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Review

Effectiveness of backward walking training on balance performance: A systematic review and meta-analysis

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ABSTRACT

Background: Backward walking (BW) training is thought to impact balance performance through improving motor system proprioception and gait characteristic, but relevant evidence remains sparse and inconclusive.
Objective: This study systematically reviewed and quantified the scientific evidence regarding the effectiveness of BW training on balance performance.
Methods: Keyword and reference search on BW training interventions was conducted in six electronic databases (PubMed, Web of science, SPORTDiscus, CINAHL, Cochrane Library, and CNKI) for peer-reviewed articles published till November 2017. A standardized form was used to extract data from each selected article that met the pre-specified eligibility criteria. Meta-analysis was conducted to estimate the pooled effects of BW training on balance performance measures.
Results: Eleven studies (nine randomized controlled trials and two pre-post studies) met the eligibility criteria and were included in the review. All studies reported some beneficial effects of BW training on balance performance. Compared to control, BW training was associated with a reduction in overall stability index score by 0.99 (95% CI = 0.37, 1.61; I^2 = 0.0%; fixed-effect model), medial-lateral stability index score by 0.95 (95% CI = 0.34, 1.57; I^2 = 0.0%; fixed-effect model), and anterior-posterior stability index score by 0.99 (95% CI = 0.37, 1.61; I^2 = 0.0%; fixed-effect model). Meanwhile, BW training was associated with an increase in open-eyes single leg standing duration by 0.91 s (95% CI = 0.29, 1.53; I^2 = 75.9%; random-effect model) in comparison to control.
Conclusions: BW training could serve as a potentially useful tool to improve balance performance among those with a high risk of fall. However, current evidence remains preliminary due to the small cohort of studies and possible learning effect in pre-post studies. Future work with larger scale and randomized experimental design is warranted to evaluate the effectiveness of BW training on balance performance across diverse population and disease subgroups, and elucidate the underlying biomechanical and neurological pathways.

1. Introduction

Balance is the capability of maintaining the body's center of gravity within the base of support while one keeps a static position, makes voluntary movement, or reacts to external disruptions [1]. It is a complex construct incorporating multiple biomechanical, neurological, and sensory systems [1]. Balance is considered as one of the key risk factors for fall, especially in older adults and those with postural control dysfunction (e.g., Parkinson's disease, Alzheimer's disease, and cerebral palsy) [2]. Fall can result in serious injuries, bone fractures, loss of independence, restricted activities, or death [3–5]. The World Health Organization (WHO) estimated 646,000 fatal falls and 37.3 million falls severe enough to require medical attention worldwide each year [6]. Fall imposes substantial economic burden on individuals and society [7]. The medical cost per fall injury in Finland and Australia averaged $3611 and $1,049, respectively [6]. In U.S. the national medical costs attributable to fatal and nonfatal falls among older adults reached $50 billion in 2015 [7].

Evidence-based training programs may improve balance and prevent falls [8–13]. Balance-enhancing interventions implemented in previous trials include Tai Chi [8,10], strength training [9,10], endurance training [9], foot and ankle exercise [11], step training [12], and virtual reality gaming (e.g., Kinect Xbox and PlayStation VR) [13]. Backward walking (BW) training is recently introduced as a means for

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balance improvement and fall prevention [14]. BW is thought not to be a simple reversal motion of forward walking (FW) but planned independently of FW [15]. During BW, an individual has to rely more on senses other than the visual system because one does not have a complete view of the road and obstacles ahead. Under specific conditions, BW is observed to have additional biomechanical benefits over FW [16]. Moriello et al (2014) reported that BW training led to greater improvement in functional balance ability compared to FW using sit-to-stand test [17]. Zhang et al (2014) documented BW training to enhance balance performance by reducing peak plantar pressure [18]. Weng et al (2006) found significantly improved balance function following a three-week BW training [19]. Wang et al (2018) reported BW training to be associated with an increase in forward gait speed and stride length compared to FW training [20].

Moreover, BW training tends to provide certain benefits for people with degenerative disease. It is found to reduce pain resulted from knee osteoarthritis [21], and improve peak torque of lower limb muscles (e.g., quadriceps and hamstring muscles) [22], knee proprioception accuracy [22], gait synergism [23], and balance [24]. Despite some promising findings pertaining to BW training on balance performance, to our knowledge, no review has been conducted to evaluate and summarize the relevant literature. This study aimed to synthesize scientific evidence linking BW training to balance performance and quantify the effect magnitude. We hypothesized that BW training would improve some key aspects of balance performance and postural stability.

2. Methods

This review was conducted and reported in accordance with *Preferred Reporting Items for Systematic Review and Meta-analyses* (PRISMA) [25].

2.1. Study selection criteria

Studies that met all of the following criteria were included in the review: (1) Study design: intervention; (2) Participants: individuals of all ages; (3) Intervention: BW training; (4) Outcomes: balance performance (i.e., berg balance scale [BBS] score, anterior-posterior stability index [APSI], medial-lateral stability index [MLSI], overall stability index [OSI], timed up and go [TUG], and single leg standing duration [SLSD]); (5) Time window of search: peer-reviewed articles published since the inception of a bibliographic database till May 1, 2018; and (6) Language: English and Chinese.

Studies that met any of the following criteria were excluded from the review: (1) Conference proceeding, letter to editor, dissertation, or case report; (2) Review article; (3) Non-intervention study; and (4) Non-human study.

