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Featured Article

Influence of physical exercise on respiratory muscle function in older adults: A systematic review and meta-analysis

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ABSTRACT

Respiratory function decreases with aging. The literature showed that non-ventilatory specific exercise could have a positive impact on respiratory muscles. A systematic literature review was conducted to assess the effects of non-ventilatory specific exercise on maximal inspiratory (MIP) and expiratory pressure (MEP) and peak expiratory flow (PEF) in older adults. The included 9 trials investigated the effects of resistance training, yoga, Pilates, physical activity based on walking, and whole-body vibration training. The meta-analysis showed no statistically significant differences in MIP, MEP, and PEF after implementation of a non-ventilatory specific exercise program in older individuals. Between-study heterogeneity was substantial for MIP and MEP outcomes but it was not statistically significant for PEF. Further RCTs will be necessary to determine the effects of physical exercise interventions. PROSPERO registry CRD42023478262.
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Introduction

Ageing is associated with a decline in physiological reserve mechanisms.[1] Advanced age is related to low muscle mass, weakness, disability, and decreased respiratory system function, among other changes. Most of those in the respiratory system evolve from decreasing chest wall compliance, static elastic recoil of the lungs, and strength of respiratory muscles.[2] Greising et al.[3] reported diminishing type II fiber on the diaphragm muscle in mice of advanced age, which are replaced by type I muscle fiber, similarly to changes on skeletal muscles observed by Frontera et al.[4] Moreover, diaphragm strength diminishes,[3,5,6] causing a deterioration of respiratory force generation, with potential impacts on pulmonary function[7] and in turn activities of daily living and quality of life.[8] The natural accumulation of age-related physiological changes, in addition to exposure to toxic environmental factors, makes the respiratory system susceptible to chronic diseases like chronic obstructive pulmonary disease (COPD) and infectious diseases like community-acquired pneumonia.[9]

In addition to ventilatory behaviors, respiratory muscles have non-ventilatory functions, including sneezing, gagging, and coughing.[6] Older people may find it difficult to clear the upper airways properly by coughing,[6] putting them at risk for developing lung infections and other pulmonary diseases—a risk that gradually increases and contributes to age-related morbidity and mortality.[9]

Other external factors, for example a sedentary lifestyle, can exacerbate the ageing process and its specific impacts on the respiratory system.[10] Limited physical activity (PA) could accelerate the decline of respiratory muscles' capacity to generate force,[5,11] whereas a higher level of PA could translate to greater respiratory muscle pressures and a thicker diaphragm muscle.[12]

With the aim of contributing to good respiratory health in older people, different studies have explored the effects of respiratory muscle training on inspiratory[13] and expiratory muscle strength,[14] with positive outcomes in both cases. Other authors have suggested that non-ventilatory specific (NVS) exercise could have a positive impact on respiratory muscles.[13] This hypothesis posits that strenuous NVS activities involve abdominal muscle recruitment, thereby raising abdominal pressure, and the increased tension of the diaphragm minimizes the transmission of intra-abdominal pressure to the thorax, strengthening the respiratory muscles.[15] The World Health Organization (WHO) recommends regular aerobic exercise and resistance training (RT) in old people.[16] With those guidelines in mind, some

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authors have explored whether NVS exercises alone are able to improve respiratory strength and function. Assouline et al.[17] reported that during the preoperative waiting period, NVS training based on RT and/or respiratory muscle training led to an increase in maximal inspiratory pressure (MIP) compared to controls. In their systematic review and meta-analysis, Bhagel et Saha[18] reported that yoga practice in healthy individuals, including children and both younger and older adults, has a significant effect on peak expiratory flow (PEF) and maximal respiratory pressures (MIP and maximal expiratory pressure [MEP]) compared to control groups, albeit with substantial between-study heterogeneity. However, there is no systematic review investigating the effects of NVS training on respiratory muscle strength in older adults.

Our primary hypothesis is that NVS exercise interventions could positively impact MIP, MEP, and PEF in older people without chronic or acute respiratory, metabolic, neurological, or heart conditions. Thus, this review aimed to assess the effects of physical exercise targeting skeletal muscles or NVS exercise on MIP, MEP, and PEF in older adults.

Material and methods

A systematic review and meta-analysis was performed (PROSPERO registry CRD42023478262).

Bibliographic search

Electronic databases (PubMed, EMBASE and Web of Science) were searched from inception to 15 June 2023, with no restrictions on publication date. The search strategy was constructed using Boolean operators, with descriptors related to the population of interest, the intervention, and the outcomes: "(training OR exercise) AND ((old people) OR elderly) AND ((respiratory muscles) OR (respiratory strength)) NOT COPD" (chronic obstructive pulmonary disease). We specified COPD because of the large number of studies published.

Search results were screened by title; if deemed relevant to the scope of this review, abstracts were read to verify whether they met the established inclusion criteria. We handsearched reference lists of the selected studies for additional articles. The full text of all selected articles was read to extract the data of interest for this review.

