrow]	5.75	0.6	19	5.25	0.6	18	7.7%	0.82 [0.14, 1.49]
Dos Santos 2020 | [IG Wide]	6.06	0.7	18	5.25	0.6	18	7.2%	1.21 [0.50, 1.93]
Cunha 2018 [IG G3S]	6.12	0.49	20	5.36	0.51	22	7.5%	1.49 [0.80, 2.18]
Campa 2021 | [IG B]	6.8	0.8	11	5.8	0.4	11	4.8%	1.52 [0.55, 2.49]
Campa 2021 | [IG A]	6.8	0.7	11	5.8	0.4	11	4.6%	1.69 [0.69, 2.69]
Subtotal (95% CI)			**219**			**217**	**85.0%**	**0.78 [0.49, 1.07]**
Heterogeneity: Tau² = 0.12; Chi² = 21.02, df = 10 (*p* = 0.02); I² = 52%								
Test for overall effect: Z = 5.24 (*p* < 0.00001)								
1 set								
Cunha 2018 | [IG G1S]	5.9	0.61	20	5.36	0.51	22	8.2%	0.95 [0.30, 1.59]
Subtotal (95% CI)			**20**			**22**	**8.2%**	**0.95 [0.30, 1.59]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 2.89 (*p* = 0.004)								
Total (95% CI)			**254**			**254**	**100.0%**	**0.78 [0.53, 1.03]**
Heterogeneity: Tau² = 0.09; Chi² = 21.52, df = 12 (*p* = 0.04); I² = 44%								
Test for overall effect: Z = 6.17 (*p* < 0.00001)								
Test for subgroup differences: Chi² = 0.22, df = 2 (*p* = 0.90), I² = 0%								

Fig. 5. Forest plot presenting the dose–response relationships of number of sets (4 *vs.* 3 *vs.* 1 set) on phase angle. IV, independent variable; CI, confidence interval; SMD, standardized mean difference.

interventions which revealed moderate effects on PhA in favour of IG's when compared to CG's (p= 0.009, SMD= 0.72, [0.46–0.99], $I^2 = 54\%$, see Fig. 2). Figs. 3 to 6 present the dose–response analysis regarding training period, weekly frequency, number of sets and repetitions. In this sense, twelve weeks as opposed to eight weeks are most effective in producing positive effects on the overall value of the PhA (SMD's= 0.79 *vs.* 0.64, respectively).

Regarding training frequency, Fig. 4 shows that three sessions per week had most significant effects in improving PhA when compared to two sessions per week (SMD's = 0.78 *vs.* 0.40, respectively). Fig. 5 illustrates the dose–response analysis in relation to the number of sets used in the included studies. Our analysis revealed similar effects from four, three and one set on the PhA, with most studies including three sets. Finally, Fig. 6 shows that twelve repetitions produced the largest effects on PhA (SMD= 1.24 [0.66, 1.83]) when compared to twenty (SMD= 0.13 [-0.40, 0.65]) and non-fixed number (SMD= 0.68 [0.40, 0.95]).