2.2. Search strategy

A keyword search was performed in six electronic bibliographic databases: PubMed, Web of Science, SPORTDiscus, CINAHL, Cochrane Library, and China National Knowledge Infrastructure (CNKI) database. The search algorithm included all possible combinations of the keywords from the following two groups: (1) "walk*", "gait", "locomot*", "direct", "step", or "move*"; and (2) "backward". The four MeSH terms "gait", "walking", "locomotion" and "movement" were included in the PubMed search. All keywords in the PubMed were searched with the "[All fields]" tag, which are processed using Automatic Term Mapping [26]. The search function TS = Topic was used in Web of Science, SPORTDiscus, CINAHL, Cochrane Library, and CNKI, which launches a search for topic terms in the fields of title, abstract, keywords, and Keywords Plus [27–31]. Search algorithm in the six electronic bibliographic databases is reported in Appendix 1. Titles and abstracts of the articles identified through the keyword search were screened against

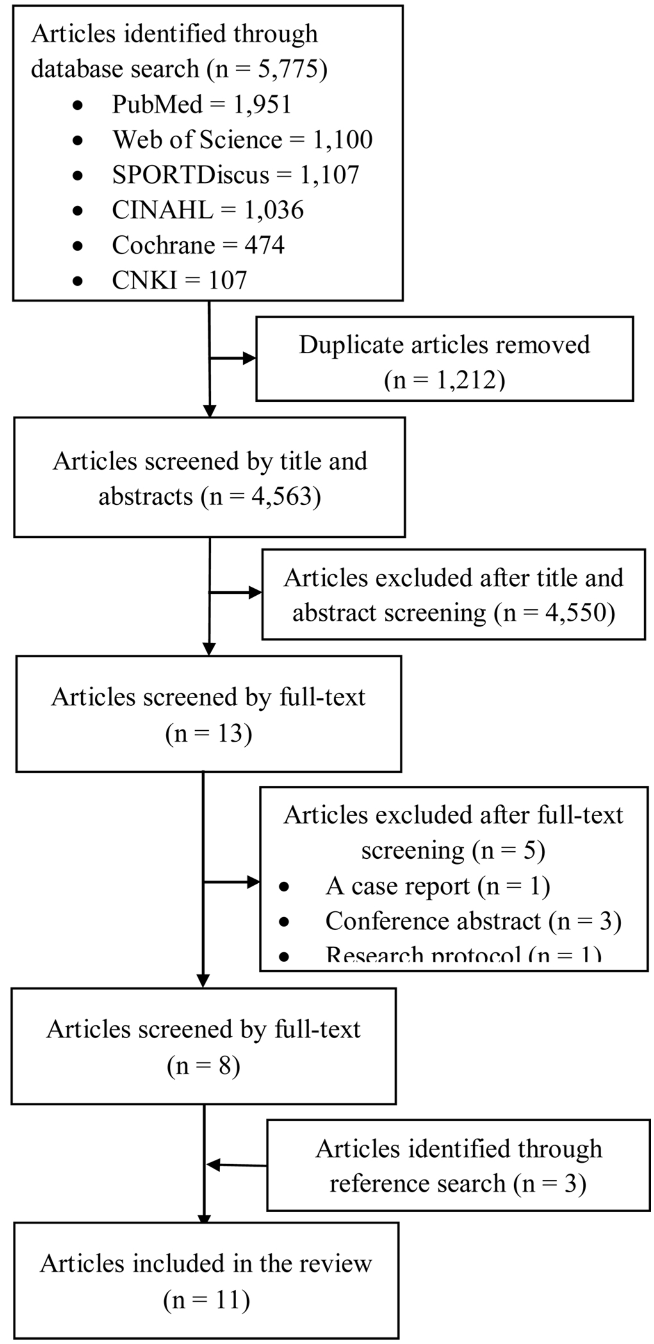

Fig. 1. Study selection flowchart.

the study selection criteria. Potentially relevant articles were retrieved for evaluation of the full text. Two reviewers, JW and JX, independently conducted title and abstract screening and identified potentially relevant articles. Inter-rater agreement was assessed using Cohen's kappa (κ = 0.88). Discrepancies were resolved through face-to-face discussion between JW, JX and RA.

A reference list search (i.e., backward reference search) and a cited reference search (i.e., forward reference search) were conducted based on the full-text articles meeting the study selection criteria that were identified from the keyword search. Articles identified from the backward and forward reference search were further screened and evaluated using the same study selection criteria. Reference search was repeated on newly identified articles until no additional relevant article was found.

Table 1
Basic characteristics of the studies included in the review.

ID	First author, year	Country	Study design	Sample size	Age (years)	Sex	Disease status	Setting	Intervention	Intervention Dose	Follow-up (weeks)
1	Rose, 2018[41]	U.S.	RCTs	16	BWG: 53.8 ± 12.1 SBT: 66.6 ± 7.3	BWG (n = 8) Male: 4 (50%) Female: 4 (50%) SBT (n = 8) Male: 2 (25%) Female: 6 (75%)	Stroke	Hospital	Backward walking over ground	30 mins/session 8 times per week	4
2	Kim, 2017[42]	Korea	Pre-post	7	6.60 ± 2.18	Male: 6 (86%) Female: 1 (14%)	Spastic hemiplegic cerebral palsy	Hospital	Backward walking over ground	20 mins/session 2 times	
3	Etefagh, 2017[43]	Iran	Pre-post	30	Mean: 16.4 ± 0.5 Range: 16-17	Female: 30 (100%)	Healthy	Basketball court	Backward walking over basketball court	15-25 min./session 3 times per week	6
4	Sun, 2017[48]	China	RCTs	14	Mean: 7.25 ± 0.56	BWG (n = 7) Male: 7 (100%) CG (n = 7) Male: 7 (100%)	Healthy	Play-ground	Backward walking over ground	30 mins/session 3 times per week	12
5	Amini, 2016[40]	Iran	RCTs	16	BWG: 8.6 ± 2.4 CG: 8.9 ± 3.7 Range: 8-10	BWG (n = 8) CG (n = 8)	Down syndrome	Lab	Backward walking over ground	25 min./session 2 times per week	8
6	Zhang, 2016[49]	China	RCTs	50	BWG: 64.6 ± 4.5 CG: 64.3 ± 3.9	BWG (n = 25) Female: 25 (100%) CG (n = 25) Female: 25 (100%)	Healthy	Lab	Backward walking over ground	60 mins/session 3 times per week	16
7	El-Basatiny, 2015[44]	Egypt	RCTs	30	BWG: 11.98 ± 1.21 CG: 12.51 ± 1.27 Range: 10-14	BWG (n = 15): Male: 7 (46.7%) Female: 8 (53.3%) CG (n = 15): Male: 9 (60.0%) Female: 6 (40.0%)	Spastic hemiplegic cerebral palsy	Hospital	Conventional physical therapy, backward walking over ground	Conventional physical therapy: 60 mins/session 3 times per week Backward walking: 25 min./session 3 times per week	12
8	Bal, 2012[45]	India	RCTs	40	BWG: 15.55 ± 1.73 CG: 15.55 ± 1.9	BWG (n = 20): Female: 20 (100%) CG (n = 20): Female: 20 (100%)	Healthy	Lab	Backward walking over treadmill	20 mins/session 5 times per week	5
9	Hao, 2011[46]	China	RCTs	12	BWG: 7.13 ± 0.35 CG: 7.25 ± 0.46	BWG (n = 6): Male: 6 (100%) CG (n = 6): Male: 6 (100%)	Healthy	Play-ground	Backward walking over playground	25 min./session 2 times per week	12
10	Takami, 2010[47]	Japan	RCTs	36	CG: 66.90 ± 10.60 FWG: 71.10 ± 10.60 BWG: 66.10 ± 6.30	CG (n = 12): Male: 6 (50%) Female: 6 (50%) FWG (n = 12): Male: 9 (75%) Female: 3 (25%) BWG (n = 12):	Stroke	Lab	Conventional training program, body weight supported backward treadmill training	Conventional training: 30 mins/session 6 times per week Body weight supported backward treadmill training 10 mins/session 6 times per week	3

