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Systematic review

Pilates improves physical performance and decreases risk of falls in older adults: a systematic review and meta-analysis

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Abstract

Background Falls are the leading cause of injury-related deaths in older adults. Physical exercise is a suitable strategy to reduce the risk of falls, but there is little research on the effectiveness of specific exercise modalities.
Objectives To estimate the effectiveness of Pilates compared to habitual or non-exercise on physical performance and the risk of falls in older adults.
Data sources Five databases were searched through April 15, 2021.
Study selection Randomized controlled trial in people aged ≥60 years. Outcomes: balance, strength, flexibility, functionality, and risk of falls.
Data synthesis Pooled standardized mean differences were calculated using a random-effects model. Subgroup analyses based on Pilates' modality, the existence of a detailed exercise protocol, supervision by a certified instructor, and overall risk of bias were performed.
Results Thirty-nine studies were included in the systematic review and meta-analyses. The meta-analyses indicated a moderate effect of Pilates on balance (ES = 0.36; 95% CI = 0.21 to 0.50), strength (ES = 0.63; 95% CI = 0.44 to 0.81), flexibility (ES = 0.41; 95% CI = 0.16 to 0.67), and functionality (ES = 0.51; 95% CI = 0.32 to 0.72) as well as a large effect on the risk of falls (ES = 0.90; 95% CI = 0.41 to 1.38) in older adults when compared with control groups. The level of certainty of the findings was low for balance, flexibility, and functionality and moderate for strength and falls.
Conclusion and implications of key findings Pilates may promote the autonomy of older people in their daily living activities.

Contribution of the Paper
- Pilates is an alternative exercise for reducing the risk of falls.
- Pilates improves balance, strength, flexibility, and functionality in older people.
- Pilates may increase the autonomy of older adults in their daily living activities.

Systematic Review Registration Number PROSPERO CRD42018116452

Keywords: Aging; Exercise therapy; Mind-body; Prevention

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Introduction

The aging process involves progressive functional and structural losses, such as a decrease in muscle mass (sarcopenia) or bone mineral density (osteoporosis), which results in a decline in muscular strength, flexibility, and balance [1]. This functional deterioration has been associated with mobility restrictions, an increased risk of falls, and loss of autonomy [1,2]. Falls are considered the major cause of mortality and injury-related deaths in older people [3], and their risk increases with age in such a way that the one-year prevalence among individuals in community dwellings is 30% and 40% for those older than 65 and 80 years, respectively [4,5]. This prevalence increases up to 50% for institutionalized older people [6].

Due to a fear of falling, older adults may limit their physical activities, which can cause mobility restrictions, decreased autonomy, and a greater risk of falls [7]. In addition to a fear of falling, the risk of falls increases in parallel with the number of falls [7]. Conversely, older adults who perform physical exercise reduce their number of visits to emergency services as well as the number and length of hospitalizations [8]. Consistent evidence supports the notion that physical exercise programs may diminish the incidence of physical complications as a result of the aging process [9,10]. Additionally, evidence suggests that they have benefits on overall health status and decrease the risk of falls [11,12]. Physical exercise is widely recognized to be a preventive strategy for the complications of the aging process, reducing the risk of falls and related injuries [13–15], thus inducing a reduction in healthcare costs [8,16].

Pilates was created by J Pilates during the 1920s as a low impact exercise to improve strength, flexibility, and muscle control of the core region [16]. There are two modalities: Mat or machine [17]. Neither one has an age limitation [3,18], so physiotherapists and geriatricians frequently recommend Pilates as a useful physical exercise for older people [19]. Pilates has shown positive effects on cognitive function and social and mental wellness [3,20]. Furthermore, benefits have been shown in risk factors related to fall outcomes in older people, such as bone mineral density, body composition, balance, strength, flexibility, endurance, and coordination [9,18–22]. It is believed that Pilates is effective in improving physical performance and risk of falls because many of the exercises challenge balance and strengthen both core muscles (e.g., transverse, rectus abdominis) and muscles involved in posture alignment and proprioception (e.g., diaphragm, pelvic floor muscles) [23,24].

Despite these findings [25–27], evidence of the comparative benefits of Pilates *vs* habitual exercise routines, daily physical activities, or usual care among older adults is far from consistent [23,24,28–33]. To date, the most recent systematic review and meta-analysis was conducted in March 2017, but the search was restricted to the previous 6 years and did not consider fall risk or functionality among older adults [33]. Therefore, considering the increasing literature related to Pilates exercise on older adults, the purpose of this systematic review and meta-analysis was to update and estimate the effectiveness of Pilates on physical performance (balance, strength, flexibility, and functionality) and the risk of falls among older adults. Moreover, the authors investigated whether the effect of the Pilates intervention depends on the effects of potential mediators or moderators, such as the Pilates' modality, existence of a Pilates exercise protocol, supervision by a certified instructor, participant age, and number of sessions per week.

Methods

This systematic review and meta-analysis was performed according to the PRISMA statement [34] and follows the recommendations of the Cochrane Handbook for Systematic Reviews of Interventions [35]. The PRISMA checklist was used and the review was registered on PROSPERO (CRD42018116452).

