Physiotherapy 116 (2022) 58–71

A systematic review on the effectiveness of perturbation-based balance training in postural control and gait in Parkinson's disease

Daniel Boari Coelho [a,*], Claudia Eunice Neves de Oliveira [a], Marcos Vinicius Carvalho Guimarães [b], Caroline Ribeiro de Souza [c], Márcio Luiz dos Santos [b], Andrea C. de Lima-Pardini [d]

[a] Biomedical Engineering, Federal University of ABC, São Bernardo do Campo, SP, Brazil
[b] Anhanguera University, São Paulo, SP, Brazil
[c] School of Physical Education and Sport, University of São Paulo, São Paulo, SP, Brazil
[d] Laboratory of Integrative Motor Behaviour, Centre for Neuroscience Studies, Queen's University, Ontario, Canada

Abstract

Background Pharmacological and surgical interventions do not improve postural control and gait effectively in people with Parkinson's disease (PD). An innovative and promising therapeutic intervention is perturbation-based balance training (PBT).
Objective To perform a systematic review to summarise the current evidence for PBT on postural control and gait in people with PD. Intervention studies including PBT, in isolation or associated with other physical interventions, were included.
Literature survey PubMed, SciELO, PEDro and Cochrane databases were searched between June 2000 and March 2020.
Methods This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, and is registered in the PROSPERO database (CRD42020203961). The quality of evidence was evaluated using the Grading of Recommendations Assessment, Development and Evaluation. Studies were assessed for methodological quality using the PEDro scale. Two of the authors reviewed the search results and selected studies using predefined selection criteria. No restrictions based on severity of PD, time since diagnosis or age were used.
Synthesis Eleven studies were selected for final evaluation. Most outcomes were downgraded in quality of evidence, mainly because of publication bias and limitations. The most consistent results indicate that PBT can improve postural control and gait in people with PD, including a reduction in the number of falls and a decrease in the severity of PD.
Conclusion PBT may be a promising option for the treatment of people with PD, and an adjunct to conventional physiotherapeutic treatment. However, deficiencies in the methodological quality and quality of evidence of studies included in this review have limited the reliability of the conclusions.
Systematic Review Registration Number : PROSPERO CRD42020203961.

Contribution of the Paper

- PBT has the potential to improve postural control and gait.
- PBT can decrease the number of falls in people with PD.
- PBT may be a promising therapeutic option for people with PD.

Keywords: Rehabilitation; Motor symptoms; Fall; Balance

* Corresponding author at: Centre for Engineering, Modeling and Applied Social Sciences, Federal University of ABC, Alameda da Universidade, s/no, Bairro Anchieta. São Bernardo do Campo, SP 09606-045, Brazil.
E-mail address: daniel.boari@ufabc.edu.br (D.B. Coelho).

https://doi.org/10.1016/j.physio.2022.02.005
0031-9406/

Introduction

Parkinson's disease (PD) is a neurodegenerative disease which becomes more common with age. An essential pathological marker is the selective degeneration of dopaminergic neurons in the compact part of the substantia nigra. PD is often associated with motor symptoms such as tremor at rest, stiffness, bradykinesia and postural instability. Postural instability usually occurs in more advanced stages of PD, and is one of the most disabling symptoms as it impairs activities of daily living and increases the risk of falls [1,2].

Postural control depends on the constant action of two mechanisms: anticipatory and reactive postural adjustments [3]. Anticipatory postural adjustments (APAs) prepare the body for internal and predictable perturbations, such as during voluntary tasks in which movement perturbations can be predicted and counterbalanced [4]. On the other hand, reactive (or compensatory) postural responses (RPRs), the focus of the present study, are responsible for maintaining postural control during external and unpredictable perturbations, such as during a push, stumble or any bodily perturbation [5]. In PD, disorders occur in both APAs and RPRs [6,7]. Specifically, RPRs in people with PD are smaller and delayed [8] compared with controls, and correlate with gait disorders [8] and falls [9].

