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REVIEW ARTICLE (META-ANALYSIS)

The Efficacy of Wearable Cueing Devices on Gait and Motor Function in Parkinson Disease: A Systematic Review and Meta-analysis of Randomized Controlled Trials

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Abstract

Objective: To summarize the efficacy of wearable cueing devices for improving gait and motor function of patients with Parkinson disease (PWP).

Data Sources: PubMed, Embase, and Cochrane CENTRAL databases were searched for papers published in English, from inception to October 23, 2022.

Study Selection: Randomized controlled trials focusing on the effects of wearable cueing devices on gait and motor function in PWP were included.

Data Extraction: Two reviewers independently selected articles and extracted the data. The Cochrane Bias Risk Assessment Tool was used to assess risk of bias and the Grading of Recommendations Assessment, Development and Evaluation was used to evaluate the quality of evidence.

Data Synthesis: Seven randomized controlled trials with 167 PWP were included in the meta-analysis. Significant effect of wearable cueing devices on walking speed (mean difference [MD]=0.07 m/s, 95% confidence interval [CI]: [0.05, 0.09], $P<.00001$) was detected; however, after sensitivity analysis, no significant overall effect on walking speed was noted (MD=0.04 m/s, 95% CI: [−0.03, 0.12], $P=.25$). No significant improvements were found in stride length (MD=0.06 m, 95% CI: [0.00, 0.13], $P=.05$), the Unified Parkinson's Disease Rating Scale-III score (MD=−0.61, 95% CI: [−4.10, 2.88], $P=.73$), Freezing of Gait Questionnaire score (MD=−0.83, 95% CI: [−2.98, 1.33], $P=.45$), or double support time (MD=−0.91, 95% CI: [−3.09, 1.26], $P=.41$). Evidence was evaluated as low quality.

Conclusions: Wearable cueing devices may result in an immediate improvement on walking speed; however, there is no evidence that their use results in a significant improvement in other gait or motor functions.

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Parkinson disease (PD) is a neurodegenerative disease that affects a significant proportion (2%-3%) of the global elderly population (aged >65 years)[1] PD is characterized by dopaminergic neurons degeneration in the substantia nigra and frequently manifest motor and non-motor symptoms.[2] Gait disorder, including difficulties in initiating, turning, and shuffling, is 1 of the major motor symptoms of PD.[3] It usually increases fall risks, which causes fractures and other complications, restricts patient's mobility and reduces confidence and quality of life.[4,5]

In patients with PD (PWP), gait disorder is related to lack of internal cues,[6] and providing external cues, such as vision, auditory, or proprioception, to daily life can improve gait in PWP.[6-10] Wearable cueing device is a convenient and portable way to provide external cues, enabling patients to receive general guidance at home without the need for doctors.[11] This improves medical service efficiency and overcomes time and space constraints.[12,13] Therefore, researchers suggest incorporating wearable cueing devices into rehabilitation training for PWP to provide external cues.[14,15]

There are 2 main wearable cueing devices categories.[16] One uses an open-loop control system to provide constant external

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Table 1 Search strategy example on PubMed

#1	(Parkinson Disease[MeSH Terms]) OR (Idiopathic Parkinson's Disease) OR (Lewy Body Parkinson's Disease) OR (Parkinson's Disease, Idiopathic) OR (Parkinson's Disease, Lewy Body) OR (Parkinson Disease, Idiopathic) OR (Parkinson's Disease) OR (Idiopathic Parkinson Disease) OR (Lewy Body Parkinson Disease) OR (Primary Parkinsonism) OR (Parkinsonism, Primary) OR (Paralysis Agitans)
#2	(Wearable Electronic Devices[MeSH Terms]) OR (Device, Wearable Electronic) OR (Devices, Wearable Electronic) OR (Electronic Device, Wearable) OR (Electronic Devices, Wearable) OR (Wearable Electronic Device) OR (Wearable Technology) OR (Technologies, Wearable) OR (Technology, Wearable) OR (Wearable Technologies) OR (wearable cueing devices) OR (Device, Wearable) OR (Devices, Wearable) OR (wearable cueing device) OR (Electronic Skin) OR (Skin, Electronic)
#3	(clinical[tiab] AND trial[tiab]) OR "clinical trials as topic"[mesh] OR "clinical trial"[pt] OR random*[tiab] OR "random allocation"[mesh] OR "therapeutic use"[sh]
#4	(#1) AND (#2) AND (#3)

cues, which are not affected by patient movements or environmental changes.[17] In a complex environment, this may confuse some patients and hinder their movement.[9,18] The other category uses a closed-loop control system that relies primarily on external sensors to detect patient movement characteristics and provides real-time feedback for dynamically adjusting motion.[16,19-21]

Sensors can be placed on body parts (such as arms, trunk, and shank) or attached to close fitting objects (such as shoes, clothes, watches, and glasses).[22] Various types of sensors have been reported, among which, inertial measurement units (IMUs), comprising a combination of accelerometers, magnetometers, and gyroscopes, are the most commonly used. IMUs can provide 3-axis posture angle and acceleration data about the body or limbs, which are processed by computers and fed back to patients.[23,24]

Wearable cueing devices are used for training purposes, and they need to be consistent and accurate. However, only a few studies have provided sufficient evidence to demonstrate their reliability and validity. One study used a mixed-reality headset to determine test-retest reliability, concurrent validity, and face validity in quantifying spatiotemporal gait parameters in PWP.[25] Oyama et al evaluated the reliability of a wrist smartwatch sensor to detect changes in motor function with medications adjustments in PWP.[26] Furthermore, estimating the test-retest reliability of a device may require a period of 7-10 days.[27] Of patients, 75% considered that wearable cueing devices were easy to use and had excellent adherence.[28] Various studies have demonstrated that wearable cueing devices can improve gait and motor function in PWP;[11,16] however, there are large variations in sample size among studies, the training regimen with wearable cueing devices for PD rehabilitation is unclear, and strong experimental evidence is lacking. Hence, summary of existing research is warranted, to provide more comprehensive and reliable conclusions for further research and applications.