Data sources and searches

A systematic literature search was conducted in the following databases: MEDLINE (via PubMed), Scopus, Web of Science, the Physiotherapy Evidence Database (PEDro), and the Cochrane Central Register of Controlled Trials (CENTRAL). The search took place from inception until April 15, 2021 for studies focused on the effect of Pilates on physical performance and risk of falls among older adults. The search algorithm was created using the PICO design and combining Medical Subject Headings, keywords, and matching synonyms of the relevant words: (1) population: "older people", "older adult", elderly, "third age", aging, aged; (2) intervention: Pilates, exercise movement techniques; (3) outcome: balance, propriocept*, strength, force, flexibility, supple*, "physical performance", functionality, fall*. The complete search strategy for all databases is presented in Appendix 1 in supplementary material.

Study selection

Titles and abstracts of retrieved articles were independently examined by two reviewers (RF-R and CA-B); at this stage, duplicates and clearly unrelated studies were excluded. Disagreements about study selection were resolved by consensus or with a third reviewer (VM-V). Studies were included in the systematic review when the inclusion and exclusion criteria were satisfied. Inclusion criteria: (1) Type of study: randomized controlled trials (RCTs) with a parallel or crossover design; (2) Type of participants: the mean age of participants was 60 years or more; (3) Type of intervention: at least one exercise intervention described as "Pilates" (Mat, machine, or both); (4) Comparison: control groups with no intervention or with habitual exercise routines, daily physical activities, or usual care among older adults; and (5) Outcome measures: balance, strength, flexibility, functionality, or risk of falls and fall-related measures. Finally, studies were excluded when the outcome data were not reported. Unpublished theses and dissertations were not considered, and no language restrictions were applied. No attempt was made to obtain missing data when articles lacked information.

Data extraction and quality assessment

Data extraction

Two authors (RF-R and CA-B) independently extracted the following information from the included studies: first author's name and year of publication, study design, health status of the participants, mean age, sample size and percentage of females, weekly frequency, period and modality of Pilates sessions, existence of a certified instructor and detailed exercise protocol, and the following outcome measurements: balance, strength, flexibility, functionality, and risk of falls or fall-related measures. Any disagreement was resolved by consensus or with a third reviewer (VM-V).

Risk of bias

The risk of bias of RCTs was assessed using the Cochrane Collaboration RoB2 tool [36]. Accordingly, five domains were evaluated: (1) randomization process, (2) deviations from intended interventions, (3) missing outcome data, (4) measurement of the outcome, and (5) reporting bias. Finally, each study was classified for the overall risk of bias as (1) "low risk of bias" when a low risk of bias was determined for all domains, (2) "some concerns" when at least one domain was assessed as raising some concerns but not to be at high risk of bias for any single domain, or (3) "high risk of bias" when a high risk of bias was reached for at least one domain or some concerns in multiple domains [36].

Two reviewers (RF-R and CA-B) independently assessed the risk of bias of the included studies. Any disagreements were resolved by consensus or with a third reviewer (VM-V).

Grading the quality of evidence

The certainty of evidence provided by this meta-analysis on the different outcomes was also evaluated with the Grading of Recommendations Assessment, Development and Evaluation (GRADE) framework [37]. Each outcome (balance, strength, flexibility, functionality, and risk of falls) could be scored as high, moderate, low, and very low evidence value, depending on the design of the studies, risk of bias, inconsistency, indirect evidence, imprecision, and publication bias. In this sense, some factors could increase or decrease the quality of evidence score as follows: (1) risk of bias (−1 when <75% of the analyzed studies were at low risk of bias), (2) inconsistency (−1 when $I^2 > 50\%$), (3) indirect evidence related to indirect population, intervention, control, or outcomes, (4) imprecision related to wide confidence intervals, and (5) publication bias (−1 when it exists) [37].

Two reviewers (RF-R and CA-B) independently assessed the quality of evidence according to the GRADE framework. Any disagreements were resolved by consensus or with a third reviewer (VM-V).

Data synthesis and analysis

Effect sizes (ESs) and their 95% confidence intervals (95% CIs) were calculated [38] for each study. The DerSimonian and Laird random effects method [39] was used to compute pooled ES estimates and respective 95% CIs. Accordingly, the pooled ES was estimated individually considering each outcome of interest (i.e., balance, strength, flexibility, functionality, and risk of falls). The heterogeneity of the results across studies was evaluated using the I^2 statistical parameter. I^2 values of 0–40% might not be important, 30–60% might represent moderate heterogeneity, 50–90% might represent substantial heterogeneity, and 75–100% might represent considerable heterogeneity. The corresponding *P* values and 95% CI for I^2 were also considered [40].

A sensitivity analysis was conducted by removing the included studies one at a time from the pooled ES to assess the robustness of the summary estimates. Subgroup analyses were performed by Pilates modality, existence or not of a detailed exercise protocol, sessions supervised or not by a certified instructor, and categories of overall score on the risk of bias. Additionally, random-effects meta-regressions were performed to determine whether the population's mean age and the number of sessions per week could modify the effect of Pilates on the outcomes of interest.

Finally, publication bias was evaluated through visual inspection of funnel plots as well as Egger's regression asymmetry test for the assessment of small study effects [41]. Statistical analyses were performed using StataSE v.15 (StataCorp, College Station, TX, USA).

Results

Flow of the studies through the review

The searches identified 1658 potential studies. Following the review of titles and abstracts and the full texts of eligible articles, 39 studies [19,20,27,28,30–32,42–72] were included in the systematic review and 33 in the meta-analysis. Further details are presented in Fig. 1. All included studies were written in English, except for one in Portuguese [65].