There is evidence that drug and surgical treatments are ineffective in treating postural disorders. For example, the gold standard for the treatment of PD motor symptoms, levodopa, has various effects on postural control in people with PD, including worsening of RPRs, improvement of APAs and no change in axial tone [10,11]. Regarding deep brain stimulation, the results are similar in terms of worsening of RPRs and improvement in APAs [12]. Recently, the authors' group has shown that while spinal cord stimulation improves APAs in people with PD and freezing of gait, RPRs are not influenced by this approach [13]. However, physical activity has consistently been shown to have a positive effect on postural control [14–16], with a consequent decrease in the risk of falls [17,18].

Physical activity in the context of rehabilitation needs to be structured so that patients with PD have efficient learning and can transfer what they learn in physiotherapy sessions into activities of daily living. Studies have shown that training is more effective if it is specific to the skill to be improved [19]; in this way, the specificity of reactive postural training is essential to improve this domain. One little-explored strategy that has potential for the improvement of postural control is perturbation-based balance training (PBT) [20–22].

PBT incorporates repeated and unexpected external perturbations to evoke rapid postural responses, allowing the individual to train reactive postural control through specific practice [23]. PBT has been shown to reduce the risk of falls, and improve postural control and gait in healthy older people, poststroke patients and people with PD [24,25]. It has been suggested that PBT stimulates the sensorimotor control system, causing lower latency of muscle in response to unpredictable perturbations [26,27].

People with PD may require more training to achieve and retain motor learning, and may require additional sensory information or motor guidance to facilitate this learning [28]. Despite the known benefits of PBT in the rehabilitation of postural control, there is a lack of consistency between studies in terms of methods used to cause perturbations, frequency, intensity, and specific improvements in postural control and gait for people with PD. As such, the aim of this systematic review was to examine the efficacy of PBT in isolation or in association with other physical interventions to improve postural control and gait in people with PD. The primary outcome parameters considered in this review were postural control and gait measured using clinical scales, the centre of pressure and spatiotemporal parameters of gait. This review sought to answer the following 'PICOS' question: 'What is the effectiveness of PBT in the rehabilitation of postural control and gait in people with PD? (Population: people with PD; Intervention: PBT in isolation or in association with other physical interventions; Comparison: none specified; Outcome: all outcomes that measure postural control and gait accepted; Study design: randomised controlled trials and controlled clinical trials).

Methods

Eligibility criteria

This review reports the effects of balance training based on intentional perturbations that cause instability during treatment to improve postural control and reactive balance. The inclusion criteria for this review were: (1) methodology involved an intervention based on perturbation training, with people with PD in at least one group [postural perturbation applied via equipment (e.g. force plate) or manually (e.g. pushed by therapist)]; (2) interventions of any duration or time; (3) eligible control groups included usual care or no treatment; (4) outcome variables were related to postural control and/or gait; (5) no restrictions on participants based on severity of PD, time since diagnosis or age; and (6) written in English.

Search strategy

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines [29], and is registered in the PROSPERO database (CRD42020203961). Two reviewers independently assessed the search strategy and the inclusion and exclusion criteria of the studies. The main term used to search for studies on PBT was 'perturbation', which is described imprecisely in the literature. However, other researchers have used the terms 'perturbation training', 'agility training' and 'dynamic balance training'. To the authors' knowledge, no articles in the literature have described relevant issues related to the specificity of the content that involves perturbation training in people with PD. The following search strategy was used to identify studies for inclusion in this review: (1) PubMed, SciELO, PEDro and Cochrane databases were searched between June 2000 and March 2020. The search terms and operators (AND, OR) used in the databases were: (train OR practice OR rehab OR exerc) AND (perturb OR slip OR 'balance training') AND Parkinson. These words were searched for in the title or abstract; (2) relevant articles and reviews on perturbation training were identified by reading the titles and abstracts; (3) articles were read in detail, including using the reference list to identify further studies reporting perturbation training; and (4) a complementary search was carried out using Google Scholar (all available dates) to find new studies and relevant articles.

Study selection

According to the titles and abstracts, two independent reviewers initially evaluated the studies identified by the search strategy. The reviewers evaluated the full articles and selected studies according to the inclusion criteria. Studies that did not meet the inclusion criteria were excluded. Disagreements between reviewers were resolved by consensus. Perturbation was defined as an intervention aiming to improve reactive postural control in a safe and controlled environment. The specific task could be stopping a treadmill while walking, waist pulls, load release, or therapist-applied pull and push.

