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EFFECTS OF PHYSICAL EXERCISE INTERVENTIONS ON BALANCE, POSTURAL STABILITY AND GENERAL MOBILITY IN PARKINSON'S DISEASE: A NETWORK META-ANALYSIS

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Objective: **To assess which type of physical exercise intervention has the most beneficial effects on balance, postural stability and general mobility in patients with Parkinson's disease. These parameters were assessed using the Activities-specific Balance Confidence (ABC) scale, Berg Balance Scale (BBS), Mini-Balance Evaluation Systems Test (MiniBESTest) and Timed Up and Go Test (TUG).**

Design: **Network meta-analysis.**

Methods: **The PubMed, Cochrane Central Register of Controlled Trials, and Web of Science databases were searched up to August 2022 to identify randomized controlled trials on the effects of physical exercise interventions on balance, postural stability, and general mobility. The network meta-analysis included pairwise and indirect comparisons of results on the ABC scale, BBS, MiniBESTest, and TUG across 8 categories of physical exercise.**

Results: **Eighty-six studies with a total of 4,693 patients were included. For the ABC scale, the indirect comparison showed that the highest effect size was observed for balance vs sensorimotor training without including endurance interventions (0.62; 95% confidence interval (95% CI) 0.06, 1.17). The highest effect sizes for BBS were observed for alternative exercises (1.21; 95% CI 0.62, 1.81), body-weight supported (BWS) interventions (1.31; 95% CI 0.57, 2.05), dance (1.18; 95% CI 0.33, 2.03) and sensorimotor training, including endurance interventions (1.10; 95% CI 0.46, 1.75) vs control groups. Indirect comparisons showed that the highest effect size for the MiniBESTest were observed for balance (0.75; 95% CI 0.46, 1.04) and resistance (0.58; 95% CI 0.10, 1.07) vs control groups. For the TUG, comparisons showed a significant effect size for alternative exercises (−0.54; 95% CI −0.82, −0.26), balance (−0.42; 95% CI −0.75, −0.08), resistance (−0.60; 95% CI −0.89, −0.31), and sensorimotor training including endurance interventions (−0.61; 95% CI −0.95, −0.27) vs control comparisons.**

Conclusion: **Balance interventions improve balance, postural stability, and general mobility in people with Parkinson's disease. Moreover, alternative exercises, dance, BWS interventions, resistance, and sensorimotor training, including and not including endurance interventions, are also effective.**

LAY ABSTRACT

This network meta-analysis aimed to assess which type of physical exercise intervention has the most beneficial effects on balance, postural stability and general mobility in patients with Parkinson's disease. These parameters were assessed using the Activities-specific Balance Confidence (ABC) scale, Berg Balance Scale (BBS), Mini-Balance Evaluation Systems Test (MiniBESTest) and Timed Up and Go Test (TUG). The comparisons of results across 8 categories of physical exercise showed that balance exercises improve balance, postural stability, and general mobility in people with Parkinson's disease. Moreover, alternative exercises, dance, body weight supported interventions, resistance training, and sensorimotor training including and not including endurance interventions, are also effective.

Key words: Parkinson's disease; exercise; physical activity modalities; postural balance; mobility limitation.

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Parkinson's disease (PD) is a complex and progressive neurodegenerative disorder that affects the patient's physical, psychological, and social functions. PD is characterized by rest tremor, muscular rigidity, bradykinesia, and postural control impairment (1). These symptoms could affect patients' balance, posture, and postural stability.

Balance is defined as the ability to control body mass by integrating the sensory, musculoskeletal, and central nervous systems in response to changes in internal and external environmental conditions (2, 3). Posture is defined as the orientation of the different body segments in relation to gravitational forces providing mechanical support to perform movements or hold stance. Postural stability is defined as balance, which compromises

the ability to maintain or change posture (4). Postural stability is one of the most difficult challenges for patients with PD, and a reduction in postural stability contributes to increased disability, increased risk of falls, and reduced quality of life (5). Both balance and postural stability are involved in the performance of activities of daily living and are fundamental aspects of the general mobility of people with PD (3, 6).

Pharmacological and surgical interventions have been shown to be useful in reducing the clinical severity of tremor and muscular rigidity symptoms. However, postural stability has not been shown to improve to the same degree as the other cardinal motor symptoms (7–9). Thus, non-pharmacological and non-surgical interventions are needed to promote usual care programmes for postural and balance impairments. In this regard, physical exercise interventions have been demonstrated to improve physical condition and functional ability in patients with PD (10).

Physical exercise programmes improve physical performance and the execution of activities of daily living for which balance, postural stability and general mobility are essential (11, 12). In particular, some physical exercise-based physiotherapy interventions have demonstrated effectiveness in improving balance and postural stability in patients with PD, although the specific effect of each type of physical exercise has not been reported (13–16).

Recent systematic reviews and meta-analyses have studied the effects of some types of physical exercise on PD and other neurological diseases, but have not reported separate and comparative effects among the different types of physical exercise (17, 18). In addition, a recently published Cochrane review compared the effectiveness of the different categories of physical exercise for the severity of motor signs, quality of life, occurrence of adverse events, gait freezing, and functional mobility and balance measured with the Timed Up and Go Test (TUG); however, the review did not evaluate balance and postural stability (19). In a previous paper, the effects of different types of physical exercise on quality of life were compared, and differences were observed between the exercise categories; therefore, it is expected that these differences will be observed in other parameters, such as balance, postural stability, and general mobility (20).

Thus, the aim of this network meta-analysis was to assess which type of physical exercise intervention has the most beneficial effects on balance, postural stability, and general mobility in patients with PD. These parameters were assessed using the Activities-specific Balance Confidence (ABC) scale, Berg Balance Scale (BBS), MiniBalance Evaluation Systems Test (MiniBESTest) and TUG.

METHODS

This systematic review and network meta-analysis was conducted in accordance with the Preferred Reporting Items for Systematic Review incorporating Network Meta-Analysis (PRISMA-NMA) and the Cochrane Collaboration Handbook (21, 22), and it was previously registered in the PROSPERO database (CRD42022351062).

Data sources and searches

The PubMed, Cochrane Central Register of Controlled Trials, and Web of Science databases were searched from inception to August 2022. Moreover, references from previous systematic reviews, meta-analyses, and suitable articles were reviewed to identify additional relevant studies.

The search strategy combined the following terms: "Parkinson's disease", "Parkinson", "physical exercise", exercise, fitness, aerobic, resistance, endurance, strength, balance, stability, posture, and equilibrium. The full strategy search for MEDLINE is shown in Table SI.

Eligibility criteria

The search aimed to identify studies reporting on the effect of physical exercise interventions on balance, postural stability, and general mobility in persons with PD. The inclusion criteria were as follows: (*i*) type of study: randomized controlled trials (RCTs); (*ii*) type of participants: adults with PD; (*iii*) type of intervention: structured physical exercise interventions compared with other physical exercise interventions or control interventions; and (*iv*) type of outcome: the ABC scale, BBS, and MiniBESTest were used to evaluate balance and postural stability, and the TUG was used to evaluate balance and general mobility.

For this network meta-analysis, the following scales were considered, as they have been the most widely used tools for the assessment of balance, postural stability, and general mobility among patients with PD. (*i*) The ABC scale is a 16-item point questionnaire in which patients rate their level of self-confidence in balance and postural stability while performing activities on a scale from 0 to 100. (*ii*) The BBS is a 14-item objective scale used to determine a patient's ability to balance and maintain postural stability safely while performing a series of predetermined tasks. (*iii*) The BESTest is a 36-item test, and its short version, the MiniBESTest, includes 16 items to assess biomechanical constraints, stability limits, anticipatory postural adjustments, postural response, sensory orientation, and stability during gait. (*iv*) The TUG measures the time needed to rise from a chair, walk to a mark 3 m away, turn around and sit back on the chair; this test is used to assess general mobility, balance, risk of falls and locomotor performance (23–26).

Studies were excluded if they: (*i*) included healthy people within the intervention or control groups, (*ii*) did not report enough data to conduct a statistical analysis, (*iii*) included groups undergoing similar interventions that cannot be categorized into different physical exercise categories, (*iv*) had a crossover design and did not report results at the end of the first intervention period, or (*v*) were not published in English or Spanish.

Data extraction

The following data were extracted from the included studies and are summarized in Table I: (*i*) reference, (*ii*) country, (*iii*) characteristics of the subjects (i.e. sample size, number of fema-

les, mean age, time since diagnosis of PD, and basal Hoehn and Yahr stage (H&Y)), (*iv*) physical exercise intervention characteristics (i.e. description of training regime, duration, frequency, and time), (*v*) physical exercise intervention categorization, and (*vi*) scale used to measure balance, postural stability and general mobility.

Risk of bias assessment

The risk of bias of the included RCTs was assessed using the Cochrane Collaboration Risk of Bias tool (RoB2) (27). This tool evaluates the risk of bias according to 6 domains: randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, selection of the reported result, and overall bias. Each of the domains could be scored as "low risk of bias", "some concerns", or "high risk of bias".

Grading the quality of evidence

The Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) tool was used to assess the quality of evidence (28). In the GRADE tool, quality of evidence could be rated as high, moderate, low, or very low across the following domains: study design, risk of bias, inconsistency, indirectness, imprecision, and publication bias.

Two researchers (PL-G and CA-B) independently performed the literature search, data extraction, risk of bias assessment, and grading of evidence. In cases of disagreement, a third researcher (IC-R) was consulted to reach a consensus.

Categorization of the interventions

Physical exercise interventions were classified into 8 categories: sensorimotor training including endurance, sensorimotor training not including endurance, resistance, endurance, dance, alternative exercises, body weight supported (BWS), and balance. (*i*) Sensorimotor interventions were defined as physical exercise interventions that improve postural stability and progressively challenge the sensorimotor system, combining aerobic, postural and stretching exercises, relaxation, and gait and balance training. Depending on whether endurance exercise was included in the sensorimotor training programme, it was classified as sensorimotor training, including endurance, or sensorimotor training not including endurance. (*ii*) Resistance training aims to increase muscular strength and power. (*iii*) Endurance interventions include physical exercise programmes aimed at increasing energy expenditure, such as walking, running, cycling, or interval exercise. (*iv*) The dance category includes interventions with balance and muscular coordination tasks that are associated with music. (*v*) Alternative exercises include balance-based exercises focused on breathing, postural control, stretching, and meditation (e.g. tai chi, yoga, qi-gong, and ai-chi). (*vi*) BWS interventions include physical exercise programmes with reduced pressure forces through robotic or mechanical assistance. (*vii*) Balance exercises are aimed at improving postural reactions and adjustments, proprioception, sensory integration, motor agility, and stability limits (29, 30).

Data synthesis and analysis

The included studies were summarized in an ad hoc table describing the types of direct and indirect comparisons. A similarity analysis was performed to assess differences in the possible confounding variables relative to the clinical and demographic characteristics of the samples among the participants included in the different types of intervention and the control groups (i.e. sex, age, disease duration, and severity) (31). In addition, consistency was assessed by checking whether the intervention effects estimated from direct comparisons were consistent with those estimated by indirect comparisons, using the node-splitting method (32).

First, a frequentist random effects multivariate network meta-analysis was used to synthesize the evidence for physical exercise interventions (31). A network geometry graph was used to summarize the available evidence, where each node represents a type of intervention, the size of the nodes proportionally represents the number of participants in the trials, and the width of the lines connecting the nodes is proportional to the number of trials that directly compared the 2 interventions (33). Rankograms were used to graphically represent the probability of each physical exercise intervention being the most effective.(33) Moreover, the surface under the cumulative ranking (SUCRA) was estimated for each intervention. SUCRA was assigned a value between 0 and 1, and the most effective intervention was the one that was closest to the value of 1 (34).

