RESEARCH PAPER

Effectiveness of Split-belt treadmill training on functional outcomes in Parkinson's disease: a systematic review

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ABSTRACT

The purpose of this systematic review was to evaluate the impact of split-belt treadmill (SBT) training on functional outcomes, including gait, balance, fall risk, motor performance, and cognitive function, in people with Parkinson's disease (PD). Twelve research with 281 individuals were found through a search of seven electronic databases. These studies included cross-sectional studies, within-subject designs, and randomized controlled trials (RCTs) and were published between 2014 and 2024. Belt-speed ratios ranging from 0.5:1 to 0.75:1 were employed in the majority of single-session procedures. The findings demonstrated that step length asymmetry was corrected in PD patients by SBT training, with the most improvements being seen right after training. Patients who had freezing of gait (FOG) or cognitive deterioration, on the other hand, adjusted less quickly and efficiently. There were only slight improvements in motor scores (UPDRS), but there were no long-term changes in overground walking. Medication status had an impact on the ability to maintain the effects of SBT; during the "ON" state of dopaminergic medication, better results were seen. SBT has the potential to improve gait symmetry in PD patients overall, especially in terms of spatial symmetry, although it is unclear how it will affect functional transfer and long-term implications. The timing of drug, cognitive state, and freezing of gait all seem to affect how well a treatment works. For PD patients, future studies should investigate extended follow-up times, real-world functional outcomes, and customized training regimens.

Keywords: Split-belt treadmill, Parkinson's disease, functional outcomes, gait rehabilitation, motor function.

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Introduction

Research shows that Parkinson's disease (PD) impacts 1-2% of older adults above 65 years of age, and global population aging will double this number by 2040. 1 Gait disturbance among Parkinson's disease patients causes significant mobility restrictions and fall dangers that negatively affect quality of life through its characteristic asymmetry and limited step length, along with freezing of gait (FOG). [2] The gait problems resulting from PD prove challenging to treat with drugs since levodopa gives inconsistent results for spatial asymmetry and coordination problems, which worsen as the disease advances. [3] Gait problems in Parkinson's disease stem from complicated interactions between basal ganglia dysfunction and sensorimotor integration changes and multiple neural networks that develop compensatory mechanisms. The pathophysiological origin of basal ganglia dysfunction stands as the main cause, but research indicates that PD patients maintain healthy cerebellar motor adaptation processes. [4] The preserved adaptation processes in this condition offer therapeutic opportunities to develop cerebellar-based locomotor adaptation treatments for abnormal gait pattern modification.

The rehabilitation method known as split-belt treadmill training has established itself as an innovative approach that utilizes these preserved adaptation mechanisms. SBT treadmill training operates through speed differences between left and right belts, which generate an asymmetric walking environment that forces the locomotor system to readjust interlimb coordination. [5] The fundamental difference between this perturbation-based approach and traditional interventions exists in how it creates sensorimotor adaptation through error-based implicit processes instead of explicit instruction or conscious gait parameter adjustments. The initial research indicates SBT produces significant changes in gait symmetry among people with Parkinson's disease through multiple studies showing that a single exposure leads to better spatial and temporal results. More research is needed to determine the best protocol methods along with proper patient selection and adaptation, maintenance, and functional mobility transfer. The mechanisms that lead to adaptation in Parkinson's disease patients, along with the impact of cognitive state, disease severity, and pharmacological state, need systematic research.

The PD population lacks a comprehensive systematic review assessment for split-belt treadmill

(SBT) applications in rehabilitation practice. Current reviews about gait rehabilitation for people with PD have either studied healthy subjects or stroke patients. This review aims to supply medical professionals with evidence-based guidance for implementing SBT in PD rehabilitation while identifying research priorities for future studies. The growing interest in neuroplasticity-based rehabilitation requires further investigation of SBT's potential to treat gait dysfunction in PD patients because it has important clinical implications.