Data extraction

The following data were extracted from the selected studies: identification of the publication; participant characteristics (sex, age, disease stage and severity); characteristics of control and perturbation interventions (type of training, frequency and duration of training sessions, duration of training programme); sample; and primary results. After analysing the articles, the data were categorised, interpreted and grouped according to the effectiveness of PBT for postural control and/or gait among people with PD.

Data synthesis

Two reviewers independently applied the PEDro scale to evaluate methodological quality, and Grading of Recommendations Assessment, Development and Evaluation (GRADE) to evaluate the quality of evidence for outcomes. Randomised controlled trials were graded as high quality evidence, and studies could be downgraded based on risk of bias, inconsistencies, indirectness, inaccuracy and publication bias. The quality of evidence was classified as high, moderate, low or very low. All studies were analysed by narrative synthesis, and grouped according to the clinical feature measured.

Outcome variables were classified using gait, posture and clinical scales. The quantitative gait variables were velocity, cadence and step length. The postural variables were anteroposterior and mediolateral oscillation of the centre of pressure. The clinical scales were Unified Parkinson's Disease Rating Scale (UPDRS), Timed Up and Go (TUG) test, Activities-specific Balance Confidence Scale (ABC), Fullerton Advanced Balance Scale, Falls Efficacy Scale (FES), and Parkinson Disease Questionnaire-39.

Results

After removing duplicates, the systematic literature search revealed 343 relevant studies. Two hundred and ninety studies were excluded after screening the titles and abstracts. The remaining 53 potentially relevant papers were analysed based on the full text and the predefined eligibility criteria. Finally, 11 studies were included in the quantitative analysis (Fig. 1).

Table 1 summarises the quality assessment of the included studies. The total scores for methodological quality ranged from 2 to 9 points, with two studies classified as low methodological quality [26,30], and nine studies classified as moderate or high methodological quality [14,17,20,21,31–35].

Table 2 displays the details of the GRADE assessment showing limitations, inconsistency of results, indirectness of evidence, imprecision of results, and publication bias. The results show that two outcome indicators were of very low quality, 1 was of low quality, 1 was of moderate quality, and none were of high quality. Limitations (100%) and publication bias (75%) were the main reasons for downgrading the quality of evidence.

Table 3 summarises the 11 selected studies, including author/year, experimental and control group samples, UPDRS, Hoehn & Yahr scale (H&Y), antiparkinsonian medication during the intervention, interventions in the experimental group (i.e. external perturbations), associated interventions in the experimental group, interventions in the control group, outcome variables, frequency, duration of the intervention and results. This review included a total of 337 participants, of whom 183 were in intervention groups and received perturbation training, and 154 participants were in control groups. Both males and females with PD participated in the 11 studies. The average age of participants in the experimental groups was 69.1 [standard deviation (SD) 4.2] years and the average age of participants in the control groups was 69.6 (SD 5.0) years. The studies were conducted in Germany, China, the USA, Italy and Sweden. The average classification of Parkinson's disease (H&Y) varied between stage II (bilateral or midline involvement without impairment of balance) and stage III (bilateral disease: mild-to-moderate disability with impaired postural reflexes; physically independent). Pasluosta *et al.* [41] used the same training protocol and participants as Klamroth *et al.* [34]. Gassner *et al.* [36], Klamroth *et al.* [37] and Steib *et al.* [38] used the same train-

Table 1
PEDro scale for evaluating the quality of selected studies.