(*continued on next page*)

Table 1 (*continued*)

ID	First author, year	Country	Study design	Sample size	Age (years)	Sex	Disease status	Setting	Intervention	Intervention Dose	Follow-up (weeks)
						Male: 5 (42%) Female: 7 (58%)					
11	Zhang, 2008[50]	China	RCTs	30	BWG: 65.63 ± 3.47 CG: 65.28 ± 3.29	BWG (n = 18) Female: 18 (100%) CG (n = 12) Female: 12 (100%)	Healthy	Lab	Backward walking over ground	40 mins/session 3 times per week	12

Notes: BWG: backward walking group; CG: control group; FWG: forward walking group; SBT: standing balance training.

2.3. Data extraction

A standardized data extraction form was used to collect the following methodological and outcome variables from each included study: author, publication year, country, sample size, age, sex, disease status, setting, intervention type, intervention dose, follow-up duration, intervention components, measures, key outcomes, other outcomes, and estimated intervention effectiveness.

2.4. Data analysis and synthesis

Meta-analysis was performed to estimate the pooled effects of BW on APSI, MLSI, OSI, and SLSD. Mean difference of a balance performance was calculated for BW training group in comparison to control group within a study. Study heterogeneity was assessed by the I^2 index [32]. The level of heterogeneity represented by the I^2 index was interpreted as small ($I^2 \leq 25\%$), moderate ($25\% < I^2 \leq 50\%$), large ($50\% < I^2 \leq 75\%$), or very large ($I^2 > 75\%$). A fixed-effect model would be estimated when a small or moderate heterogeneity was present, and a random-effect model would be estimated when a large or very large heterogeneity was present. Publication bias was assessed by the Begg's and Egger's tests [33,34]. All statistical analyses were conducted using Stata 15.1 SE version (StataCorp, College Station, TX). Specific Stata commands included "metan" and "metabias". All analyses used two-sided tests, and a *p*-value less than 0.05 was considered statistically significant.

Four of the 11 studies included in the review shared the same balance measures—OSI, APSI, and MLSI [40,44,46,48], five adopted SLSD [42,45,48–50], and two used BBS score [41,47]. Combining studies of the same intervention type, measure, and participants' health status, we were able to include two studies in the meta-analysis for OSI, APSI, and MLSI [40,44], and four studies for SLSD [45,48–50]. We excluded the two studies measuring BBS score from the meta-analysis due to their differential intervention type [41,47]. In addition, the two studies [46,48] measuring OSI, APSI, and MLSI were excluded from the meta-analysis due to their adoption of different measurement equipment (i.e., Biodex stability system versus BTP-200DP balance system). One study measuring SLSD was excluded from the meta-analysis due to different heath status of its analytic sample in comparison to other studies [42]. That study recruited patients with cerebral palsy, whereas the remaining four studies recruited healthy individuals [45,48–50]. Moreover, one randomized controlled trials (RCTs) measured left and right SLSD for both BW training and control groups [50]. Therefore, four studies with five comparisons were available for the meta-analysis on SLSD [45,48–50].

2.5. Study quality assessment

We designed a study quality assessment tool that rates each study based on the following nine criteria. (1) Was the research question and/or study objective clearly stated? (2) Were the study subjects a population-based sample? (3) Was the study an RCT? (4) Was the sample size larger than 100? (5) Was a sample size justification (e.g., power analysis) provided? (6) Was duration of BW training measured? (7) Was balance performance (e.g., BBS score, APSI, MLSI, OSI, TUG, and SLSD) objectively measured? (8) Was a dose-response relationship between BW training and balance performance examined? (9) Was the differential effectiveness of BW training on alternative balance performance examined? For each criterion, a score of one was assigned if "yes" was the response, whereas a score of zero was assigned otherwise (i.e., an answer of "no", "not applicable", "not reported", or "cannot determine"). A study-specific global score, ranging from zero to nine, was calculated by summing up scores across all criteria. Study quality assessment helped measure the strength of scientific evidence but was not used to determine the inclusion of studies.

Table 2
Intervention components, measures, outcomes, statistical models, and estimated effects on balance performance.