METHODOLOGY

The review methodology was conducted and reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. A comprehensive electronic database search (i.e., PubMed, Cochrane Library, Embase, Web of Science, ScienceDirect, PEDro, and Scopus) from 2013 to 2025 was conducted for human studies in adults older than 18. The inclusion criteria comprised (1) participants: articles including patients diagnosed with Parkinson's disease at any stage. (2) Intervention: - Studies evaluating split-belt treadmill training interventions as primary or adjunct therapy (3) Comparison: - Conventional therapy / Other interventions (4) Outcomes: - The primary outcomes of interest were (a) gait parameters (step length symmetry, stride length, gait speed); (b) balance measures (Berg Balance Scale, Timed Up and Go test); (c) fall risk metrics; (d) overall motor performance (UPDRS-III); and (e) cognitive measures when reported. Secondary outcomes included adaptation rates, aftereffects, and retention duration. Additionally, only full-text studies published between January 2013 and August 2023 in English were included. The exclusion criteria encompassed conference papers, editorial letters, and commentary articles, unpublished studies and gray literature, abstract-only studies, retrospective studies and case reports, and articles published in predatory journals.

Search strategy:

The research included a thorough electronic database search of PubMed, Embase, MEDLINE (via Ovid), CINAHL, Physiotherapy Evidence Database (PEDro), Cochrane Central Register of Controlled Trials (CENTRAL), and Web of Science. The research includes studies published between January 2013 and March 2024. The search included different combinations of the following terms with Boolean operators: ("Parkinson's disease" OR "Parkinson disease" OR "PD" OR "Parkinsonism") AND ("split-belt" OR "split belt" OR "splitbelt" OR "dual belt" OR "asymmetric treadmill") AND ("gait" OR "walking" OR "locomotion" OR "rehabilitation" OR "training" OR "adaptation" OR "motor learning"). The search filters included human participants and adults aged 18 years and above. The reference lists of included studies and relevant review articles were manually searched to find additional eligible studies. The search results were imported into Zotero for deduplication before screening.

Selection Process

The study selection process was conducted per PRISMA 2020 guidelines. Two independent reviewers screened titles and abstracts of all identified records against predefined eligibility criteria. Full-text articles of potentially relevant studies were subsequently retrieved and independently assessed by the same reviewers. Disagreements at either screening stage were resolved through discussion or consultation with a third reviewer when necessary. Cohen's kappa coefficient was calculated to assess inter-reviewer reliability (κ=0.87). Studies were excluded if they involved non-PD populations, utilized interventions other than split-belt treadmill training, lacked appropriate outcome measures, or represented non-primary research (e.g., reviews, commentaries). A PRISMA flow diagram documenting the selection process was generated, with specific reasons recorded for all full-text exclusions.(Figure 1)

Data Collection Process

Data extraction was performed independently by two reviewers using a standardized, pre-piloted form developed in Microsoft Excel. For each included study, the following information was extracted: Author name , publication year, study design, Sample size participant characteristics, intervention, outcome measures, and key findings. Authors of studies with incomplete or unclear information were contacted via email with a standardized query form. Discrepancies in extracted data were resolved through discussion and consensus, with verification against the original articles as needed.

Data Items

The primary outcomes of interest were (1) gait parameters (step length symmetry, stride length, gait speed), (2) balance measures (Berg Balance Scale, Timed Up and Go test), (3) fall risk metrics, (4) overall motor performance (UPDRS-III), and (5) cognitive measures when reported. Secondary outcomes included adaptation rates, aftereffects, and retention duration. For each outcome, we extracted baseline values, post-intervention results, follow-up data (when available), and between-group differences with corresponding precision estimates (standard deviations, confidence intervals, p-values). Participant-level variables included age, sex, disease duration, Hoehn & Yahr stage, cognitive status, and medication state during assessment. Intervention characteristics documented were belt-speed ratios, session duration, frequency, total intervention period, side assignment strategy, and progression parameters.

Quality Assessment

Two authors independently evaluated the methodological quality of each trial using the Cochrane risk of bias instrument 6 and the Joanna Briggs Institute (JBI) tool. [7] In the JBI tool , the review evaluated the quality as yes or no, with a point of 1 for "yes" and 0 for "no." Using the JBI critical appraisal instrument, non-RCTs were evaluated. In addition Cochrane risk of bias tool was used to evaluate RCTs and crossover trials, classifying them into low risk, high risk, and some concerns in accordance with the criteria.