PEDro scale	Toole 2000 [30]	Hirsch 2003 [14]	Jobges 2004 [26]	Protas 2005 [17]	Smania 2010 [31]	Shen 2012 [21]	Shen 2015 [20]	Schlenstedt 2015 [32]	Landers 2016 [33]	Klamroth 2016 [34]	Steib 2017 [35]
Eligibility criteria specified	No	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Random allocation	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Concealed allocation	No	No	No	No	No	Yes	Yes	No	Yes	Yes	Yes
Groups similar at baseline	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Subject blinding	No	No	No	No	No	No	No	No	No	No	Yes
Therapist blinding	No	No	No	No	No	No	No	No	No	No	No
Assessor blinding	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No
Less than 15% dropouts	No	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No	Yes
Intention-to-treat analysis	No	No	No	No	No	No	Yes	Yes	Yes	No	Yes
Between-group statistical comparisons	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Point measures and variability data	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Total	3	6	2	6	7	8	9	6	8	6	9

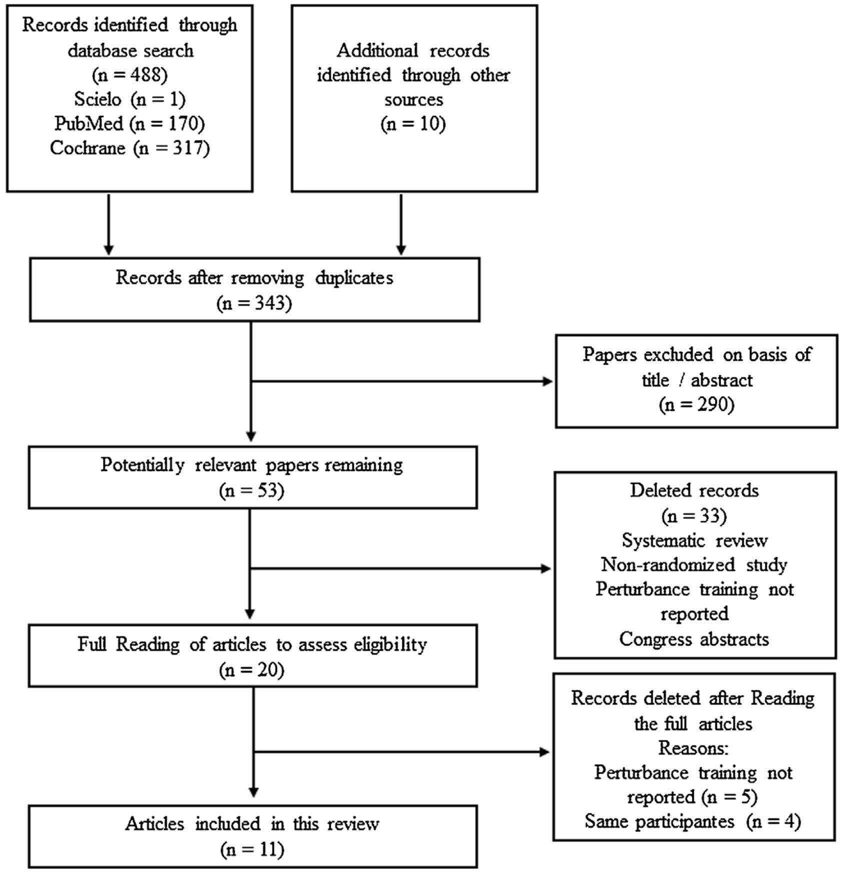

Fig. 1. Research strategy summary. Sixteen studies were selected and included in the final analysis.

Table 2
GRADE evidence profile for the effects of perturbation-based balance training on postural control and gait in people with Parkinson's disease.

Number of studies	Limitation	Inconsistency	Indirectness	Imprecision	Publication bias	Quality of evidence
Posture, centre of pressure						
6	−1	0	0	0	0	Moderate
Posture, clinical scales						
7	−1	−1	0	0	−1	Very low
Gait, spatiotemporal parameters						
4	−1	0	0	0	−1	Low
Gait, clinical scales						
3	−1	0	0	−1	−1	Very low

ing protocol and participants as Steib *et al.* [35]. Eight studies included a control group [14,20,21,31–35]. In four studies, the intervention used for the control group was not reported [17,26,30,33]. In one study, the control group included balance and/or mobility exercises [14]; in two studies, the control intervention included lower limb strengthening exercises [20,21]; in one study, the control intervention included resistance exercises [32]; and in two studies, the control intervention included treadmill walking [34,35].

The intervention characteristics were described according to frequency, intensity, time and type of perturbation training. For six studies [14,17,20,21,39,40], the frequency of training sessions was three times per week. Three studies [30,31,35] reported training sessions twice per week. Klamroth *et al.* [27] reported a single intervention session. Jobges *et al.* [26] reported two intervention sessions per day for 14 days. Training intensity was not specified in any of the studies in terms of the magnitude of perturbations (e.g. speed or acceleration).