ID	Intervention components	Measures	Main outcomes	Other outcomes	Estimated intervention effects
1	Backward walking training consists of backward walking over ground without use of assistive devices. A therapy aide provided postural assistance if needed.	Observational questionnaire evaluation, stopwatch	BBS	Gait speed, activities-specific balance confidence, mobility, fall incidence	Increase in BBS score was from 11.4 ± 10.7 (pre-intervention) to 41.9 ± 11.8 (post-intervention) in BWG.
2	Backward walking was repeated once for 20 minutes.	Stopwatch for SLS, SR, TUG, and TSC, questionnaires for GMFCS, and MAS	TUG, TSC, SLSD	GMFCS, MAS, SR	The results showed significant difference in SLSD on affected side (2.29 s vs 4.93 s, $P < 0.05$), TUG (12.64 s vs 10.21 s, $P < 0.05$) and TSC (17.64 s vs 14.86 s, $P < 0.05$) from pre- to post-test.
3	The duration of each training session was initially 15 minutes and would gradually increase, and finally reached 25 minutes.	Y balance test, modified Romberg test	Y balance test scores, modified Romberg test score		The results of pre-post test showed significant increase in the modified Romberg test score (10.09 ± 5.26 vs 21.9 ± 14.1, $P \le 0.000$) and Y balance test score (anterior: 68.4 ± 0.79 vs 79.5 ± 0.09, $P \le 0.000$; posteromedial: 45.9 ± 0.10 vs 59.9 ± 0.10, $P \le 0.000$) except posterolateral (57.8 ± 0.12 vs 69.8 ± 0.88, $P \le 0.086$).
4	The participants in backward walking group wearing Polar heart rate monitor, were instructed to backward walking on the playground, and requested to keep 75% maximal heart rate on the whole session.	BTP-200DP dynamic balance system (China), JVC9800 motion capture system (Japan)	Balance index (OSI, APSI, MLSI)	Kinematic parameters (e.g., gait speed, stride length, swing duration)	The results showed significant difference between control and BWG (OSI: 1.80 ± 0.09 vs 0.82 ± 0.04, $P < 0.001$; APSI: 1.49 ± 0.07 vs 0.70 ± 0.03, $P < 0.001$; MLSI: 1.12 ± 0.08 vs 0.81 ± 0.08, $P < 0.001$) after 12 weeks BW intervention.
5	The participants were instructed to walk at a self-selected speed, look straight ahead, and walk as naturally as possible.	Biodex stability system (USA)	Balance index (OSI, APSI, MLSI)		The results showed significant difference between control and BWG (OSI: 2.20 ± 0.61 vs 1.40 ± 0.61, $P < 0.01$; APSI: 2.10 ± 0.61 vs 1.30 ± 0.61, $P < 0.01$; MLSI: 2.30 ± 0.69 vs 1.40 ± 0.69, $P < 0.01$) after eight weeks BW intervention.
6	In the training session, the subjects walked backward over ground at the approximate speed of 0.8 m/sec.	Metitur goodbalance (Finland), DJ2L-2 balance system (China)	SLSDSLS	The speed and distance of COP in the anterior-posterior direction, the speed and distance of COP in the medial-lateral direction	Compared with CG, open eyes and closed eyes SLSD showed significant difference in BWG (open eyes: 23.70 ± 9.53 s in BWG vs 18.72 ± 7.58 s in CG, $P < 0.05$; closed eyes: 9.53 ± 6.12 s in BWG vs 7.10 ± 4.65 s in CG, $P < 0.05$).
7	60 mins traditional physical therapy program (the upper and lower limbs in a regular and rhythmic manner, stretching and strengthening exercises of the upper, lower limbs, and back muscles, training of postural stability and equal weight shift especially on the affected side, postural reactions exercises), and 25 minutes backward walking training.	Biodex stability system (USA)	Balance index (OSI, APSI, MLSI)		The results showed improvement from pre- to post-test in BW group was significant different in most stable platform (OSI: 1.86 ± 0.56 vs 1.40 ± 0.44, $P = 0.001$; APSI: 1.54 ± 0.42 vs 1.11 ± 0.34, $P = 0.001$; MLSI: 2.65 ± 0.69 vs 1.93 ± 0.51, $P = 0.001$). In addition, the improvement of APSI and MLSI in BW group was significant higher than the improvement of control in most stable level (APSI: 1.11 ± 0.34 vs 1.44 ± 0.44, $P = 0.028$; MLSI: 1.93 ± 0.51 vs 2.39 ± 0.65, $P = 0.039$).
8	In the training session, the subjects walked backward on the treadmill at the speed of 1.33 m/sec.	Stopwatching for stork stand test, and wobble board tests	SLSD	Double leg standing duration on wobble board	The results showed stork stand test and wobble board tests in BWG significantly improved compared with control (38.9 ± 6.33 s vs 26.55 ± 3.57 s; 30.4 ± 5.03 s vs 26.7 ± 2.90 s), significant differences between pre- and post-test in stork stand test and wobble board test in BWG (35.65 ± 3.51 s vs 38.90 ± 6.33 s; 27.65 ± 3.50 s vs 30.40 ± 5.03 s).
9	Self-selected comfortable speed in a 60 meters long straight track in a playground. No constraint or indication about head and trunk position during backward walking training.	Biodex stability system (USA), Qualisys motion capture system (Sweden)	Balance index (OSI, APSI, MLSI)	Stride lengths, cadence, angle ranges, stance and swing durations of the stride cycle	OSI, APSI and MLSI in BWG were all significantly less than those of CG ($P < 0.001$; ES = 3.56˜5.07). Compared with post-test value of CG, BWG showed significant differences in OSI ($P = 0.012$; ES = 1.44) and APSI ($P = 0.003$; ES = 1.77), no significant difference in MLSI ($P > 0.05$).
10	30 minutes conventional training (including strengthening, stretching, proprioceptive neuromuscular facilitation, function and mobility activities, over ground walking 150-200meter, and other training activities) and 10 minutes of partial body weight support treadmill backward walking training (reducing 30% of weight), starting with a low load, increasing the speed and time as the experiment progressed.	Cardiovascular monitoring, stopwatch for 10-m maximum walking speed, questionnaires for balance and mobility ability	BBS	Gait speed, cadence, step length, rivermead mobility index, forward walk-ratio, backward walk-ratio	The pre and post-test values of BBS score were 43.2 ± 8.9 vs 54.8 ± 2.4 in BWG, 42.7 ± 10.8 vs 50.6 ± 5.6 in FWG, and 41.7 ± 8.1 vs 48.1 ± 9.2 in CG, respectively. Significant differences in BBS were observed between pre-test and post-test values of intergroup ($P < 0.01$).

