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Review

# Dual-Task Training and Walking Performance After Stroke: Neurological and Functional Perspectives

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**Abstract**

Post-stroke ambulation demands significant cognitive regulation, particularly in complex environments that require concurrent motor and cognitive processing. Challenges in the coordination between cognitive functions and motor skills lead to reduced adaptability in walking, an increased fall risk, and limitations in moving around the community among stroke survivors. To integrate recent evidence on dual-task gait training post-stroke, with particular focus on the neurological mechanisms underlying cognitive-motor interference and their

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relationship to functional walking outcomes. A structured literature search was conducted using PubMed and Scopus to identify studies published between January 2015 and December 2025. Medical Subject Headings (MeSH) and related keywords on dual-task walking training, cognitive-motor interference (CMI), and stroke rehabilitation were used to retrieve relevant evidence. The review focused on the neurological mechanisms underlying gait coordination and the effects of dual-task interventions on walking performance in stroke survivors. The Scale guided the methodological rigor of the narrative review for the Assessment of Narrative Review Articles (SANRA). The examined studies indicated that participation in dual-task gait training was positively correlated with enhancements in walking speed, stride parameters, stability, and overall walking performance, even under cognitive load. Neuroimaging and neurophysiological investigations consistently reported increased recruitment of prefrontal and premotor-supplementary motor networks during dual-task walking, reflecting compensatory cortical recruitment and diminished gait automaticity post-stroke. Training-related modifications in cortical activation patterns imply enhanced neural efficiency and adaptive reorganization of cognitive-motor control networks. The use of dual-task gait training is considered a neurologically validated strategy to diminish the cognitive-motor obstacles that occur after stroke. By focusing on executive control and cortical network activation during ambulation, dual-task paradigms may facilitate functional gait recovery across the stroke phases/Further investigation integrating neurophysiological measures with clinical outcomes is warranted.

**Keywords**
Dual-task training; walking performance; stroke; post-stroke ambulation

## 1. Introduction

Stroke is a leading cause of adult disability worldwide, frequently resulting in persistent gait impairments and reduced functional mobility that limit independent ambulation and quality of life [1-3]. Cognitive-motor interactions play a crucial role in human walking, and the ability to perform concurrent cognitive and motor tasks (dual tasking) is essential for safe navigation of complex real-world environments [4]. However, stroke survivors commonly exhibit pronounced deficits in dual-task walking, characterized by decreased gait speed, shortened stride length, and increased cognitive-motor interference relative to age-matched controls, which in turn elevate fall risk and reduce community participation [5]. Traditional single-task gait rehabilitation may not sufficiently address these deficits, prompting the emergence of dual task training paradigms that integrate concurrent cognitive and motor challenges into gait practice [6]. Emerging evidence from randomized controlled trials and meta-analyses indicates that dual-task training can significantly improve dual-task walking performance, including step length, cadence, and 10-meter walk test results in post-stroke populations. However, effects on balance and single-task gait speed remain variable across studies [7]. Mechanistically, dual-task training is thought to enhance cognitive resource allocation and executive control during locomotion by engaging shared neural networks and promoting neuroplastic adaptation, thereby improving both motor and cognitive function post-stroke [8]. Despite these promising findings, inconsistencies in intervention protocols, task complexity, and outcome measures across studies underscore the need to synthesize current evidence to inform clinical practice and future research.

Stroke should not be regarded as a single disease entity but rather as a heterogeneous cerebrovascular syndrome encompassing distinct etiologies, clinical trajectories, and recovery potentials [9]. Accurate neurological characterization therefore requires differentiation among major stroke subtypes, including cardioembolic, atherothrombotic, lacunar (small-vessel disease), and other less common ischemic strokes, as well as intracerebral hemorrhage. These subtypes differ in their underlying vascular mechanisms, risk-factor profiles, biomarker signatures, and patterns of brain network disruption. Such pathophysiological heterogeneity influences the extent of executive network impairment and, consequently, modulates the severity of cognitive-motor interference and the response to dual-task rehabilitation.

## 2. Methods

### *2.1 Study Design and Guidelines*

This review was conducted as a structured narrative review to provide a comprehensive synthesis of current evidence on dual-task walking interventions after stroke. Although not designed as a systematic review, the literature identification, screening, and selection processes were guided by the Scale for the Assessment of Narrative Review Articles (SANRA) to enhance methodological transparency, reduce selection bias, and improve reproducibility. This framework facilitated a structured appraisal of the neurological mechanisms and functional outcomes associated with dual-task gait rehabilitation.