Secondly, a standard meta-analysis was performed on standardized mean differences for each direct comparison between 2 physical exercise interventions, using the DerSimonian–Laird random effects method (35). The corresponding pooled effect size (ES) and confidence intervals (95% CI) for each outcome were reported. In the analyses of the ABC scale, BBS, and BESTest, or MiniBESTest, a higher score indicates better balance and postural stability, but in the analyses of the TUG, a higher score (higher time of execution) indicates worse balance and general mobility (36–39). Furthermore, the heterogeneity of the results was examined using the I^2 statistic, their corresponding *p*-values, and the 95% CIs. I^2 values up to 30% were considered to indicate "non-important" heterogeneity; values form 30% to 60% represented "moderate" heterogeneity; values from 60% to 90% represented "substantial" heterogeneity; and values from 90% to 100% represented "considerable" heterogeneity. The $\tau 2$ statistic was calculated to determine the size and clinical relevance of heterogeneity and interpreted as low when $\tau 2$ was lower than 0.04, moderate when $\tau 2$ was from 0.04 to 0.14 and substantial when $\tau 2$ was higher than 0.14 (40). To detect whether a particular trial represented an important proportion of the heterogeneity, a sensitivity analysis was conducted by excluding studies one at a time from the pooled estimates. Furthermore, publication bias was assessed using Egger's test and visually examined using a funnel plot (41). All statistical analyses were performed in Stata 16.0 (StataCorp, College Station, TX, USA).

RESULTS

From the 4,474 studies identified in the systematic search, 86 RCTs were ultimately included in this network meta-analysis (Fig. S1 and Appendix S1). A total of 4,693 patients with PD were included in the trials; 3,206 in 133 intervention groups and 1487 in 60 control groups. Overall, 41.19% of the participants were women, and the mean age of all patients was 67.06 years.

The physical exercise frequency ranged from 2 to 5 times per week, the intervention duration ranges from 1 to 4 months, and the duration of each exercise session ranged from 30 to 120 min. The most common physical exercise intervention category was balance ($n=23$),

Table I. Characteristics of the included studies

Author, year	Country	Sample size (*n* women)	Age years (mean±SD)	Duration of PD (years) (mean±SD)	H&Y stage (mean±SD)	Physical exercise characteristics	Physical exercise category	Outcome
Abraham et al., 2018 (S1)	USA	IG: 10 (1) CG: 10 (3)	IG: 66.4 (12.5) CG: 65.1 (7.5)	IG: 6.1 (3.8) CG: 8.5 (4.5)	IG: 2.0 [1.8–2.5]* CG: 2.0 [2.0–2.5]*	IG: Dynamic Neuro-Cognitive Imagery. Imagery, kinaesthetic and proprioceptive techniques; postural, balance and coordination exercises. 2 weeks, 5 s × week (120 min) CG: Home learning and exercise programme. Reading related to health and wellness and a 30-min exercise video of standing and stepping. 2 weeks, 5 s × week (120 min)	IG: SMT not END CG: CN	ABC MiniBESTest TUG
Acarer et al., 2015 (S2)	Turkey	IG: 29 (12) CG: 11 (3)	IG: 67 (51–81) CG: 60 (40–71)	IG: 4.5 (1–24) CG: 8 (1–18)	IG: 22 (II)–7 (III) CG: 6 (II)– 5 (III)	IG: Customized vestibular rehabilitation. Adaptation, substitution, habituation, and balance exercises. 8 weeks, 1 s × week (30–45 min) CG: Control group. Usual care	IG: BLN CG: CN	ABC BBS TUG
Albrecht et al., 2021 (S3)	Sweden	IG: 34 (14) CG: 31 (11)	IG: 70.26 (5.82) CG: 70.45 (6.11)	IG: 5.71 (4.55) CG: 4.52 (3.49)	IG: 2.12 (0.33) CG: 2.20 (0.41)	IG: HiBalance group. Highly challenging balance and gait training program based on sensory integration, anticipatory postural adjustments, motor agility and stability limits. 10 weeks, 2 s × week (60 min) CG: Active control group. Speech and communication programme. 10 weeks, 2 s × week (60 min)	IG: BLN CG: CN	MiniBESTest
Alencar de Lima et al., 2019 (S4)	Brazil	IG: 17 CG: 16	IG: 66.2 (5.5) CG: 67.2 (5.2)	NA	IG: 4 (I)– 8 (II) 6 (III) CG: 5 (I)–6 (II) 4 (III)	IG: Resistance training group. 8–12 repetitions of 5 exercises with an increase of 2–10% of the load every 2 sessions. 20 weeks, 2 s × week (30–40 min) CG: Control group. Usual care	IG: RST CG: CN	TUG
Arfa-Fatollahkhani et al., 2019 (S5)	Iran	IG: 11 (3) CG: 9 (2)	IG: 60.63 (9.36) CG: 61.55 (8.57)	IG: 8.89 (5.14) CG: 8.50 (6.34)	IG: 2.13 (0.32) CG: 2.0 (0.35)	IG: Treadmill training group. Treadmill gait training at moderate intensity (60% HRR) 10 weeks, 2 s × week (30 min) CG: Control group. Usual care	IG: END CG: CN	TUG
Ashburn et al., 2007 (S6)	UK	IG: 70 (32) CG: 72 (24)	IG: 72.7 (9.6) CG: 71.6 (8.8)	IG: 7.7 (5.8) CG: 9.0 (5.8)	IG: 8 (II)– 44 (III) 18 (IV) CG: 8 (II)– 48 (III) 16 (IV)	IG: Exercise group. Strengthening, range of movement, balance training, walking, strategies for falls prevention. 6 weeks, 1 s × week (60 min) CG: Control group Usual care	IG: SMT + END CG: CN	BBS
Atan et al., 2019 (S7)	Turkey	IG1: 10 (6) IG2: 10 (6) IG3: 10 (7)	IG1: 68.6 (8.2) IG2: 72.2 (7.9) IG3: 69.7 (8.0)	IG1: 7.6 (6.4) IG2: 9.8 (9.0) IG3: 5.6 (5.3)	IG1: 4 (II)– 5 (III) 1 (IV) IG2: 3 (II)– 6 (III) 1 (IV) IG3: 5 (II)– 4 (III) 1 (IV)	IG1: 20% body weight supported treadmill training group. 30 min of conventional rehabilitation (stretching, range of motion) + 30 min of 20% body weight supported treadmill training at submaximal intensity. 6 weeks, 5 s × week (60 min) IG2: 10% body weight supported treadmill training group. 30 min of conventional rehabilitation (stretching, range of motion) + 30 min of 10% body weight supported treadmill training at submaximal intensity. 6 weeks, 5 s × week (60 min) IG3: Unsupported body weight treadmill training group. 30 min of conventional rehabilitation (stretching, range of motion) + 30 min of 0% body weight supported treadmill training at submaximal intensity. 6 weeks, 5 s × week (60 min)	IG1: BWS IG2: BWS IG3: END	BBS
Cakit et al., 2007 (S8)	Turkey	IG: 21 CG: 10 Total: 31 (15)	IG: – CG: – Total: 71.8 (6.4)	IG: – CG: – Total: 5.58 (2.9)	NA	IG: Training group. Stretching, range of motion and incremental-speed treadmill training (increments of 0.6 km/h every 5 min) 8 weeks (30–45 min) CG: Control group. Usual care	IG: END CG: CN	BBS
Capato et al., 2020 (S9)	The Netherlands	IG1: 56 (29) IG2: 50 (18) CG: 48 (19)	IG1: 74.0 (8.0) IG2: 67.0 (13.0) CG: 73.0 (10.0)	IG1: 5 [2–9]* IG2: 6 [2–10]* CG: 8 [2–15]*	IG1: 11 (I)– 17 (II) 28 (III) IG2: 11 (I)– 16 (II) 23 (III) CG: 7 (I)– 18 (II) 23 (III)	IG1: RAS-supported multimodal balance training. Balance exercises combined with rhythmical auditory stimuli, provided by a metronome. 5 weeks, 2 s × week (45 min) IG2: Regular multimodal balance training. Balance training without auditory stimuli. 5 weeks, 2 s × week (45 min) CG: Control intervention. General education program about PD, falls prevention and self-care. 5 weeks, 2 s × week (45 min)	IG1: BLN IG2: BLN CG: CN	BBS MiniBESTest TUG

(*Continued*)

Table I. (Continued) Characteristics of the included studies

Author, year	Country	Sample size (*n* women)	Age years (mean±SD)	Duration of PD (years) (mean±SD)	H&Y stage (mean±SD)	Physical exercise characteristics	Physical exercise category	Outcome
Capecci et al., 2019 (S10)	Italy	IG1: 48 (29) IG2: 48 (24)	IG1: 68.1 (9.8) IG2: 67.0 (7.6)	IG1: 8.9 (5.3) IG2: 8.9 (4.3)	IG1: 3 [2–4]* IG2: 3 [2–4]*	IG1: Robot-assisted gait training. Robot-assisted walking at variable speeds (30–40% BWS at 1.5 km/h; 20% BWS at 2.2–2.5 km/h) 4 weeks, 5 s × week (45 min) IG2: Treadmill training. Treadmill gait training at 0.8–1 km/h at the beginning and gradually increased to 2.0 km/h. 4 weeks, 5 s × week (45 min)	IG1: BWS IG2: END	TUG
Carda et al., 2012 (S11)	Italy	IG1: 15 (NA) IG2: 15 (NA)	IG1: 67.87 (7.05) IG2: 66.93 (5.13)	IG1: 3.73 (2.49) IG2: 3.73 (1.91)	IG1: 2.17 (0.24) IG2: 2.23 (0.26)	IG1: Lokomat. Robot-assisted walking at variable speeds (50% BWS at 1.5 km/h; 30% BWS at 3.0 km/h) 4 weeks, 3 s × week (30 min) IG2: Treadmill. Treadmill gait training at 1.5 km/h at the beginning and gradually increased to 3.0 km/h. 4 weeks, 3 s × week (30 min)	IG1: BWS IG2: END	TUG
Cheng et al., 2017 (S12)	Taiwan	IG1: 12 (3) IG2: 12 (4)	IG1: 65.8 (11.5) IG2: 67.3 (6.4)	IG1: 6.1 (4.1) IG2: 8.1 (4.6)	IG1: 1.8 (0.6) IG2: 2.0 (0.8)	IG1: Curved-walking training group. 30 min walking on a turning-based treadmill at 80% of comfortable speed + 10 min walking on ground with verbal cues. 4–6 weeks, 2–3s × week (40 min) IG2: Control exercise group. Trunk and upper extremity movements in a sitting position + 10 min walking on ground with verbal cues. 4–6 weeks, 2–3s × week (40 min)	IG1: END IG2: SMT not END	TUG
Cherup et al., 2021 (S13)	USA	IG1: 15 (5) IG2: 18 (7)	IG1: 69.8 (7.3) IG2:71.4 (12.1)	NA	IG1: 1.7 (0.5) IG2: 2.0 (0.8)	IG1: Yoga meditation. Body meditation and 15 gentle poses. 12 weeks, 2 s × week (45 min) IG2: Proprioceptive training. Balance and proprioceptive exercises (walking across uneven surfaces, balancing on devices. 12 weeks, 2 s × week (45 min)	IG1: ALT IG2: BLN	TUG
Choi et al., 2013 (S14)	Korea	IG: 11 (NA) CG: 9 (NA)	IG: 60.81 (7.6) CG: 65.54 (6.8)	IG: 5.2 (2.7) CG: 5.2 (2.7)	IG: 1.6 (0.6) CG: 1.8 (0.3)	IG: Tai Chi. Stretching, Tai Chi exercises and meditation. 12 weeks, 2 s × week (60 min) CG: No exercise control. Usual care.	IG: ALT CG: CN	TUG
Collett et al., 2017 (S15)	UK	IG: 54 (23) CG: 51 (21)	IG: 66.0 (9.0) CG: 67.0 (7.0)	IG: 4.8 (4.1) CG: 5.3 (4.1)	NA	IG: Exercise group. 30 min of aerobic training (55–85% HRR) + 30 min of resistance training. 24 weeks, 2 s × week (60 min) CG: Handwriting. Hand and writing exercises. 24 weeks, 2 s × week (60 min)	IG: SMT + END CG: CN	TUG
Combs et al., 2013 (S16)	USA	IG1: 14 IG2: 17	IG1: 68.0 [31.0]* IG2: 66.5 [28.0]*	IG1: 4.16 [8.25]* IG2: 3.46 [15.2]*	IG1: 2 [3.0]* IG2: 2 [3.0]*	IG1: Exercise group. Range of motion, stretching, strengthening, endurance and balance exercises. 12 weeks, 2–3s × week (90 min) IG2: Boxing group. Boxing specific activities via a circuit training regimen + general endurance activities. 12 weeks, 2–3s × week (90 min)	IG1: SMT + END IG2: END	ABC BBS TUG
Conradsson et al., 2015 (S17)	Sweden	IG: 47 (19) CG: 44 (22)	IG: 72.9 (6.0) CG: 73.6 (5.3)	IG: 6.0 (5.1) CG: 5.6 (5.0)	IG: 20 (II)– 27 (III) CG: 19 (II)– 25 (III)	IG: Training group. Exercises based on 4 balance components: sensory integration, anticipatory postural adjustments, motor agility and stability limits. 10 weeks, 3 s × week (60 min) CG: Control group. Usual care.	IG: BLN CG: CN	MiniBESTest
Cugusi et al., 2015 (S18)	Italy	IG: 10 (2) CG: 10 (2)	IG: 68.1 (8.7) CG: 66.6 (7.3)	IG: 7.0 (2.0) CG: 7.0 (4.0)	IG: 2.4 (0.8) CG: 2.3 (0.5)	IG: Nordic Walking program. Warm-up period, practicing Nordic walking competence, improving intensity and distance of Nordic walking, and cool down period. Intensity at 60–80% of HRR. 12 weeks, 2 s × week (60 min) CG: Control group. Conventional care.	IG: END CG: CN	BBS TUG
da Silva et al., 2019 (S19)	Brazil	IG: 14 (8) CG: 11 (6)	IG: 63.12 (13.61) CG: 64.23 (13.45)	NA	IG: 3.0 (1.0) CG: 3.0 (1.0)	IG: Experimental group. Aquatic dual task exercise program including walking, standing, exercises with ball. 10 weeks, 2 s × week (60 min) CG: Control group. Usual care.	IG: SMT + END CG: CN	BBS TUG
Dipasquale et al., 2016 (S20)	Italy	IG1: 20 (7) IG2: 20 (7)	IG1: 69.9 (6.42) IG2: 66.4 (9.32)	IG1: 2.25 (0.58) IG2: 2.33 (0.67)	IG1: 16 (II) IG2: 15 (II)	IG1: Physiotherapy group. Transfers, body posture, reaching and grasping, balance and gait. 16 weeks, 2 s × week (60 min) IG2: General exercise group. Exercises for the upper limbs, lower limbs, spine, balance and breathing. 16 weeks, 2 s × week (60 min).	IG1: SMT + END IG2: SMT not END	TUG