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Table 2 (*continued*)

ID	Intervention components	Measures	Main outcomes	Other outcomes	Estimated intervention effects
11	The participants in the BWG spent two weeks to learn BW, eight weeks to BW training, and two weeks to intensive training. The heart rate retained 110-120 beats/min which was supervised by Polar heart rate monitor.	Motion capture system (USA), Kistler force plate (Switzerland), DJ2L-2 balance system (China)	SLSD	Kinematics parameters of trunk and lower limb, dynamic parameters	The results showed significant difference on open eyes SLSD between BWG and CG (left SLSD: 10.80 ± 13.88 s in BWG vs 5.79 ± 2.41 s in CG, $P < 0.05$; right SLSD: 13.26 ± 13.66 s in BWG vs 5.45 ± 3.41 s in CG; $P < 0.05$) after 12 weeks BW intervention. Meanwhile, significant differences in SLSD were observed between pre-test and post-test values of BWG ($P < 0.05$).

Note: ES: effect size; BWG: backward walking group; CG: control group; BBS: berg balance scale; APSI: anterior-posterior stability index; MLSI: medial-lateral stability index; OSI: overall stability index; N-EO: normal stance-eyes open; N-EC: normal stance-eyes close; P-EO: perturbed stance-eyes open; P-EC: perturbed stance-eyes closed; LOS: limits of stability; SLSD: single leg standing duration; TUG: timed up and go; TSC: timed stair climbing; GMFCS: gross motor function classification system; MAS: modified ashworth scale; SR: symmetry ratio; RMI: rivermead mobility index; COP: center of pressure.

3. Results

3.1. Literature search

Fig. 1 shows the study selection flowchart. We identified 5775 articles by the keyword search, including 1951 articles from PubMed, 1100 articles from Web of Science, 1107 articles from SPORTDiscus, 1036 articles from CINAHL, 474 articles from Cochrane Library, and 107 articles from CNKI. After removing duplicates, 4563 unique articles entered title and abstract screening, in which 4550 articles were excluded. The full texts of the remaining 13 articles were reviewed against the study selection criteria. Of these, five articles were excluded. The reasons for exclusion included: three studies were conference abstracts or posters [35–37], one was a case report [38], and the other was a study protocol with no results reported [39]. Three articles were identified from the reference search [40–42]. In total, 11 studies met the selection criteria and were included in the review [40–50].

3.2. Basic characteristics of the included studies

Table 1 summarizes the basic characteristics of the 11 included articles. Nine were RCTs [40,41,44–50], and the other two were pre-post studies [42,43]. Four studies were conducted in China [46,48,45–50], two in Iran [40,43], and one each in Egypt [44], U.S. [41], Korea [42], India [45], and Japan [47]. Sample size ranged from seven to 50, with a mean of 26 participants. Seven studies focused on children and adolescent aged 7–17 years, whereas the other four focused on adults aged 18 years and older [41,47,49,50]. Two studies included men only [46,48], and four included women only [43,45,49,50]. The proportion of men accounted for over half (52%–100%) of the study sample in five of the 10 studies that reported sex distribution, and below half (0%–38%) in the remaining five studies [41,43,45,49,50].

Five of the 11 included studies recruited participants with chronic diseases—two with stroke [41,47], two with hemiparetic cerebral palsy [42,44], and one with Down syndrome [40]. Six studies recruited healthy children, adolescents and adults [43,45,46,48–50]. Five were conducted in a research laboratory [40,45,47,49,50], three in hospital or rehabilitation center [41,42,44], and the other three in playground or basketball court [43,46,48]. Seven studies included BW training and control as the two arms [40,44–46,48–50], one study included BW training and standing balance training as the two arms [41], one study included three arms—BW training, FW training, and control [47], and the remaining two were pre-post studies with a single arm of BW training [42,43]. Nine studies included BW training only, and the remaining two included additional therapeutic activities besides BW or FW, such as endurance training and physiotherapy education [44,47].

Walking was administered on ground [40–44,46,48–50] or treadmill [45,47]. One study using treadmill partially supported body weight to reduce participants' load [47]. Intervention duration, frequency, and session length differed across studies. Intervention duration varied from three to 16 weeks. Five interventions took place three times a week [43,44,48–50], two interventions two times a week [40,46], one intervention five times a week [45], one intervention six times a week [47], one intervention 30-minute/session for eight times [41], and the remaining one 20-minute/session for two times [42]. Session length ranged from 10 min (among participants with stroke) [47] to 85 min (among children with hemiparetic cerebral palsy) [44]. The mean and median follow-up period were nine and 10 weeks, respectively.

Table 2 reports intervention components, measures, outcomes, and intervention effectiveness of the 11 included studies. Nine adopted BW training only [40–43,45,46,48–50], and the remaining two combined BW training with other therapeutic exercises [44,47]. Common therapeutic exercises included muscle strengthening, stretching, functional and mobility training, postural control training (i.e., facilitation of righting, equilibrium, and protective reactions), and reflex inhibiting

Table 3
Results from meta–analysis.