### *2.2 Search Strategy and Information Sources*

A comprehensive literature search was performed in PubMed/MEDLINE and Scopus to identify studies published between January 2015 and December 2025. The search strategy combined Medical Subject Headings (MeSH) and free-text terms related to stroke, dual-task training, cognitive-motor interference, gait performance, and neuroplasticity using Boolean operators (AND, OR). The search strategy was as follows: (“stroke” OR “cerebrovascular accident” OR “hemiparesis” OR “brain infarction”) AND (“dual-task training” OR “dual-task walking” OR “cognitive-motor interference” OR “concurrent training”) AND (“gait performance” OR “walking speed” OR “stride parameters” OR “mobility” OR “fall risk” OR “neuroplastic change”). To maximize retrieval, the reference lists of eligible articles, relevant systematic reviews, and meta-analyses were manually screened to identify additional studies not captured through the electronic database search.

### *2.3 Eligibility Criteria*

Studies were selected according to predefined eligibility criteria to ensure the clinical relevance and methodological consistency of the evidence. Eligible studies included randomized controlled trials, non-randomized clinical trials, and quasi-experimental studies investigating dual-task interventions in adult stroke survivors (≥18 years) with ischemic or hemorrhagic stroke across the acute, subacute, or chronic stages. Interventions were required to incorporate simultaneous motor-cognitive or motor-motor dual-task paradigms and to compare these with single-task training, conventional rehabilitation, or no intervention. Studies were also required to report quantitative measures of gait performance, including gait speed, stride length, cadence, dual-task cost, or other neurophysiological outcomes, and to be published as full-text articles in peer-reviewed English-language journals.

Conference abstracts, editorials, case reports, book chapters, dissertations, and animal or pediatric studies were excluded. Studies evaluating isolated cognitive or motor training without concurrent dual-task components, as well as those lacking quantitative gait-related outcome data, were also excluded.

### *2.4 Study Selection and Qualitative Synthesis*

Study selection was performed in two sequential stages. First, two reviewers independently screened the titles and abstracts of all retrieved records according to the predefined eligibility criteria. Potential disagreements were resolved through discussion and, when necessary, consultation with a third-party neurorehabilitation expert. Full-text articles meeting the initial screening criteria were subsequently assessed independently for final inclusion. Data extraction included study characteristics, participant demographics, stroke subtype, intervention protocols, comparator interventions, outcome measures, and principal findings related to gait performance and neurophysiological adaptations. The extracted evidence was synthesized narratively to characterize the effects of dual-task walking interventions and to integrate current knowledge regarding their underlying neurorehabilitation mechanisms. The results were summarized in Table 1.

**Table 1** Summary of Studies on Dual-Task Walking Training Post-Stroke.

| **Study ID (Author, Year)** | **Design & Participants (n, Stroke Phase)** | **Intervention (Dual-Task Type)** | **Main Gait Outcomes (Results)** |
|---|---|---|---|
| [7] | Meta-analysis & RCT review (Various Phases) | Cognitive-Motor Dual-Task | Significant improvements in gait and balance |
| [10] | RCT pilot, n = 28 (Chronic stroke) | Cognitive Dual-Task Gait Training vs Motor Dual-Task Gait Training vs conventional Physical Therapy | CDTT: improved stride length & DTC-speed<br>MDTT: improved gait speed, stride length, DTC-speed |
| [11] | RCT-based meta-analysis (not a single primary RCT), Chronic stroke | Cognitive-motor Dual-Task training (pooled across multiple RCTs) | Improvements in gait speed, cadence, stride length |
| [12] | Single-blind RCT, n = 25 (Chronic stroke) | Motor-Motor Dual Task (4-week ball exercise/tray-carrying) vs no training | Improved gait speed, cadence, stride time, stride length, and Functional Ambulation Profile during single- and dual-task walking |