In this systematic review, we aimed to evaluate the efficacy of wearable cueing devices in improving gait and motor function of PWP.

List of abbreviations:

CI	**confidence interval**
DS	**Double Support**
FOG	**freezing of gait**
FOGQ	**Freezing of Gait Questionnaire**
GRADE	**Grading of Recommendations Assessment, Development and Evaluation**
H&Y	**Hoehn and Yahr**
IMU	**inertial measurement units**
MD	**mean difference**
PD	**Parkinson disease**
PWP	**patients with Parkinson disease**
UPDRS-III	**Unified Parkinson's Disease Rating Scale-III**

Methods

Literature sources

The review protocol was registered in PROSPERO (CRD42022365530) and reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.[29] Publications in English were searched in PubMed, Embase, and the Cochrane Library databases from inception to October 23, 2022.

Search strategy

The keywords "Parkinson disease", "wearable electronic device", and "clinical trials" were used to search for published articles about the effects of wearable cueing devices on gait and motor function in PWP. The search strategy used for PubMed is provided as an example (table 1).

Eligibility criteria

The PICOs[30] eligibility criteria were (1) Participants: PWP diagnosed according to the UK Parkinson's Disease Society Brain Bank Diagnostic Criteria[31]; (2) Intervention: using wearable cueing devices for gait in training; (3) Comparison: training without wearable cueing devices or no training; (4) Outcome: outcomes related to gait and motor function are reported in no less than 2 studies; (5) Study design: randomized controlled trials.

Study selection and data extraction

According to the eligibility criteria, 2 reviewers independently evaluated titles and abstracts of identified publications. Eligible studies were then selected by reading the full text. Disagreements between 2 reviewers were resolved by a third reviewer participating in the discussion.

Finally, relevant data were extracted from eligible publications, including (1) characteristics of the study (including first author, year of publication); (2) characteristics of participant

Table 2 Information extraction schedule

Subject	Content
Literature information	Name of the first author, year of publication
Participant	Number of participants, mean age, sex, H&Y stage, disease duration
Intervention	Types of wearable cueing device, feedback characteristics, details of the intervention, frequency and duration of training, training situation
Outcome	Gait and motor outcomes

(including number of participants, age, sex, Hoehn and Yahr [H&Y] stage, disease duration); (3) intervention protocol (including types of wearable cueing device, feedback characteristics, details of the intervention, frequency and duration of training, training situation); and (4) outcome measures (including gait and motor outcomes) (table 2).

Outcome measures

The primary outcomes were improvement in gait function based on spatiotemporal parameters, including walking speed, stride length, and cadence; such parameters are obtained from walking processes and objectively describe the patient' s walking ability.[32-34] Secondary outcomes included Unified Parkinson's Disease Rating Scale-III (UPDRS-III) score,[35] Freezing of Gait Questionnaire (FOGQ) score,[36] double support (DS) time, and adverse events. UPDRS-III and FOGQ are widely-accepted scales for assessing motor function and freezing of gait (FOG) in PD. DS reflects stability during walking, and adverse events are necessary measurements to ensure the safety of devices for use in humans.[37,38] Outcome measures reported in fewer than 2 studies were not included in the analysis.

Assessment of risk of bias

The Cochrane risk of bias tool[39] was used to assess the risk of bias for eligible studies in 7 domains: (1) random sequence generation (selection bias), (2) allocation concealment (selection bias), (3) blinding of participants and personnel (performance bias), (4) blinding of outcome assessment (detection bias), (5) incomplete outcome data (attrition bias), (6) selective reporting (reporting bias), and (7) other bias. The quality of each eligible study was determined as "low risk of bias" ("green"), "high risk of bias" ("red"), or "unclear risk of bias" ("yellow") for the above domains.

Statistical analysis

Review Manager software (Revman5.3) was used for the meta-analysis. The data included for analysis were sample number of experimental groups and control groups, mean, standard deviation, mean difference (MD), and 95% confidence interval (95% CI) as outcomes were all continuous data. The $P<.05$ or 95% CI excluding 0 was considered as statistically significance.

The I^2 statistic (low, 0%-50%; moderate, 50%-75%; high >75%[40]) and Cochrane Q test (significance set at $P<.1$) were used to assess heterogeneity. If I^2 was <50% and $P\geq.1$, a fixed-effects model was used; otherwise, a random-effects model was applied. The leave-one-out method was used for sensitivity analysis to observe whether the synthesis result changed significantly.

Grading of Recommendations Assessment, Development and Evaluation evaluation of evidence

We applied the Grading of Recommendations Assessment, Development and Evaluation (GRADE)[41] approach to evaluate the quality of evidence for each outcome, in terms of risk of bias, inconsistency, indirectness, imprecision, and publication bias. Reasons for the downgrades or upgrades are recorded as footnotes (table 3).

Results

Eligible studies

Database search retrieved 387 potentially relevant studies, of which 87 were duplicates. After screening titles and abstracts, 251 studies were excluded for at least 1 of the following reasons: (1) no PD patients, (2) no wearable cueing device, and (3) no gait training; and 49 studies were remained to read full texts. Finally, 7 studies[9,13,15,20,24,42,43] were included in the systematic review (fig 1).

Study characteristics

The study characteristics included sex, age, H&Y stage, disease duration, wearable cueing device, feedback characteristics, intervention duration, training situation, and outcomes (table 4). A total of 167 participants were included, with numbers in each study ranging from 11 to 38. Six studies were conducted in Canada,[20] Switzerland,[43] Brazil,[9] Japan,[15] Italy,[24] and Egypt,[42] respectively, and 1 study[13] was conducted jointly in Belgium, Italy, Israel, and Australia.