Balance performance	Intervention	Author, year	I^2 index	Pooled effect size (95% CI)	Model	Note
OSI	BWG vs CG	Amini, 2016† El-Basatiny, 2015‡	0.0%	−0.99 (−1.61, −0.37)	Fixed-effect	†: Participants with Down syndrome ‡: Participants with cerebral palsy
APSI	BWG vs CG	Amini, 2016† El-Basatiny, 2015‡	0.0%	−0.99 (−1.61, −0.37)	Fixed-effect	†: Participants with Down syndrome ‡: Participants with cerebral palsy
MLSI	BWG vs CG	Amini, 2016† El-Basatiny, 2015‡	0.0%	−0.95 (−1.57, −0.34)	Fixed-effect	†: Participants with Down syndrome ‡: Participants with cerebral palsy
SLSD	BWG vs CG	Sun, 2017 Zhang, 2016 Bal, 2012 Zhang, 2008a Zhang, 2008b	75.9%	0.91 (0.29, 1.53)	Radom-effect	Healthy children, adolescent student athletes and older adults. Zhang (2008a) compare post-test value of left SLSD between BWG and CG; Zhang (2008b) compare post-test value of right SLSD between BWG and CG.

Note: BWG: backward walking group; CG: control group; APSI: anterior-posterior stability index; MLSI: medial-lateral stability index; OSI: overall stability index; SLSD: single leg standing duration; 95% CI: 95% confidence interval.

patterns. In seven studies, the intervention was carried out by at least one qualified physical therapist or supervisor, who provided participants with assistance in accordance with the training protocol [41,42,44,47,49,50]. All studies adopted objective measures of balance performance. The quantitative measurements applied included Biodex stability system (made in the U.S.); Kistler force plate (made in Switzerland); BTP-200DP dynamic balance system (made in China); Metitur Good Balance (made in Finland); DJ2L-2 balance system (made in China); stopwatch for stork stand test, wobble board test, modified Romberg test, TUG, timed stair climbing (TSC) test, and SLSD; and meter stick for Y balance test. The sampling frequency of Biodex stability system, Kistler force plate, and BTP-200DP dynamic balance system was 20 Hz [40,46], 1200 Hz [50], and 200 Hz [48], respectively. It was unreported in two studies [44,49]. Two studies adopted BBS test, a qualitative measure of balance performance [51].

3.2.1. Estimated intervention effectiveness in RCTs

Rose (2018) found that the change in BBS score before and after BW training was statistically nonsignificant (pre-BW training: 11.4 ± 10.7 vs post-BW training: 41.9 ± 11.8, $P > 0.05$) [41], whereas Takami (2010) reported the improvement in BBS before and after BW training was significant (pre-training: 43.2 ± 8.9 vs post-training: 54.8 ± 2.4, $P < 0.01$) [47]. Sun (2017) reported significant difference between control and BW training (OSI: 1.80 ± 0.09 in control vs 0.82 ± 0.04 in BW training, $P < 0.001$; APSI: 1.49 ± 0.07 in control vs 0.70 ± 0.03 in BW training, $P < 0.001$; MLSI: 1.12 ± 0.08 in control vs 0.81 ± 0.08 in BW training, $P < 0.001$) after a 12-week BW training intervention [48]. Amini (2016) documented significant improvement in OSI, APSI, and MLSI between BW training and control (OSI: 2.20 ± 0.61 in control vs 1.40 ± 0.61 in BW training, $P < 0.01$; APSI: 2.10 ± 0.61 in control vs 1.30 ± 0.61 in BW training, $P < 0.01$; and MLSI: 2.30 ± 0.69 in control vs 1.40 ± 0.69 in BW training, $P < 0.01$) [40]. El-Basatiny (2015) documented significant improvement in OSI, APSI, and MLSI before and after BW training (OSI: 1.86 ± 0.56 in control vs 1.40 ± 0.44 in BW training, $P = 0.001$; APSI: 1.54 ± 0.42 in control vs 1.11 ± 0.34 in BW training, $P = 0.001$; and MLSI: 2.65 ± 0.69 in control vs 1.93 ± 0.51 in BW training, $P = 0.001$) following an eight-week BW training [44]. Similarly, Hao (2011) reported that OSI, APSI, and MLSI in the BW training group were significantly improved over those in the control group (OSI: 2.78 ± 0.38 in control vs 0.94 ± 0.19 in BW training, $P < 0.01$; APSI: 2.25 ± 0.38 in control vs 0.78 ± 0.33 in BW training, $P < 0.01$; and MLSI: 2.28 ± 0.42 in control vs 1.06 ± 0.09 in BW training, $P < 0.01$) following a 12-week BW training [46]. Zhang (2016) found that compared to the control group, significant difference in SLSD was observed in BW training (open eyes: 23.70 ± 9.53 s in BW training vs 18.72 ± 7.58 s in control, $P < 0.05$; closed eyes: 9.53 ± 6.12 s in BW training vs 7.10 ± 4.65 s in control, $P < 0.05$) [49]. Bal (2012) reported the stork stand test (38.9 ± 6.33 in control vs 26.55 ± 3.57 in BW training) and wobble board test (30.4 ± 5.03 in control vs 26.7 ± 2.90 in BW training) were significantly improved among the BW training group in comparison to control [45]. Zhang (2008) documented significant difference in open eyes SLSD between BW training and control (left SLSD: 10.80 ± 13.88 s in BW training vs 5.79 ± 2.41 s in control, $P < 0.05$; right SLSD: 13.26 ± 13.66 s in BW training vs 5.45 ± 3.41 s in control; $P < 0.05$) after a 12-week BW training intervention. Moreover, significant differences in SLSD were observed between pre-test and post-test values of BW training ($P < 0.05$) [50].

3.2.2. Estimated intervention effectiveness in pre-post studies

Kim (2017) reported significant changes in SLSD on the affected side of children with cerebral palsy (2.29 s vs 4.93 s, $P < 0.05$), TUG (12.64 s vs 10.21 s, $P < 0.05$) and TSC (17.64 s vs 14.86 s, $P < 0.05$) before and after BW training [42]. Etefagh (2017) found significant changes in Romberg test (10.09 ± 5.26 vs 21.90 ± 14.10, $P \le 0.001$) and Y balance test scores (anterior: 68.4 ± 0.79 vs 79.5 ± 0.09, $P \le 0.001$; and posteromedial: 45.9 ± 0.10 vs 59.9 ± 0.10, $P \le 0.001$) before and after BW training [43]. In contrast, no significant change was identified in posterolateral direction before and after BW training using Y balance test (57.8 ± 0.12 vs 69.8 ± 0.88, $P = 0.09$) [43].