Characteristics of the included studies (systematic review)

The study and intervention characteristics are summarized in Table 1. The 39 included studies were conducted between 2010 and 2021, and there were a total of 1650 par-

Table 1
Summary of included studies.

Author	Design	Health status	Mean age (SD)	Sample size (%female)	Frequency	Period	Type of pilates	CI/DP	Comparison	Outcome measures
Siqueira-Rodrigues *et al*., 2010	RCT	Healthy	66 (4)	100% PG = 27 CG = 25	2xwk/60’	8wks	Machine	Y/Y	CG	Balance Functionality
Irez *et al*., 2011	RCT	Institutionalized	PG 73 (7) CG 78 (6)	100% PG = 30 CG = 30	3xwk/60’	12wks	Mat	Y/NA	CG	Balance Strength Flexibility Functionality Falls
Appell *et al*., 2012	RCT	Healthy	PG 70 (3)	53% PG = 19	2xwk/60’	10wks	Mat	Y/Y	–	Balance
Bird *et al*., 2012	RCT (cross-over)	Healthy	67 (7)	78% PG = 32/27	2xwk/60’	5wks PG *vs* 5wks UA	Machine	Y/Y	CG (UA)	Balance Strength
Plachy *et al*., 2012	RCT	Healthy	PG 66 (4) CG 68 (3)	PG = 15 CG = 12	3xwk	24wks	NA	Y/NA	CG	Strength Flexibility Functionality
Fourie *et al*., 2013	RCT	Institutionalized	PG 66 (5) CG 65 (5)	NA% PG = 25; CG = 25;	3xwk/60’	8wks	Mat	Y/NA	CG (non-exercising)	Flexibility
Gildenhuys *et al*., 2013	RCT	Healthy	PG 66 (5) CG 65 (5)	100% PG = 25 CG = 25	3xwk	8wks	Mat	Y/NA	CG (UA)	Strength Functionality
Kovách *et al*., 2013	RCT	Healthy	PG 67 (6) CG 65 (6)	PG = 22; 72% CG = 15; 73%	3xwk/60’	24wks	Mat	NA/NA	CG	Strength Flexibility Functionality
Irez, 2014	RCT	Institutionalized	PG 65+ CG 65+	PG = 15; 67% CG = 15; 67%	3xwk/60’	14wks	Mat	Y/NA	CG	Balance Strength Flexibility Falls
Taskiran *et al*., 2014	RCT	Institutionalized	PG 76 (8) CG 80 (6)	PG = 18; 84% CG = 22; 59%	3xwk/50’	8wks	Mat	Y/Y	CG	Balance Strength Flexibility Functionality

Table 1 (*Continued*)

Author	Design	Health status	Mean age (SD)	Sample size (%female)	Frequency	Period	Type of pilates	CI/DP	Comparison	Outcome measures
Barker *et al*., 2015	RCT	Healthy	PG 69 (7) CG 69 (6)	PG = 20; 90% CG = 29; 86%	2xwk/60'	12wks	Machine	Y/NA	CG (standard care from primary healthcare practitioners)	Balance Strength Flexibility Falls
Cruz-Díaz *et al*., 2015	RCT	Healthy	PG 70 (2)	100% PG = 50	2xwk/60'	6wks	NA	NA/NA	TENS, massage, stretching	Balance Falls
Markovic *et al*., 2015	RCT	Healthy	Both groups 77 (4)	100% PG = 17/14	3xwk/60'	8wks	Mat	NA/Y	Vibratory platform (Huber)	Balance Strength
Mesquita et al., 2015	RCT	Healthy	PG 67 (5) CG 72 (6)	100% PG = 21/20 CG = 21/18	3xwk/50'	4wks	Mat	Y/Y	CG (UA)	Balance
Donath *et al*., 2016	RCT	Healthy	PG 71 (7) CG 69 (6)	PG = 17; 77% CG = 15; 73%	2xwk/60'	8wks	Mat	Y/NA	CG	Balance
Gabizon *et al*., 2016	RCT	Healthy	PG 70 (4) CG 72 (5)	PG = 44; 35% CG = 44; 48%	3xwk/60'	12wks	Mat	Y/NA	CG (balance reference group)	Balance Functionalityi
Josephs *et al*., 2016	RCT	Healthy	PG 76 (6)	PG = 12;67%	2xwk/60'	12wks	Machine	Y/Y	CG (traditional home exercise)	Balance
Mazini *et al*., 2016	RCT	Healthy	PG 64 (3) CG 69 (3)	100% PG = 21 CG=24	3xwk/60'	24wks	Machine	NA/Y	CG	Balance Strength Flexibility Functionality
Oliveira *et al*., 2016	RCT	Healthy	PG 65 (4) CG 66 (3)	100% PG = 15 CG = 15	2xwk/60'	12wks	Machine	Y/Y	CG (UA)	Strength Functionality

Table 1 (*Continued*)