Inclusion and exclusion criteria

Randomized controlled trials (RCTs) written in either English or Spanish were included. Studies were considered eligible if they fulfilled the pre-determined criteria for participants, interventions, comparisons, outcomes, and study design (PICOS) (Table 1). The eligible population was older adults (mean age $\geq$ 60 years) with no chronic or acute respiratory, metabolic, neurological, or heart conditions that could affect respiratory function or performance. Interventions comprised NVS physical exercise programs, which were compared to a control group and/or other interventions to assess outcomes that included MIP, MEP, PEF, or any combination of these. We excluded interventions consisting of breathing exercises (e.g. sandbag respiratory exercises, inspiratory muscle training, expiratory muscle training, or others), whether studied alone or in conjunction with physical exercise.

Two review authors (CF-R and FMM-A) independently searched for, selected, and assessed the quality of the included records. Disagreements were resolved by consensus, involving a third review author when necessary (PP-R).

Data extraction

The following data were extracted: study information (first author, year of publication, and country); sample size; participant characteristics (mean age by intervention groups, sex, other relevant characteristics of targeted population; parameters analyzed (measurement units); description of experimental and comparator intervention, including intensity, frequency, and duration; and assessment time points.

Quality assessment

The PEDro quality scale was used to assess the internal and external validity of the included studies.[19] The 11-item PEDro scale is based on the 9-item Delphi list developed by Verhagen and colleagues at the Department of Epidemiology, University of Maastricht. Two authors (CF-R and FMM-A) independently reviewed each included study along the domains of the PEDro scale.[19] Scores rated at 9–11 points were considered of excellent quality, 6–8 good, 4–5 fair, and $\leq$ 3 poor. No study was excluded based on poor quality. Discrepancies were resolved by involving a third review author (PP-R).

Assessment of risk of bias

The reviewers independently rated the quality of the studies using the Cochrane risk of bias tool (RoB2),[20] which assesses seven domains: random sequence generation; allocation concealment; blinding of participants and personnel; blinding of outcome assessment; incomplete outcome data; selective reporting; and other sources of bias. For each study and domain, we assigned ratings of high, low, or unclear risk of bias. The judgements were made independently by two review authors (CF-R and FMM-A), with any discrepancies resolved with the involvement of a third (PP-R).

Table 1
Inclusion and exclusion criteria

PICOS criteria	Inclusion	Exclusion
Population	Healthy older adults with a mean age ≥60 years	Populations with medical conditions that could affect the magnitude of improvement in respiratory muscle parameters (i.e. neurological, respiratory, cardiac and/or metabolic diseases, acute clinical conditions [hospitalized, organ transplantation, mechanical ventilation])
Intervention	Physical exercise intervention	Specific inspiratory or expiratory muscle training, respiratory exercises, and incentive spirometry
Comparison	Participants receiving no intervention, sham intervention, educational intervention	Other intervention than physical exercise or usual care
Outcomes	Inspiratory muscle strength, expiratory muscle strength and peak expiratory flow	
Studies	Randomized and non-randomized controlled trials	Animal and non-human studies

Data analysis

Meta-analysis was performed using Review Manager software (RevMan V5; Cochrane Collaboration, Oxford, UK). Outcomes were continuous, and change scores with standard deviations (SD) were used to obtain effect sizes, reported as standardized mean differences (MD) with 95% confidence intervals (CI). Between-study heterogeneity was assessed using the I^2 statistic, with values classified as "might not being important" (0% to 40%), "moderate heterogeneity" (30% to 60%), "substantial heterogeneity" (50% to 90%), and "considerable heterogeneity" (75% to 100%).[20] MIP, MEP, and PEF values at baseline and at postintervention assessment were analyzed, taking into account possible group × time interactions (Supplementary data. Tables S1, S2 and S3). A random-effects model was used for the meta-analysis, as methods varied between included studies beyond random sampling. The level of significance for all analyses was set at $p < 0.05$.

Results

The search yielded 435 records, and 9 studies were finally included.[21–29] Fig. 1 shows the PRISMA flow chart for study selection.[30]

The meta-analysis included eight studies assessing MIP,[21,22,24–27,29] six assessing MEP,[22,24–27,29] and two considering PEF.[24,28] Eight included RCTs were further evaluated for risk of bias according to the Cochrane Review guidelines.[20] Table 2 summarizes the main characteristics of included studies.