(*Continued*)

Table I. (Continued) Characteristics of the included studies

Author, year	Country	Sample size (*n* women)	Age years (mean±SD)	Duration of PD (years) (mean±SD)	H&Y stage (mean±SD)	Physical exercise characteristics	Physical exercise category	Outcome
Ebersbach et al., 2010 (S21)	Germany	IG1: 20 (13) IG2: 19 (12) CG: 19 (11)	IG1: 67.1 (3.6) IG2: 65.5 (9.0) CG: 69.3 (8.4)	IG1: 6.1 (3) IG2: 7.8 (4.4) CG: 7.4 (5.9)	IG1: 2.8 (0.37) IG2: 2.6 (0.4) CG: 2.5 (0.7)	IG1: Lee Silverman Voice Treatment BIG. Whole-body movements, stretching, goal-directed activities of daily living. 4 weeks, 4 s × week (60 min) IG2: Walk group. Supervised Nordic walking training. 8 weeks, 2 s × week , (60 min) CG: Home group. Nonsupervised stretching, high amplitude movements and active work for muscular power and posture. 1 h of instruction	IG1: SMT not END IG2: END CG: CN	TUG
Ganesan et al., 2014 (S22)	India	IG1: 20 (5) IG2: 20 (5) CG: 20 (4)	IG1: 57.7 (10.3) IG2: 57.6 (9.1) CG: 59.1 (6.8)	IG1: 4.9 (3.1) IG2: 5.7 (3.9) CG: 5.5 (3.4)	IG1: 17 (II)– 3 (II.5) IG2: 17 (II)– 3 (II.5) CG: 16 (II)– 4 (II.5)	IG1: Conventional gait training. Walking in a straight path, turning, swinging strategies while walking. Verbal auditory cues to encourage longer steps. 4 weeks, 4 s × week (35 min). IG2: Partial weight supported treadmill training. Treadmill with visual feedback of step length and step speed and a 20% unweighing support system. 4 weeks, 4 s × week (35 min). CG: Control group. Usual care.	IG1: SMT + END IG2: BWS CG: CN	BBS
Gao et al., 2014 (S23)	China	IG: 37 (14) CG: 39 (12)	IG: 69.54 (7.32) CG: 68.28 (8.53)	IG: 9.15 (8.58) CG: 8.37 (8.24)	IG: 1(I)– 19(II)–17(III) CG: 6(I)– 12(II)–21(III)	IG: Tai Chi group. 24-form Yang style Tai Chi (diagonal weight shifting, awareness of body position and breathing) 12 weeks, 3 s × week (60 min) CG: Control group. Usual care.	IG: ALT CG: CN	BBS TUG
Goodwin et al., 2011 (S24)	UK	IG: 64 (25) CG: 66 (31)	IG: 72.0 (8.6) CG: 70.1 (8.3)	IG: 9.1 (6.4) CG: 8.2 (6.4)	IG: 2.6 (0.9) CG: 2.4 (0.9)	IG: Intervention group. Strengthening, balance training exercises, stretching, marching, range of movement exercises. 10 weeks, 1 s × week (60 min) + 2 s × week of no-supervised home exercise. CG: Control group. Usual care	IG: SMT not END CG: CN	BBS TUG
Hackney et al., 2009 (S25)	USA	IG1: 17 (6) IG2: 14 (3) CG: 17 (5)	IG1: 66.8 (2.4)** IG2: 68.2 (1.4)** CG: 66.5 (2.8)**	IG1: 9.2 (1.4)** IG2: 6.9 (1.3)** CG: 5.9 (1.0)**	IG1: 2.0 (0.2)** IG2: 2.1 (0.1)** CG: 2.2 (0.2)**	IG1: Waltz and Foxtrot group. Waltz and Foxtrot progressive lessons. 13 weeks, 1–2s × week (60 min) IG2: Tango group. Tango progressive lessons. 13 weeks, 1–2s × week (60 min) CG: Control group. No intervention.	IG1: DNC IG2: DNC CG: CN	BBS TUG
Hubble et al., 2018 (S26)	Australia	IG: 11 (4) CG: 11 (3)	IG: 63.3 (4.9) CG: 67.5 (5.8)	IG: 6.5 (5.2) CG: 7.0 (5.0)	IG: 1.8 (0.6) CG: 2.0 (0.7)	IG: Exercise group. Trunk mobility exercises, endurance and stability of trunk muscles exercises, stretching and gait 12 weeks, 3 s × week (90 min) + Falls prevention education. 12 weeks, 1 s × week. CG: Education group. Falls prevention education. 12 weeks, 1 s × week.	IG: SMT + END CG: CN	ABC TUG
Johansson et al., 2020 (S27)	Sweden	IG: 7 (1) CG: 6 (3)	IG: 72.0 [60–78]* CG: 67.5 [63–70]*	IG: 10.0 [3–13]* CG: 7.0 [3–11]*	IG: 5 (II)– 2(III) CG: 3 (II)– 3(III)	IG: HiBalance intervention group. Highly challenging balance exercises targeting sensory integration, anticipatory postural adjustments, motor agility and stability limits. 10 weeks, 2 s × week (60 min) CG: HiCommunication control group. Training program for speech and communication. 10 weeks, 2 s × week (60 min)	IG: BLN CG: CN	ABC MiniBESTest
Jung et al., 2020 (S28)	USA	IG: 44 (14) CG: 42 (14)	IG: 67.7 (6.7) CG: 70.0 (8.2)	IG: 6.2 (4.4) CG: 6.7 (5.5)	IG: 1 (I)– 38 (II) 4 (III)– 1 (IV) CG: 31 (II)– 4 (III) 7 (IV)	IG: Exercise group. Gait training, agility exercises, boxing, lunges, tai chi movements. 6 weeks, 3 s × week (80 min) CG: Education group. Education based on self-management of care, sleep, nutrition, stress, mood and medication. 6 weeks, 1 s × week (80 min)	IG: SMT + END CG: CN	MiniBESTest
Khalil et al., 2017 (S29)	Jordan	IG: 16 (4) CG: 14 (7)	IG: 58.4 (13.5) CG: 60.7 (15.4)	IG: 8.0 (6.4) CG: 7.5 (4.0)	IG: 2.4 (0.72) CG: 2.2 (0.8)	IG: Intervention group. Flexibility, strength, balance and endurance exercises, training on performing functional tasks, relaxation, stretching and breathing techniques. 8 weeks, 3 s × week + 8 weeks, 1 s × week (45 min) of walking. CG: Control group. Usual care.	IG: SMT + END CG: CN	MiniBESTest
Khuzema et al., 2020 (S30)	India	IG1: 9 (3) IG2: 9 (3) IG3: 9 (2)	IG1:72.0 (5.22) IG2: 68.11 (4.23) IG3: 70.89 (6.01)	IG1: 5.67 (2.33) IG2: 6.2 (1.67) IG3: 5.23 (3.12)	IG1: 3 (II.5)– 6 (III) IG2: 3 (II.5)– 6 (III) IG3: 4 (II.5)– 5 (III)	IG1: Tai Chi group. Six Tai Chi poses repeated about five times initially and gradually increased to 10 repetitions. 8 weeks, 5 s × week (30–40 min) IG2: Yoga group. Six Yoga poses repeated about five times initially and gradually increased to 10 repetitions 8 weeks, 5 s × week (30–40 min). IG3: Conventional balance exercise group. Standing back extension, standing trunk rotations. Backwards walking, side-ways walking, tandem walking and single limb stance. Each exercise was repeated about five times initially and gradually increased to 10 repetitions. 8 weeks, 5 s × week (40–45 min)	IG1: ALT IG2: ALT IG3: BLN	BBS TUG

(*Continued*)