Daily training time ranged from 10 min to 4 h, training frequency was 1-6 times per week, and duration was 1-12 weeks. One study[43] was a crossover study, which only provided mean and standard deviation values for the wearable cueing device and placebo groups; therefore, we chose the approach of taking all measurements from the wearable cueing device and placebo groups and analyzing them as if the trial was a parallel-group trial according to the Cochrane Handbook. The types of feedback provided by wearable cueing devices included auditory, proprioceptive, and combined visual-auditory feedback. Four studies[9,15,42,43] used open-loop stimulation systems, and 3 studies[13,20,24] used closed-loop stimulation systems.

Risk of bias assessment

The risk of bias summary (fig 2A) revealed that 5 studies presented a low risk of bias in random sequence generation, and 4 studies clarified allocation concealment. Regarding blinding, only 1 study mentioned the blinding measures and blinding of the outcome assessment. Most studies presented an unclear risk of bias due to incomplete outcome data, selective reporting, and other biases (fig 2B).

Table 3 GRADE evidence profile of wearable cueing device vs conventional training

Certainty Assessment							No of Patients		Effect		Quality	Importance
No of Studies	Study Design	Risk of Bias	Inconsistency	Indirectness	Imprecision	Other Considerations	Wearable Cueing Device	Conventional Training	Relative (95% CI)	Absolute (95% CI)	Certainty	Importance
Speed (Better indicated by higher values)												
6	Randomized trials	Serious*	Not serious	Not serious	Serious†	None	77	79	-	MD 0. 07 Higher (0.05-0.09 higher)	⊕⊕◯◯ Low	CRITICAL
Stride length (Better indicated by higher values)												
5	Randomized trials	Serious*	Not serious	Not serious	Serious†	None	60	59	-	MD 0. 06 Higher (0-0.13 higher)	⊕⊕◯◯ Low	CRITICAL
FOGQ (Better indicated by lower values)												
3	Randomized trials	Serious*	Not serious	Not serious	Serious†	None	42	44	-	MD 0.83 lower (2.98 lower to 1.33 higher)	⊕⊕◯◯ Low	CRITICAL
UPDRS-III (Better indicated by lower values)												
3	Randomized trials	Serious*	Not serious	Not serious	Serious†	None	42	45	-	MD 0.61 lower (4.1 lower to 2.883 higher)	⊕⊕◯◯ Low	CRITICAL
DS time (Better indicated by lower values)												
2	Randomized trials	Serious*	Not serious	Not serious	Serious†	None	30	27	-	MD 0.91 lower (3.09 lower to 1.26 higher)	⊕⊕◯◯ Low	CRITICAL

* Downgraded 1 level because of risk of bias: none of the studies applied a double-blind design, most of whom also ignored blind assessors; some did not report the method used to generate the random allocation sequence or achieve allocation concealment.
† Downgraded 1 level owing to possible literature bias: the total number of participants was <200.

Effects of wearable cueing devices on gait outcomes

Walking speed

Six studies[9,13,15,24,42,43] analyzed the effects of training with wearable cueing devices on walking speed in PWP. Our meta-analysis included 77 patients in the wearable cueing device group and 79 in the control group. The results showed a significant effect on walking speed (MD=0.07 m/s, 95% CI: [0.05, 0.09], $P<.00001$, $I^2=0\%$, Q=1.23; fig 3A). MD=0.07 m/s is beyond the minimal clinically important difference, which ranges from 0.04 to 0.06 m/s;[44] therefore, the improvement of walking speed was clinically significant. However, we found that the study by El-Tamawy et al[42] accounted for 92% of weight, and substantially influenced the results. After sensitivity analysis, heterogeneity remained unchanged ($I^2=0\%$), but there was no significant effect (MD=0.04 m/s, 95% CI: [−0.03, 0.12], $P=.25$; fig 3B) after excluding the study by El-Tamawy et al.[42]

Stride length

Five studies[9,13,15,42,43] analyzed the effects of training with wearable cueing device on stride length in PWP. Our meta-analysis included 60 patients in the wearable cueing device group and 59 in the control group. There was no significant effect on stride length in the wearable cueing device group (MD=0.06 m, 95% CI: [0.00, 0.13], $P=.05$; fig 4A). I^2 was 59% indicating moderate heterogeneity. Although heterogeneity decreased after conducting sensitivity analysis ($I^2=0\%$), there remained no significant effect on stride length (MD=0.03 m, 95% CI: [−0.02, 0.08], $P=.28$; fig 4B).

UPDRS-III score

Three studies[13,15,24] analyzed the effects of training with wearable cueing device on UPDRS-III score in PWP. In our meta-analysis, there were 42 patients in the wearable cueing device group and 45 in the control group. UPDRS-III score in the wearable cueing device group showed no significant effect (MD=−0.61, 95% CI: [−4.10, 2.88], $P=.73$, $I^2=0\%$, Q=1.40; fig 5) compared with the control group. Furthermore, MD=−0.61 did not meet the minimal clinically important difference (range -2.3 to -2.7),[45] indicating that the changes in UPDRS-III score did not have clinical implications.

FOGQ score

Three studies[13,20,24] analyzed the effects of training with wearable cueing devices on FOGQ scores in PWP. There were 42 patients in the wearable cueing device group and 44 in the control group. The results showed that no significant difference in FOGQ scores was detected between the groups (MD=−0.83, 95% CI: [−2.98, 1.33], $P=.45$, $I^2=0\%$, Q=1.79; fig 6).

DS time

Two studies[9,13] analyzed the effects of training with wearable cueing devices on DS time in PWP. And our meta-analysis included 30 patients in the wearable cueing device group and 27 in the control group. Wearable cueing devices had no significant effect on DS time (MD=−0.91, 95% CI: [−3.09, 1.26], $P=.41$, $I^2=0\%$, Q=0.28; fig 7).