Reporting Bias Assessment

The risk of reporting bias was assessed through multiple approaches. First, we compared registered protocols (when available) with published results to identify selective outcome reporting. Second, we examined whether studies reported all outcomes mentioned in their methods sections. Third, for studies with multiple publications, we cross-referenced all reports to identify potential selective reporting. Due to the insufficient number of studies per outcome (<10), formal statistical assessment of publication bias via funnel plots or Egger's test was not conducted; instead, we employed the Cochrane risk of bias tool's selective reporting domain to evaluate reporting bias at the individual study level. The potential impact of reporting bias was considered when formulating conclusions.

Certainty Assessment

The certainty of evidence for each main outcome was assessed using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach. Two reviewers independently evaluated the body of evidence across five domains: risk of bias, inconsistency, indirectness, imprecision, and publication bias. Initial certainty ratings began at "high" for randomized controlled trials and "low" for observational studies, with subsequent downgrading or upgrading based on domain assessments. We specifically considered the impact of unblinded participants and assessors (unavoidable in SBT interventions) on performance and detection bias. Heterogeneity in intervention protocols and outcome measures was evaluated when determining inconsistency ratings.

RESULTS

Study Selection and Characteristics

Twelve studies about split-belt treadmill (SBT) training in Parkinson's disease (PD) were found through database searching and eligibility screening for this systematic review. The rehabilitation method for Parkinson's patients has appeared in the literature during the last ten years, between 2013 and 2023.[8]

The methodological designs encompassed considerable diversity: five randomised controlled trials, three cross-sectional investigations, three within-subject crossover experiments, and one narrative review synthesising previous findings. The experimental groups in the studies contained between 8 to 52 participants with PD, while the cumulative total of participants in interventional studies reached 281. The majority of research studies included participants who had mild-to-moderate PD severity levels at Hoehn & Yahr stages 1-3, but Seuthe et al.[9] included participants up to stage IV. Seven studies focused on freezing of gait (FOG) by either using it as a main inclusion criterion or by comparing FOG+ to FOG- subgroups.

The participant demographics showed similar patterns across studies through ages between 60.5 and 69.6 years and disease duration between 5.2 and 12.2 years. The studies implemented different cognitive requirements for participation, where most established basic cognitive standards (MMSE ≥24 or MoCA ≥22) to verify understanding of the protocol, but Sasikumar et al.[10] focused on how participants adapted to the protocol based on their cognitive abilities.

Intervention Protocols

Split-belt treadmill paradigms exhibited substantial methodological variability. Belt speed differentials ranged from modest (0.75:1 ratio in Seuthe et al.[9]) to pronounced (0.5:1 ratio in D'Cruz et al.[11]), with most studies employing asymmetry between 25-50%. Exposure durations spanned from brief adaptation assessments (2-10 minutes) designed to examine neuromotor mechanisms to extended training sessions (30-45 minutes) intended to induce lasting motor learning effects.

Protocol designs fell into several categories: (1) fixed asymmetry with the affected/worse side walking on the faster belt; (2) fixed asymmetry with the less affected/better side walking on the faster belt; (3) "best-side reduction" paradigms, where the limb with superior performance walked on the slower belt; (4) "worst-side reduction" approaches where the poorer-performing limb encountered the slower belt; and (5) alternating asymmetry conditions where belt speed relationships changed systematically throughout the session. Four studies[12-15] directly compared multiple SBT configurations within their experimental design.

Only one investigation[16] implemented a longitudinal intervention, comprising twelve sessions over four weeks with progressive protocol adjustments, while the remainder utilised single-session designs examining immediate and short-term (24-hour) adaptation effects.