Table I. (Continued) Characteristics of the included studies

Author, year	Country	Sample size (*n* women)	Age years (mean±SD)	Duration of PD (years) (mean±SD)	H&Y stage (mean±SD)	Physical exercise characteristics	Physical exercise category	Outcome
Kurt et al., 2018 (S31)	Turkey	IG1: 20 (9) IG2: 20 (7)	IG1: 62.41 (6.76) IG2: 63.61 (7.18)	NA	IG1: 9 (II)– 7 (II.5) 4 (III) IG2: 11 (II)– 5 (II.5) 4 (III)	IG: Ai Chi exercises group. 16 different movements of Ai Chi based on balance, strength, relaxation, flexibility and breathing. 5 weeks, 5 s × week (60 min) IG2: Land based exercises group. Stretching, balance and gait training. 5 weeks, 5 s × week (60 min)	IG1: ALT IG2: SMT not END	BBS TUG
Kwok et al., 2019 (S32)	Hong Kong	IG1: 71 (34) IG2: 67 (39)	IG1: 63.7 (8.2) IG2: 63.5 (9.3)	NA	IG1: 23 (II)–48 (III) IG2: 2 (I)–19 (II) 46 (III)	IG1: Mindfulness Yoga. 12 basic Hatha yoga poses (sun salutations + controlled breathing + mindfulness meditation) 8 weeks, 1 s × week (90 min) IG2: Stretching and Resistance Training. Resistance and stretching training exercises. 8 weeks, 1 s × week (60 min)	IG1: ALT IG2: RST	TUG
Landers et al., 2016 (S33)	USA	IG1: 10 (6) IG2: 11 (3) IG3: 10 (3) CG: 10 (4)	IG1: 72.2 (4.4) IG2: 70.2 (4.4) IG3: 70.1 (9.5) CG: 74.3 (8.8)	NA	IG1: 4 (I.5)– 2 (II) 1 (II.5)– 2 (III) 1 (IV) IG2: 2 (I.5)– 1 (II.5) 6 (III)– 2 (IV) IG3: 4 (II)– 3 (II.5) 3 (III) CG: 1 (I.5)– 4 (II.5) 4 (III) 1 (IV)	IG1: Balance training + external focus instructions. Balance training in treadmill, exercise of obstacle course negotiation and exercises on a compliant surface with external focus instructions. 4 weeks, 3 s × week (45 min) IG2: Balance training + internal focus instructions. Balance training in treadmill, exercise of obstacle course negotiation and exercises on a compliant surface with internal focus instructions. 4 weeks, 3 s × week (45 min) IG3: Balance training without attentional focus instructions. Balance training in treadmill, exercise of obstacle course negotiation and exercises on a compliant surface. 4 weeks, 3 s × week (45 min) CG: Control. Usual care.	IG1: BLN IG2: BLN IG3: BLN CG: CN	ABC BBS
Leal et al., 2019 (S34)	Brazil	IG: 27 (13) CG: 27 (13)	IG: 65.2 (2.05) CG: 64.9 (2.32)	NA	IG: 2 [1–3]* CG: 2 [1–3]*	IG: Resistance training group. 2 sets of 12 repetitions of each exercise (bench press, deadlift, unilateral rowing, standing calf rise and abdominal reverse crunch. Incremental load of 2–10%. 24 weeks, 2 s × week (30–40 min) CG: Control group. Usual care.	IG: RST CG: CN	TUG
Lee et al., 2015 (S35)	Korea	IG: 10 (5) CG: 10 (5)	IG: 68.4 (2.9) CG: 70.1 (3.3)	NA	NA	IG: Experimental group. Virtual reality dance exercise using K-Pop Dance Festival game for Wii. 6 weeks, 5 s × week (30 min). CG: Control group. Usual care.	IG: DNC CG: CN	BBS
Lee et al., 2018 (S36)	Korea	IG: 25 (15) CG: 16 (9)	IG: 65.8 (7.2) CG: 65.7 (6.4)	IG: 4.5 (3.3) CG: 4.4 (3.0)	IG: 7 (I)– 10 (II) 8 (III) CG: 7 (I)– 5 (II) 4 (III)	IG: Turo program. Relaxing the meridians, circulating Qi, stabilizing Qi with dance movements. 8 weeks–2s × week (60 min) CG: Wait-list control. Usual care	IG: ALT CG: CN	BBS
Lei et al., 2016 (S37)	China	IG: 28 (17) CG: 26 (12)	IG: 65.84 (5.45) CG: 62.5 (3.13)	NA	NA	IG: Health Qigong experimental group. 10 Qigong movements practiced three times each one. 10 weeks, 5 s × week (60 min) CG: Control group. Usual care.	IG: ALT CG: CN	TUG
Li et al., 2012 (S38)	USA	IG1: 65 (27) IG2: 65 (20) CG: 65 (26)	IG1: 69.0 (8.0) IG2: 68.0 (9.0) CG: 69.0 (9.0)	IG1: 8.0 (9.0) IG2: 8.0 (9.0) CG: 6.0 (5.0)	IG1: 14 (I – I.5) 27 (II – II.5) 24 (≥ III) IG2: 9 (I – I.5) 34 (II – II.5) 22 (≥ III) CG: 8 (I – I.5) 28 (II – II.5) 29 (≥ III)	IG1: Resistance training group. Strenghtening muscles that are important for posture, balance and gait (8–10 exercises: 1–3 sets of 10–15 repetitions). Loads were introduced at week 10. 24 weeks, 2 s × week (60 min). IG2: Tai Chi group. Six Tai Chi movements integrated into an 8-form routine. 24 weeks, 2 s × week (60 min). CG: Stretching group. Seated and standing stretches involving the upper body and lower extremities. 24 weeks, 2 s × week (60 min).	IG1: RST IG2: ALT CG: CN	TUG
Li et al., 2022 (S39)	China	IG1: 32 (15) IG2: 31 (9) CG: 32 (13)	IG1: 62.7 (5.51) IG2: 61.9 (5.64) CG: 61.9 (6.76)	IG1: 5.91 (4.01) IG2: 3.82 (1.87) CG: 4.32 (2.46)	IG1: 9 (I)– 5 (I.5) 13 (II)– 5 (II.5) IG2: 8 (I)– 7 (I.5) 13 (II)– 3 (II.5) CG: 1 (I)– 11 (I.5) 13 (II)– 7 (II.5)	IG1: Tai Chi group. Standardized Yi Tai Chi postures. 52 weeks, 2 s × week (60 min) IG2: Brisk Walking group. Moderate intensity walking training at 50–60% of HRR. 52 weeks, 2 s × week (60 min) CG: Control group. Usual care.	IG1: ALT IG2: END CG: CN	BBS TUG

(*Continued*)

Table I. (Continued) Characteristics of the included studies

Author, year	Country	Sample size (*n* women)	Age years (mean±SD)	Duration of PD (years) (mean±SD)	H&Y stage (mean±SD)	Physical exercise characteristics	Physical exercise category	Outcome
								(*Continued*)
Liao et al., 2015 (S40)	Taiwan	IG1: 12 (6) IG2: 12 (6) CG: 12 (7)	IG1: 67.3 (7.1) IG2: 65.1 (6.7) CG: 64.6 (8.4)	IG1: 7.9 (2.7) IG2: 6.9 (2.8) CG: 6.4 (3.0)	IG1: 2.0 (0.7) IG2: 2.0 (0.8) CG: 1.9 (0.8)	IG1: Virtual Reality Wii group. Wii Fit exercises: yoga, strengthening and balance games. + Treadmill training. 6 weeks, 2 s × week (60 min) IG2: Traditional exercise group. Stretching, strengthening (3 sets; 10–15 repetitions) and balance exercises + Treadmill training. 6 weeks, 2 s × week (60 min) CG: Control group. Usual care	IG1: SMT + END IG2: SMT + END CG: CN	TUG
Mak et al., 2021 (S41)	China	IG: 33 (22) CG: 31 (22)	IG: 61.9 (6.4) CG: 62.7 (7.2)	IG: 5.8 (6.0) CG: 5.0 (4.0)	IG: 2.4 (0.4) CG: 2.5 (0.3)	IG: Brisk walking group. Postural re-education, warm-up exercises, balance training with musical cues and progressive brisk walking at 40–60% of HRR. 24 weeks, 3 s × week (60–90 min) CG: Active control group. Upper limb and hand dexterity training. 24 weeks, 3 s × week (60–90 min)	IG: SMT + END CG: CN	MiniBESTest TUG
Mollinedo-Cardalda et al., 2018 (S42)	Spain	IG1: 13 (8) IG2: 13 (9)	IG1: 62.85 (9.75) IG2: 66.0 (13.14)	IG1: 5.77 (3.39) IG2: 5.69 (4.4)	IG1: 2.08 (0.49) IG2: 2.0 (0.82)	IG1: Mat Pilates group. Pilates floorwork exercises using Medium-resistant TheraBand and 0.5 kg ankle and wristbands. 7 exercises in 3 sets of 8 repetitions 12 weeks, 2 s × week (60 min) IG2: Control group. Calisthenics, aerobic exercises, marching, strength, flexibility, articular mobility, coordination tasks. 12 weeks, 2 s × week (60 min)	IG1: RST IG2: SMT + END	TUG
Monticone et al., 2015 (S43)	Italy	IG1: 35 (11) IG2: 35 (13)	IG1: 74.1 (6.0) IG2: 73.4 (7.0)	IG1: 15.7 (2.6) IG2: 15.3 (3.0)	IG1: 8(II.5)– 20(III) 7(IV) IG2: 7(II.5)– 22(III) 6(IV)	IG1: Experimental group. Task-oriented exercises, transfers, balance, and gait training (treadmill training). 8 weeks, 5 s × week (90 min) IG2: Control group. Neuromotor techniques, passive, and active articular mobilization, strengthening and stretching of the spine and limbs, proprioceptive and walking exercises. 8 weeks, 5 s × week (90 min)	IG1: SMT + END IG2: SMT not END	BBS
Moon et al., 2020 (S44)	Korea	IG: 8 (3) CG: 7 (5)	IG: 63.38 (5.37) CG: 62.14 (5.55)	NA	IG: 2.63 (0.52) CG: 2.71 (0.49)	IG: Experimental group. Balance training using Wii Fit (30 min) + traditional occupational therapy (30 min) 8 weeks, 3 s × week (60 min) CG: Control group. Occupational therapy. 8 weeks, 3 s × week (30 min)	IG: BLN CG: CN	BBS TUG
Morris et al., 2009 (S45)	Australia	IG1: 14 (NA) IG2: 14 (NA)	IG1: 68 IG2: 66	NA	II–III	IG1: Moving strategies group. Walking, turning, standing and obstacle negotiation strategies.2 weeks, 4–5s × week (45 min) IG2: Exercises group. Strengthening and flexibility exercises. 2 weeks, 4–5s × week (45 min)	IG1: SMT not END IG2: RST	TUG
Morris et al., 2015 (S46)	Australia	IG1: 70 (28) IG2: 69 (23) CG: 71 (19)	IG1: 67.4 (10.4) IG2: 68.4 (9.9) CG: 67.9 (8.4)	IG1: 7.2 (6.2) IG2: 6 (5.5) CG: 6.9 (5.2)	IG1: 11 (I)– 33 (II) 21 (III)– 5 (IV) IG2: 12 (I)– 32 (II) 19 (III)– 6 (IV) CG: 11 (I)– 24 (II) 23 (III)– 13 (IV)	IG1: Progressive Resistance Strength Training. Functional resistance exercises with Thera-band and body weight + education to prevent falls. 8 weeks, 1 s × week (120 min) + 1 s × week of home exercise (120 min) IG2: Movement Strategies Training. Strategies to prevent falls, improve mobility and balance during functional tasks + education to prevent falls. 8 weeks–1 s × week (120 min) + 1 s × week of home exercise (120 min) CG: Life Skills Program. social activities, practical advice, information sessions and group discussion.	IG1: RST IG2: SMT not END CG: CN	TUG
Nadeau et al., 2013 (S47)	Canada	IG1: 12 (4) IG2: 11 (1) IG3: 11 (2)	IG1: 64.0 (6.6) IG2: 60.1 (6.8) IG3: 64.3 (5.6)	NA	IG1: 1.92 (0.20) IG2: 1.92 (0.20) IG3: 1.86 (0.23)	IG1: Speed Treadmill Training. Treadmill at 70–75% HRR with incremental speed (+0.2 km/h). 24 weeks–3s × week (60 min) IG2: Mixed Treadmill Training. Treadmill at 70–75% HRR with incremental speed (+0.2 km/h) and inclination (+1%). 24 weeks–3s × week (60 min) IG3: Control group. Tai Chi, Latin dance, resistance band exercises and coordination movements. 24 weeks–2s × week (60 min)	IG1: END IG2: END IG3: SMT not END	ABC
Ni et al., 2015 (S48)	USA	IG1: 14 (5) IG2: 13 (2) CG: 10 (6)	IG1: 71.6 (6.6) IG2: 71.2 (6.5) CG: 74.9 (8.3)	IG1: 6.6 (4.4) IG2: 6.9 (6.3) CG: 5.9 (6.2)	IG1: 2.2 (0.6) IG2: 2.2 (0.7) CG: 2.1 (0.7)	IG1: Power training. 11 pneumatic machines. 3 sets of 10–12 repetitions at loads of 50–70% of the optimal loads calculated for each participant. 12 weeks, 2 s × week (45–60 min) IG2: Yoga group. Vinyasa Yoga poses. 12 weeks, 2 s × week (60 min) CG: Control group. Health education classes. 3 m, 1 sxm (60 min)	IG1: RST IG2: ALT CG: CN	MiniBESTest BBS TUG
								(*Continued*)