3.3. Meta-analysis

Table 3 summarizes four parameters (APSI, MLSI, OSI, and SLSD) from the meta-analysis based on the six RCTs that reported the same balance performance measures [40,44,45,48–50]. Compared to the control, BW training was associated with a significant reduction in OSI score by 0.99 (95% CI = 0.37, 1.61; $I^2 = 0.0\%$; fixed-effect model), MLSI score by 0.95 (95% CI = 0.34, 1.57; $I^2 = 0.0\%$; fixed-effect model), and APSI score by 0.99 (95% CI = 0.37, 1.61; $I^2 = 0.0\%$; fixed-effect model) [40,44]. BW training was associated with a significant increase in open eyes SLSD by 0.91 s (95% CI = 0.29, 1.53; $I^2 = 75.9\%$; random-effect model) in comparison to the control [45,48–50]. No evidence of publication bias based on the Egger's test (*p*-value = 0.26) and Begg's test (*p*-value = 0.33) was present in SLSD between BW training and control [45,48–50]. Corresponding forest plots are presented in Fig. 2.

3.4. Study quality assessment

Table 4 reports criterion-specific and global ratings from the study quality assessment. The included studies on average scored 4.7 out of nine, with a range from four to five. All 11 studies included in the review clearly stated the research question and/or study objective,

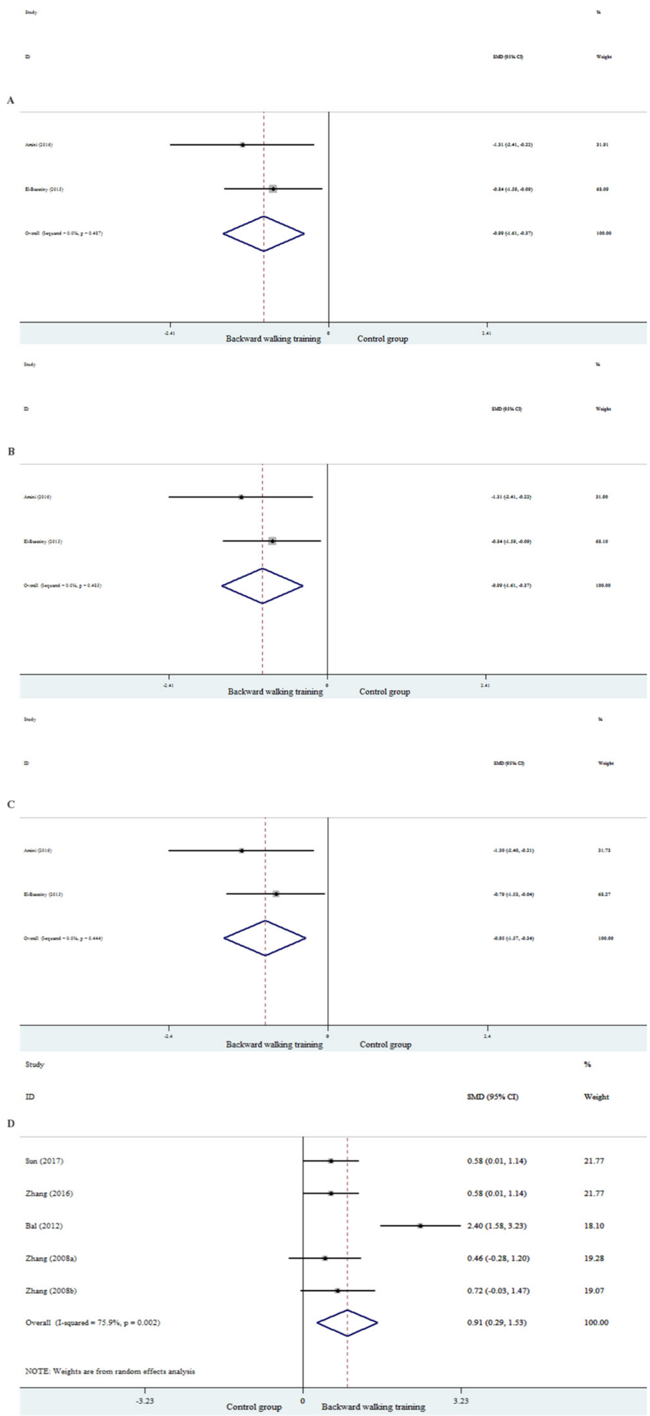

Fig. 2. Forest plots from meta-analysis regarding the effectiveness of backward walking training on balance performance (A—OSI, B—APSI, C—MLSI, D—SLSD).

recorded the duration of BW training, objectively measured the balance performance (e.g., BBS score, APSI, MLSI, OSI, TUG, and SLSD), and estimated the specific impact of BW training on balance performance. Nine of 11 studies adopted a randomized experimental design. In contrast, none of the studies recruited a population-based sample, had a sample size larger than 100, conducted a power analysis, or examined a dose-response relationship between BW training and balance performance.

4. Discussion

To our knowledge, this study serves as the first systematic review and meta-analysis regarding the effectiveness of BW training on balance performance. It provides some preliminary evidence that BW training may be a potentially useful tool for balance performance improvement. BW training in combination with traditional physical therapy may provide additional benefits in improving balance performance than traditional physical therapy alone (e.g., forward walking, strength training, and foot and ankle exercise) in clinical practice and/or neurological rehabilitation, especially among older adults and those with dysfunctions in postural control and balance (e.g., Parkinson's disease, Alzheimer's disease, and cerebral palsy).