Characteristics of included studies

Three of the nine included studies took place in Brazil,[22,26,27] three in Asia (one in Japan, one in Taiwan, and one in Thailand), two in Europe (Spain),[24,25] and one in the USA.[21] Five studies included only older women,[22–24,26,28] and four studies included women and men.[21,25,27,29] Most studies were carried out in community-dwelling people, with just one including institutionalized people.[25] Studies included sedentary[21,22,27] and active older people.[26,27]

CG: control group; HE: health education; HIRT: high-intensity resistance training; IOA: Institutionalized older adults; IPAQ-SF: international physical activity questionnaire short form; MEP: maximal expiratory pressure; MIP: maximal inspiratory pressure; N/A: not available; OCA: older community-dwelling adults; PA: physical activity; PEF: peak expiratory flow; rep: repetitions; RM: repetition

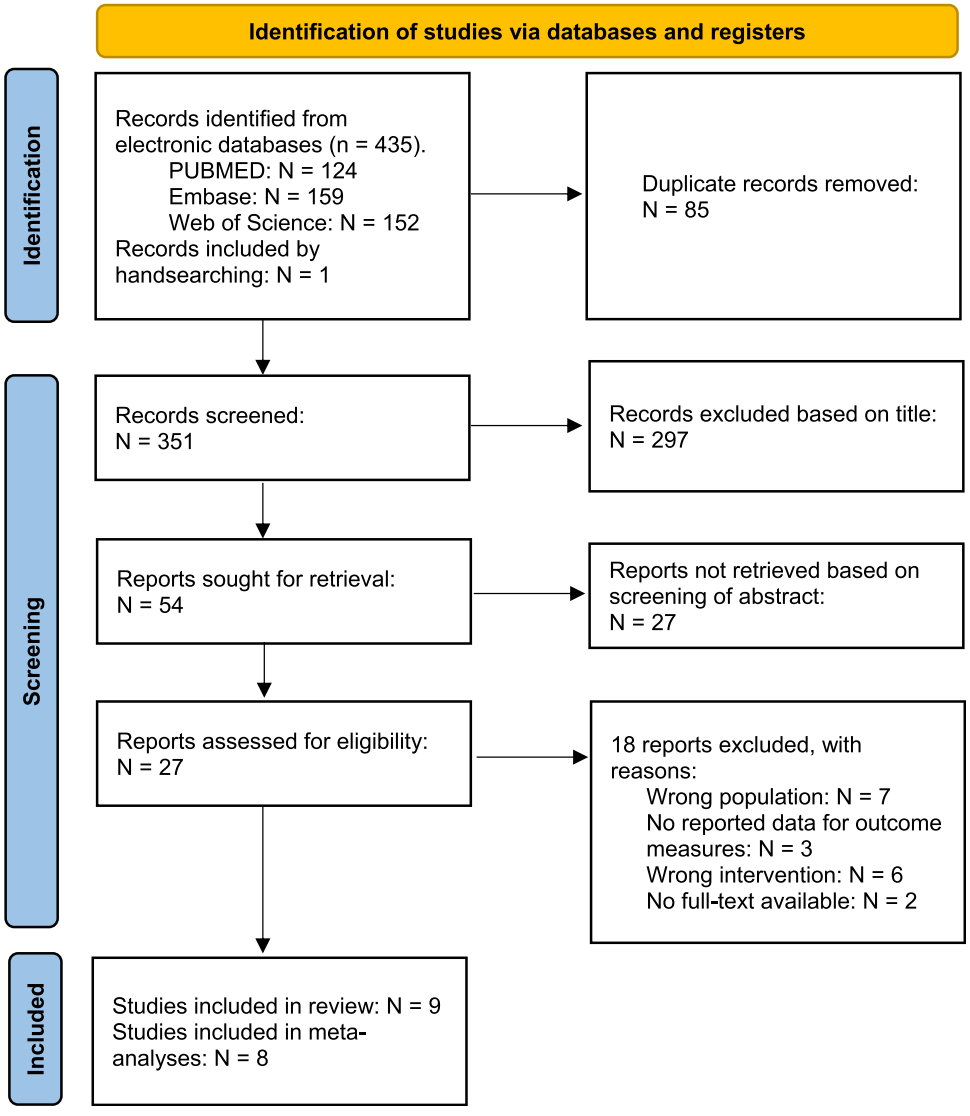

Fig. 1. PRISMA 2020 flow chart for systematic reviews.

Table 2
Main characteristics of included studies in the systematic review.