In seven studies, perturbations were generated by pulling or pushing the shoulder of the participant in several directions [20,21,31,32,34,35,40]. In four studies, perturbations were generated by placing an unexpected object on the treadmill surface, or by an unexpected sudden stop [20,21,34,35]. All participants were medicated (ON status) during treatment, and the most common medication was levodopa. All studies that found improvement used balance scales such as the Berg Balance Scale, ABC and miniBESTest [20,21,31,36,37], and centre of pressure with the force plate [14,26,30,38,41]. Four

Table 3
Characteristics of the studies included in the systematic review.

1st Author/Date	Group sample	UPDRS motor	H&Y	MED	Intervention in the experimental group	Associated interventions in the experimental group	Intervention in the control group	Outcome variables	Frequency, duration of intervention	Results
Toole, 2000	EG: $n = 4$; age = 73 (8) years	NI	2.2 (0.8)	On	A therapist applied a backward pull on the shoulders	Strengthening of lower limbs. Visual manipulation while maintaining balance on fixed and unstable surfaces	NI	*Domain:* posture *Task:* Sensory organisation test score. Joint torque	3 times per week, 1 hour, 10 weeks	Improved joint torque and postural control – EG only
	CG: $n = 3$; age = 71 (5) years									
Hirsch, 2003	EG: $n = 6$; age = 71 (3) years	NI	1.8 (0.4)	On	A therapist applied a backward pull on the shoulders	Sensory organisation test in quiet standing.	Sensory organisation test in quiet standing.	*Domain:* posture *Task:* Sensory organisation test score. Joint torque	3 times per week, 45 minutes (EG) and 30 minutes (CG), 10 weeks	Improvement in postural balance. In the retention of CG performance, four decreased to pretreatment levels
	CG: $n = 9$; age = 76 (2) years					Strengthening of lower limbs. Weight transfer exercises with eyes open for 5 seconds	A therapist applied a backward pull on the shoulders			
Jobges, 2004	EG: $n = 14$; age = 73 (6) years	On: 45.35 (19.3)	2.9 (0.5)	On	A therapist applied multiple directions, pulls and shoves on the shoulder	None	Without CG	*Domain:* posture *Task:* Score of the sensory organisation test	2 times per day, 14 days	EG significantly improved step length and cadence in post-training and retention of 2 weeks and 2 months Postural control did not change

Table 3 (*Continued*)

1st Author/Date	Group sample	UPDRS motor	H&Y	MED	Intervention in the experimental group	Associated interventions in the experimental group	Intervention in the control group	Outcome variables	Frequency, duration of intervention	Results
	CG: none	Off: 51.28 (21.3)						*Domain:* clinical scale *Task:* quality of life PDQ-39 *Domain:* gait *Task:* gait at a self-selected velocity		
Protas, 2005	EG: $n = 9$; age = 71 (7) years	EG: 28.3 (13.6)	EG: 2.8 (0.35)	On	Perturbations through sudden and unexpected treadmill stops	None	NI	*Domain:* gait *Task:* gait at a self-selected velocity	3 times per week, 1 hour, 8 weeks	EG, but not CG, increased gait cadence and step length. Velocity during step test increased in EG
	CG: $n = 9$; age = 74 (9) years	CG: 30.4 (8.0)	CG: 2.9 (0.17)					*Domain:* posture *Task:* step test		
Smania, 2010	EG: $n = 28$; age = 68 (7) years	EG: 46.1 (11.5)	EG: 3.0 (0.1)	On	A therapist applied an anteroposterior pull	Self-destabilising exercises of the centre of mass on a fixed or unstable surface	Mobilisation exercise, muscle stretching and coordination exercises	*Domain:* clinical scale	3 times per week, 50 minutes, 7 weeks	EG showed improvement in all outcome measures regarding balance, except for UPDRS scale. Improvement after 1 month of retention
	CG: $n = 27$; age = 67 (7) years	CG: 43 (16.9)	CG: 3.1 (0.3)					*Task:* Scores of postural balance (BBS and ABC)		