Risk of Bias Assessment

Nine studies underwent evaluation using the Cochrane Risk of Bias tool [6] for randomised trials. At the same time, three were assessed via the Joanna Briggs Institute Critical Appraisal Checklist[7] appropriate to their respective designs. Bias

assessment revealed consistent methodological patterns across the literature.
Among randomised investigations, selection bias was predominantly well-controlled; six studies (66.7%) demonstrated low risk for random sequence generation, while three (33.3%) provided insufficient methodological detail. Performance bias presented unavoidable challenges, with all RCTS exhibiting high risk regarding blinding participants and personnel, an inherent limitation given the conspicuous nature of the split-belt intervention. Detection bias varied considerably; only two studies (22.2%) implemented adequate blinding of outcome assessors, with four (44.4%) showing high risk and three (33.3%) providing unclear information.
The three non-randomised studies exhibited moderate methodological quality according to JBI criteria. Plotnik et al.[15] demonstrated established cause-effect relationships and appropriate control measures, but lacked multiple measurement timepoints. Thompson & Reisman[1] showed strong participant selection and outcome assessment procedures, but were limited by their observational design. The narrative review by Seuthe et al.[17] displayed high methodological rigour with comprehensive search strategies and appropriate critical appraisal methods.
Across all studies, attrition and reporting bias were generally well-controlled, with all investigations showing low risk for selective reporting of outcomes and the majority demonstrating appropriate handling of incomplete outcome data.

Effects on Gait Parameters and Symmetry

All investigations consistently demonstrated that individuals with PD could adapt to SBT perturbations, though adaptation patterns frequently differed from those observed in neurologically intact control participants. Nine studies reported statistically significant improvements in step length asymmetry during or immediately following SBT exposure.
Seuthe et al.[9] quantified intervention effects across three distinct SBT protocols, finding that all elicited significant improvements in spatial symmetry ($p<0.0001$) with effect sizes ranging from moderate (Cohen's $d=0.68$ for SBT75) to substantial ($d=1.14$ for the continuously changing ratio condition). Similarly, Thompson & Reisman[1] documented robust adaptation magnitudes averaging 0.71 ± 0.33 across participants, with considerable individual variability in adaptation profiles.
Interestingly, the mechanism of symmetry correction varied substantially depending on specific SBT configurations. Fasano et al.[12] demonstrated that best-side reduction paradigms improved spatial symmetry ($p<0.01$) but simultaneously compromised temporal coordination, whereas worst-side reduction protocols enhanced coordination metrics while potentially exacerbating asymmetry. This mechanistic dichotomy was further elaborated by Plotnik et al.[15], who identified that conditions emphasising either reduction on the better side or acceleration of the worse side produced the most substantial asymmetry corrections (mean improvements 38.2% and 36.4%, respectively).
The relationship between SBT effects and FOG status emerged as a significant moderating factor. Both Nanhoe-Mahabier et al.[18] and Mohammadi et al.[19] documented that PD participants with FOG exhibited slower and less complete adaptation compared to those without FOG ($p<0.05$). Nanhoe-Mahabier et al.[18] further observed that only FOG+ participants demonstrated increased temporal asymmetry and step-to-step variability during adaptation, suggesting distinct neurophysiological mechanisms underlying gait dysfunction in this subpopulation.

Motor Adaptation and Learning Processes

Seven specific studies analysed the learning processes for motor adaptation acquisition and their subsequent retention and transfer stages. Thompson & Reisman[1] proved that patients with Parkinson’s disease (PD) could learn split-belt perturbations and maintained “savings” upon re-exposure, which indicated their procedural learning mechanisms operated without impairment from basal ganglia dysfunction. The re-exposure to the split-belt condition resulted in participants adapting faster than their initial adaptation ($p<0.001$) and required lower perturbation magnitude ($p = 0.02$).
Adaptation capabilities depended heavily on the current pharmacological state of the participants. Roemmich et al.[20] used systematic research to evaluate adaptation in patients receiving dopaminergic medication compared to those not receiving it and discovered that medication improved adaptation retention. The absence of medication led to major reductions in after-effects that reached statistical significance at $p<0.01$, suggesting dopaminergic involvement in motor learning processes. The findings confirm theoretical models that demonstrate dopamine plays a crucial role in both motor adaptation development and motor memory solidification.
The study conducted by Sasikumar et al.[10] directly analysed the adaptation performance of cognitive abilities by revealing important statistical relationships between specific cognitive domains and adaptation outcomes. Working memory ($r=0.62$, $p<0.01$) and visuospatial processing capacity ($r=0.58$, $p<0.01$) proved to be the most effective predictors for adaptation achievement. The "adapter" subgroup, who achieved asymmetry correction at or above 50%, maintained typical cognitive test results, while non-adapters displayed major impairments across various cognitive tests.