Study (year) country	Population	N participants (Intervention/ control)	Mean age in years (SD), by trial arm	Female, n (%)	Parameters (units)	Comparator	Intervention	Intensity	Frequency and duration of the intervention	Assessment time points
Bezerra et al. (2014) Brazil	Sedentary women without pulmonary disease	N = 36 (18/18)	Yoga: 63.1 (13.3) CG: 61.0 (6.9)	36 (100)	MIP (cmH_2O) MEP (cmH_2O)	N/A	**Yoga**: 15 positions (asanas) with 15-20 s per each rep. Supervised Duration: 65 min	N/A	3 sessions a week for 12 weeks	Baseline and after 12 weeks of intervention
Vaz-Fragoso et al. (2016) USA	Sedentary OCA (age 70-89 years) with mobility limitations[a]	N = 1635 (818/817)	Physical activity (PA): 78.7 (5.2) Health education (HE): 79.1 (5.2)	1098 (67.2)	MIP (cmH_2O)	**HE**: weekly workshop on topics relevant to older adults and upper extremity stretching exercises	**PA:** walking (goal of 150 min/week) and strength, flexibility, and balance training. 10 min of primarily lower extremity strength training (ankle weights), 10 min of balance training, and large muscle group flexibility exercises. Supervised and also home-based Duration: 20 min + walking	The PA sessions progressed after the 2nd week towards a goal of 30 minutes of walking, 5 days a week at a moderate intensity (determined with Borg)	2 center-based sessions per week and home-based activity 3-4 times per week, for 24-42 months	Baseline and at 6, 18, and 30 months of intervention
Pessoa et al. (2017) Brazil	OCA aged 60-74 years, sedentary or moderately active according to IPAQ-SF	N = 28 WBV n=9 WBV+RT n=10 RT n=9	WBV: 66.4 (2.6) WBV+RT: 64.9 (2.8) RT: 68.2 (2.4)	15 (53.6)	MIP (cmH_2O) MEP (cmH_2O)	**WBV group: WBV and sham for RT** performed with similar movements without load, during similar time **WBV + RT:** Participants performed both training protocols	**RT** (+ sham WBV): RT of the arm, forearm, thigh, and leg flexors and extensors were performed using muscular strength machines. 2 series of 8 rep. **Sham WBV** was performed with a disconnected platform and device reproducing platform noise. Supervised Duration: 60 min per session	RT at 75% of 1RM	3 times per week, for 12 weeks	Baseline and at 12 weeks of intervention
Chen et al. (2018) Taiwan	OCA but women aged 65-75 y with signs of sarcopenia[b]	N = 33 (17/16)	Kettlebell: 66.7 (5.3) CG: 68.3 (2.8)	33 (100)	PEF (L/s)	Participants were contacted and monitored regularly to ensure that their daily lifestyles were maintained.	**RT with kettlebells**: Authors described a battery of 11 movements, participants did 5 movements in each session. Each movement was performed for 3 sets of 8-12 rep. Supervised[c] Duration: 60 min	Load was adjusted at 60-70% of 1RM. Load was increased when the participant performed > 10 rep and was reduced when the participant performed <8 rep. Every other week the load was adjusted	Twice a week for 8 weeks	Baseline, after 8 weeks of training; and after 4 weeks of detraining
Cebrià I Iranzo et al. (2018) Spain	IOA but Spanish (≥65 y) with sarcopenia[d] and without clinical situations and without a moderate-cognitive deterioration	N = 81 (11/17)	CG: 81.2 (5.4) RT: 82.6 (9.1)	21 (75)	MIP (cmH_2O) MIP (pred%) MEP (cmH_2O) MEP (pred%)	Usual care	**RT**: 10 isotonic RT exercises with dumbbells and ankle/wrist weights. 1 set of 12 rep per exercise. Supervised Duration: 20-30 min	Load at 40-60% of maximal isometric muscle strength. 6 sessions of familiarization to guarantee appropriate technique (at low training workload of 5-10 of	3 times a week for 12 weeks	Baseline (after 2-week familiarization) and after 12 weeks of intervention

(*continued on next page*)

Table 2 (*Continued*)

Study (year) country	Population	N participants (Intervention/ control)	Mean age in years (SD), by trial arm	Female, n (%)	Parameters (units)	Comparator	Intervention	Intensity	Frequency and duration of the intervention	Assessment time points
								maximal muscle strength)		
Medeiros de Alvarenga et al. (2018) Brazil	Active women ≥60 years, who had no fractures in the 3 months prior to the study, did not use walking devices, and had an arterial tension ≤140/90 mm/Hg. Women who had less than an 85% attendance rate at the sessions were excluded	N = 36 (11/9)	Pilates: 65.45 (3.3) CG:73.33 (5.6)	20 (100)	MIP (cmH_2O) MEP (cmH_2O)	Usual care	**Pilates**: Using Pilates machines like the Cadillac, Combo chair and reformer. A total of 9 exercises were used per session. Supervised Duration: 45 min	The strength of the springs was adjusted individually and progressively according to the capacity/ability of each participant	Twice a week for 20 sessions. 10 weeks	Baseline and after 10 weeks of intervention
Uchida et al. (2020) Japan	OCA but women	N = 24 RT, n=14 Walking, n=10	RT: 77 (N/A) Walking: 74.9 (N/A)	28 (100)	MEP (mmHg) MIP (mmHg)	**Aerobic training**: walking fast for 3000 steps. Unsupervised Duration: N/A	**RT:** Low-intensity home exercises with therabands focused on upper extremity. 3 sets of 10 rep.	Intensity was set as a fatigue level of 60-70 mm on the VAS after completion of 10 rep. Walking speed was set to an exertion level of "slightly tiring" or about 12-13 on the 15-level Borg Scale	RT: Twice daily (morning and afternoon) Fast walking group: once daily 6 months	Baseline and after 6 months of intervention
Flor-Rufino et al. (2022) Spain	OCA (aged ≥70), but women with sarcopenia[e] able to walk independently (with or without technical aids)	N = 38 (20/18)	HIRT: 79.9 (7.2) CG: 79.6 (7.7)	38 (100)	MIP (cmH_2O) MEP (cmH_2O) PEF (L/s)	Usual care; participants were encouraged to stay active	**RT**: 45-min HIRT circuit with strength machines (6 strength exercises (2 trunk, 2 arm, and 2 leg exercises). 3 sets per exercise and 10-15 rep per set, until failure. 2-min rest between series. Supervised Duration: 60 min	Every 6 sessions (3 weeks) the 1RM of each participant was calculated to train at 70% of the new 1RM	2 weekly 65 min group sessions for 6 months (39 sessions)	Baseline and after 6-month intervention
Yuenyongchaiwat et Akekawatchai (2022) Thailand	OCA with sarcopenia[b] (aged ≥60)	N = 60 (28/29)	IG: 69.23 (6.7) CG: 71.93 (5.2)	44 (73.3)	MIP (cmH_2O) MEP (cmH_2O)	Usual care	**Walking + RT**: walking ≥7500 steps daily plus performing RT with a theraband. Supervision N/A Duration: N/A	Not specified	5 days/week of walking and 2 days/week of RT, for 12 weeks	Baseline and after 12 weeks of intervention