Table I. (Continued) Characteristics of the included studies

Author, year	Country	Sample size (*n* women)	Age years (mean ± SD)	Duration of PD (years) (mean ± SD)	H&Y stage (mean ± SD)	Physical exercise characteristics	Physical exercise category	Outcome
Nieuwboer et al., 2007 (S49)	Belgium	IG: 76 (28) CG: 77 (37)	IG: 67.5 [61.5–72]* CG: 69 [62.5–73]*	IG: 7.0 [4–11]* CG: 8.0 [4–12]*	IG: 39 (II)–29 (III) 8 (IV) CG: 32 (II)–35(III) 10 (IV)	IG: Intervention group. Supervised cueing (auditory, visual and somatosensory) gait training aimed to improve step length, walking speed and balance. 3 weeks, 3 s × week (30 min) CG: Control group. No active control.	IG: SMT not END CG: CN	TUG
Ortiz-Rubio et al., 2017 (S50)	Spain	IG: 23 (6) CG: 23 (7)	IG: 74.2 (5.8) CG: 75.4 (6.5)	IG: 4.0 (2.15) CG: 4.27 (1.96)	IG: 11 (II)–12 (III) CG: 14 (II)–9 (III)	IG: Intervention group. Resistance training program with elastic bands (resistance 1.5–2.7 kg). 1–3 sets with 10–15 repetitions. 8 weeks, 2 s × week (30 min). CG: Control group. Breathing, stretching and relaxation activities in a seated position. 8 weeks, 2 s × week.	IG: RST CG: CN	MiniBESTest
Paul et al., 2014 (S51)	Australia	IG: 20 (7) CG: 20 (8)	IG: 68.1 (5.6) CG: 64.5 (7.4)	IG: 7.8 (5.2) CG: 7.8 (5.9)	IG: 2.0 (0.7) CG: 1.9 (0.9)	IG: Muscle power training. Resistance exercises for lower limbs. 3 sets of 8 repetitions at 40–60% of 1RM. 12 weeks, 2 s × week (45 min) CG: Control group. Low intensity exercises for the trunk and legs independently at home. 1 set of 10–12 repetitions. 12 weeks, 2 s × week.	IG: RST CG: CN	TUG
Pérez de la Cruz, 2017 (S52)	Spain	IG: 15 CG: 15 Total: 30 (16)	IG: 67.53 (9.89) CG: 66.8 (5.267)	IG: 6.7 (3.225) CG: 6.2 (2.541)	IG: 2.66 (1.02) CG: 2.82 (0.22)	IG: Aquatic Ai Chi. Recreational warm-up activity, 19 possible movements of Ai Chi and calming down activity. 10 weeks, 2 s × week (45 min) CG: Dry land therapy. Gait, trunk mobility, strength and aerobic exercises, functional, facial muscle, proprioceptive and stretching exercises. 10 weeks, 2 s × week (45 min)	IG: ALT CG: SMT + END	BBS TUG
Pérez de la Cruz, 2018 (S53)	Spain	IG: 14 (9) CG: 15 (8)	IG: 65.87 (7.09) CG: 66.44 (5.726)	NA	I–III	IG: Aquatic Ai Chi. Recreational warm-up activity, 19 possible movements of Ai Chi and calming down activity. 11 weeks, 2 s × week (45 min) CG: Dry land therapy. Gait, trunk mobility, strength and aerobic exercises, functional, facial muscle, proprioceptive and stretching exercises. 11 weeks, 2 s × week (45 min)	IG: ALT CG: SMT + END	TUG
Picelli et al., 2012 (S54)	Italy	IG1: 17 IG2: 17 Total: 34 (14)	68.3	7.5	3.45	IG: Robot-assisted gait training. Robotic assisted gait training at 20% BWS at 1.3 km/h and 10% BWS at 1.6 km/h. 4 weeks, 3 s × week (40 min) CG: Physical therapy training. Lower limbs active joint mobilization, muscle stretching and motor coordination exercises. 4 weeks, 3 s × week (40 min)	IG1: BWS IG2: SMT not END	ABC BBS TUG
Picelli et al., 2013 (S55)	Italy	IG1: 20 (11) IG2: 20 (14) IG3: 20 (12)	IG1: 68.5 (10.1) IG2: 68.8 (7.72) IG3: 67.55 (7.08)	IG1: 6.52 (5.3) IG2: 6.99 (6.17) IG3: 6.79 (6.3)	3.0	IG1: Robot assisted gait training. Robotic assisted gait training at 20% BWS at 1.0 km/h, 10% BWS at 1.5 km/h and 0% BWS 2.0 km/h. 4 weeks, 3 s × week (45 min) IG2: Treadmill training. Gait training in a treadmill 10 min at 1 km/h – 10 min at 1.5 km/h – 10 min at 2 km/h. 4 weeks, 3 s × week (45 min) IG3: Physical therapy training. Gait training according to the proprioceptive neuromuscular facilitation concept. 4 weeks, 3 s × week (30 min)	IG1: BWS IG2: END IG3: SMT not END	BBS
Picelli et al., 2015 (S56)	Italy	IG1: 33 (21.2) IG2: 33 (33.3)	IG1: 68.2 (9.2) IG2: 69.7 (7.2)	IG1: 7.5 (5.6) IG2: 8.3 (4.1)	3.0	IG1: Robot assisted gait training. Robotic assisted gait training at 20% BWS at 1.0 km/h, 10% BWS at 1.5 km/h and 0% BWS at 2.0 km/h. 4 weeks, 3 s × week (45 min) IG2: Balance training group. Self-destabilization of the centre of body mass exercises, externally induced destabilization, postural adjustment, coordination, and locomotor dexterity exercises. 4 weeks, 3 s × week (45 min)	IG1: BWS IG2: BLN	ABC BBS TUG
Romenets et al., 2015 (S57)	Canada	IG: 18 (6) CG: 15 (8)	IG: 63.2 (9.9) CG: 64.3 (8.1)	IG: 5.5 (4.4) CG: 7.7 (4.6)	IG: 1.7 (0.6) CG: 2.0 (0.5)	IG: Tango intervention. Review of previous class, new step or elements, improvisation activities and standard footwork exercises. 12 weeks, 2 s × week (60 min) CG: Control group. Usual care.	IG: DNC CG: CN	MiniBESTest TUG

(*Continued*)

Table I. (Continued) Characteristics of the included studies

Author, year	Country	Sample size (*n* women)	Age years (mean±SD)	Duration of PD (years) (mean±SD)	H&Y stage (mean±SD)	Physical exercise characteristics	Physical exercise category	Outcome
Sage et al., 2009 (S58)	Canada	IG1: 18 (6) IG2: 13 (7) CG: 15 (8)	IG1: 64.2 (10.3) IG2: 65.1 (9.3) CG: 68.6 (8.7)	IG1: 4.7 (4.9) IG2: 3.2 (2.9) CG: 2.5 (2.2)	NA	IG1: Sensory attention focused exercise. Nonaerobic gait exercises focused on body coordination + sensory attention exercises utilizing TheraBand. 11 weeks, 3 s × week (40–60 min) IG2: Aerobic training. Exercising on Ellipticals at 60–75% HRR. 12 weeks, 3 s × week (30 min) CG: Control group. Usual care.	IG1: SMT not END IG2: END CG: CN	TUG
Santos et al., 2017 (S59)	Brazil	IG1: 19 (3) IG2: 21 (5)	IG1: 67.0 (7.9) IG2: 68.5 (6.5)	IG1: 5.6 (4.2) IG2: 5.4 (5.3)	IG1: 2.3 (0.5) IG2: 2.3 (0.6)	IG1: Resistance training. Muscular strengthening and stretching training of lower limbs and trunk. 2 sets of 10 repetitions with load intensity between 1–2 kg. 12 weeks, 2 s × week (60 min) IG2: Balance training. Sensory integration, motor coordination, postural stability limits, anticipatory and reactive postural adjustments exercises. 12 weeks, 2 s × week (60 min)	IG1: RST IG2: BLN	MiniBESTest
Schlenstedt et al., 2015 (S60)	Germany	IG1: 17 (5) IG2: 15 (6)	IG1: 75.7 (5.5) IG2: 75.7 (7.2)	IG1: 10.1 (6.0) IG2: 9.3 (7.9)	IG1: 2.8 (0.26) IG2: 2.7 (0.4)	IG1: Resistance training. Strengthening of lower limbs with elasticated bands, cuff weights and body weights. 7 weeks–2s × week (60 min) IG2: Balance training. Stance and gait tasks with feedforward and feedback postural control. 7 weeks–2s × week (60 min)	IG1: RST IG2: BLN	TUG
Sedaghati et al., 2016 (S61)	Iran	IG1: 14 (5) IG2: 15 (5) CG: 15 (4)	IG1: 58.77 (8.06) IG2: 59.13 (8.37) CG: 57.22 (6.87)	NA	IG1: 2.57 (0.5) IG2: 2.53 (0.5) CG: 2.6 (0.5)	IG1: Exercise group with no balance pad. Balance and postural control exercises with an emphasis on gait training activities. 10 weeks, 3 s × week (60 min) IG2: Exercise group with balance pad. Balance and postural control exercises with an emphasis on gait training activities with a balance pad. 10 weeks, 3 s × week (60 min) CG: Control group. Usual care	IG1: BLN IG2: BLN CG: CN	BBS TUG
Shen et al., 2014 (S62)	China	IG1: 22 (9) IG2: 23 (11)	IG1: 63.3 (8.0) IG2: 65.3 (8.5)	IG1: 8.1 (4.3) IG2: 6.6 (4.0)	IG1: 2.4 (0.5) IG2: 2.5 (0.5)	IG1: Balance group. Anticipatory postural adjustment exercises and training for the response to external perturbation on treadmill. 12 weeks, 3–5s × week (60 min) IG2: Control group. Resistance training of the hip and knee using machines at 60% of 1RM and sandbags strapped to lower extremities with 0.5–1.5 kg. 12 weeks, 3–5s × week (60 min)	IG1: BLN IG2: RST	ABC
Silva-Batista et al., 2016 (S63)	Brazil	IG1: 13 (3) IG2: 13 (3) CG: 13 (4)	IG1: 64.1 (9.1) IG2: 64.2 (10.6) CG: 64.2 (8.3)	IG1: 9.6 (3.9) IG2: 10.5 (4.1) CG: 10.7 (6.1)	IG1: 2.5 (0.5) IG2: 2.5 (0.4) CG: 2.5 (0.4)	IG1: Resistance training group. Five resistance exercises with a progressive increase of load/resistance. 12 sessions-2s × week (50 min) IG2: Resistance training with instability group. Five resistance exercises with a progressive increase of load/resistance and instability. 12 sessions–2s × week (50 min) CG: Control group. Games and education. 12 weeks–1 s × week (60 min)	IG1: RST IG2: RST CG: CN	TUG
Silva- Batista et al., 2018 (S64)	Brazil	IG1: 13 (3) IG2: 13 (3) CG: 13 (4)	IG1: 64.1 (9.1) IG2: 64.2 (10.6) CG: 64.2 (8.3)	IG1: 9.6 (3.9) IG2: 10.5 (4.1) CG: 10.7 (6.1)	IG1: 2.5 (0.5) IG2: 2.5 (0.4) CG: 2.5 (0.4)	IG1: Resistance training group. Five resistance exercises with a progressive increase of load/resistance. 12 sessions-2s × week (50 min) IG2: Resistance training with instability group. Five resistance exercises with a progressive increase of load/resistance and instability. 12 sessions-2s × week (50 min) CG: Control group. Games and education. 12 weeks–1 s × week (60 min)	IG1: RST IG2: RST CG: CN	MiniBESTest
Soke et al., 2021 (S65)	Turkey	IG1: 14 (4) IG2: 12 (4)	IG1: 57.7 (8.1) IG2: 56.2 (8.7)	IG1: 8.4 (5.3) IG2:6.8 (3.4)	IG1: 1 (I)– 8 (II) 5 (III) IG2: 2 (I)– 6 (II) 4 (III)	IG1: Experimental group. Task-oriented circuit training with 11 workstations (3 min each one) based on maintaining balance, walking and reaching + 20 min walking at 60–80% HR. 8 weeks, 3 s × week (65 min) IG2: Control group. Aerobic training consisted of walking on a treadmill at 60–80% HR. 8 weeks, 3 s × week (30)	IG1: SMT + END IG2: END	ABC BBS TUG
Solla et al., 2019 (S66)	Italy	IG: 10 (4) CG: 10 (3)	IG: 67.8 (5.9) CG: 67.1 (6.3)	IG: 4.4 (4.5) CG: 5.0 (2.9)	IG: 2.1 (0.6) CG: 2.3 (0.4)	IG: Ballu Sardu group. Sardinian folk dance program (warm-up exercises, monostructured and bistructured forms). 12 weeks, 2 s × week (90 min) CG: Control group. Usual care.	IG: DNC CG: CN	BBS TUG

(*Continued*)