Study or Subgroup	Experimental Group's Mean	Experimental Group's SD	Experimental Group's Total	Control Group's Mean	Control Group's SD	Control Group's Total	Weight	Std. Mean Difference IV, Random, 95% CI
20 repetitions								
Yamada 2019	3.26	1.03	28	3.13	1.01	28	8.8%	0.13 [-0.40, 0.65]
Subtotal (95% CI)			**28**			**28**	**8.8%**	**0.13 [-0.40, 0.65]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.47 (p = 0.64)								
12 repetitions								
Campa 2018	5.9	0.5	15	5.5	0.5	15	6.5%	0.78 [0.03, 1.52]
Campa 2021 | [IG B]	6.8	0.8	11	5.8	0.4	11	4.7%	1.52 [0.55, 2.49]
Campa 2021 | [IG A]	6.8	0.7	11	5.8	0.4	11	4.6%	1.69 [0.69, 2.69]
Subtotal (95% CI)			**37**			**37**	**15.7%**	**1.24 [0.66, 1.83]**
Heterogeneity: $Tau^2 = 0.06$; $Chi^2 = 2.55$, df = 2 (p = 0.28); $I^2 = 22\%$								
Test for overall effect: Z = 4.19 (p < 0.0001)								
Non-fixed number								
Skelton 1995	6.2	1.1	20	6.3	0.7	20	7.7%	-0.11 [-0.73, 0.51]
Ribeiro 2017 | [IG A]	5.63	0.61	26	5.48	0.46	25	8.5%	0.27 [-0.28, 0.82]
Ribeiro 2017 | [IG B]	5.76	0.59	25	5.48	0.46	25	8.3%	0.52 [-0.04, 1.09]
Ribeiro 2020	5.78	0.63	18	5.44	0.44	15	6.9%	0.60 [-0.10, 1.30]
Souza 2017	5.89	0.63	19	5.49	0.6	22	7.6%	0.64 [0.01, 1.27]
Tomeleri 2018	5.8	0.7	24	5.4	0.5	22	8.0%	0.64 [0.05, 1.24]
Dos Santos 2020 | [IG Narrow]	5.75	0.6	19	5.25	0.6	18	7.2%	0.82 [0.14, 1.49]
Cunha 2018 | [IG G1S]	5.9	0.61	20	5.36	0.51	22	7.5%	0.95 [0.30, 1.59]
Dos Santos 2020 | [IG Wide]	6.06	0.7	18	5.25	0.6	18	6.7%	1.21 [0.50, 1.93]
Cunha 2018 [IG G3S]	6.12	0.49	20	5.36	0.51	22	7.0%	1.49 [0.80, 2.18]
Subtotal (95% CI)			**209**			**209**	**75.4%**	**0.68 [0.40, 0.95]**
Heterogeneity: $Tau^2 = 0.09$; $Chi^2 = 16.81$, df = 9 (p = 0.05); $I^2 = 46\%$								
Test for overall effect: Z = 4.85 (p < 0.00001)								
Total (95% CI)			**274**			**274**	**100.0%**	**0.72 [0.46, 0.99]**
Heterogeneity: $Tau^2 = 0.13$; $Chi^2 = 27.96$, df = 13 (p = 0.009); $I^2 = 54\%$								
Test for overall effect: Z = 5.44 (p < 0.00001)								
Test for subgroup differences: $Chi^2 = 7.89$, df = 2 (p = 0.02), $I^2 = 74.6\%$								

Fig. 6. Forest plot presenting the dose–response analysis regarding number of repetitions (4 *vs.* 3 *vs.* 1 set) on phase angle. IV, independent variable; CI, confidence interval; SMD, standardized mean difference.

4. Discussion

The main purpose of the present systematic review and meta-analysis was to calculate the effects of exercise programs on PhA in older people, and as ancillary purpose to describe the characteristics of the exercise programs as well as provide recommendations for future studies. Our systematic review provides evidence that exercise programs had a positive effect on PhA in older people, especially from RT considering that only one study did not use this type of intervention (Yi et al., 2019). These results were corroborated by our meta-analysis that showed evidence of a causal relationship, wherein differences in PhA from the baseline were significantly higher for the IG than the CG.

Considering the study that did not perform an RT program (Yi et al., 2019), the authors used an intervention program that consisted in a "forest bathing trip" which, according to the literature has effects on human immune function and physiology (Li et al., 2007; Park et al., 2007, 2010; Song et al., 2016). A "forest bathing trip" involves a visit to a forest field for the purpose of relaxation and recreation. Moreover, Park et al. (2010) defined the term as "making contact with nature and taking in the atmosphere of the forest: a process intended to improve an individual's state of mental and physical relaxation". This study recorded increases in the whole body and segmental PhA's. The authors stated that the contrasting behaviors of segmental PhA's are mostly caused by the changes in reactance values rather than impedance values. Despite the authors did not present a plausible explanation for the increase in PhA, evidence suggests that active people, have better PhA (Pessoa et al., 2020), and as a consequence, better health outcomes.