| | | | |
|---|---|---|---|
| [13] | RCT, n = 26 (Chronic stroke) | Progressive Treadmill Cognitive Dual-Task Gait Training vs Conventional Treadmill Gait Training | PTCDG showed improvement in gait speed, stride length, and cadence, with reduced double-support time. |
| [14] | RCT, n = 34 (Chronic stroke) | Simultaneous (concurrent) treadmill Cognitive Dual-Task gait training vs same components delivered separately | The simultaneous Dual-Task group achieved improvements in dual-task gait speed, stride length, variability, dual-task cost, and fall efficacy. |
| [15] | RCT, n = 57, randomized to 3 groups (Cognitive-Motor Multi-Task, Cognitive Dual-Task, Motor Dual-Task) (Ambulatory stroke, Chronic stroke) | Multi-task balance training combining stepping, postural transitions, and concurrent cognitive tasks | Both Cognitive-Motor Multi-Task and Cognitive Dual-Task groups demonstrated the greatest improvements in gait speeds under single- and dual-task conditions post-treatment and at follow-up. Only the Cognitive-Motor Multi-Task group demonstrated significant improvements in dual-task TUG, FGA, and ABC at post-treatment and follow-up. |
| [16] | Single-blind RCT, n = 34 (Subacute to chronic stroke) | Dual-task cognitive-gait walking vs aerobic exercise (treadmill, cycling, pedal exerciser), 12 weeks | Gait outcomes were not primarily reported; aerobic exercise produced greater cognitive gains than dual-task walking. |

### *2.5 Pathophysiology of Gait Impairment After Stroke*

Post-stroke gait impairment is primarily driven by motor deficits such as muscle weakness, spasticity, and impaired coordination, which are direct consequences of upper motor neuron lesions. Hemiparesis and reduced force generation in the lower extremity diminish propulsion and compromise gait symmetry, leading to reduced walking speed and step length. In addition to motor weakness, sensory and proprioceptive dysfunction contributes significantly to gait abnormalities after stroke. Impaired proprioception, the loss of accurate afferent feedback about limb position and movement, disrupts corrective adjustments during the stance and swing phases, leading to instability and increased dependence on vision for balance control. Observational studies have shown that deficits in sensory reweighting, including proprioceptive processing, are associated with greater walking impairment severity in chronic stroke survivors, indicating that disrupted somatosensory integration undermines postural control during gait [17, 18].

Stroke-related proprioceptive loss often co-occurs with diminished tactile and vibration sensation, further degrading the central nervous system’s ability to regulate timing and coordination during locomotion. Reduced somatosensory input from the affected limb limits anticipatory postural adjustments and reduces the precision of foot placement, thereby increasing variability in step length and gait rhythm. Thus, sensory pathway damage—especially involving proprioceptive circuits—has been implicated as a key contributor to maladaptive gait patterns that persist even when motor strength partially recovers [18]. Beyond sensorimotor impairments, cognitive and executive dysfunctions play a substantial role in post-stroke gait disturbance. Patients with greater cognitive impairment often exhibit poorer gait performance and slower rehabilitation progress, suggesting that effective ambulation depends not only on motor capacity but also on higher-order neural processes that guide adaptive locomotion [19]. Deficits in these cognitive domains exacerbate gait variability and increase fall risk, indicating that post-stroke walking is not an automated motor act but a cognitively demanding task. This cognitive-motor interaction underscores the need to incorporate attention and executive function assessments into gait rehabilitation [20].

### *2.6 Neurological Framework of Dual Tasking After Stroke*

After stroke, walking in real-world environments rarely occurs in isolation: survivors must ambulate while talking, scanning traffic, or manipulating objects, and such dual-task situations reliably elicit disproportionate decrements in gait speed, spatial-temporal regularity, and cognitive performance compared with age-matched adults without stroke, reflecting heightened cognitive-motor interference (CMI). Experimental work demonstrates that adding a concurrent cognitive task (for example, serial subtraction or auditory Stroop) during overground walking produces higher dual-task costs on gait and cognition in people with stroke than in neurologically healthy controls, indicating a reduced capacity to flexibly share limited attentional resources between locomotor and non-locomotor tasks [10, 21]. From a theoretical perspective, dual-task behaviour after stroke can be understood through capacity-sharing and bottleneck models of attention, in which damaged neural systems require greater voluntary control to maintain basic gait stability, leaving fewer resources for concurrent information processing [22, 23].

Dual-task walking requires simultaneous engagement of cognitive and motor systems, particularly executive functions that allocate attention and regulate gait. Primary neuroimaging research in healthy adults showed that dual-task walking increases prefrontal cortex activation, demonstrating that higher-order cognitive control is essential for coordinating concurrent cognitive-motor demands [24-26]. In stroke survivors, lesions affecting frontal and parietal regions disrupt these executive control circuits, resulting in impaired coordination between cognitive task execution and gait modulation [27]. This disruption reduces adaptability during ambulation under cognitive load, reflected in slower gait speed and diminished stability during dual-task walking. Individual differences in motor and cognitive impairment further refine this theoretical model. In community-dwelling adults with chronic stroke, higher dual-task costs on gait are correlated with poorer lower-limb motor scores and slower usual gait speed, implying that those with greater baseline impairment operate closer to their attentional capacity limits even in single-task conditions [28]. Deficits in executive function and processing speed similarly magnify gait-related dual-task interference, indicating that the integrity of fronto-subcortical networks shapes the effectiveness with which patients allocate resources across concurrent tasks. The dual-task paradigm captures the interaction between residual motor control, cognitive reserve, and compensatory frontal recruitment after stroke.