Table I. (Continued) Characteristics of the included studies

Author, year	Country	Sample size (*n* women)	Age years (mean±SD)	Duration of PD (years) (mean±SD)	H&Y stage (mean±SD)	Physical exercise characteristics	Physical exercise category	Outcome
Smania et al., 2010 (S67)	Italy	IG1: 27 (12) IG2: 28 (14)	IG1: 67.26 (7.18) IG2: 67.64 (7.41)	IG1: 8.63 (5.39) IG2: 10.39 (4.76)	IG1: 3.1 (0.3) IG2: 3.0 (0.1)	IG1: Control group. Active joint mobilization, muscle stretching, and motor coordination exercises. 7 weeks, 3 s × week (50 min). IG2: Experimental group. Balance training consisting of postural reactions exercises. 7 weeks, 3 s × week (50 min).	IG1: SMT not END IG2: BLN	ABC BBS
Song et al., 2019 (S68)	Australia	IG: 31 (16) CG: 29 (20)	IG: 68.0 (7.0) CG: 65.0 (7.0)	IG: 7.0 (4.0) CG: 9.0 (6.0)	NA	IG: Intervention group. *Stepmania* exergame performed at home with physiotherapist supervision. 12 weeks, 3 s × week (15 min) CG: Control group. Usual care	IG: SMT not END CG: CN	TUG
Sparrow et al., 2016 (S69)	USA	IG: 7 CG: 9 Total: 16 (6)	Total: 66.7 (5.7)	Total: 4.3 (3.3)	Total: 4 (II)– 8 (II.5) 4 (III)	IG: Active group. Highly challenging balance program consisting of strengthening, range of motion, anticipatory and reactive balance activities, altering sensory input and balance during gait training. 12 weeks, 2 s × week (90 min). CG: Inactive group. Usual care.	IG: BLN CG: CN	MiniBESTest
Szefler-Derela et al., 2020 (S70)	Poland	IG1: 20 (10) IG2: 20 (10)	IG1: 65.5 [54–57]* IG2: 62.5 [50–75]*	IG1: 6.0 [3–18]* IG2: 5.0 [2–14]*	IG1: 11 (II)– 9 (III) IG2: 9 (II)– 11 (III)	IG1: Standard rehabilitation group. Stretching, high amplitude movements, strengthening, flexibility, balance, gait, and transfers exercises. 6 weeks, 2 s × week (45 min) IG2: Nordic walking group. Nordic walking training aimed at improving walking intensity and distance. 6 weeks, 2 s × week (90 min)	IG1: SMT not END IG2: END	TUG
Tollar et al., 2018 (S71)	Hungary	IG: 35 (18) CG: 20 (8)	IG: 67.3 (3.4) CG: 67.6 (4.1)	IG: 6.7 (2.3) CG: 7.1 (2.8)	NA	IG: Intervention group. Sensorimotor and visuomotor agility training (gait, coordination, posture, balance, and body scheme exercises) and Kinect exergames. 3 weeks, 5 s × week (60 min) CG: Control group. Usual care	IG: SMT not END CG: CN	TUG
Tollar et al., 2019 (S72)	Hungary	IG1: 19 (8) IG2: 16 (10) CG: 20 (8)	IG1: 67.5 (3.91) IG2: 67.6 (3.26) CG: 67.6 (4.08)	IG1: 6.5 (2.67) IG2 6.8 (1.76) CG: 7.1 (2.75)	IG1: 2.5 (0.51) IG2: 2.31 (0.48) CG: 2.40 (0.50)	IG1: Exercise + maintenance group. High intensity sensoriomotor and visiomotor agility training including: gait, coordination, posture, balance, and body scheme training at 80%HRR. 3 weeks, 5 s × week (60 min) + Maintenance program for 2 years. IG2: Exercise group. High intensity sensoriomotor and visiomotor agility training including: gait, coordination, posture, bal1ance, and body scheme training at 80% HRR. 3 weeks, 5 s × week (60 min) CG: Control group. Usual care	IG1: SMT + END IG2: SMT + END CG: CN	TUG
Tollar et al., 2019 (73)	Hungary	IG1: 25 (13) IG2: 25 (14) CG: 24 (11)	IG1: 70.0 (4.69) IG2: 70.6 (4.10) CG: 67.5 (4.28)	IG1: 7.5 (1.76) IG2: 7.5 (2.16) CG: 7.3 (2.21)	IG1: 2.3 (0.48) IG2: 2.4 (0.51) CG: 2.4 (0.51)	IG1: Exercise group. Kinect Adventures video game (reflexively respond to visual stimuli, special orientation, combination of movement sequences) 5 weeks, 5 s × week (60 min) IG2: Cycling group. Spinning classes riding at 110–140 beats/min. 5 weeks, 5 s × week (60 min) CG: Control group. Usual care.	IG1: SMT not END IG2: END CG: CN	BBS MiniBESTest
van der Kolk et al., 2019 (S74)	The Netherlands	IG: 65 (23) CG: 65 (27)	IG: 59.3 (8.3) CG: 59.4 (9.3)	IG: 3.4 [1.3–7.3]* CG: 3.2 [1.6–6.8]*	IG: 4 (I)– 61 (II) CG: 3 (I)– 63 (II)	IG: Aerobic intervention. Stationary cycling at 50–70% of HR. 24 weeks–3s × week (30–45 min) CG: Active control intervention. Stretching, flexibility and relaxation exercises. 24 weeks–3s × week (30 min)	IG: END CG: CN	MiniBESTest TUG
van Puymbroeck et al., 2018 (S75)	USA	IG: 15 (5) CG: 12 (5)	IG: 65.53 (6.09) CG: 70.5 (4.44)	NA	I.5 – III	IG: Yoga Experimental group. Controlled dynamic yoga postures connected to specific breathing patterns. 8 weeks, 2 s × week CG: Wait-list control. Usual care	IG: ALT CG: CN	MiniBESTest
Vergara-Diaz et al., 2018 (S76)	USA	IG: 16 (7) CG: 16 (9)	IG: 65.7 (3.86) CG: 62.0 (7.77)	IG: 2.9 (2.38) CG: 2.9 (2.20)	IG: 11 (II)– 5 (III) CG: 13 (II)– 3 (III)	IG: Tai chi group. Tai Chi exercises focusing on balance, stretching, mindfulness and breathing. 24 weeks, 2 s × week (60 min). CG: Control group. Usual care.	IG: ALT CG: CN	ABC TUG
Vieira de Moraes et al., 2020 (S77)	Brazil	IG: 25 (5) CG: 15 (5)	IG: 64.7 (1.8) CG: 64.4 (3.7)	IG: 5.7 (0.8) CG: 7.2 (1.9)	I–III	IG: Training group. Resistance training program using weight machines (chest press, knee extension, hamstrings curl, leg press and seated row; 2 sets of 10–12 repetitions) 9 weeks, 2 s × week (50–60 min) CG: Control group. Orientation program with lectures on health, quality of life and scientific update on PD.	IG: RST CG: CN	TUG
Volpe et al., 2013 (S78)	Italy	IG1: 12 (5) IG2: 12 (6)	IG1: 61.6 (4.5) IG2: 65.0 (5.3)	IG1: 9.0 (3.6) IG2: 8.9 (2.5)	IG1: 2.2 (0.4) IG2: 2.2 (0.4)	IG1: Irish dance group. Supervised Irish dance with a health partner. 24 weeks, 1 s × week (90 min) IG2: Physiotherapy group. Supervised strength, balance, postural re-education, and gait training. 24 weeks. 1 s × week (90 min)	IG1: DNC IG2: SMT not END	BBS

(*Continued*)

Table I. (Continued) Characteristics of the included studies

Author, year	Country	Sample size (*n* women)	Age years (mean±SD)	Duration of PD (years) (mean±SD)	H&Y stage (mean±SD)	Physical exercise characteristics	Physical exercise category	Outcome
Wallen et al., 2018 (S79)	Sweden	IG: 51 (19) CG: 49 (24)	IG: 73.1 (5.8) CG: 73.0 (5.5)	IG: 5.9 (5.1) CG: 5.6 (4.8)	IG: 23 (II)– 28 (III) CG: 21 (II)– 28 (III)	IG: Training group. HiBalance program based on sensory integration, anticipatory postural adjustments, motor agility and stability limits. 10 weeks, 3 s × week (60 min) CG: Control group. Usual care	IG: BLN CG: CN	MiniBESTest
Wan et al., 2021 (S80)	China	IG: 20 (12) CG: 20 (9)	IG: 64.95 (7.83) CG: 67.03 (7.47)	IG: 3.63 (1.52) CG: 3.25 (1.73)	I–IV	IG: Experimental group. Qigong exercises therapy, each movement was repeated 3–6 times. 12 weeks, 4 s × week (60 min) CG: Control group. Usual care	IG: ALT CG: CN	TUG
Wong-Yu et al., 2015 (S81)	China	IG: 32 (13) CG: 36 (16)	IG: 60.2 (9.0) CG: 61.9 (8.5)	IG: 7.3 (4.3) CG: 5.4 (3.6)	IG: 2.5 (0.3) CG: 2.5 (0.4)	IG: Balance group. Multisystem postural control strategies (postural reeducation, balance-dance, functional exercises). 8 weeks, 1 s × week (120 min) CG: Control group. Dexterity training, upper limb exercises, calligraphy. 8 weeks, 1 s × week (120 min)	IG: BLN CG: CN	MiniBESTest TUG
Wong-Yu et al., 2015 (82)	China	IG: 41 (16) CG: 39 (18)	IG: 59.4 (9.0) CG: 62.6 (8.9)	IG: 7.1 (4.3) CG: 5.6 (3.8)	IG: 2.5 (0.3) CG: 2.4 (0.3)	IG: Experimental group. Multisystem postural control and balance strategies (postural reeducation, balance-dance, functional exercises). 8 weeks, 1 s × week (120 min) CG: Control group. Dexterity training, upper limb exercises, calligraphy. 8 weeks, 1 s × week (120 min)	IG: BLN CG: CN	ABC MiniBESTest TUG
Xiao et al., 2015 (S83)	China	IG1: 48 (14) IG2: 48 (15)	IG1: 66.52 (2.13) IG2: 68.17 (2.27)	IG1: 6.15 (2.63) IG2: 5.45 (3.61)	IG1: 2.1 (0.23) IG2: 2.2 (0.21)	IG1: Control group. Walking routine. 24 weeks, 7 s × week (30 min) IG2: Baduanjin Qigong group. Eight movement routines repeated six times plus breathing techniques. 24 weeks, 4 s × week (45 min)	IG1: END IG2: ALT	BBS TUG
Youm et al., 2020 (S4)	Korea	IG: 10 (4) CG: 7 (3)	IG: 68.0 (6.8) CG: 72.1 (6.0)	IG: 6.4 (3.6) CG: 8.0 (4.0)	IG: 2.4 (0.32) CG: 2.29 (0.39)	IG: Exercise group. Progressive trunk resistance and stretching exercise program. 12 weeks, 3 s × week (60–90 min) CG: Control group. Usual care	IG: RST CG: CN	TUG
Yuan et al., 2020 (S85)	Taiwan	IG: 12 (10) CG: 12 (3)	IG: 67.8 (5.5) CG: 66.5 (8.8)	NA	IG: 4 (I)– 5 (II) 3 (III) CG: 3 (I)– 4 (II) 5 (III)	IG: Interactive video-game based exercise. Multidirectional step tasks and target-directed stepping tasks with visual feedback for coordination, balance, and stability. 6 weeks, 3 s × week (30 min). CG: Control group. Usual care.	IG: SMT not END CG: CN	BBS
Zhang et al., 2015 (S86)	China	IG1: 20 (9) IG2: 20 (7)	IG1: 64.35 (10.53) IG2: 66.0 (11.8)	IG1: 4.85 (3.72) IG2: 6.8 (5.43)	IG1: 3 (I.5)– 6 (II) 10 (II.5)– 1 (III) IG2: 4 (I)– 7 (II) 7 (II.5)– 2 (III)	IG1: Multimodal Exercise Training group. Core muscle training, crossing obstacle training, standing on ankle joint correcting board, and cycling ergometer. 12 weeks, 2 s × week (60 min) IG2: Tai Chi group. Yang style 24 tai chi forms. 12 weeks, 2 s × week (60 min)	IG1: SMT + END IG2: ALT	BBS TUG

ABC: Activities-specific Balance Confidence Scale; ALT: alternative exercises; BBS: Berg Balance Scale; BLN: balance interventions; BWS: body weight supported interventions; CG, control group; CN: control; DNC, dance; END: endurance; HRR, hearth rate; H&Y: Hoehn & Yard; IG: intervention group; MiniBESTest: Mini Balance Evaluation Systems Test; NA, not available; PD: Parkinson disease; RM: repletion maximum; RST: resistance; SMT + END: sensorimotor training including endurance; SMT not END: sensorimotor training not including endurance; s × week: sessions per week; TUG: Timed Up and Go Test;
*Median [interquartile range]; **Mean + SE.

followed by sensorimotor training not including endurance ($n=21$), sensorimotor training including endurance ($n=20$), and resistance, alternative, and endurance with 19 interventions each. In addition, dance ($n=6$) and BWS interventions ($n=8$) were included.