Author	Design	Health status	Mean age (SD)	Sample size (%female)	Frequency	Period	Type of pilates	CI/DP	Comparison	Outcome measures
Roh *et al*., 2016	RCT	Healthy	PG 68 (2) CG 68 (3)	PG = 10; 50% CG = 10; 30%	3xwk/60'	8wks	Mat	Y/Y	CG	Functionality
Sofianidis *et al*., 2016	RCT	Healthy	PG 71 (5) CG 70 (6)	72 % PG = 12 CG = 12	2xwk/60'	12wks	Mat	NA/NA	CG	Balance
Badiei *et al*., 2017	RCT	Institutionalized	PG 68 (6) CG 71 (4)	100% PG = 22 CG = 22	3xwk/60'	8wks	Mat	NA/Y	CG (UA)	Falls
Curi *et al*., 2017	RCT	Healthy	PG 64 (1) CG 64 (1)	100% PG = 31 CG = 30	2xwk/60'	16wks	Mat	Y/Y	CG	Balance Strength Flexibility Functionality
De Carvalho *et al*., 2017	RCT	Healthy	69 (6)	100% PG = 21/20 CG = 21/20	3xwk/50'	4wks	Mat	NA/NA	CG	Strength
Oksuz *et al*., 2017	RCT	Healthy	PG 60 (8) CG 61 (8)	100% PG = 20 CG = 20	3xwk/60'	6wks	Mat	Y/Y	CG (normal daily routines)	Balance Strength Flexibility
Oliveira *et al*., 2017	RCT	Healthy	PG 64 (1) CG 64 (1)	100% PG = 16 CG= 16	2xwk/60'	12wks	Machine	Y/Y	CG (static stretching)	Strength
Roller *et al*., 2017	RCT	Institutionalized	PG 79 (8) CG 77 (7)	PG = 31/27; 70% CG = 28; 68%	8-10ss/45'	NA	Machine	Y/Y	CG	Balance Flexibility Functionality
Vieira *et al*., 2017	RCT	Healthy	PG 66 (1) CG 63 (1)	100% PG = 26/21 CG = 26/19	2xwk/60'	12wks	Mat	Y/Y	CG (UA)	Balance Strength Functionality
Alvarenga *et al*., 2018	RCT	Healthy	PG 66 (3) CG 73 (6)	100% PG = 12/11 CG = 12/9	2xwk/45'	20ss	Machine	Y/Y	CG	Strength Functionality
Carrasco-Poyatos *et al*., 2018	RCT	Institutionalized	PG 68 (4) CG 66 (5)	100% PG = 20 CG = 20	2xwk/60'	18wks	Mat	Y/NA	CG (UA)	Balance Functionality
Tozim *et al*., 2018	RCT	Healthy	PG 68 (3) CG 65 (4)	100% PG = 17/14 CG = 22/17	2xwk/45'	8wks	Mat	Y/Y	CG (Educational group)	Strength

Table 1 (*Continued*)

Author	Design	Health status	Mean age (SD)	Sample size (%female)	Frequency	Period	Type of pilates	CI/DP	Comparison	Outcome measures
Aibar-Almazán *et al*., 2019	RCT	Healthy	PG 70 (8) CG 67 (10)	100% PG = 55 CG = 55/52	2xwk/60’	12wks	Mat	Y/Y	CG (daily lifestyles)	Balance Falls
Kayaoğlu, 2019	RCT	Institutionalized	PG 73 (8) CG 78 (7)	PG = 21; 52% CG = 22; 68%	3xwk/60’	12wks	Mat	NA/Y	CG (daily activities)	Balance Strength
Ferreira and Ferreira, 2020	RCT	Healthy	PG 66 (6) CG 70 (7)	100% PG = 14 CG = 15	2xwk/60’	8wks	Mat	NA/Y	CG	Balance Falls
García-Garro *et al*., 2020	RCT	Healthy	PG 70 (8) CG 67 (10)	100% PG = 55 CG=52	2xwk/60’	12wks	Mat	Y/NA	CG	Strength Flexibility
Mueller *et al*., 2020	RCT	Healthy	65 (3)	100% PG = 15 PG2 = 16 (Mat/machine) CG = 17	2xwk/50’	8wks	Mat and Machine	Y/Y	CG (UA)	Balance Strength Flexibility Functionality
Tozim *et al*., 2020	RCT	Chronic low back pain	PG 67 (4) CG 68 (5)	100% PG = 14 CG = 14	2xwk/60’	8wks	Mat	Y/Y	CG (Educational group)	Strength Flexibility
Dlugosz-Bós *et al*., 2021	RCT	Healthy	PG 68 (4) CG 68 (3)	100% PG = 30 CG = 20	2xwk/45’	12wks	Mat	Y/Y	CG (daily activities)	Balance
Patti *et al*., 2021	RCT	Healthy	PG 64 (4) CG 63 (4)	PG = 18;78% CG = 23;61%	3xwk/50’	13wks	Mat	Y/Y	CG (non-specific physical activity)	Balance Strength

ss: sessions; wk: week; PG: Pilates group; CG: control group; CI/DP: certified Instructor/detailed protocol; Y/NA: yes/not available; UA: usual activity.