Neurophysiological studies suggest that dual-task (motor-cognitive) practice after stroke engages a distributed cortical control network—with particularly strong contributions from the prefrontal cortex (PFC) (attentional/executive control) and premotor-supplementary motor areas (planning and gait regulation)—and that rehabilitation may work partly by reshaping how intensively this network must be recruited to maintain performance. Using fNIRS during dual-task walking, Lu and colleagues showed that adding a concurrent cognitive task increases activation across PFC and motor-planning regions (PMC/SMA), and that greater PMC/SMA activation covaries with gait metrics during interference, consistent with compensatory cortical upregulation to stabilize gait when automaticity is reduced post-stroke [29]. In subacute hemiplegic stroke, Nosaka et al. similarly found higher PFC oxygenation during dual-task stepping/walking than during single tasks, with a notable contralesional predominance across conditions and meaningful associations between PFC activation, frontal-lobe function scores, and dual-task interference—supporting the idea that post-stroke dual-tasking depends on executive “top-down” resources whose availability constrains motor-cognitive trade-offs [30]. Complementing hemodynamic measures, an intervention study leveraging EEG (FFT-based spectral analysis) reported that after a short course of dual-task training, participants showed reductions across multiple EEG bands (delta-beta) alongside clinical improvements, a pattern the authors interpret as training-related modulation of cortical dynamics (potentially reflecting reduced maladaptive slow-wave activity and/or greater neural efficiency). However, the small sample underscores the need for larger mechanistic trials linking spectral shifts directly to dual-task gait outcomes [31]. This evidence indicates that dual-task training after stroke promotes adaptive reorganization of cortical networks involved in executive control and motor planning. Training appears to modulate prefrontal and premotor-supplementary motor area activity, enhancing neural efficiency during cognitively demanding gait and supporting improved motor-cognitive integration.

When evaluating dual-task performance after stroke, the effects of the acute lesion should be interpreted within the context of pre-existing cerebral white matter pathology. Advancing age is frequently accompanied by chronic vascular risk factors, including hypertension, dyslipidemia, metabolic syndrome, and impaired glucose metabolism, which contribute to cerebral small vessel disease and the development of white matter hyperintensities. These microstructural alterations, reflected by reduced fractional anisotropy on diffusion imaging, are associated with slower information processing and impaired executive function [32]. Collectively, they disrupt fronto-subcortical networks that support attentional control and cognitive flexibility, thereby diminishing cognitive reserve before stroke onset [33]. Superimposition of an acute ischemic or hemorrhagic lesion on this pre-existing network vulnerability further compromises neural systems involved in attentional allocation and executive control. As a result, individuals with a greater burden of white matter pathology exhibit higher dual-task costs, poorer gait performance, and reduced capacity to allocate cognitive resources during complex walking tasks [34-36].

### *2.7 Differences in Brain Responses to Dual Tasks in Lacunar and Non-Lacunar Stroke*

An important yet underexplored area of neurorehabilitation research is the differential response to dual-task interventions between lacunar and non-lacunar ischemic stroke. These stroke subtypes differ substantially in their underlying vascular pathology, lesion distribution, and functional consequences, which may influence rehabilitation outcomes. Lacunar stroke, resulting from cerebral small vessel disease, primarily affects deep subcortical structures and is often associated with relatively favorable early functional recovery but an increased risk of executive dysfunction and vascular cognitive impairment over time [37].

Non-lacunar stroke, particularly large-artery and cardioembolic stroke, is more frequently associated with territorial or large-vessel infarction that may involve cortical motor, sensory and higher-order associative networks. By contrast, lacunar infarcts occur within deep subcortical structures, including the internal capsule, basal ganglia, thalamus, corona radiata and pons, and may disrupt corticospinal, thalamocortical or fronto-subcortical pathways. These differences in lesion topology could produce distinct patterns of motor and cognitive impairment relevant to dual-task walking. Cortical or corticospinal injury may predominantly constrain motor execution. In contrast, disruption of fronto-subcortical connectivity and accompanying cerebral small vessel disease may increase reliance on attentional and executive resources during gait. However, direct evidence demonstrating systematically greater cognitive-motor interference in lacunar than in non-lacunar stroke remains limited. Comparative studies stratified by stroke mechanism, lesion location, white matter disease burden and baseline impairment are therefore needed to determine whether dual-task rehabilitation should be tailored according to ischemic stroke subtype [38-42].