The most relevant characteristics of the RCTs included in this network meta-analysis are shown in Table I.

Similarity and consistency analysis

There were no differences in the baseline values of potential confounding variables among the different types of physical exercise interventions and the control groups (i.e. sex, age, disease duration, and severity) (Table SII). The consistency analyses revealed that inconsistences were detected only for 2 of the 24 triangular loops of the BBS network meta-analysis and 2 of the 25 triangular loops of the TUG network meta-analysis (Table SIII).

Risk of bias and quality of evidence

According to the RoB2 tool, the overall risk of bias was high for 39.5% of the RCTs, while 52.3% had some concern of bias and 8.1% had a low risk of bias. By individual domains, 66.3%, 31.4% and 2.3% of the RCTs had a low risk, some concerns, and high risk of bias, respectively, for the randomization process. For deviations from intended interventions, 46.5% and 37.2% of studies had some concerns and a high risk of bias, respectively. For missing outcome data, 100% of the RCTs had a low risk of bias. For the measurement of the outcome, 84.9% and 9.3% of the RCTs had a low risk of bias and some concern, respectively. Finally, for selection of the reported results, 88.4% of the RCTs had some concern of bias (Fig. S2).

As evaluated by the GRADE system, the quality of evidence was moderate in 68.25% of the pairwise comparison studies, low in 30.16% and very low in 1.59%. The complete assessment is detailed in Table SIV.

Activities-specific Balance Confidence scale

Effect of physical exercise modalities on Activities-specific Balance Confidence scale scores. The network geometry graph shows the relative amount of evidence available for the effect of physical exercise interventions on ABC scale scores (Fig. S3). Direct comparisons from the standard meta-analysis did not show a statistically significant ES. The indirect comparison showed the highest ES for balance vs sensorimotor training not including endurance interventions (0.62; 95% CI 0.06, 1.17) (Table II and Fig. S4).

Best treatment probabilities. The probabilities of being the best treatment were 34.1% for alternative interventions and 25.5% for BWS interventions. Furthermore, the highest SUCRAs were for balance (76.4%), alternative exercise interventions (73.1%) and BWS interventions (71.1%) (Fig. S5 and Table SV).

Sensitivity analysis, heterogeneity, and publication bias. In the sensitivity analysis, the pooled ES was not modified by removing any study (Table SVI). Balance vs control direct comparison showed no important heterogeneity or clinical heterogeneity ($I2=29.5$; $\tau2=0.06$) (Table SVII) or publication bias ($p=0.666$) (Table SVIII and Fig. S6).

Berg Balance Scale

Effect of physical exercise modalities on Berg Balance Scale scores. The network geometry graph of physical exercise interventions on BBS scores is shown in Fig. S7. Indirect comparisons showed positive results for alternative exercises (1.21; 95% CI 0.62, 1.81), balance (0.85; 95% CI 0.32, 1.38), BWS interventions (1.31; 95% CI 0.57, 2.05), dance (1.18; 95% CI 0.33, 2.03), sensorimotor training including endurance interventions (1.10; 95% CI 0.46, 1.75) and sensorimotor training not including endurance interventions (0.64; 95% CI 0.05, 1.23) vs control groups (Table II and Fig. S8). Unlike the indirect effects, the endurance (0.67; 95% CI 0.09, 1.25) and resistance (1.78; 95% CI 0.83, 2.74) interventions showed positive results vs the control in the direct comparisons, but not for the BWS interventions and sensorimotor training including endurance. Moreover, the categories of balance, BWS, and sensorimotor training including endurance showed positive results compared with sensorimotor training not including aerobic exercise in the direct comparisons, and this was not the case in the indirect effects of the network meta-analysis (Table II).

Best treatment probabilities. The probability of being the best treatment was 32.8% for BWS interventions and 24.0% for dance. Furthermore, BWS interventions showed the highest SUCRA (80.4%), followed by alternative exercises (75.0%) and dance (69.8%) (Fig. S9 and Table SV).

Sensitivity analysis, heterogeneity, and publication bias. In the sensitivity analysis, the pooled ES was modified by removing the following trials: (*i*) Gao et al., 2014 (s23); Lee et al., 2018 (s36); Li et al., 2022 (s39) and Ni et al., 2016 (s48) from alternative exercises vs control groups, (*ii*) Cakit et al., 2007 (s8); Cugusi et al., 2015 (s18) and Tollar et al., 2019 (s73) from the endurance interventions vs control groups (Table SVI).

Two direct comparisons showed moderate heterogeneity: alternative vs balance ($I2=47.8$; $\tau2=0.21$) and alternative vs control ($I2=55.9$; $\tau2=0.11$). Moreover, 4 direct comparisons showed substantial heterogeneity: endurance vs BWS interventions ($I2=80.7$; $\tau2=0.75$), endurance vs control ($I2=66.4$; $\tau2=0.23$), sensorimotor

Table II. Pooled mean differences of physical activity on outcome scales

ABC							
Control	0.27 (−0.43, 0.96)	0.24 (−0.13, 0.61)	NA	NA	NA	−0.30 (−1.14, 0.54)	−0.21 (−1.09, 0.66)
0.33 (−0.37, 1.03)	**Alternative**	NA	NA	NA	NA	NA	NA
0.30 (−0.09, 0.69)	−0.03 (−0.83, 0.77)	**Balance**	0.00 (−0.48, 0.48)	NA	−0.09 (−0.67, 0.05)	NA	−0.35 (−0.89, 0.18)
0.28 (−0.43, 0.99)	−0.05 (−1.05, 0.94)	−0.02 (−0.64, 0.60)	**BWS**	NA	NA	NA	−0.45 (−1.16, 0.26)
−0.39 (−1.23, 0.45)	−0.72 (−1.81, 0.37)	−0.69 (−1.53, 0.15)	−0.67 (−1.63, 0.30)	**Endurance**	NA	0.23 (−0.29, 0.75)	0.00 (−0.58, 0.59)
0.13 (−0.78, 1.05)	−0.20 (−1.35, 0.95)	−0.17 (−0.99, 0.66)	−0.15 (−1.18, 0.89)	0.52 (−0.66, 1.70)	**Resistance**	NA	NA
−0.12 (−1.00, 0.75)	−0.45 (−1.57, 0.67)	−0.42 (−1.32, 0.48)	−0.40 (−1.43, 0.63)	0.27 (−0.41, 0.94)	−0.25 (−1.48, 0.97)	**SMT + endurance**	NA
−0.32 (−0.92, 0.29)	−0.65 (−1.57, 0.27)	**−0.62 (−1.17, −0.06)**	−0.60 (−1.29, 0.10)	0.07 (−0.66, 0.80)	−0.45 (−1.45, 0.54)	−0.20 (−1.06, 0.67)	**SMT not endurance**

BBS								
Control	**0.48 (0.03, 0.93)**	**0.41 (0.17, 0.64)**	0.52 (−0.11, 1.15)	**0.66 (0.26, 1.05)**	**0.67 (0.09, 1.25)**	**1.78 (0.83, 2.74)**	0.46 (−0.20, 1.11)	**0.96 (0.02, 1.90)**
1.21 (0.62, 1.81)	**Alternative**	−0.18 (−1.10, 0.73)	NA	NA	−0.24 (−0.55, 0.08)	0.07 (−0.69, 0.82)	−0.09 (−0.56, 0.38)	−0.53 (−1.16, 0.10)
0.85 (0.32, 1.38)	−0.36 (−1.08, 0.36)	**Balance**	0.00 (−0.48, 0.48)	NA	NA	NA	NA	**−0.61 (−1.15, −0.07)**
1.31 (0.57, 2.05)	0.10 (−0.77, 0.97)	0.46 (−0.38, 1.30)	**BWS**	NA	0.54 (−0.55, 1.64)	NA	−0.34 (−0.96, 0.29)	**−0.81 (−1.30, −0.33)**
1.18 (0.33, 2.03)	−0.03 (−1.06, 0.99)	0.33 (−0.66, 1.32)	−0.13 (−1.24, 0.97)	**Dance**	NA	NA	NA	−0.37 (−1.08, 0.35)
0.57 (−0.02, 1.17)	−0.64 (−1.38, 0.10)	−0.28 (−1.03, 0.48)	−0.74 (−1.49, 0.01)	−0.61 (−1.62, 0.41)	**Endurance**	NA	0.17 (−0.35, 0.70)	−0.40 (−1.10, 1.78)
0.80 (−0.57, 2.16)	−0.42 (−1.78, 0.94)	−0.06 (−1.50, 1.38)	−0.52 (−2.04, 1.01)	−0.38 (−1.98, 1.22)	0.22 (−1.24, 1.68)	**Resistance**	NA	NA
1.10 (0.46, 1.75)	−0.11 (−0.85, 0.63)	0.25 (−0.54, 1.04)	−0.21 (−1.05, 0.63)	−0.08 (−1.12, 0.97)	0.53 (−0.19, 1.25)	0.31 (−1.16, 1.78)	**SMT + endurance**	**−0.81 (−1.30, −0.32)**
0.64 (0.05, 1.23)	−0.57 (−1.32, 0.17)	−0.21 (−0.94, 0.51)	−0.67 (−1.45, 0.10)	−0.54 (−1.51, 0.43)	0.06 (−0.62, 0.75)	−0.16 (−1.31, 1.30)	−0.47 (−1.22, 0.28)	**SMT not endurance**

MiniBESTest							
Control	1.38 (−1.13, 3.90)	**0.58 (0.26, 0.89)**	0.52 (−0.17, 1.22)	0.25 (−0.38, 0.89)	**0.95 (0.36, 1.53)**	**0.37 (0.07, 0.66)**	0.45 (−0.03, 0.93)
0.55 (−0.19, 1.29)	**Alternative**	NA	NA	NA	−0.34 (−1.10, 0.42)	NA	NA
0.75 (0.46, 1.04)	0.20 (−0.59, 0.99)	**Balance**	NA	NA	−0.42 (−1.05, 0.20)	NA	NA
0.67 (−0.44, 1.77)	0.12 (−1.21, 1.45)	0.08 (−1.06, 1.23)	**Dance**	NA	NA	NA	NA
0.22 (−0.30, 0.74)	−0.33 (−1.23, 0.58)	−0.53 (−1.13, 0.07)	−0.45 (−1.67, 0.77)	**Endurance**	NA	NA	−0.25 (−0.81, 0.31)
0.58 (0.10, 1.07)	0.03 (−0.76, 0.82)	−0.17 (−0.70, 0.36)	−0.09 (−1.29, 1.12)	0.36 (−0.35, 1.07)	**Resistance**	NA	NA
0.41 (−0.11, 0.93)	−0.14 (−1.05, 0.77)	−0.34 (−0.94, 0.26)	−0.26 (−1.48, 0.97)	0.19 (−0.55, 0.93)	−0.17 (−0.88, 0.54)	**SMT + endurance**	NA
0.18 (−0.46, 0.82)	−0.37 (−1.35, 0.61)	−0.57 (−1.27, 0.13)	−0.49 (−1.76, 0.79)	−0.04 (−0.72, 0.63)	−0.40 (−1.20, 0.39)	−0.23 (−1.05, 0.59)	**SMT not endurance**