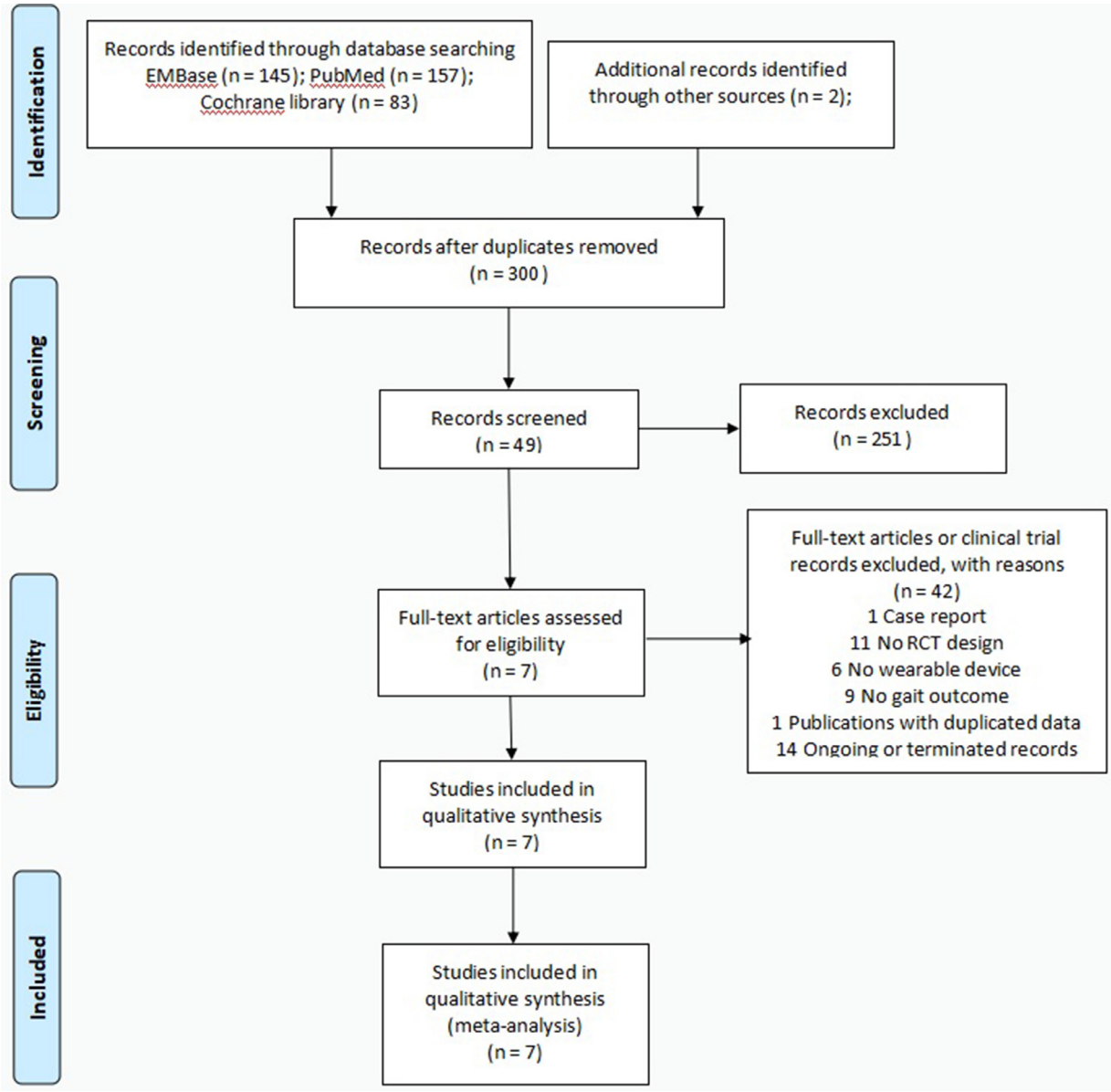

Fig 1 PRISMA 2009 flow diagram.

Subgroup analysis

We conducted subgroup analysis according to types of feedback and stimulation systems for walking speed, stride length, FOGQ and UPDRS-III scores, but did not detect any clinically significant results (supplemental file; available online only at http://www.archives-pmr.org/). Overall, our data indicated that the meta-analysis results regarding gait speed were influenced by the study of El-Tamawy et al and other motor functions assessed likely did not show any significant improvement.

Quality of evidence

We graded the quality of evidence as low for all outcomes. Most studies did not describe the use of blind designs and ignored the blinding of assessors. Methods used to generate a random allocation sequence or achieve allocation concealment were also not reported. These factors resulted in a serious risk of bias. Furthermore, the total number of participants in our review was small, which may lead to a lack of precision. In summary, the quality of evidence in our review was low, and the results should be interpreted with caution and used as a reference (table 3).

Discussion

In this review, we systematically examined the efficacy of wearable cueing devices in enhancing gait and motor function among PWP. The results showed that PWP using wearable cueing devices performed similarly to those receiving conventional training on gait and motor function except walking speed. However, our analysis suggests that there may be an immediate improvement on gait when using wearable cueing devices for PWP.

Types of wearable cueing devices

This review revealed the diversity of wearable cueing devices used for gait training in PWP. Four of the 7 studies included in our