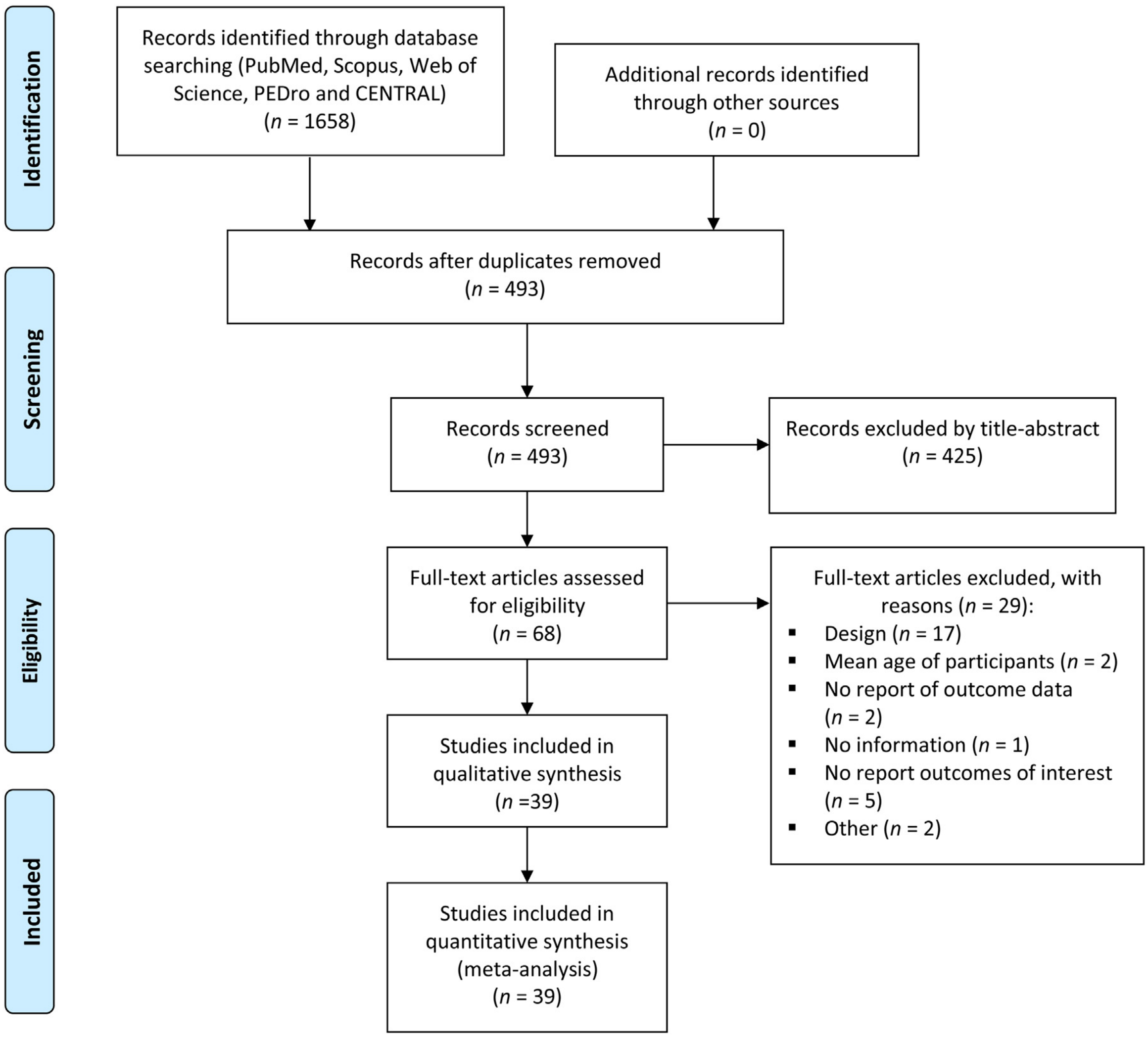

Fig. 1. Flow of the included studies.
From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta- Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097.

ticipants, of which 898 were in the Pilates group (54%) and 752 were in the control group (46%). Across the studies, 1288 (78%) participants were healthy older adults, and 362 (22%) were institutionalized older adults. Moreover, 24 studies (62%) were conducted among older women only. The overall mean age of the participants ranged between 60 and 80 years.

Participants in the control groups usually performed their habitual exercise routines, continued their daily physical activities, or received usual care. Regarding the main characteristics of the Pilates interventions, the frequency of sessions was two (55%) or three (45%) sessions per week. Moreover, the sessions ranged mostly from 45 to 60 minutes, although two studies did not report time [28,61]. The length of interventions lasted from four to 24 weeks, and two studies did not report length [43,72]. Additionally, 28 studies described the Pilates intervention as Pilates Mat (72%) and 10 as Pilates machine (28%). Finally, 30 studies (77%) were conducted by a certified instructor, and 25 (64%) were conducted with a detailed exercise protocol.

Quality

After assessing the risk of bias of RCTs with the Cochrane Collaboration RoB2 tool, [36] 25 RCTs (64%) were assessed as having a high risk of bias, and 14 (36%) were assessed as having an unclear risk of bias (Appendix 2 in supplementary material).

According to the GRADE summary of findings, the main limitations were the risk of bias and the “substantial” or “considerable” heterogeneity among the RCTs included, in addition to the publication bias shown for balance. Therefore, the level of certainty of the findings was low for balance, flexibility and functionality and moderate for strength and risk of falls. Further details are available in Appendix 3 in supplementary material.

Table 2
Included studies for the meta-analysis.

Outcome	Studies (number)	PG	CG	Mean age	Pilates modality	Most utilized tests	Risk of bias	GRADE
Balance	21	497	497	68	Mat:16; machine: 5	TUG: 16 studies (76%) Force platform: 12 studies (57%)	HR: 13 studies SC: 8 studies	Low certainty
Strength	21	440	449	67	Mat:15; machine: 6	STS test: 7 studies (33%)	HR: 14 studies SC: 7 studies	Moderate certainty
Flexibility	14	305	308	68	Mat:10; machine: 4	SRt: 7 studies (50%)	HR: 9 studies SC: 5 studies	Low certainty
Functionality	14	325	327	68	Mat:7; machine: 7	Aerobic endurance tests (i.e., 6MWT, etc.): 8 studies (57%)	HR: 12 studies SC: 2 studies	Low certainty
Falls	5	136	134	70	Mat:5	FoF: 3 studies (60%)	HR: 1 study SC: 4 studies	Moderate certainty

PG: Pilates group; CG: control group; TUG: timed up and go test; STS: sit to stand; SRt: sit and reach test; 6MWT: 6 m walking test; FoF: fear of falling; HR: high risk of bias; SC: some concerns.