The present review found that thirteen studies improve PhA through the application of RT. This is supported by several studies that have shown that RT is effective for improving strength and PhA in older adults (Campa et al., 2021; Cunha et al., 2018; Dos Santos et al., 2016; Dos Santos et al., 2020a; Nabuco et al., 2019; Osco et al., 2021; Ribeiro et al., 2017, 2018, 2020; Souza et al., 2017; Taaffe et al., 2009; Yi et al., 2019). Interestingly, PhA is closely associated with changes in muscle strength (Souza et al., 2017; Toselli et al., 2020; Yamada et al., 2019b).

A recent review suggested that there is a graded dose–response relationship between RT volume and muscular strength adaptations (Grgic et al., 2018). A number of reviews and meta-analyses already examined the effects of different exercise programs in older adults (Campa et al., 2021; Cunha et al., 2018; Dos Santos et al., 2016, Dos Santos et al., 2020a; Nabuco et al., 2019; Osco et al., 2021; Ribeiro et al., 2017, 2018, 2020; Souza et al., 2017; Taaffe et al., 2009; Yi et al., 2019) revealing that among others, RT is recommended if the main goal is to increase strength, cellular health, reduce risk and rate of falls in older adults. However, it was not found any systematic review and meta-analysis about the effects of exercise programs on PhA.

In this sense, the present study reveals the effects of exercise programs *vs.* a passive CG on increasing PhA values (Fig. 2). The efficacy of the exercise programs is highlighted by the significant increases in PhA that can be interpreted as increases in body cellular mass. The effectiveness of these exercise programs in improving the PhA may depend on the use of the exercise variables, *i.e.*, intensity, volume, frequency, and density, which may result in different load management methods (constant load and upward pyramidal load) (Sardinha, 2018).

4.1. Dose–response relationships

The general health benefits of exercise are well established. However, the relationship between exercise volume, intensity and health benefits remains unclear, particularly the benefits of low or high volume and intensity exercise. Current recommendations promote physical activity/exercise volumes of at least 150 min/week (Tremblay et al., 2011; Warburton et al., 2010). The vast majority of studies in the present review focus on RT, in which the applied load is considered important for the improvement of muscle strength and mass in older adults and is related to PhA (Borde et al., 2015). Several studies (Borde et al., 2015; Csapo & Alegre, 2016; Fatouros et al., 2005; Raymond et al., 2013; Steib et al., 2010), where it was indicated that there is a dose–response relationship between magnitude of load and muscle strength increase in older adults which consequently may produce changes in body composition, and thus on PhA.

Our investigation identified improvements among the larger volume and intensity training programs, supporting the greater amounts of RT. The small ES of some studies in improving the PhA may be related to the type of resistance and equipment used, as well as to the periodization and volumes of the training stimulus (Campa et al., 2021; Dos Santos et al., 2020a; Ribeiro et al., 2017). On the other hand, the largest PhA improvements were observed among training programs of greater duration and/or intensity supporting the dose–response relationship demonstrated consistently in epidemiological research. The benefits associated with RT depend on the manipulation of the training variables mentioned above (Ribeiro et al., 2017) underlying the RT prescription, (*i.e.*, intensity, volume, frequency, and density) (ACSM, 2009; Borde et al., 2015; Schoenfeld, 2010).

The frequency of a RT program has also an effect on physiological adaptations due to RT performance with several studies showing a dose-response relationship between RT frequency and muscular adaptations (Borde et al., 2015; Dankel et al., 2017; Lera Orsatti et al., 2014; Schoenfeld et al., 2016a, 2016b; Wernbom et al., 2007). Consequently, it seems that there is a dose-response between the RT variables and the adaptations related to the subjects' general health. However, it is still unclear whether there is a dose-response between the training variables and the PhA.

4.2. *Training method and type of equipment*

As mentioned above, the training method and the type of equipment can have different effects on neuromuscular and body composition adaptations. For instance, RT can induce changes in body composition which may alter the electrical conductivity of the body, consequently resulting in PhA changes. Souza et al. (2017) investigated the effects of twelve weeks of RT in older women and observed an increase in PhA in a 2-arm randomized controlled trial using a constant load method. This method is characterized by the use of the same loads related to a given number of repetitions in the sets of a given exercise. However, other training methods have been explored in an attempt to maximize the benefits induced by RT.