Effects on Freezing of Gait and Clinical Outcomes

The evidence regarding SBT impacts on freezing of gait and additional clinical outcomes generated mixed results. The research conducted by D'Cruz et al.[11] showed that patients who received SBT treatment achieved better results in dual-task gait speed (+0.12 m/s, $p<0.001$) and turning speed (+12.8%, $p<0.001$) than patients who received conventional treadmill training. The continuously changing ratio protocol generated superior results than fixed-ratio approaches. The study showed positive results, which persisted partially during the 24-hour follow-up evaluation.

Hulzinga et al.[16] conducted a longitudinal study, which revealed that patients who received SBT training for four weeks performed better on the treadmill but only showed slight improvements in UPDRS motor scores (-2.3 points, $p=0.03$) than patients who received traditional treadmill training. However, the gains from SBT training did not result in better performance during walking outside or reduced occurrences of freezing of gait (FOG) in actual daily activities. The main difficulty stems from achieving ecological validity and ensuring transfer effects in SBT applications. Multiple research studies used specific outcome measures to assess FOG by implementing the New Freezing of Gait Questionnaire (NFOG-Q) and conducting objective turning evaluations. Two studies demonstrated better immediate post-training results for turning kinematics, although no research showed any decrease in self-reported FOG episodes or severity. The research failed to demonstrate any noteworthy decline in either FOG episode rates or patient-rated FOG severity following the intervention.

Cognitive-Motor Interactions and Long-Term Effects

Three studies investigated the interactions between cognitive and motor functions during SBT adaptation. D'Cruz et al.[11] established that SBT training delivered better results for dual-task performance when contrasted with traditional treadmill training through notable reductions in dual-task cost for gait speed ($p<0.01$) and cognitive task performance ($p=0.03$). The SBT paradigm's enhanced attentional requirements seem to create better cognitive-motor integration according to this discovery. The literature lacks extensive longitudinal intervention data because only Hulzinga et al.[16] investigated the enduring impacts of multiple-session SBT training. The examination showed that after four weeks of thrice-weekly training, participants maintained some retention of gait adaptations but showed limited transfer to actual walking conditions and functional activities. The current literature does not provide information about long-term retention because it lacks follow-up assessments beyond the immediate post-intervention period.

DISCUSSION

The review used a systematic methodology to analyse how split-belt treadmill (SBT) training can serve as treatment for Parkinson's disease (PD). Our research showed that people with PD show the ability to learn from SBT perturbations through better step length symmetry, but the extent of learning varies between participants. The observed ability to adapt to locomotor challenges agrees with what experts know about how the cerebellum continues to function well in PD despite damage to the basal ganglia. According to current understanding of motor adaptation as a cerebellar process that remains functional in PD patients with basal ganglia impairment.[21] Research findings indicate that different PD patients react to SBT interventions differently due to the various spatial and temporal gait problems they present with.