The balance indices—OSI, APSI, and MLSI that measure a subject's ability to maintain center of balance, are validated and reliable measures for static and dynamic postural stability. OSI, APSI, and MLSI capture one's balance control capacities in all directions, in an anterior-posterior direction, and in a medial-lateral direction, respectively [40]. Regarding OSI, APSI and MLSI, a lower score is more desirable than a higher score [52]. The estimated pooled effects of BW training included a reduction of OSI by 0.99, APSI by 0.99, and MLSI by 0.95, which indicate sway reduction of balance center in relevant directions and improved balance performance. Single-leg stance is usually used for training and testing balance performance [53]. Results from meta-analysis suggest that BW training increased open-eyes SLSD by 0.91 s in comparison to control. BBS is a widely adopted balance measure that assesses one's capacity in completing specific functional tasks such as standing up, turning to look behind, and standing with eyes closed [54,55]. Y balance test is a dynamic balance assessment tool that evaluates the integration of sensorimotor subsystems [56]. TUG is a screening tool to assess fall risk of patients [57]. Stork stand test, wobble board test, modified Romberg test, TSC, and SLSD are also commonly adopted to assess balance performance [42,43,45].

Motor systems contribute to balance by initiating timely and appropriate responses to counteract various disturbances [58]. They launch, select, and employ motor command programs and synergies to modify the biomechanical state towards the desired equilibrium condition [59]. Changes in movement control system and gait characteristics resulted from BW training may contribute to its positive impact on balance performance. Due to the reduced dependence on vision, BW training participants may learn to rely more on neuromuscular proprioceptive (e.g., knee joint and ankle joint) and vestibular senses to maintain postural equilibrium. Compared to FW, BW training is found to be more effective in improving knee proprioception accuracy and peak torque of quadriceps and hamstring muscles [60]. The increased heel force and decreased standing foot angle following BW training [61] could contribute to the change in gait characteristics and improvement in balance performance. BW training could increase forward gait speed [62–64], enhance hamstring flexibility [65], and improve stride length by strengthening the leg muscles related to push-off [66]. Besides, BW training could strengthen quadriceps and hamstring muscles [67,68], resulting in greater muscle strength compared to FW training [69] and reduced knee joint compression force [70]. Improved muscle strength of lower extremity could contribute to increased forward gait speed and further improve balance performance [71].

Several limitations of this review and the included studies should be noted. Only 11 studies were identified that assessed the relationship between BW training and balance performance. These studies recruited diverse participants, adopted different study designs, and administered alternative balance measures. It is possible that these heterogeneities in study populations, experimental designs, and outcome measures to some extent contributed to the variations in findings. In addition, repeated testing in pre-post studies could introduce a learning effect—-study participants performed better due to their familiarity to the testing procedures instead of improved gait balance. However, none of the studies included in the review tested or controlled the possible

Table 4
Quality assessment of the studies included in the review.

Criteria	Study ID										
	1	2	3	4	5	6	7	8	9	10	11
1. Was the research question and/or study objective clearly stated?	1	1	1	1	1	1	1	1	1	1	1
2. Were the study subjects a population-based sample?	0	0	0	0	0	0	0	0	0	0	0
3. Was the study a randomized controlled trial?	1	0	1	1	1	1	1	1	1	0	1
4. Was the sample size larger than 100?	0	0	0	0	0	0	0	0	0	0	0
5. Was a sample size justification (e.g., power analysis) provided?	0	0	0	0	0	0	0	0	0	0	0
6. Was duration of backward walking training measured?	1	1	1	1	1	1	1	1	1	1	1
7. Were balance performance (e.g., BBS score, APSI, MLSI, OSI, TUG, and SLSD) objectively measured?	1	1	1	1	1	1	1	1	1	1	1
8. Was a dose-response relationship between backward walking training and balance performance examined?	0	0	0	0	0	0	0	0	0	0	0
9. Was the differential effectiveness of backward walking training on alternative balance performance examined?	1	1	1	1	1	1	1	1	1	1	1
Sum score	4	4	5	5	5	5	5	5	5	4	5

learning effect by incorporating repeated baseline measures. Only one study included a FW control group, which may not provide sufficient evidence to support the initiative of switching from a conventional FW training to BW training. Study participants were heterogeneous in terms of their health/disease status and age, who might respond differently to the BW training intervention. Interventions included in the review were also different in training frequency, duration, and intensity. Merely two and four studies were included in the two separate meta-analyses as these studies shared the same balance measures. The source of study heterogeneities could not be formally assessed by a meta-regression due to the small number of studies. We limited our search to English and Chinese publications as we do not have the resource and/or expertise to search in other languages. All studies were small in scale, which might compromise their statistical power to identify a statistically significant relationship. In addition, none examined a dose-response relationship between BW training and balance performance.

Studies on human balance control have primarily focused on quantifying movement responses based on kinematic measurements (e.g., spatial-temporal variability and dynamic stability) and kinetic measurements (e.g., center of pressure, force, and torque) [72]. Little is known regarding how cognitive functioning, multiple-segment dynamics, and process of neuromuscular proprioceptive senses impact balance performance during BW. Future research should employ larger sample size and rigorous study design to examine the dose-response relationship between BW training and balance performance, and elucidate the integration process of proprioceptive and visual information in balance control during BW. Moreover, the dynamic characteristic and neuromuscular proprioceptive senses of lower extremity segments (e.g., hip joint, knee joint, and ankle joint), brain/cortical activity, and cooperative interaction between the central nervous system and the musculoskeletal system (e.g., order and type of the motor unit recruitment) should be investigated in BW training interventions.

5. Conclusion

BW training was found to significantly improve balance performance and posture control measures such as OSI, APSI, MLSI, and SLSD. BW training could serve as a potentially useful tool to improve balance performance among those with a high risk of fall. However, current evidence remains preliminary due to the small cohort of studies. Future work with larger scale and experimental design are warranted to evaluate the effectiveness of BW training on balance performance across diverse population and disease subgroups, and elucidate the underlying biomechanical and neurological pathways.

Conflict of interests

The authors have no conflict of interests to declare.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.gaitpost.2019.01.002.

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