Table 3 (*Continued*)

1st Author/Date	Group sample	UPDRS motor	H&Y	MED	Intervention in the experimental group	Associated interventions in the experimental group	Intervention in the control group	Outcome variables	Frequency, duration of intervention	Results
Shen, 2012	EG: $n = 14$; age = 63 (9) years	EG: 4.0 (1.2)	EG: 2.2 (0.5)	On	Perturbations through sudden and unexpected treadmill stops	Manipulation of visual cues while maintaining balance on an interactive dance mat	Strengthening of lower limbs	*Domain:* posture *Task:* Stability limit (LOS test - Equitest)	3 times per week, 25 minutes	Compared with CG, EG improved postural balance, decreased reaction time, increased step length and decreased UPDRS. Cadence increased in CG. No patients in EG reported a fall during the training period
	CG: $n = 14$; age = 67 (9) years	CG: 4.2 (1.5)	CG: 2.3 (0.5)					*Domain:* clinical scale *Task:* UPDRS *Domain:* gait *Task:* gait at self-selected velocity, number of falls	4 weeks	
Shen, 2015	EG: $n = 22$; age = 63 (8) years	EG: 24.0 (8.3)	EG: 2.4 (0.5)	On	Perturbations through sudden and unexpected treadmill stops	Manipulation of visual cues while maintaining balance on an interactive dance mat	Strengthening of lower limbs.	*Domain:* clinical scale	3 times per week	The EG demonstrated a reduction in the postural response latency and an increase in the step length compared to the CG an increase in the time in the unipodal position, a decrease in falls in the post-training, and the retention of 3, 6, and 15 months.

Table 3 (*Continued*)

1st Author/Date	Group sample	UPDRS motor	H&Y	MED	Intervention in the experimental group	Associated interventions in the experimental group	Intervention in the control group	Outcome variables	Frequency, duration of intervention	Results
	CG: $n = 23$; age = 65 (9) years	CG: 23.2 (6.5)	CG: 2.5 (0.5)					*Task:* Scores of the postural balance scales (SLS test) *Domain:* gait *Task:* gait at a self-selected velocity	12 weeks	
Schlenstedt, 2015	EG: $n = 15$; age = 76 (7) years	EG: 37.7 (13.1)	EG: 2.7 (0.4)	On	A therapist applied an anteroposterior pull	Generic balance training (unstable surfaces)	Strengthening of lower limbs	*Domain:* clinical scale	2 times per week, 60 minutes, 7 weeks	Lower values for maintaining postural control in the post-test in EG compared with CG. Only CG improved balance. FAB was correlated with rate of strength development and step variability. Only CG increased gait velocity
	CG: $n = 17$; age = 76 (6) years	CG: 40.2 (12.5)	CG: 2.8 (0.3)					*Task:* Scores of postural balance scales (FAB, TUG, maximum isometric strength)		

Table 3 (*Continued*)

1st Author/Date	Group sample	UPDRS motor	H&Y	MED	Intervention in the experimental group	Associated interventions in the experimental group	Intervention in the control group	Outcome variables	Frequency, duration of intervention	Results
Landers, 2016	EG: $n = 31$; age = 71 (6) years	NI	EG: 2.5 (0.7)	On	Load release attached to the participant's trunk	Generic balance training, treadmill, obstacle avoidance, walking on a rope, visual manipulation	No targeted activity, maintenance of daily activities	*Domain:* clinical scale	3 times per week, 45 minutes	No differences between groups for investigated variables, except gait velocity. Everyone improved, including CG.
	CG: $n = 10$; age = 74 (9) years		CG: 2.7 (0.6)					*Task:* Scores of postural balance scales (ABC), sensory organisation *Domain:* gait *Task:* gait at self-selected velocity (DGI)	4 weeks	
Klamroth, 2016	EG: $n = 19$; age = 65 (10) years	EG: 16.7 (5.5)	EG: 2.4 (0.6)	On	Perturbation is generated by an unexpected object placed on the surface of the belt and inclination	None	Walk on treadmill	*Domain:* posture	1 session of 15 minutes, retention in 10 minutes	EG improved walking velocity. Decrease in gait variability. Sustained result in retention of 10 minutes. No effect on postural sway
	CG: $n = 20$; age = 64.2 (8.5) years	CG: 17.7 (8.7)	CG: 2.2 (0.9)					*Task:* quiet standing		