[a] Community-dwelling elderly adults (70-89 y) with mobility limitations (short physical performance battery < 10 points), but able to walk 400 m in 15 min or less; no cognitive impairment (Mini-mental state examination <1.5 SD below education- and race-specific norms) and sedentary status (<20 min/week of regular PA in the past month and <125 min/week of moderate PA).
[b] Sarcopenia was diagnosed by Asian Working Group for Sarcopenia criteria published in 2010 and 2019.
[c] Training ranged from basic (single-movement training) to advanced (comprehensive movement training) levels.
[d] Sarcopenia was diagnosed by Tyrovolas et al. (2015) as low skeletal muscle index and slow gait speed.
[e] Sarcopenia was diagnosed by European Working Group on Sarcopenia in Older People criteria published in 2010.

maximum; RT: resistance training; VAS: visual analogue scale; WBV: Whole body vibration; y: years.

Interventions

Six studies implemented resistance training;[23–25,27–29] one, aerobic training consisting of a walking activity;[29] one, Pilates ;[26] one, yoga;[22] and one, a passive exercise intervention over a whole body vibration platform.[27] Just one study used a multicomponent training intervention.[21] The duration of the intervention ranged from 8 weeks[28] to 30 months,[21] with most lasting around 3 months.[22,25,27,29]

PEDro methodological assessment

Of the nine studies included in the systematic review, five were rated as good quality;[24–27,29] three, fair quality; [21,22,28] and one, poor quality.[23] (Table 3). The high methodological quality was observed mainly in between-group comparisons, point estimates and variability, eligibility, baseline comparability and random allocation. The main shortcomings were due to lack of blinding in participants and therapists, intention-to-treat analysis, and allocation concealment.

Risk of bias assessment of randomized controlled trials

The summary of the risk of bias assessment for included RCTs is shown in Fig. 2.

The lack of information in the study reports translated to a high number of items being deemed at unclear risk of bias. The lowest risk was observed for the randomization sequence, and the highest risk of bias was due to lack of blinding of study participants, lack of reported data, and shortcomings in allocation concealment.

Narrative findings of the included studies

Regarding MIP, three studies reported significant within-group differences in the groups receiving the NVS physical exercise intervention.[22,26,29] Three studies reported significant between-group differences in postintervention assessments,[25–27] two showing a decrease in MIP,[25,26] and one showing a significant group × time interaction.[26] Comparative interventions included whole-body vibration training (WBVt).[27] WBVt plus sham resistance training had a significant effect on MIP (MD 33.6 cmH_2O), which was not obtained after resistance training alone (MD 1.4 cmH_2O).[27]

For MEP, three studies reported a significant within-group difference in groups receiving the physical NVS exercise intervention,[22,24,26] and three studies reported significant within-group differences in the control group,[25–27] one with an increasing tren,[27] and two a decrease.[25,26] Two studies reported a significant difference between groups in postintervention assessments,[26,27] and two showed a significant group × time interaction.[24,26] Again, WBVt showed a significant impact on MEP (MD 27.4 cmH_2O) compared with RT (MD 0.9 cmH_2O).[27]

Finally, for PEF, only one[28] of the two included studies assessing this outcome showed a significant improvement in exercise group, with significant worsening in the control group.

Meta-analysis results

Fig. 3 shows the synthesis forest plot for MIP, MEP and PEF analyses. The meta-analysis found no statistically significant differences in MIP following an NVS exercise program (7 studies, N = 1832, SMD 0.14, 95% CI −0.39 to 0.68; Fig. 3A), but it did show relevant evidence of between-study heterogeneity (I^2=83%, $p<0.001$).

Six included studies analyzing MEP were amenable to meta-analysis, which found no statistically significant differences after an NVS

Table 3
Assessment of methodological quality of studies using PEDro scale.