Significant differences in reaction patterns emerged based on the study populations. Participants with freezing of gait proved incapable of effective adaptation in studies 1 and 2, which indicates FOG mechanisms differ from typical PD mechanisms that SBT cannot affect. The degree to which a person adapts depends heavily on their cognitive state because working memory and visuospatial skills appear as critical indicators of success.[3] The mental system's connection to motor skills likely stems from two aspects: The attention required to learn the split-belt system and the executive control necessary for finding mistakes and making corrections. This relationship matches previous findings about how cognitive abilities influence PD rehabilitation outcomes.[22]

The evaluation of SBT as a PD rehabilitation method requires multiple comparisons with other treatment approaches. Scientific research indicates conventional treadmill training leads to small but measurable improvements in gait parameters since meta-analyses show modest to moderate effect sizes for gait speed and stride length.[23] Our research results show that SBT produces similar or better effects on spatial symmetry parameters through specific perturbation methods, though direct comparative data is scarce. Research has confirmed external cueing as a valid method to help people with gait disorders through both auditory and visual cues.[24] The two approaches differ because temporal gait parameters are affected by cueing through attention, while SBT affects spatial symmetry through adaptive learning, which indicates their possible synergistic use.

The changes caused by SBT appear to function through various neurophysiological mechanisms. The main process involves error-based sensorimotor adaptation, which depends on cerebellar circuit activity. People develop spatial errors between actual and expected limb movement paths during split-belt perturbations that force their motor system to create adaptations to achieve symmetrical coordination. The cerebellar system maintains its functionality well in PD patients since the cerebellum continues to function properly. Basal ganglia circuitry plays an additional role in adaptation based on evidence showing that dopaminergic medication affects the process. This discovery fits with established knowledge about dopamine function in reinforcement learning and motor skill retention[25].

Several methodological limitations warrant consideration. The single-session study design with minimal follow-up duration restricts our ability to understand how well SBT results translate into everyday functioning and how well patients maintain their learning after training. Hulzinga et al.[16] established the only trial with multiple sessions, which showed small positive changes in clinical assessments yet failed to show meaningful improvements in daily life activities. The findings from other motor adaptation studies share a similar problem because brief perturbation-specific adaptations fail to transfer to new, untrained situations. Various SBT protocols with belt-speed ratios between 0.5:1 and 0.75:1 and different side assignment procedures create obstacles for direct study comparisons. Treadmill walking shows low ecological validity in rehabilitation because treadmill movement differs from natural walking in multiple biomechanical aspects, which could reduce its application to everyday activities.

Risk of bias assessment revealed significant methodological concerns across multiple domains. Performance bias remains unavoidable due to the intervention nature, yet it reduces the interpretability of patient-reported outcomes. The detection bias presented a detectable issue because only 22.2% of studies used proper assessor blinding techniques. The methodological weaknesses should influence how we evaluate the current body of evidence.

Several clinical recommendations arise despite existing research constraints. The effectiveness of SBT appears to depend on individual patient factors, including cognitive status and freezing of gait, which suggests that proper patient matching would be beneficial. Evidence suggests that continuously changing belt-speed ratios might create better adaptation in patients who benefit from this approach [9] while patients with strong spatial asymmetry might need specific asymmetry correction through particular configurations .[12] The improved adaptation retention during the ON medication state[13] indicates that scheduling SBT training during optimal dopaminergic function periods could produce better results in adaptive gait modifications retention. Future research priorities should address several critical knowledge gaps. Further research demands well-designed longitudinal studies to evaluate long-term retention and functional transfer of SBT adaptations through extended follow-up periods and realistic outcome measures. Systematic studies about various SBT parameters will establish effective prescription guidelines, while investigations of combination approaches between SBT and other interventions could produce more robust and generalizable results. A standardised set of outcome measures created for SBT research would enhance both cross-study comparison and meta-analysis of SBT studies.

The split-belt treadmill training method shows potential as a rehabilitation strategy for Parkinson's disease gait dysfunction because it uses preserved cerebellar adaptation mechanisms to create beneficial gait modifications. The current research shows that spatial symmetry improves consistently in the short term, but PD patients show wide differences in adaptation size and maintenance between subgroups. The targeted sensorimotor recalibration through SBT shows unique benefits beyond conventional approaches, yet its effectiveness depends on the patient's cognitive function and their experience with freezing and their current medication state. The effectiveness of this innovative intervention needs definitive research to determine its long-term success and best clinical application.