Outcomes

All the included studies assessed participants at the end of the Pilates intervention, and no additional follow-up measurements were reported. Data related to studies included for each outcome in the meta-analysis are presented in Table 2.

Data synthesis

Meta-analysis

The pooled ES for the meta-analyses of RCTs (Pilates *vs*. the control group) was 0.36 (95% CI: 0.21 to 0.50; $I^2 = 73.4\%$, $P \leq 0.001$) for balance, 0.63 (95% CI: 0.44 to 0.81; $I^2 = 67.3\%$, $P \leq 0.001$) for strength, 0.41 (95% CI: 0.16 to 0.67; $I^2 = 78.8\%$, $P \leq 0.001$) for flexibility, 0.51 (95% CI: 0.32 to 0.71; $I^2 = 47.7\%$, $P = 0.02$) for functionality, and 0.90 (95% CI: 0.41 to 1.38; $I^2 = 73.3\%$, $P \leq 0.001$) for risk of falls. These meta-analyses are presented in Figs. 2 and 3.

Sensitivity and subgroup analyses and meta-regression models

After removing studies from the analysis one at a time, none of them modified the pooled ES estimate. The subgroup analyses showed that the Pilates modality, the existence of a detailed exercise protocol, whether sessions were supervised by a certified instructor, or the overall risk of bias of the included studies did not substantially modify the pooled ES across studies. Sensitivity and subgroup analyses are included in Appendices 4 and 5 in supplementary material, respectively.

The random effects meta-regression models did not show any significant influence on the outcomes analyzed (Appendix 6 in supplementary material).

Publication bias

There was significant publication bias, as evidenced by both funnel plot asymmetry and Egger's test, for balance ($P = 0.02$) (Appendix 7 in supplementary material).

Discussion

This systematic review and meta-analysis aimed to estimate the effectiveness of Pilates on physical performance and the risk of falls among older adults. Our findings support the notion that Pilates is effective for improving balance, strength, flexibility, and functionality and reducing the risk of falls. Moreover, our results are not substantially modified by potential mediators or moderators, such as age, number of sessions per week, Pilates modality, the existence of a Pilates exercise protocol, being supervised by a certified instructor, or overall risk of bias of included studies. Finally, the level of certainty of the findings based on the GRADE report was low for balance, flexibility and functionality and moderate for strength and risk of falls.

Our results are in accordance with those of recent studies [33] that show a positive effect of Pilates on balance. The negative ES shown by some studies [42,60] could be due to the ceiling effect of static balance tests. These results may be related to the fact that strength in the lower limbs and the trunk may positively influence the center of gravity distribution for balance strategies [14]. Our data also support those of previous studies reporting an improvement in strength [17,23,24,47,73,74]; likewise, our data show balance improvements, which have been suggested to be explained through the relationship with strength and trunk stabilization [14], along with a higher proprioception sensitivity caused by neuromuscular changes that contribute to cortical remapping [42]. Furthermore, better neuromotor recruitment patterns could explain strength gains [75]. However, to pro-