Table 4 Characteristics of included studies

First Author (Year)	Number and Sex (Men)	Age	H&Y Stage	Disease Duration	Wearable Cueing Device	Feedback Characteristics	Stimulation System	Intervention		Training Situation	Duration/ Frequency	Outcomes
								Control	Experimental			
Chomiak et al (2017) [20]	N=11 C:6 (4) T:5 (5)	C: 69.0±5.7 T: 70.8±5.6	C: 2.7±0.41 T: 2.5±0.50	C: 11.2±5.0 T: 15.4±5.4	The Ambulosono platform; iPod Touch	Auditory	Closed-loop	Receive contingent CBC podcast	Receive contingent music playback	Both groups trained at home	4 weeks 3 days/week 10-20 min/day	(4)
Spolaor et al (2020) [43]	N=20 (13) C:10 T:10	67.46±10.27	2.46±0.51	11.88±3.23	Equistasi	Proprioception	Open-loop	Receive a placebo device	Receive an active proprioceptive mechanical stimulation	Both groups did not train at home	8 weeks 5-6 days/week 1-4 h/day	(2)
Lirani-Silva et al (2017) [9]	N=19 C:9 T:10	C:72.0±6.2 T:70.4±6.87	C:1.9±0.4 T:2±0.5	N/A	Textured insole	Proprioception	Open-loop	Conventional insole	Textured insole	Both groups performed daily activities at home	1 week	(2) (5)
Kawashima et al (2022) [15]	N=12 C:7 (1) T:5 (2)	C:75.4±5.7 T:76.6±5.3	C:2.4±0.79 T:2.4±0.55	C: 12.4±4.6 T: 11.2±5.8	SMA exoskeleton	Proprioception	Open-loop	Gait training without SMA	Gait training with SMA	Both groups trained at home	3 months 10 session 30 min/session	(2) (3)
Carpinella et al (2017) [24]	N=37 C:20 (9) T:17 (14)	C:75.6±8.2 T:73±7. 1	C:2.9±0.5 T:2.7±0.7	C:10.3±5.7 T:7.5±3.2	Gamepad	Vision, Auditory	Closed-loop	Structured physiotherapy without biofeedback	Biofeedback training with Gamepad	Both groups trained in a typical rehabilitation gym	3 days/week 20 session 45 min	(3) (4)
El-Tamawy et al (2012) [42]	N=30 C:15 T:15	C:63.2±5.6 T:61.4±7.28	C:2.6±0.4 T:2.8±0.5	C:3.8±0.9 T:4.0±0.9	The vibratory devices (VDs)	Proprioception	Open-loop	Physiotherapy program	PNF and vibratory stimuli+ physiotherapy program	T: walked on the treadmill in a laboratory; C: treated with physiotherapy in a laboratory	8 weeks 3 times/week 45 min	(2)
Ginis et al (2016) [13]	N=38 C:18 (13) T:20 (17)	C:66.11±8.07 T:67.3±8.13	C:2.2±0.39 T:2.3±0.44	C:11.67±7.63 T:10.65±5.39	CuPiD system	Auditory	Closed-loop	Active control, in which personalized gait advice was provided	CuPiD, in which a smartphone application offered positive and corrective feedback on gait	Both groups trained at home	6 weeks 3 times/week 30 min	(2) (3) (4) (5)

NOTES. (1): Walking speed, (2): stride length, (3): UPDRS-III, (4): FOGQ, and (5): DS time.
Abbreviations: C, control group; N, number; N/A, not applicable; PNF, proprioceptive neuromuscular facilitation; SMA, the stride management assist; T, trial group.

review used wearable cueing devices with open-loop systems. These devices provided external cues to PWP, which were not affected by the patient movement. Previous studies have revealed that the open-loop system might provide some benefits for PWP but also caused confusion in some patients who had substantial gait variability.[9,18] Closed-loop control systems, which use IMUs as external sensors to obtain motion signals from patients, such as postural changes and position information from the torso or limbs, can effectively avoid this problem.[23,24]

Closed-loop control systems provide real-time feedback to improve functions based on patient performance. However, whether a closed-loop control system is more effective than an open-loop system in enhancing gait function remains controversial. A recent study showed that prefrontal cortex activity during walking with cues was similar to that during walking without cues in PWP.[46] Other study showed that the closed-loop system may be most closely related to interaction between the salience and subcortical networks, as well as cingulo-parietal and subcortical networks, whereas the open-loop system may be most closely associated with interactions between the salience and retrosplenial-temporal networks.[47]

The major forms of cues provided by wearable cueing devices are visual, auditory, and proprioceptive, all of which were included in our review. Visual and auditory cues are commonly used in wearable cueing devices and have proven validity for influencing gait performance in PWP. Auditory cues are widely-used owing to their non-invasive nature, easy accessibility, lack of adverse effects,[48,49] and can improve gait parameters, such as walking speed, stride length, and cadence.[50,51] At present, beats as auditory cues are commonly set 10% faster than the comfortable cadence for PWP to enhance gait function.[52] The effect of auditory cues on gait parameters appears to be the same during "on" and "off" medications states.[53] Furthermore, the effective mechanism remains unclear and may be related to the spontaneous synchronization of movements and auditory beats in humans.[49,50,54,55]

According to previous studies, auditory cues mainly improve temporal parameters, such as walking speed, whereas visual cues influence spatial parameters, such as stride length.[14,56] Visual cues can be provided using laser canes, smart glasses, and laser shoes. PWP rely more on vision during walking than healthy individuals as their gait automation process is impaired and require more visual attention to compensate.[57] Although visual cues are reported to potentially provide benefits for spatiotemporal parameters of PWP, their effective use in daily life is difficult, because of the use of light color or intensity.[58] Thus, more studies are required to clarify the specific details of visual cues.

In both research and applications, visual and auditory cues were used more frequently than proprioceptive cues in the real world. However, our review found that proprioceptive cues were the most commonly applied in studies and are particularly