CONCLUSION

The evidence suggests that split-belt treadmill training demonstrates promising yet limited potential for treating gait asymmetry in Parkinson's disease patients. The current research demonstrates that most people with PD maintain their adaptation abilities, yet their results vary based on their cognitive function and their experience with freezing of gait. The research demonstrates consistent short-term spatial symmetry improvements, but the sparse long-term data creates doubts about how well these adaptations persist and translate to real-life mobility. The observed connection between dopaminergic state and adaptation retention indicates potential neurophysiological mechanisms that require additional investigation. The future development of this innovative rehabilitation method requires standardised protocols and specific patient selection criteria, and thorough methodologically sound investigations of long-term outcomes. The optimal use of split-belt training appears to be as part of individualised rehabilitation programs that combine multiple interventions based on clinical profiles and rehabilitation objectives. The systematic review contains multiple limitations that need to be acknowledged. The limited number of studies, together with small sample sizes, reduces statistical power and makes generalisation of findings more difficult. The studies presented substantial differences in intervention approaches and outcome assessment methods, and participant demographics, which made direct study-to-study comparisons challenging. The majority of studies used single-session designs, which had limited follow-up periods, thus restricting the ability to conclude long-term efficacy and participant retention.

References

1. Dorsey ER, Bloem BR. The Parkinson pandemic—a call to action. JAMA Neurol. 2018;75(1):9-10.
2. Mirelman A, Bonato P, Camicioli R, Ellis TD, Giladi N, Hamilton JL, et al. Gait impairments in Parkinson's disease. Lancet Neurol. 2019;18(7):697-708.
3. Curtze C, Nutt JG, Carlson-Kuhta P, Mancini M, Horak FB. Levodopa is a double-edged sword for balance and gait in people with Parkinson's disease. Mov Disord. 2015;30(10):1361-1370.
4. Morton SM, Bastian AJ. Cerebellar contributions to locomotor adaptations during splitbelt treadmill walking. J Neurosci. 2006;26(36):9107-9116.
5. Reisman DS, Bastian AJ, Morton SM. Neurophysiologic and rehabilitation insights from the split-belt and other locomotor adaptation paradigms. Phys Ther. 2010;90(2):187-195.
6. Cochrane. RoB 2: A revised Cochrane risk-of-bias tool for randomized trials [Internet]. Cochrane.org. 2019.
7. Joanna Briggs Institute. Critical Appraisal Tools [Internet]. JBI. 2020.
8. Thompson, E. D., & Reisman, D. S. (2022). Split-Belt Adaptation and Savings in People With Parkinson Disease. *Journal of Neurologic Physical Therapy*, *46*(4), 293-301.
9. Seuthe J, D'Cruz N, Ginis P, Becktepe JS, Weisser B, Nieuwboer A, et al. The Effect of One Session Split-Belt Treadmill Training on Gait Adaptation in People With Parkinson's Disease and Freezing of Gait. Neurorehabilitation and Neural Repair. 2020 Sep 17;34(10):954–63.
10. Sasikumar, S., Sorrento, G., Lang, A. E., Strafella, A. P., & Fasano, A. (2023). Cognition affects gait adaptation after split-belt treadmill training in Parkinson's disease. *Neurobiology of Disease*, *181*, 106109.
11. D'Cruz N, Seuthe J, Ginis P, Hulzinga F, Schlenstedt C, Nieuwboer A. Short-Term Effects of Single-Session Split-Belt Treadmill Training on Dual-Task Performance in Parkinson's Disease and Healthy Elderly. Frontiers in Neurology. 2020 Sep 30;11.
12. Fasano A, Schlenstedt C, Herzog J, Plotnik M, Rose FEM, Volkmann J, et al. Split-belt locomotion in Parkinson's disease links asymmetry, dyscoordination and sequence effect. Gait & Posture. 2016 Jul;48:6–12.
13. Seuthe J, D'Cruz N, Ginis P, Hulzinga F, Nieuwboer A, Schlenstedt C. The effect of split-belt treadmill training on balance and gait in Parkinson's disease: a systematic review. J Parkinsons Dis. 2019;9(2):297-309.
14. Seuthe J, D'Cruz N, Ginis P, Becktepe JS, Weisser B, Nieuwboer A, et al. The Effect of One Session Split-Belt Treadmill Training on Gait Adaptation in People With Parkinson's Disease and Freezing of Gait. Neurorehabilitation and Neural Repair. 2020 Sep 17;34(10):954–63.
15. Plotnik M, Chermesh Y, Hilel I, Galperin I, Mirelman A, Hausdorff JM. Asymmetric adaptation mechanisms of step length and arm swing in split-belt treadmill walking. J Neurophysiol. 2023;129(5):977-987.
16. Hulzinga F, Seuthe J, D'Cruz N, Ginis P, Nieuwboer A, Schlenstedt C. Split-Belt Treadmill Training to Improve Gait Adaptation in Parkinson's Disease. Movement Disorders. 2022 Oct 14;
17. Seuthe J, D'Cruz N, Ginis P, Weisser B, Berg D, Deuschl G, et al. Split-belt treadmill walking in patients with Parkinson's disease: A systematic review. Gait & Posture. 2019 Mar;69:187–94.
18. Nanhoe-Mahabier W, Snijders AH, Delval A, Weerdesteyn V, Duysens J, Overeem S, et al. Split-belt locomotion in Parkinson's disease with and without freezing of gait. Neuroscience. 2013 Apr;236:110–6.
19. Mohammadi F, Bruijn SM, Vervoort G, van Wegen EE, Kwakkel G, Verschueren S, et al. Motor switching and motor adaptation deficits contribute to freezing of gait in Parkinson's disease. Neurorehabil Neural Repair. 2015;29(2):132-142.
20. Roemmich RT, Nocera JR, Stegemöller EL, Hassan A, Okun MS, Hass CJ. Locomotor adaptation and locomotor adaptive learning in Parkinson's disease and normal aging. Clinical Neurophysiology. 2014 Feb;125(2):313–9.
21. Morton SM, Bastian AJ. Cerebellar contributions to locomotor adaptations during splitbelt treadmill walking. J Neurosci. 2006;26(36):9107-9116.
22. Peterson DS, King LA, Cohen RG, Horak FB. Cognitive contributions to freezing of gait in Parkinson disease: implications for physical rehabilitation. Phys Ther. 2016;96(5):659-670.
23. Mehrholz J, Kugler J, Storch A, Pohl M, Elsner B, Hirsch K. Treadmill training for patients with