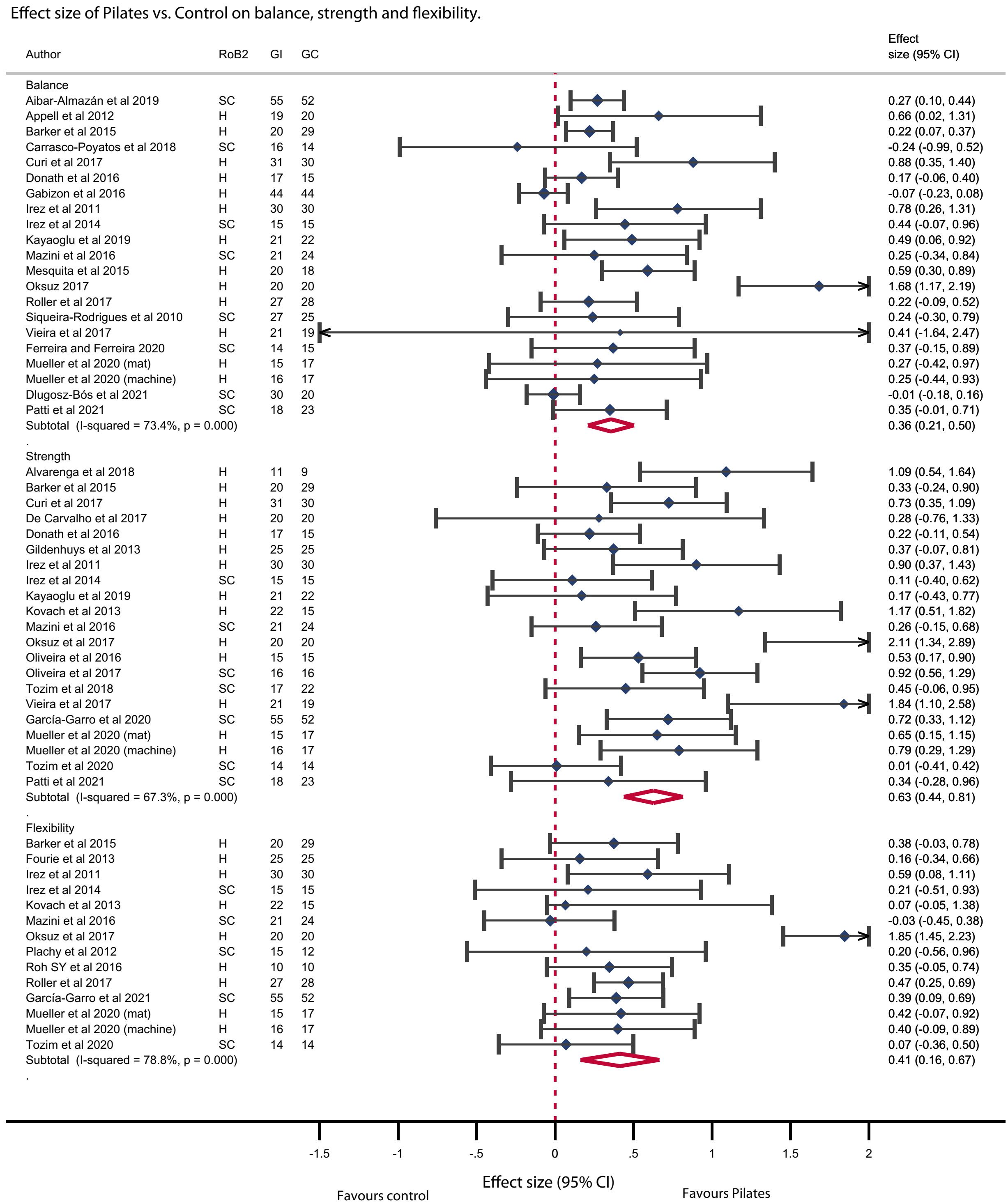

Fig. 2. Meta-analyses on balance, strength and flexibility.

mote neuromuscular stimulation that allows for an increase in muscular strength, training load and length are postulated to be crucial [49].

Regarding flexibility, a positive effect of Pilates was found in the back and upper and lower limbs; these results are consistent with those of a previous meta-analysis [33], except for upper limbs, in which the effect was not as clear. Anatomical barriers that arise and block tissues from stretching during the aging process could explain this fact [76]. Moreover, shoulder pain is one of the most common disorders in older people (13–26%), mainly among women [77,78], and over half (62%) of the included studies were conducted in older