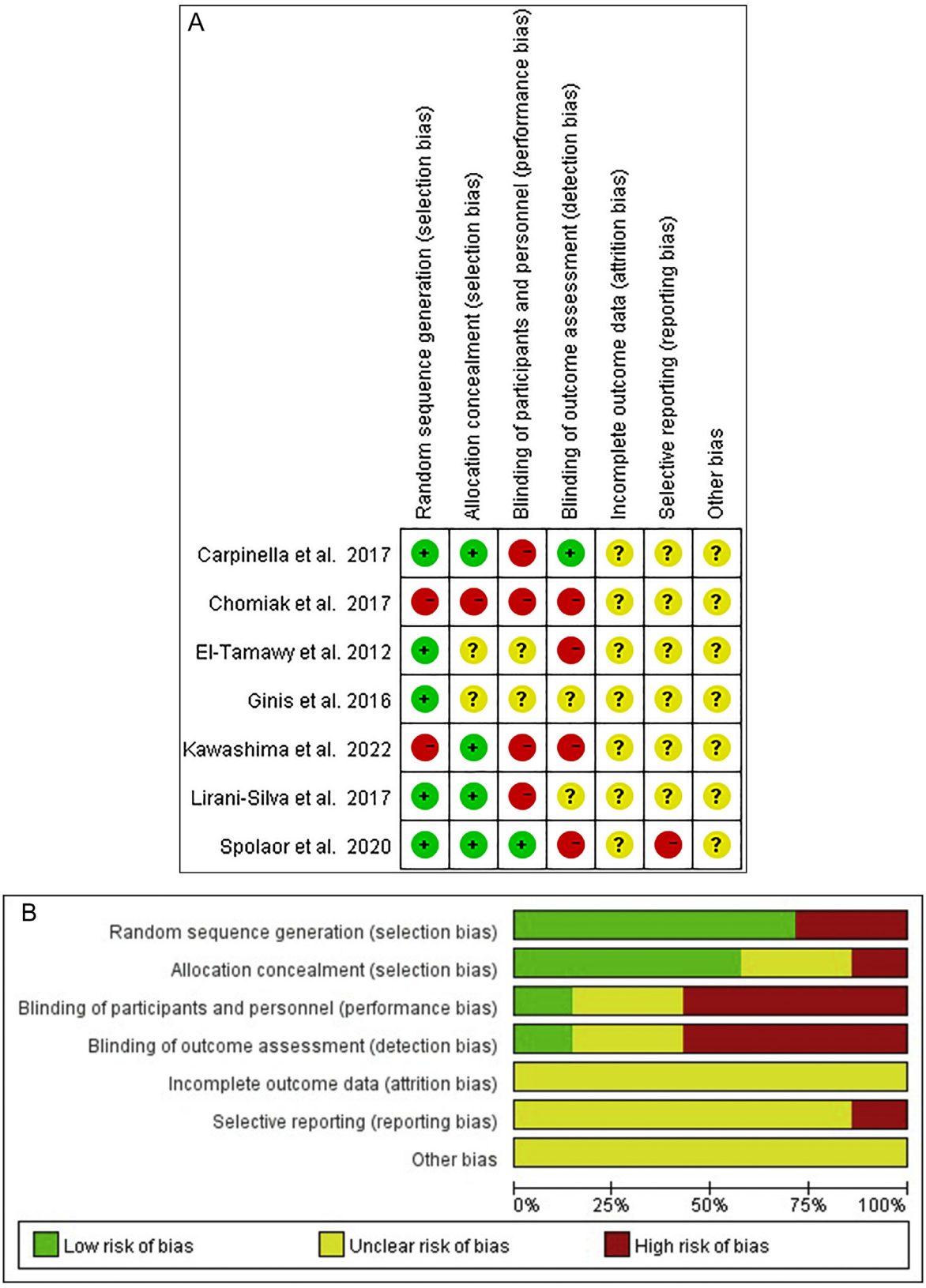

Fig 2 (A) Risk of bias summary. (B) Risk of bias graph.

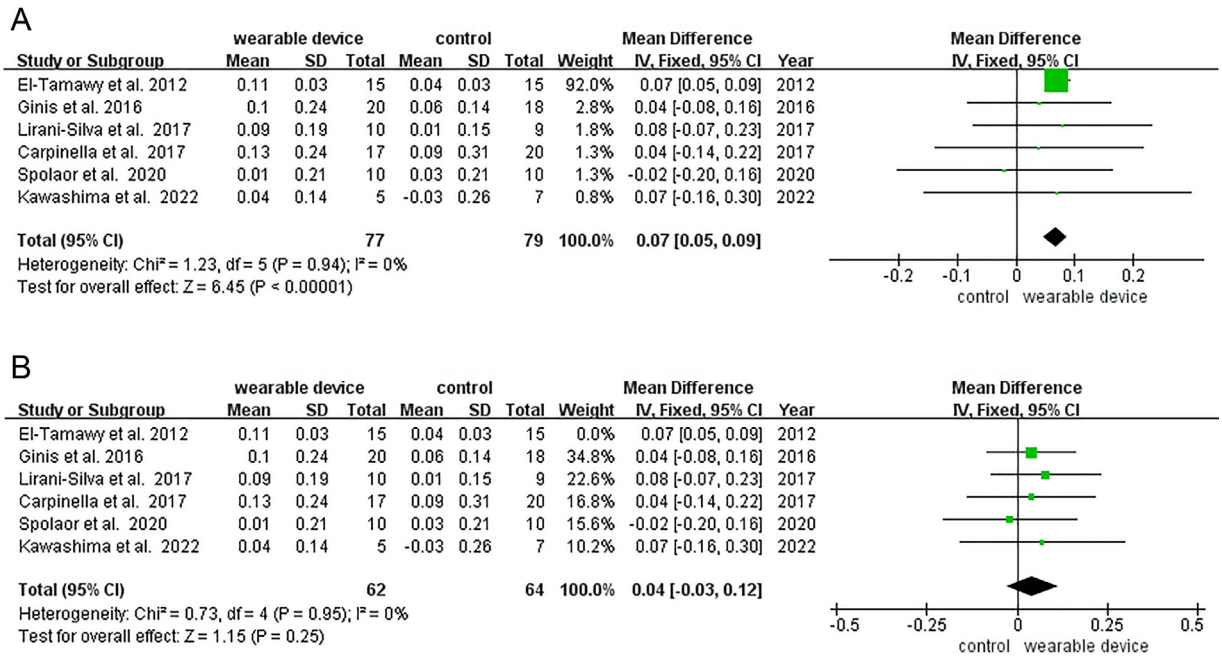

Fig 3 Forest plots for walking speed. (A) Effect of wearable cueing device vs control on walking speed. (B) Effect of wearable cueing device vs control on walking speed (excluding study of El-Tamawy et al[42]).

effective for reducing trunk sway in PWP, even after training.[59] Other study revealed that the effects of proprioceptive cues were smaller than those of visual and auditory cues on amplitude of anticipated posture adjustment.[60] The challenge of using proprioceptive cues is the sensory impairment in PWP, which is more difficult to compensate than vision or auditory impairment.