Study Author (Year)	Eligibility	Random allocation	Concealed allocation	Baseline comparability	Blind subjects	Blind therapists	Blind assessors	Adequate follow-up	Intention-to-treat analysis	Between-group comparisons	Point estimates and variability	Total Points	Quality
Bezerra et al.[22]	Yes	Yes	No	Yes	No	No	No	Yes	No	Yes	No	5/11	Fair
Cebrià I Iranzo et al.[25]	Yes	Yes	No	Yes	No	No	Yes	No	No	Yes	Yes	6/11	Good
Chen et al.[28]	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	5/11	Fair
Flor-Rufino et al.[24]	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	8/11	Good
Madeiros de Alvarenga et al.[26]	Yes	Yes	No	Yes	No	No	No	Yes	No	Yes	Yes	6/11	Good
Pessoa et al.[27]	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	8/11	Good
Uchida et al.[23]	No	No	No	Yes	No	No	No	No	No	Yes	Yes	3/11	Poor
Vaz-Fragoso et al.[31]	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	5/11	Fair
Yuenyongchaiwat et Akekawatchai[29]	Yes	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes	7/11	Good

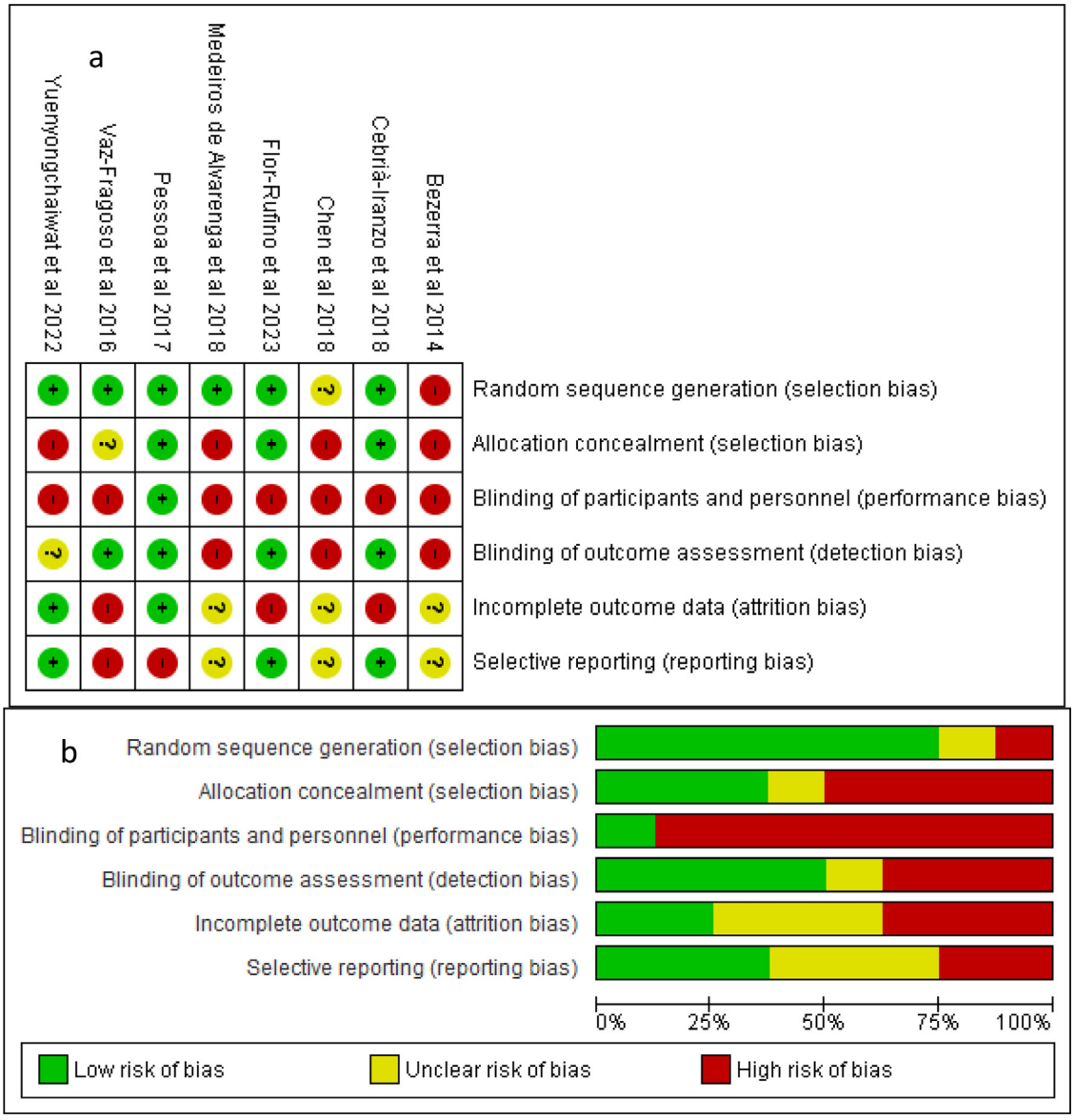

Fig. 2. Risk of bias graph (a) and risk of bias summary(b).

exercise program (N = 197 patients, SMD 0.07, 95% CI −0.70 to 0.83; Fig. 3B). The heterogeneity of the studies was substantial (I^2=83%, p<0.001).