Among the different RT methods, the pyramid is a training approach frequently used by athletes and non-athletes in order to improve neuromuscular adaptations (Fleck & Kraemer, 2014). Due to its inherent characteristic of varying loads and number of repetitions, allowing RT to be carried out at absolute loads compared to constant method, the pyramid method may induce a favorable stimulus to increase strength (Fleck & Kraemer, 2014). However, the results showed by Souza et al. (2017) failed to demonstrate the superiority of the pyramid method over the constant method. The authors reported that both RT methods similarly improved PhA in older women. Whereas Dos Santos et al., 2020a when comparing the effects of the crescent pyramid RT system with two repetition zones on PhA, reported greater changes for the pyramid with a wide repetition zone training (D% = 10.6; ES = 0.64) when compared to pyramid with a narrow repetition zone training (D% = 5.3; ES = 0.41) and CG (D% = −6.4; ES = −0.40). The results revealed that the crescent pyramid RT system with both repetition zones (wide repetition zone and narrow repetition zone) were effective for inducing improvements on PhA in older women, although the pyramid with a wide repetition zone training increases the PhA more than the narrow repetition zone. The study by Ribeiro et al. (2017) also reported that the RT based on a constant or an ascending pyramidal load routine promotes equal improvements in PhA in older women.

Most studies in this review used a combination of free weights and machines (Cunha et al., 2018; Dos Santos et al., 2020a; Nabuco et al., 2019; Osco et al., 2021; Ribeiro et al., 2017, 2018, 2020; Souza et al., 2017; Tomeleri et al., 2018). The use of this type of equipment allows for a more accessible manipulation of training intensity with the adjusted weekly load of each exercise (Dos Santos et al., 2020a; Fukuda et al., 2016; Nunes et al., 2019; Ribeiro et al., 2016, 2020; Skelton et al., 1995; Souza et al., 2017). However, in some studies, the load was constant during the performance of all sets of an exercise (Souza et al., 2017). Studies that manipulate the applied load use different methodologies: weekly change or every two weeks (Nunes et al., 2019; Osco et al., 2021) or increase the applied load by 2-5% for the upper limb exercises and 5-10% for the lower limb exercises to the next session when the number of the set of repetitions was completed for two consecutive training sessions (ACSM, 2009; Dos Santos et al., 2020a; Ribeiro et al., 2016, 2017, 2018). A similar methodology was used by Nabuco et al. (2019) and Fukuda et al. (2016), by determining that when subjects completed twelve repetitions for the last set of an exercise for two consecutive lifting sessions, weight was increased by at least 2.5–10% in considering the nature of the exercise.

Studies that used body weight, suspension device and elastic bands in the RT program manipulated the intensity of the exercises by changing the inclination of the body from an upright position or increased the resistance of the bands (Campa et al., 2018; Campa et al., 2021; Osco et al., 2021; Yamada et al., 2019b). Still, others increased the time under tension by performing slow movements that had the effect of increasing the PhA by 0.21±0.09° (Yamada et al., 2019b), although the authors did not clarify whether there was any manipulation of the intensity and volume of the training program. Taking into account the results of the analysed studies, it seems that the adjustment of the load when the upper limit of the repetition interval is reached is the key element in the adaptations that promote an increase in PhA.

4.3. *Training period*

Our analysis illustrates that most of the RT programs between eight to twelve weeks were effective in enhancing PhA. No relationship was found between the duration of the intervention period and changes in the PhA. However, it is likely that longer interventions may be more effective in improving PhA as compared to shorter training periods (Sardinha, 2018). Fukuda et al. (2016) found that PhA values increased in older women after a 6-month RT program. However, the lack of a CG did not allow a more consistent analysis of impact of chronic adaptations to RT on PhA values.

Several studies reported that functional changes induced by prolonged exposure mainly through RT with different permutations of stimuli in exercise programming, including frequency, have differential exercise-induced effects on cellular physiology and tissues (Dos Santos et al., 2016; Ribeiro et al., 2016; Sardinha, 2018). In this vein, the studies that showed a greater effect on PhA had a twelve weeks duration (Campa et al., 2018, 2021; Cunha et al., 2018; Skelton et al., 1995; Souza et al., 2017; Tomeleri et al., 2018; Yamada et al., 2019b). In the present meta-analysis, we found a greater impact of studies with longer duration (twelve *vs.* eight weeks; SMD = 0.79 [0.40, 1.18] *vs.* SMD = 0.64 [0.33, 0.94]) on the PhA.