TUG								
Control	**−0.48 (−0.82, −0.13)**	**−0.34 (−0.53, −0.16)**	NA	**−0.46 (−0.83, −0.09)**	−0.03 (−0.26, 0.20)	**−0.86 (−1.32, −0.40)**	**−0.51 (−0.95, −0.06)**	−0.18 (−0.49, 0.13)
−0.54 (−0.82, −0.26)	**Alternative**	0.05 (−0.42, 0.53)	NA	NA	0.12 (−0.20, 0.44)	0.15 (−0.17, 0.48)	0.29 (−0.12, 0.71)	−0.60 (−1.24, 0.03)
−0.42 (−0.75, −0.08)	0.12 (−0.28, 0.52)	**Balance**	0.06 (−0.43, 0.54)	NA	NA	−0.41 (−1.11, 0.29)	NA	NA
−0.42 (−1.01, 0.18)	0.12 (−0.51, 0.75)	0.00 (−0.62, 0.63)	**BWS**	NA	−0.12 (−0.47, 0.23)	NA	NA	0.32 (−0.39, 1.03)
−0.56 (−1.22, 0.10)	−0.02 (−0.74, 0.69)	−0.14 (−0.88, 0.60)	−0.14 (−1.04, 0.75)	**Dance**	NA	NA	NA	NA
−0.31 (−0.64, 0.01)	0.23 (−0.15, 0.60)	0.11 (−0.34, 0.55)	0.10 (−0.48, 0.68)	0.25 (−0.49, 0.98)	**Endurance**	NA	−0.23 (−0.82, 0.36)	−0.16 (−0.54, 0.23)
−0.60 (−0.89, −0.31)	−0.06 (−0.41, 0.28)	−0.18 (−0.60, 0.24)	−0.19 (−0.83, 0.46)	−0.04 (−0.76, 0.68)	−0.29 (−0.70, 0.12)	**Resistance**	0.48 (−0.37, 1.33)	−0.08 (−0.39, 0.22)
−0.61 (−0.95, −0.27)	−0.07 (−0.46, 0.31)	−0.19 (−0.66, 0.27)	−0.20 (−0.86, 0.47)	−0.05 (−0.80, 0.69)	−0.30 (−0.73, 0.13)	−0.01 (−0.43, 0.41)	**SMT + endurance**	**1.19 (0.43, 1.96)**
−0.28 (−0.57, 0.01)	0.26 (−0.11, 0.62)	0.14 (−0.29, 0.56)	0.13 (−0.48, 0.75)	0.28 (−0.44, 1.00)	0.03 (−0.34, 0.40)	0.32 (−0.05, 0.69)	0.33 (−0.09, 0.75)	**SMT not endurance**

Upper right triangle gives the pooled mean differences from pairwise comparisons from the standard meta-analyses (column intervention relative to row), *lower left triangle* pooled mean differences from the network meta-analysis (row intervention relative to column).
ABC: Activity-specific balance confidence; BBS: Berg Balance Scale; BWS: body weight support; MiniBESTest: Mini-Balance Evaluation System Test; NA: not available; SMT: sensorimotor training; TUG: Timed Up and Go test.

training including endurance interventions vs control (I2 = 73.4; τ2 = 0.24) and sensorimotor training not including endurance interventions vs control (I2 = 86.3; τ2 = 0.59). Sensorimotor training not including endurance vs endurance intervention comparisons showed considerable heterogeneity (I2 = 91.0; τ2 = 0.98) (Table SVII).

No publication bias was observed for the BBS pairwise comparison groups (Table SVIII and Fig. S10).

Mini-Balance Evaluation Systems Test

Effect of physical exercise modalities on Mini-Balance Evaluation Systems Test scores. The network geometry graph shows the relative amount of evidence available for the effect of physical exercise interventions on MiniBESTest scores (Fig. S11). The indirect comparison showed the highest ES for balance exercises (0.75; 95% CI 0.46, 1.04) and resistance interventions (0.58; 95% CI 0.10, 1.07) vs control groups (Table II and Fig. S12). Similarly, in the pairwise analysis, the highest ES was for the resistance (0.95; 95% CI 0.36, 1.53) and balance (0.58; 95% CI 0.26, 0.89) interventions vs control comparisons. Furthermore, sensorimotor training including endurance also showed positive results (0.37; 95% CI 0.07, 0.66) vs control comparisons in the standard meta-analysis (Table II).

Best treatment probabilities. Dance and balance interventions showed the highest probability of being the best physical exercise for improving MiniBESTest scores (36.2% and 28%, respectively). In addition, balance interventions showed the highest SUCRA (82.4%), followed by dance (66.5%) and resistance interventions (65.7%) (Fig. S13 and Table SV).

Sensitivity analysis, heterogeneity, and publication bias. In the sensitivity analysis, the pooled ES was not modified by removing any trials (Table SVI).

Two direct comparisons showed substantial heterogeneity: balance vs control (I2 = 71.5; τ2 = 0.16) and endurance vs control (I2 = 72.5; τ2 = 0.15). Moreover, a direct comparison showed moderate heterogeneity: resistance vs control (I2 = 56.1; τ2 = 0.20). The alternative vs control comparison showed considerable heterogeneity (I2 = 92.9; τ2 = 3.06) (Table SVII).

No publication bias was found for the MiniBEST pairwise comparison groups (Table SVIII and Fig. S14).

Timed Up and Go Test

Effect of physical exercise modalities on Timed Up and Go Test results. The network geometry graph of the physical exercise interventions on TUG results is shown in Fig. S15.

Indirect comparisons showed significant ES for alternative exercises (–0.54; 95% CI –0.82, –0.26), balance (–0.42; 95% CI –0.75, –0.08), resistance (–0.60; 95% CI –0.89, –0.31), and sensorimotor training including endurance interventions (–0.61; 95% CI –0.95, –0.27) vs control comparisons (Table II and Fig. S16). In direct comparisons, dance interventions showed a significant ES (–0.46; 95% CI –0.83, –0.09) vs control interventions, in addition to those mentioned above for indirect comparisons. Moreover, in the pairwise analysis of the standard meta-analysis, the sensorimotor training including endurance category showed a significant ES (–1.19; 95% CI –1.96, –0.43) vs sensorimotor training not including endurance (Table II).

Best treatment probabilities. The probability of being the best treatment was 30.3% for dance, 23.6% for sensorimotor training, including endurance interventions, and 20.0% for resistance. Moreover, sensorimotor training, including endurance interventions and resistance, showed the highest SUCRA (76.0%, both), followed by alternative exercises (66.8%) and dance (64.0%) (Fig. S17 and Table SV).

Sensitivity analysis, heterogeneity, and publication bias. The pooled ES was modified by removing the following trials in the sensitivity analysis: (*i*) Solla et al., 2019 (s67) from the dance vs control groups, and (*ii*) Liao et al., 2015 (s40); Tollar et al., 2019 (s72) and da Silva et al., 2018 (s19) from the sensorimotor training including endurance interventions vs control groups (Table SVI).

Four direct comparisons showed substantial heterogeneity: alternative vs control (I2 = 62.6; τ2 = 0.14), resistance vs control (I2 = 82.0; τ2 = 0.41), sensorimotor training including endurance interventions vs control (I2 = 71.6; τ2 = 0.28), and sensorimotor training not including endurance interventions vs control (I2 = 70.2; τ2 = 0.13). Furthermore, a direct comparison showed moderate heterogeneity: resistance vs alternative (I2 = 41.8; τ2 = 0.03).

Publication bias was observed for the direct comparison of the resistance vs control groups ($p = 0.000$) (Fig. S18 and Table SVIII).

DISCUSSION

This network meta-analysis provides a synthesis of the evidence comparing the effects of different physical exercise modalities on balance, postural stability, and general mobility in people with PD. These parameters were assessed using the ABC scale, BBS, MiniBESTest, and TUG. The results of the network meta-analysis show that balance exercises were the only physical exercise modality that improved all outcomes compared with control interventions, except for the ABC scale for which balance exercises were superior to sensorimotor training including endurance interven-

tions. Alternative exercises and sensorimotor training including endurance, are also effective interventions for improving balance, postural stability, and general mobility, as measured by the BBS and TUG. In addition, the results show that resistance interventions improve balance, postural stability, and general mobility as indicated by higher MiniBESTest scores and lower TUG times. Finally, BWS interventions, dance, and sensorimotor training not including endurance show positive effects on balance, as indicated by the BBS. In line with the current study results, previous reviews have shown that physical exercise interventions are effective in managing PD symptoms such as balance, postural stability, and mobility impairments (17, 18).

Balance interventions showed the best results in the current study. It has been shown previously that balance interventions improve patients' perceived level of confidence in balance when performing activities of daily living. In addition, balance training has been reported to be a very effective type of physical therapy exercise for improving balance and PD features directly related to balance, such as postural stability and risk of falls (42–45). These results may be due to the design of balance treatment, which is specifically aimed at improving the balance outcomes studied in this meta-analysis, in other words, patients could improve what they practice, as these intervention programmes adapted to this clinical feature of PD. This is because these balance interventions usually focus on 4 characteristics of postural control and balance that are often affected in patients with PD: sensory integration, anticipatory postural adjustment, motor agility, and stability limits (46).

In the current study, alternative exercises and dance showed the highest probability of being one of the 3 best treatments and one of the highest SUCRAs in all scales assessed. Moreover, alternative exercises and dance have already shown improvements in motor and non-motor symptoms of PD related to cognition, memory, attention, and emotional well-being (47–49). The positive results of these interventions may also be due to these exercises being performed as part of group classes, thus involving socialization, making them enjoyable forms of rehabilitation and facilitating adherence to treatment (50). Both categories have multidimensional benefits, and although they are not complete balance physiotherapy techniques, they have a high balance- and posture-based component. In fact, both dance and alternative exercises are considered "highly challenging" balance exercises (45). Dance consists of a combination of steps that involve starts and stops of movement, changes in direction, rhythmic variation, and changes in the centre of body mass and speed. These features may specifically target the motor symptoms of PD. Furthermore, dance contributes to the configuration of the body schema, increasing awareness of the body and its movements (51). Alternative exercises focus on the interactions between body position and movement, breathing and the mind, through the practice of focused attention and a sequence of controlled movements. This improves the perception of position and movements increasing the ability to control balance (49, 52).

The sensorimotor training interventions, which are also multicomponent treatments that involve a balanced combination of exercise categories, combine all the benefits of the different parts of the programmes into one (53). These interventions stimulate the sensorimotor control system, causing lower latency of muscles in response to unexpected external stimuli (19).

Furthermore, BWS interventions showed positive results in balance assessed using BBS in the current study. BWS interventions seem to improve balance and posture during gait due to facilitation of straightening and alignment of the lower limbs and trunk by reducing patients' weight, as previously reported. The positive results of the BWS can be explained by the patient's sense of security being more suitable in advanced stages of PD with a great alteration of balance and postural instability. This technique also allows us to establish greater speed on the treadmill, thus increasing training intensity (13, 54, 55).

PD progresses towards a loss of muscle mass and strength that contributes to balance, postural stability, and general mobility impairments. As previously reported, resistance interventions potentially increase muscular strength, improving balance skills on the MiniBESTest and general mobility on the TUG (56, 57). In addition, resistance training has been shown to improve functional activities involving balance, general mobility, and postural stability; and reduce falls (29). In the current network meta-analysis, no effects were found for endurance interventions, although previous studies have reported positive effects on balance, posture stability and their related factors (58, 59). Furthermore, in a recent clinical practice guideline, endurance training is strongly recommended to be prescribed by physical therapists very early in the course of PD, given the potential benefits in oxygen consumption, motor symptoms and functional outcomes (29).

Based on the results of the current study and previous evidence, physical exercise programmes to improve balance, postural stability, and general mobility should contain a balance component or target these characteristics of the disease (60).

The design of an exercise programme for PD should be based on the interests and needs of each patient, although, in general, and for these specific characteristics of the disease, it would be recommended to perform:

(*i*) balance training for 20–30 min approximately 2–3 times per week, with dance and alternative exercises being a good activity to replace some of these sessions; (*ii*) resistance training 2–3 times a week preferably included in multimodal training; (*iii*) endurance training for more than 30 min per session 2–5 times per week; and (*iv*) flexibility exercises as a warm-up and cool-down for each physical exercise workout (29, 61–63).

Study limitations

Some limitations of this network meta-analysis should be acknowledged: (*i*) some characteristics (i.e. intensity, frequency, and duration) of interventions classified in the same physical exercise category varied widely among them; (*ii*) control interventions were highly heterogeneous related to the type of training (i.e. health education classes, breathing techniques, stretching, and usual pharmacological care); (*iii*) the analysis showed substantial and considerable heterogeneity for multiple comparisons; (*iv*) significant publication bias was reported for the direct comparison of resistance vs control groups for the TUG; (*v*) no further potential effect modifiers could be included in the similarity analysis as they were not reported in most of the studies; and (*vi*) given the risk of bias, quality of evidence and inconsistencies in the current analyses, the results should be interpreted with caution.

Conclusion

The results of the network meta-analysis show that the balance exercise category was the only physical exercise modality that improved balance, postural stability, and general mobility in people with PD. These parameters were assessed using the ABC scale, BBS, MiniBESTest, and TUG. Moreover, these results show that alternative exercises, dance, BWS interventions, resistance, and sensorimotor training including and not including endurance interventions are also effective in improving balance, postural stability, and general mobility. More research is needed to establish the types of physical exercise interventions that provide the strongest benefits for all characteristics of PD.

The authors have no conflicts of interest to declare.

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