Parkinson’s disease. Mehrholz J, editor. Cochrane Database of Systematic Reviews. 2015 Aug 22;
24. Ghai S, Ghai I, Schmitz G, Effenberg AO. Effect of rhythmic auditory cueing on parkinsonian gait: a systematic review and meta-analysis. Sci Rep. 2018;8(1):506.
25. Beeler JA, Cao ZF, Kheirbek MA, Ding Y, Koranda J, Murakami M, et al. Dopamine-dependent motor learning: insight into levodopa's long-duration response. Ann Neurol. 2010;67(5):639-647.

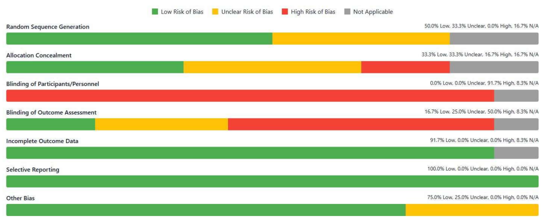

Figure 1 :- Risk of bias across domains

Figure 2:- risk of bias assessment for individual studies

Domain	Low Risk (%)	Unclear Risk (%)	High Risk (%)	Not Applicable (%)
Random Sequence Generation	50.0	33.3	0.0	16.7
Allocation Concealment	33.3	33.3	16.7	16.7
Blinding of Participants/Personnel	0.0	0.0	91.7	8.3
Blinding of Outcome Assessment	16.7	25.0	50.0	8.3
Incomplete Outcome Data	91.7	0.0	0.0	8.3
Selective Reporting	100.0	0.0	0.0	0.0
Other Bias	75.0	25.0	0.0	0.0

figure 3 :- detailed risk of bias assessment percentages