Research limitation in the study of the influence of the training period on PhA is that most studies examined adaptations in previously inactive or moderately active populations. Program efficacy differentiation is difficult because inactive individuals respond favorably to a multitude of training stimuli. As the "window of adaptation" decreases during long-term resistance training, more scientific recommendations are needed to properly address program design in trained populations targeting muscle strength and hypertrophy increases (ACSM, 2009).

4.4. *Training frequency*

Regarding the specific training volume for the number of RT sessions to be performed per week, a recent meta-analyses indicates that the higher the frequency, the greater the gains in strength (Grgic et al., 2018) and hypertrophy (Schoenfeld et al., 2019).

Our review reveals that RT performed three- or two-times week induces similar changes in PhA, however our meta-analysis shows that three sessions per week had most significant effects in improving PhA when compared to two sessions per week (SMD = 0.78 [0.50, 1.07] *vs.* 0.40 [-0.23, 1.03], respectively). It is relevant to consider that only two studies used a frequency of two weekly sessions which reduces the strength of the analysis.

Ribeiro et al. (2017) analyzed a sample of 45 older women, divided them into one of two RT groups (frequency of two and three times per week, respectively). The main result from this intervention was that RT performed with higher frequency had the same positive adaptations in the PhA when compared with a lower RT frequency. Nevertheless, the authors reported that the absolute change in PhA was greater in the group with a frequency of three sessions per week than the group with two sessions per week (10.3% *vs.* 5.6%, respectively) with an ES of 0.29

[small effect], indicating a potential positive correlation between the frequency of the volume training and the effects in PhA.

To our knowledge only Ribeiro et al. (2017) have examined the impact of RT frequency on PhA. Therefore, whether dose-response exists between training frequency and PhA in the older people is still limited more research is needed to answer the question of the effects of RT frequency on PhA in the older people (Grgic et al., 2018).

4.5. *Training intensity and volume*

As previously mentioned, the potential benefits provided by RT seem to depend on the correct manipulation of several training variables that make up the training programs, including intensity and volume (ACSM, 2009; Cunha et al., 2018; Schoenfeld, 2010). Current guidelines for RT programs recommend that healthy older adults should perform one to three sets for improvements in muscle mass and muscular strength (ACSM, 2009; Borde et al., 2015; Garber et al., 2011; Silva et al., 2014). It has been suggested that higher training volumes of RT may elicit greater metabolic stress, which may provide different responses to hypertrophic adaptations (Grgic & Schoenfeld, 2018; Schoenfeld, 2013). Thus, it is possible that an increase in RT volumes provides greater adaptations in PhA in older adult women, given that it may cause changes in lean tissue mass (Fragala et al., 2015; Gonzalez et al., 2016; Nunes et al., 2019).

The number of sets performed in the studies analyzed in this review and meta-analysis varied between one (Cunha et al., 2018; Ribeiro et al., 2018) to four per exercise (Campa et al., 2018), and only one study used a non -fixed number of sets (Osco et al., 2021). Our analysis revealed similar effects on the PhA for all scenarios. At this stage, it seems plausible that the PhA is affected by small changes generated by RT interventions, but there is lack of evidence on the effects of distinct RT protocols on PhA, in older women. In the present analysis, only Cunha et al. (2018) examined how different RT volumes could impact PhA in untrained older women. Findings from this study showed that both training groups (with different volumes) improved intracellular and total body water, and PhA, when compared to the CG. The study by Ribeiro et al. (2017) compared equal volumes of RT albeit based in constant and in ascending pyramidal load routines concluding that both promote equal improvements in PhA, in older women. The authors present as rationale that the pyramid system would allow training with higher loads (at least in the latter sets).