Table 3 (*Continued*)

1st Author/Date	Group sample	UPDRS motor	H&Y	MED	Intervention in the experimental group	Associated interventions in the experimental group	Intervention in the control group	Outcome variables	Frequency, duration of intervention	Results
								Domain: clinical scale *Task:* TUG *Domain:* gait *Task:* gait at self-selected velocity		
Steib, 2017	EG: $n = 21$; age = 68 (8) years	EG: 17.7 (6.1)	EG: 2.6 (0.5)	On	Small three-dimensional tilting movements of the treadmill while walking	None	Walk on treadmill	*Domain:* gait *Task:* 2-minute walk test	16 sessions, held twice per week within 8 to 9 weeks, 30 minutes. Retention in 3 months	Decrease in TUG time in EG alone, increase in gait resistance. Sustained results in 3-month retention
	CG: $n = 22$; age = 63 (8) years	CG: 20.4 (8.2)	CG: 2.5 (0.5)					*Domain:* clinical scale *Task:* TUG, ABC and miniBESTest scale *Domain:* posture *Task:* quiet standing		

EG, experimental group; CG, control group; UPDRS, Unified Parkinson's Disease Rating Scale; PIGD, postural instability and gait disorder; TUG, Timed-Up-and-Go Test; ABC, Activities-specific Balance Confidence Scale; FAB, Fullerton Advanced Balance Scale; FES, Falls Efficacy Scale; PDQ-39, Parkinson Disease Questionnaire–39; SLS, single-leg stance; LOS, limits of stability; NI, not informed; MED, medication.
Values presented as mean (standard deviation).

studies found that PBT had no effect on posture or gait [26,32,34,40]. Only Schlentedt *et al.* [32] found that strength training had a more significant effect on postural control compared with PBT.

Most studies found that step length increased after PBT [17,20,21,26]. Three studies found an increase in gait speed [17,26,27], an increase in gait endurance and a decrease in TUG time [35]. The results also point to a decrease in gait variability [27,38] and an increase in cadence [26]. Only one study did not report the effect of PBT on gait variables [40]. A decrease in the number of falls [21] and a lower score on the PD severity scale (UPDRS) [20,31,36] were also identified. Of the 11 studies, seven (64%) considered retention of improvements as well as pre- and post-test measures, which ranged from 10 minutes [27] to 15 months [20]. Only Steib *et al.* [35] found that the positive results of PBT were not sustained 3 months later. Six of the 11 studies (54%) used PBT exclusively as an intervention [17,26,30,31,34,40]. The other studies included strength training [20,30], visual manipulation [21] and attention [40], and other balance training [14] in the intervention protocol. Strength training was the intervention most often associated with PBT. No adverse effects of the proposed interventions were reported.

Discussion

The results of this review provide evidence that PBT, as verified previously in healthy older people [40], is a promising approach in the rehabilitation of postural control and gait in people with PD. The most consistent results of this review indicate that PBT can improve some domains of postural control and gait in people with PD. However, there were many limitations in the studies included in this review, so it is not possible to draw robust conclusions about the effects of PBT in people with PD.

Most of the studies in this review showed that PBT improved postural control in people with PD. However, as most of the studies used subjective scales, it is difficult to determine objectively which postural control domains benefited. For example, the miniBESTest, used by Steib *et al.* [35], includes reactive, anticipatory control and sensory integration domains. A few studies evaluated postural control through biomechanics with a force plate to generate more reliable postural control data. The results from the force plate showed improved sensory integration [14,26,30,34,35,38,41], and only one study showed better control of the centre of pressure [41]. However, Schlenstedt *et al.* [32], based on kinematic results, found that strength training led to better postural control than PBT. However, PBT was poorly controlled in the study by Schlenstedt *et al.* [32], as a therapist applied the perturbations, and likely applied inconsistent force between perturbations. Studies showed that the best biomechanical results were obtained for PBT given as a combined intervention [14,20,21,31,32], or using perturbations caused by sudden interruption of a treadmill [20,21,34–38,41]; this made it difficult to identify whether the improvements occurred exclusively due to PBT.