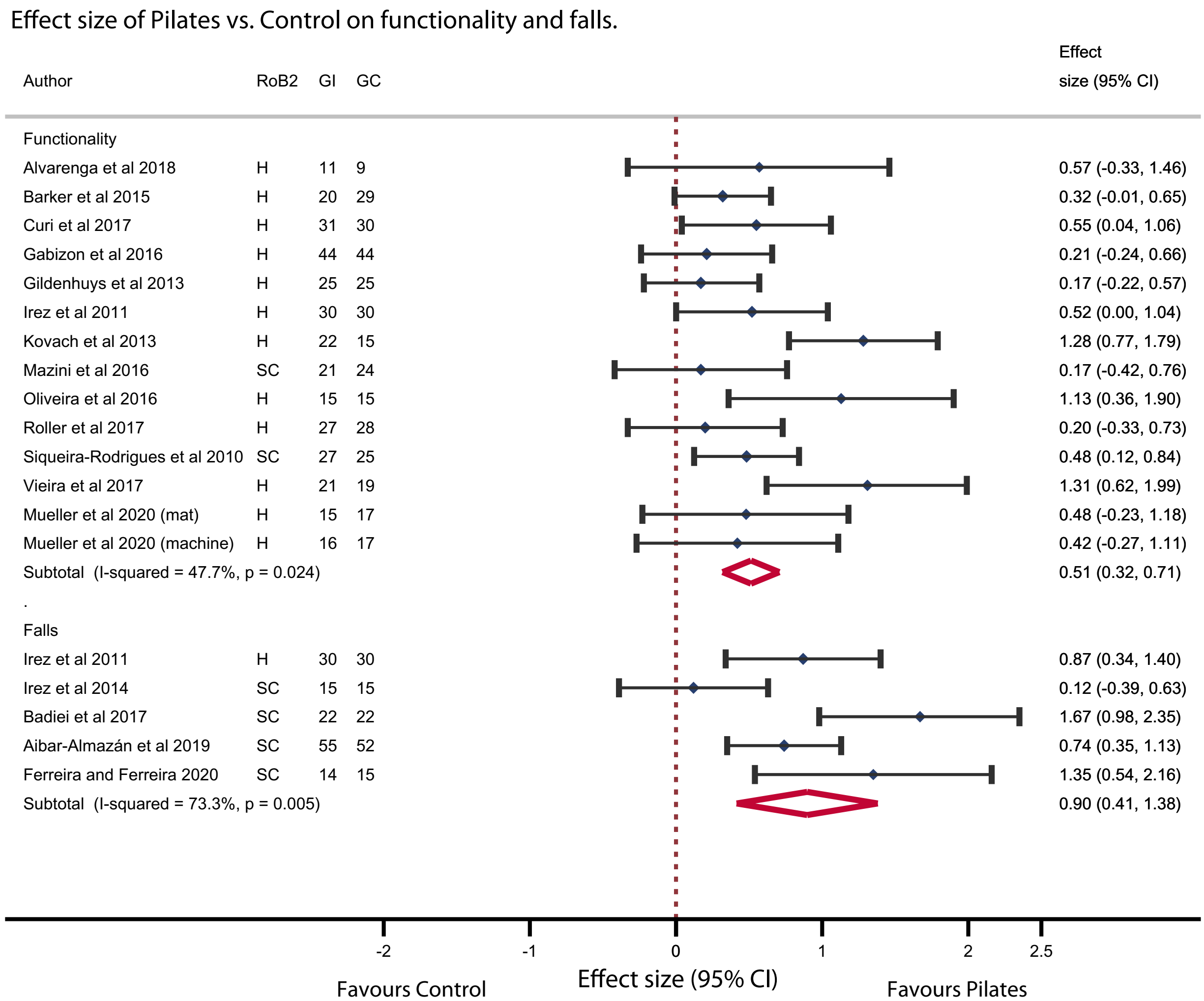

Fig. 3. Meta-analyses on functionality and falls.

women. This, and the lack of specific exercises for upper limbs, may explain the differences between our results and those of previous studies. In contrast, Pilates could demand morphological changes in muscle fibers, resulting in tissue adaptations [79] and, therefore, better flexibility. Finally, a loss of flexibility has been shown to increase the occurrence of gait disorders, representing a challenge to perform several daily tasks [76,80] and, consequently, decreasing the autonomy of older adults as well as increasing their risk of falls.

Related to physical performance in daily tasks, the functionality term includes aerobic endurance, gait parameters, and activities of daily living (ADLs), and it plays an essential role in avoiding falls or fear of falling and the autonomy of older people in their ADLs [25]. Our results are in line with those of recent studies showing positive effects of Pilates on functionality [20,46,47]; moreover, none of the studies included in our review showed a negative ES for this outcome. Evidence suggests that Pilates improves functionality through postural stability [70], joint mobility [28], and strengthening of the muscular structures involved [49]. Consequently, a better score is achieved in ADLs by older people who perform Pilates.

As has been reported in several studies [7,76,80,81], the risk of falls is strongly linked to benefits in physical performance through improvements in balance, strength, flexibility, and functionality. Our analyses showed agreement with previous studies [19,27] that revealed a significant improvement of Pilates on the risk of fall outcomes. In this way, Pilates could decrease the risk of falls because of greater postural and dynamic stability, along with the reduction in a fear of falling or kinesiophobia [42]. However, because there are only five studies reporting data on the risk of falls, our results should be interpreted cautiously. In this context, further studies are needed to study the effects of Pilates on the risk of falls, as it is a crucial outcome in older adults.

To increase the clinical applicability of the present review, the authors summarized the most commonly used Pilates exercises among older adults. Although some studies did not report the Pilates protocol, most of them showed similarly structured Pilates sessions. First, there is a warm-up phase lasting 5–10 min performing breathing exercises, mobilization of the principal joints, and key principles of the Pilates method. After this, the central phase (approximately 30 minute) aimed at improving physical performance usually includes the following exercises: hundreds, roll-up, roll-down, single leg circles, bridge, pelvic tilts, one side leg kick, swimming, spine rotations, *etc*. Moreover, exercises in supine, prone, seating, and standing positions are performed focusing on challenging the balance. Finally, the cool-down phase (5–10 minute) usually includes single leg stretches, spine stretch, mermaid, stretching of the related muscles involved in the central phase, and breathing techniques. It should be stated that the exercises were modified according to the participant characteristics and following the overload principle of training (e.g., chair-based, with implements).

Strengths and limitations

The limitations of this study are as follows. (1) Blinding of exercise interventions was not possible, and some of the studies did not explain the randomization sequence or the allocation concealment. (2) Thus, over half of the studies were classified as having a high risk of bias. (3) Additionally, considerable levels of heterogeneity shown by analyses and the baseline physical status of the participants should be considered. (4) Furthermore, unpublished literature was not reviewed. (5) Otherwise, caution should be taken when extrapolating the results to all older populations because the amount of physical exercise in Pilates varies depending on the intensity of the intervention across studies. (6) Additionally, the lack of uniformity in the test used for measuring the dimensions of physical performance could threaten the generalizability of our estimates. (7) Finally, due to a lack of long-term assessments of the effect of Pilates interventions impedes us from foreseeing how long the benefits of Pilates could be preserved.

In contrast, our study presents some strengths. (1) The authors considered the multifactorial characteristics that could influence the risk of falls (balance, strength, flexibility, and functionality). (2) Subgroup analyses and meta-regressions were performed to minimize potential sources of heterogeneity and bias.

Conclusion

Pilates programs could be an effective, well-accepted, and safe physical exercise for improving balance, strength, flexibility, and functionality and reducing the risk of falls in older people. Moreover, our results are important from the clinical point of view because they support the notion that Pilates may prevent falls and their related negative consequences as well as may increase the autonomy of older adults in their ADLs. Regardless, maintaining physical exercise as a routine and encouraging a healthy lifestyle is essential to maintain an active aging process. Finally, additional high-quality studies with long-term measurements are needed, as the present systematic review showed a low-to-moderate level of certainty of the findings, mainly because of the heterogeneity and risk of bias of the included studies.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.physio.2021.05.008.

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