Only two included studies assessed PEF. Pooled results showed no statistically significant differences following an NVS exercise program (N = 71, SMD 0.83, 95% CI −0.39 to 2.06; Fig. 3C). There was no statistically significant heterogeneity between studies (I^2=71%, p=0.06).

Discussion

This systematic review and meta-analysis aimed to assess the effects of NVS exercise programs on respiratory muscle strength parameters in older adults without any chronic or acute respiratory, metabolic, neurological, or heart conditions. Although changes in respiratory function parameters related to the ability to perform a respiratory effort have been observed with different types of strength exercises, the meta-analysis showed no statistically significant differences in MIP, MEP, or PEF.

Respiratory function naturally decreases as a consequence of physiological changes associated with aging, including a thinning diaphragm and loss of respiratory muscle strength. MIP, MEP, and PEF parameters have been used to detect those changes. Even healthy older people have a thinner diaphragm and lower MIP, MEP, and PEF, mainly in the presence of sarcopenia and/or frailty, which require specific mitigating interventions. Among the interventions that have shown the best results for managing age-related loss of strength and skeletal muscle mass is exercise, especially strength exercise.

Regarding MIP and MEP, six of the nine included studies implemented a program based on RT.[23–25,29,31,32] The high heterogeneity helps explain the divergent and even contradictory outcomes. Indeed, a multitude of factors can influence these parameters, including participant age and sex, smoking history,[5] thoracic structure,[8] previous muscular state,[33] level of physical activity,[12] and factors intrinsic to the program implemented, such as exercise intensity. (48,49) In the meta-analysis, it was not possible to perform different subanalyses to disentangle the impact of each of these factors on the outcomes. However, overall the included studies reflect inconclusive results, as no greater improvements were achieved in patients starting with poorer muscular strength, whether physical[24,25,28,29] or specifically in respiratory pressures.[24,29] Likewise, the studies testing

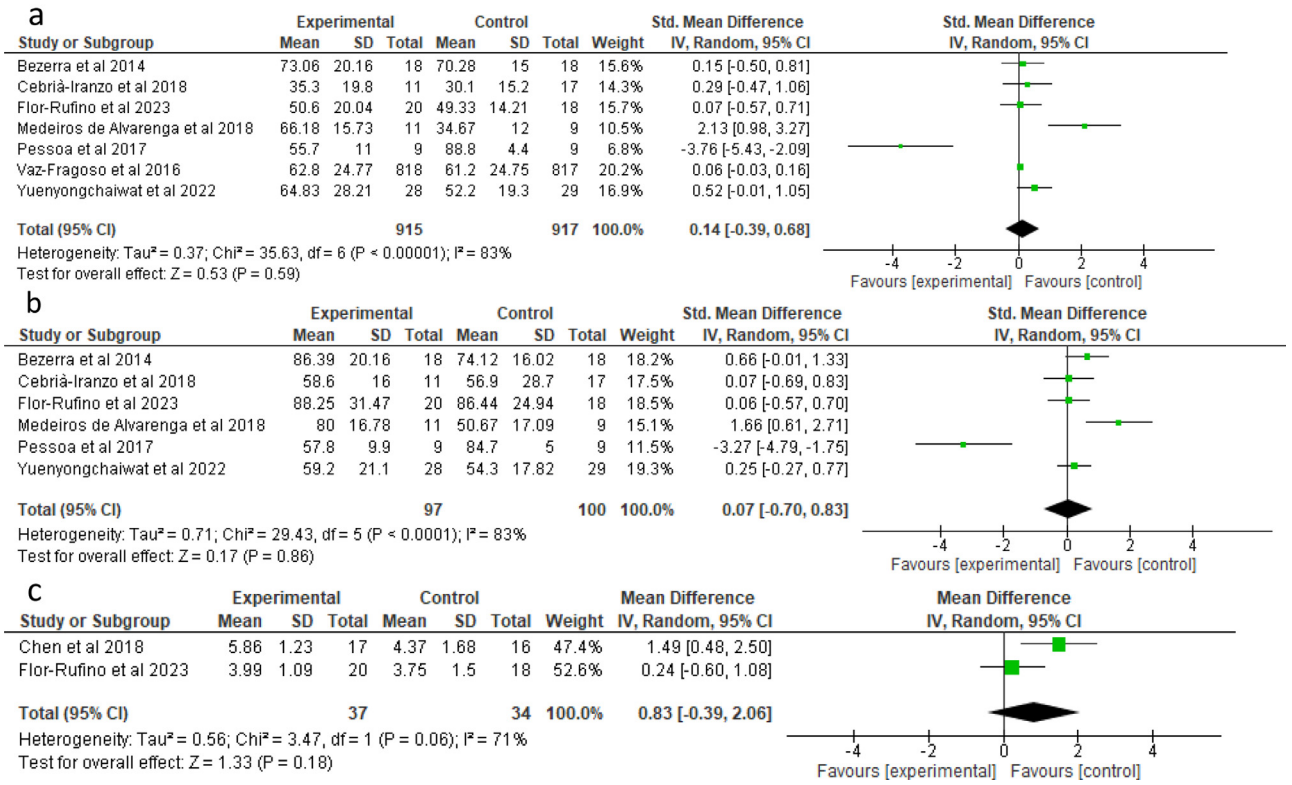

Fig. 3. Synthesis forest plot for analyzing (A) MIP, (B) MEP, and (C) PEF in older adults. The small boxes with squares represent the point estimate of the effect size and sample size. The lines on either side of the box represent a 95% confidence interval (CI).