The intensity of the sessions of the analyzed studies was quantified through RM (Cunha et al., 2018; Dos Santos et al., 2020a; Osco et al., 2021; Ribeiro et al., 2017, 2018; Souza et al., 2017; Tomeleri et al., 2018) and RPE (Campa et al., 2021; Yi et al., 2019). To be effective, RT needs to overload the muscles by providing an amount of resistance (e.g., with a weight or exercise band) that ensures that an exercise can only be done 8–15 times before muscles fatigue (Chodzko-Zajko et al., 2009). Accordingly, the present review suggests that the intensity used in most studies may have been sufficient to promote similar adaptive responses on PhA.

Concerning the number of repetitions used per set of exercise, our analysis revealed that an overall number of four (Skelton et al., 1995) to 20 repetitions (Yamada et al., 2019b) were used. However, some studies used a range of ten to fifteen repetitions (Cunha et al., 2018; Osco et al., 2021; Ribeiro et al., 2018; Souza et al., 2017; Tomeleri et al., 2018). A lower number of repetitions implies that the movement of higher loads may produce larger effects in terms of neuromuscular adaptations in a short intervention period (Bemben et al., 2000; Coelho-Júnior et al., 2019; Kalapotharakos et al., 2005; Raymond et al., 2013). Nevertheless, both range of repetitions zones are found to be equally effective in promoting changes in the PhA (Campa et al., 2018, 2021; Cunha et al., 2018; Dos Santos et al., 2020b; Nabuco et al., 2019; Osco et al., 2021; Ribeiro et al., 2017, 2018, 2020; Souza et al., 2017; Tomeleri et al., 2018). The present meta-analysis shows that twelve repetitions produced the largest effects on PhA (SMD= 1.24 [0.66, 1.83]) when compared to twenty (SMD= 0.13 [-0.40, 0.65]) and non-fixed number (SMD= 0.68 [0.40, 0.95]).

Despite the interventions using different training intensity and volumes, the RT seems to play an important role in PhA improvements as well as being safe and highly recommended for eliciting increases in muscle mass and qualitative remodeling.

In summary, it appears that the functional capabilities of muscle in elderly can be enhanced with minimal engagement in RT. Further research contrasting higher dosages and greater volume with lower dosages/volumes seem warranted.

5. Conclusions

The present review with meta-analysis presented three important findings regarding the effects of the exercise programs on PhA in older adults. Firstly, RT causes positive changes in the PhA, with this being the most used intervention when assessing the effects on that variable. Secondly, we recommend that RT programs should last at least twelve weeks, with three sessions per week, six to ten exercises with twelve repetitions per set in order to enhance PhA. Finally, the RT prescription in older adults is safe and effective and should be implemented for the purposes of preventing the decline of cellular health.

6. Future lines of research

There are still some challenges that need to be addressed in order to further improve our understanding about how the PhA can be improved through exercise programs. Firstly, there is a need to improve exercise research programs aimed at cellular adaptations through cardiorespiratory exercise with moderate and high intensities, sprint training and high intensity interval training. Secondly, another relevant area of research is the concurrent training (RT and endurance training). Combining these two different types of exercise may induce-specific cellular adaptations that can attenuate each other or have a synergistic effect on PhA. Subsequently, we strongly recommend that future studies in this field clearly report further information namely: (i) level of previous training of the participants, (ii) position adopted during the assessment (i.e., sitting or lying position), and (iii) if participants are fasting or not before the assessment.

Finally, researchers should aim to include a follow-up period in their investigations to confirm the potential long-term effects of exercise programs on the PhA (chronic effects).

All authors approved the final version of the manuscript.

CRediT authorship contribution statement

Alexandre Duarte Martins: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration, Funding acquisition. **Orlando Fernandes:** Conceptualization, Validation, Formal analysis, Writing – original draft, Writing – review & editing, Visualization, Supervision. **Rafael Oliveira:** Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Funding acquisition. **Vitor Bilro:** Conceptualization, Resources, Data curation, Visualization. **Gabriel Lopes:** Conceptualization, Resources, Data curation, Visualization. **António Maia Rego:** Conceptualization, Resources, Data curation, Visualization. **José A. Parraça:** Conceptualization, Writing – review & editing, Visualization. **Armando Manuel Mendonça Raimundo:** Conceptualization, Writing – review & editing, Visualization. **João Paulo Brito:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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