Considering gait, most studies showed an increase in step length [17,21,26] and gait speed [17,20,27,32,33,35], a decrease in step variability [27,38], and an increase in cadence [14,17,21]. The improvements in postural control and gait performance indicate that PBT can enhance the global mobility of people with PD. However, the neurophysiological mechanisms involved in this improvement remain poorly understood. There is a need to characterise studies focusing on a specific postural control or training domain, and to avoid mixing intervention types. It is possible to assume that repeated exposure to perturbations favours brain plasticity in regions involved in controlling posture and gait, thus increasing motor flexibility.

A difficulty in generalising the results of this systematic review is the low external validity due to the lack of randomisation and determination of the control group in some studies. For example, some studies did not even report the activities performed by the control group. Another factor is that all studies included older patients with PD with more advanced disease, and did not include a significant number of young participants [42]. None of the studies differentiated between participants with freezing of gait and those without this symptom. This fact is essential, considering that participants with freezing of gait have more significant postural control and gait [43], and may respond differently to the same intervention. Another factor limiting external validity is the sole inclusion of participants with moderate disease (H&Y 2–3), and from countries in Europe and Asia. There is a need to perform studies of this type in other parts of the world, such as Latin America, as cultural and socio-economic conditions can influence responses to interventions [43]. In addition, investigation of the effect of PBT in patients at other stages of disease may clarify the optimum time to perform this type of intervention in order to achieve a more effective response.

There was much inconsistency between the studies. In some studies, the perturbation method involved the therapist pushing the subject [21,31,32,40,41], whereas other studies used equipment such as a treadmill programmed to stop suddenly [20,35–38]. In addition to variations in perturbation methods, different postural mechanisms were trained. In the case of perturbation by pushing, reactive postural control on the same support base, or quasi-static, is encouraged [43]. For perturbations during gait, dynamic reactive postural control is trained [2]. In these cases, different neurophysiological mechanisms are stimulated, and in the case of perturbations during gait, the demand for control against gravity is more intense compared with perturbation in quiet standing. Another bias identified was that none of the studies reported the intensity of the perturbation (i.e. acceleration, speed, strength). Even studies that used equipment such as a treadmill did not report the parameters for postural perturbation. Another critical limitation that impairs the transferability of the benefits of PBT was the unpredictability of the perturbations applied. Although the participants could not predict the moment of perturbation, they could predict the direction and intensity, which significantly reduces the ability to prepare an individual for unexpected day-to-day perturbations. Finally, the frequency and number of trials varied widely between studies, making it difficult to analyse the optimum number of trials to achieve rehabilitation goals. It is suggested that in addition to methodological care concerning population, number of trials, frequency, training and experimental design, the assessment of brain function using techniques such as electroencephalography, functional near-infra-red spectroscopy and functional magnetic resonance imaging may be used to complement understanding of the effects of PBT in people with PD.

In consideration with safety, no adverse effects associated with PBT were identified.

This review has limitations. First, publication bias may have occurred because positive findings are more likely to be published. This evidence may exist that PBTs are ineffective that we have not reviewed. According to GRADE, limitations and publication bias were the main causes for downgrading the quality of evidence, including listing and selection of inclusion/exclusion criteria, description of baseline characteristics, interpretation of heterogeneity, and underpowered samples. Second, the term 'perturbation' is loosely described in the literature, with several synonyms. The search terms used in this review included the most common synonyms, but articles involving PBT but described using other terms may have been excluded. Finally, despite the small number of randomised controlled studies on PBT in people with PD, most of the studies assessed in this review had good methodological quality according to PEDro. However, future studies should elucidate the specific type of perturbation and dosage for use in rehabilitation, given the potential therapeutic effect of PBT in posture and gait rehabilitation of people with PD. Based on this information, PBT may be a promising therapeutic option for people with PD and/or an adjunct to conventional physiotherapeutic treatment.

Data availability

Data will be made available on request.

Conflict of interest: None declared.

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