interventions at different intensities found no direct relationship with this parameter. Including endurance training within the intervention may be necessary to bring about a greater cardiorespiratory adaptation that increases the stimulus and the consequent strengthening of the inspiratory muscles.[34] The same occurs when analyzing studies that have performed strength training in sedentary young women,[35] in older people with COPD,[36] in those with COPD plus low muscle mass,[37] and in patients in the preoperative waiting period,[17] without finding conclusive results on the improvement of respiratory muscle strength.

In the literature, the studies obtaining better outcomes in respiratory muscle strength have combined strength training with specific training of the respiratory muscles.[17,25] These studies suggest that in people with respiratory muscle weakness, physical exercise and especially RT—with or without specific training of the respiratory muscles—could improve strength. Positive results after specific training of the respiratory muscles in older adults have been reported in different meta-analyses.[13,14] On the one hand, inspiratory muscle training has been shown to improve MIP and diaphragm thickness, but these changes were not accompanied by a significant improvement in functional capacity.[13] On the other hand, expiratory muscle training has a positive impact on MEP, without improvements in lung function or cough flow.[14] However, the heterogeneity of the interventions and the few conclusive results indicate the need for more randomized studies to provide robust evidence.

Among the NVS physical exercise interventions used in the included studies, Pilates and yoga programs integrate breath control, coordination of breathing with physical exercises, and conscious activation of the abdominal muscles[38] as basic pillars. In addition, in these interventions an abdominal breathing pattern is encouraged, which specifically strengthens the diaphragm and intercostal muscle.[18] In this review, studies that performed a yoga-based intervention[22] and Pilates[26] did obtain significant improvements in MIP and MEP. These results are supported by a meta-analysis[18] which reported that yoga practice significantly impacts on PEF, MIP and MEP in healthy adults. The positive effects of the maintenance of yoga postures[18] reinforce Pessoa et al.'s[27] contention that maintained isometric contractions are effective in strengthening the respiratory musculature.

Finally, PEF is a measure of the maximum expiratory flow during a forced expiratory maneuver. However, it depends on the state of the airways (pulmonary function) as well as the strength of the respiratory muscles. In this review, only two studies analyzed the effects of high-intensity physical exercise on this parameter, both in women with sarcopenia,[24,28] since some authors consider PEF as a representative parameter of respiratory sarcopenia.[39] Our meta-analysis did not find evidence that NVS exercise significantly changed PEF. This outcome showed an improvement after an RT intervention based on kettlebells[28] but only showed a trend towards an increase after high-intensity RT based on machine exercises.[24] In the literature, the positive effect of exercise, such as yoga, on PEF has been reported in young people[18] but not in people with COPD.[36] In some included studies, aerobic exercise was performed in addition to RT,[35] which could have influenced PEF.

One limitation of this review is the high heterogeneity of studies, which hinders a clear comparison of outcomes. In addition, there are other factors that could be important in the improvement of respiratory parameters, such as a person's age; the baseline values of MIP, MEP, and PEF; and the assessment methodology, which differs between studies. Moreover, the number of included studies did not allow subgroup analysis, and not all included studies were amenable to meta-analysis.

Conclusions

In conclusion, the meta-analysis did not produce evidence supporting the beneficial effects of NVS exercise on respiratory muscle strength. More studies analyzing the effects of NVS exercises are required. Based on the results of this review, and in the absence of a greater number of conclusive studies, a specific training protocol for the ventilatory muscles should be included in a multicomponent exercise program in order to effectively improve the strength of the ventilatory musculature.

Declarations

Ethical approval: None.
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Conflict of interest

The authors have no conflicts of interest.
Authors Contributions

Criteria	Author Initials
Conceptualization	C.F-R and F.M. M-A
Data curation	C.F-R, P.P-R and F.M. M-A
Formal Analysis	F.M. M-A
Methodology	C.F-R and F.M. M-A
Project administration	C.F-R and F.M. M-A
Supervision	F.M. M-A
Writing – original draft	C.F-R, P.P-R and F.M. M-A
Writing – review & editing	C.F-R, P.P-R and F.M. M-A

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
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CRediT authorship contribution statement

Cristina Flor-Rufino: Conceptualization, Data curation, Methodology, Project administration, Writing – original draft, Writing – review & editing. **Pilar Pérez-Ros:** Data curation, Writing – original draft, Writing – review & editing. **Francisco M Martínez-Arnau:** Conceptualization, Data curation, Formal analysis, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.gerinurse.2024.04.016.

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