Although all 3 types of cues are effective in improving gait and motor function in PWP, we cannot draw a definitive conclusion on which type is the best based on our analyses. The feedback in the included studies was mainly negative, but Ginis et al[13] also provided positive reinforcement for good patient performance. Previous studies have suggested that positive reinforcement can increase patient confidence and enthusiasm during a long-term training process, which is related to the reward system in the striatum.[22,61,62]

Wearable cueing device training regimens

In this meta-analysis, we found that training regimens were not standardized among the included studies. Currently, wearable cueing devices are mainly used in the home rehabilitation of PWP.[16] These devices can effectively reduce the burden on medical

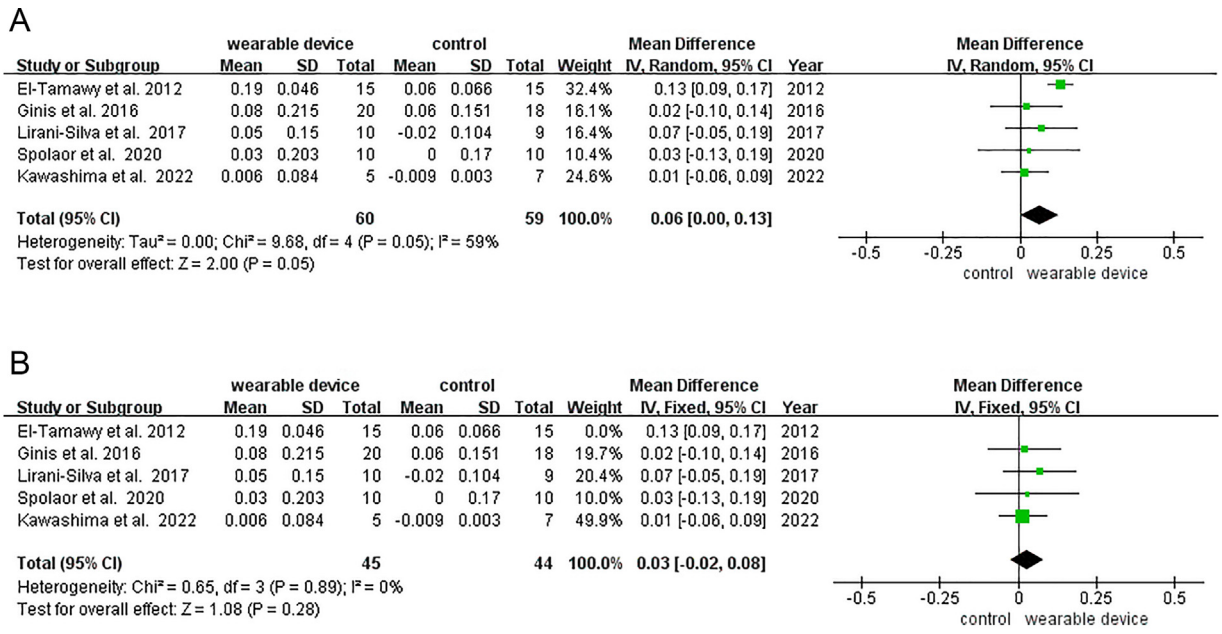

Fig 4 Forest plots for stride length. (A) Effect of wearable cueing device vs control on stride length. (B) Effect of wearable cueing device vs control on stride length (excluding study of El-Tamawy et al).

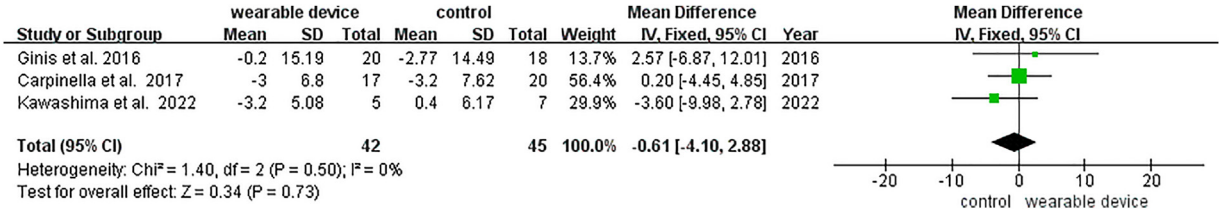

Fig 5 Effect of wearable cueing device on the UPDRS-III score.

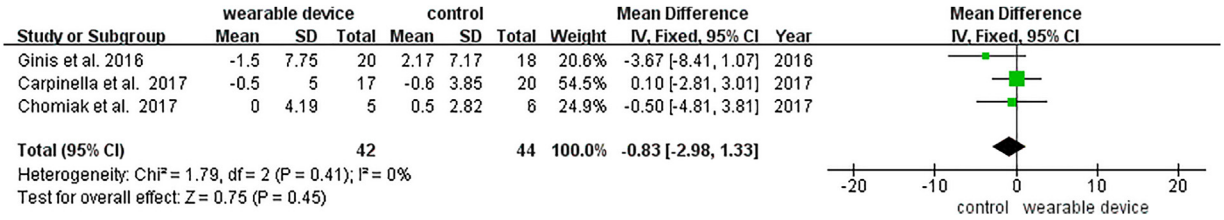

Fig 6 Effect of wearable cueing device on the FOGQ score.

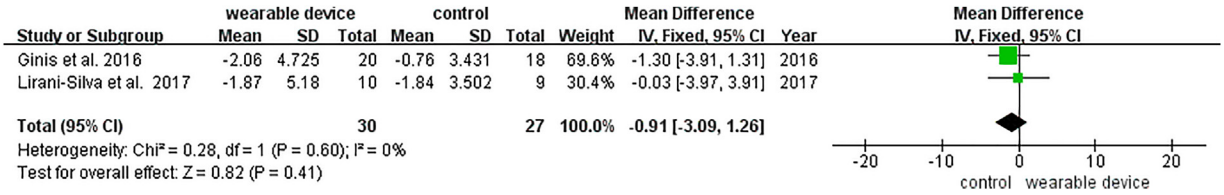

Fig 7 Effect of wearable cueing device on DS time.

personnel, as well as travel cost and time for patients. Furthermore, patients perform more realistically in a home setting, whereas in a laboratory setting, they tend to take the initiative to perform better when asked to exercise. Some of the included studies were conducted in a laboratory, which does not guarantee the positive effects will remain in a realistic environment.

The inclusion of training regimens with multiple durations and frequencies also influenced comparison. Previous studies have indicated a benefit of gait training when the duration is 20-60 min and the frequency is 3-5 days per week for 4-12 weeks.[63] Although the frequency of 3 days/week in included studies was essentially the same as that used in previous investigations, there was a large variation in duration of training among the studies, the shortest training duration was 1 week and the longest was 3 months. These large variation in training duration can be expected to result in significant differences in training effect. A previous study showed that intensive inpatient rehabilitation over 4-8 weeks improved PD performance, which disappeared within a short period after treatment.[64,65] Au et al found that spaced training (1 session every 2 weeks for 6 months) maintained the efficacy, whereas burst training (2 sessions weekly for 6 weeks) did not.[66] It is necessary to provide uniform guidance on training regimens. However, all studies included in this analysis were small trials with a limited number of subjects from restricted sources. The optimal training regimen is required validation in larger, multicenter studies and should be considered in relation to patient characteristics and training setting.

Effects of wearable cueing devices on gait and motor function

We evaluated the gait and motor function of PWP using walking speed, stride length, UPDRS-III and FOGQ scores, and DS time. Previous research has demonstrated that external cueing can improve gait parameters, including walking speed, stride length, and cadence.[67] Because of the insufficient number of studies involving cadence, we were unable to confirm the efficacy of wearable cueing devices for improving cadence. This is a potential area of research that poses challenges due to the irregular cadence of PWP, some of them exhibit festinating gait with increased cadence, while others display decreased or slow cadence.[55,68,69]

Furthermore, the study of El-Tamawy et al[42] had a greater effect on results of walking speed and stride length. We considered there may be 3 reasons for this heterogeneity. Firstly, El-Tamawy et al conducted assessment during the training process, while others assessed after training. This suggests that wearable cueing devices may have an immediate effect. Other reasons for the heterogeneity may be that El-Tamawy et al used treadmills for the gait training and the training sessions were of sufficient length to have the reported effect. In addition, sufficient training time can effectively differentiate between patients with different walking abilities. A previous study confirmed that cues provided during treadmill training had superior effects to those during overground gait training.[70] Thirdly, the study of El-Tamawy et al[42] was conducted in a laboratory environment, participants trained in more unified conditions and received additional professional guidance, whereas others trained at home or in the community had poorer adherence. Whether laboratory efficiency can be applied to daily life remains to be investigated.

DS time reflects the stability of dynamic posture in PWP.[37,71] During the walking cycle, PWP restore stable posture by increasing the proportion of DS time.[55] However, we found that wearable cueing devices did not significantly improve the DS time of PWP in this review. Only 2 studies[9,13] included the DS time, and the participants in these studies were mainly at H&Y stage II, whose balance deficits may be not clinically apparent. The proportion of

DS time was between 20% and 30% in included studies, this is slightly higher than the proportion of 20% observed in healthy adults. Considering that PWP are older adults with an average age of approximately 70 years, their stability of dynamic posture may physiologically reduce due to aging. The effects of wearable cueing devices may not significant. We propose to explore DS time in patients with advanced PD.

We used the UPDRS-III score to assess the severity of motor disease. Several studies identified improvements in movement function using wearable cueing devices.[63,72,73] However, our results showed no effect on the severity of motor impairments when training with wearable cueing devices. This finding may be related to the PD stage. As all participants were at H&Y II-III stage in included studies, it is likely that their motor function was relatively good. This may have limited the detectable effect of wearable cueing devices on them, and a longer period of application may be necessary to observe significant effects. Moreover, further research is needed to confirm whether wearable cueing devices are sufficiently effective and safe for patients with advanced PD. FOGQ reflects the severity of FOG in PWP.[74] We found that wearable cueing devices did not significantly improve FOG, possibly due to the short duration of FOG training and nonstandard training methods.

In this review, wearable cueing devices were not found to demonstrate efficacy on most gait and motor functions. This lack of effect may be related to the loss of these devices' immediate effect during walking, which are subsequently not maintained when measured after short term training. Considering the poor plasticity of PWP, it is difficult to effectively restore complete function during short-term treatment.[75] Previous studies have shown immediate positive effects on gait and motor function after training with external cues, but no residual effects.[76,77] It is possible to apply wearable cueing devices as auxiliary tools in the daily activities of PWP, rather than as training means.

The GRADE result showed that the quality of evidence in our study was low, and the results should be interpreted with caution and used as a reference. We hope that in the future more high-quality studies will be available for analysis to improve the level of evidence.

Study limitations

Our review has several limitations. First, we only searched the literature published in English, and there may be some relevant literature in other languages that were not included in our analysis. Second, the number of included studies was limited, and some of them were in the preliminary stage. We were unable to draw firm conclusions regarding the efficacy of wearable cueing devices in improving gait and motor function. Finally, the types of wearable cueing devices and training regimens varied among the included studies, which resulted in heterogeneity and poor comparability.

Conclusions

In this systematic review, we examined the effectiveness of wearable cueing devices in enhancing gait and motor function among PWP. Our findings indicate that while these devices may improve walking speed, they do not appear to have significant effects on most other aspects of gait and motor function. However, our analysis suggests that wearable cueing devices may result in an immediate improvement on gait for PWP. Additionally, there was considerable variation in the types of devices used across studies. In the future, we suggest conducting more large-scale randomized controlled trials to confirm the effectiveness of wearable cueing devices in enhancing gait and motor function among PWP, as well as establishing a standardized training regimen.

Keywords

Gait; Meta-analysis; Parkinson's disease; Rehabilitation; Wearable cueing device

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