### *2.8 Types of Dual-Task Interventions*

In stroke rehabilitation, dual tasks are typically grouped into motor-motor (e.g., walking while carrying a tray) and cognitive-motor (e.g., walking while doing serial subtraction or verbal fluency), and the chosen secondary task strongly shapes the type and magnitude of interference observed [10]. Because task demands are not interchangeable, modern frameworks emphasize matching tasks to targeted real-world goals and documenting task features (domain, complexity, prioritization demands) to improve interpretability and comparability across studies [43]. Critically, task complexity and ecological validity matter: dual-task performance can change substantially when walking is tested in more context-rich, challenging environments (e.g., stepping targets or obstacles) rather than in straight, unobstructed corridors, supporting the idea that assessment—and training—should resemble daily-life walking to capture clinically relevant cognitive-motor control [44].

Cognitive-motor dual-task training typically combines walking with concurrent cognitive tasks, such as mental arithmetic, verbal fluency, or working memory challenges, to reduce cognitive-motor interference and improve gait adaptability in complex environments. Randomized trials in people with stroke show that cognitive-motor dual-task gait training yields greater gains in gait speed, balance, and dual-task cost than single-task gait training, particularly when tasks are progressively difficult and task-specific to community ambulation [5, 11, 45]. These interventions are most effective when therapists explicitly instruct patients how to prioritize tasks (gait first vs cognitive first) and when outcome measures capture both gait and cognitive performance under dual-task conditions [5, 46]. Motor-motor dual-task training emphasizes simultaneous performance of two motor activities, for example, obstacle negotiation while carrying objects, manipulating the upper limb, or performing postural transitions. Studies in stroke and older adults demonstrate that adding secondary motor tasks to balance or gait exercises increases postural demand, improves dynamic balance, and enhances mobility. However, it may temporarily increase gait variability during training

[47]. Experimental work on obstacle crossing shows that both physical and cognitive secondary tasks can degrade step length and clearance, underscoring the need to grade task difficulty and provide appropriate safety measures (e.g., harness, close supervision) when training obstacle negotiation under dual-task conditions [48].

Dual-task interventions can be implemented on treadmills, overground, or in combined paradigms, and the choice of modality influences both gait biomechanics and dual-task interference. Comparative work in stroke survivors suggests that treadmill walking can promote more automatic and symmetrical gait patterns, while overground training may better approximate real-world demands, especially during obstacle negotiation and turning [49, 50]. Experimental dual-task studies indicate that overground walking often shows larger decrements in stride velocity and increased variability under dual-task conditions. In contrast, treadmill walking may maintain gait performance with reduced prefrontal activation, consistent with greater locomotor automaticity [51, 52]. Dual-task training may be delivered individually or in group-based formats, each with distinct advantages for feasibility and adherence. Group programs have been shown in older adults to improve mobility, executive function, and dual-task performance, and they may enhance motivation through social interaction [53]. By systematically integrating cognitive-motor and motor-motor challenges across various delivery formats and environments, these interventions can enhance gait adaptability, safety, and real-world functional mobility. Future clinical practice and research should prioritize individualized task progression, standardized outcome measures, and long-term follow-up to optimize translation of dual-task training.

### *2.9 Evidence from Randomized Controlled Trials on Walking Performance*

Randomized controlled trials evaluating dual-task training after stroke consistently indicate that embedding concurrent cognitive or motor challenges into gait practice can yield measurable gains in walking performance, particularly under dual-task conditions. In one of the earliest trials, Yang and colleagues randomly assigned individuals with chronic stroke to a dual-task exercise program incorporating concurrent cognitive and motor challenges during walking or to conventional exercise; the dual-task group showed greater improvements in gait velocity, stride length, and walking endurance, suggesting that practicing walking under attentionally demanding conditions enhances locomotor capacity beyond single-task therapy of similar duration. Treadmill-based cognitive dual-task paradigms provide more granular evidence that adding a concurrent cognitive task to gait training can modify spatiotemporal gait parameters and reduce dual-task cost. Kim and colleagues applied progressive treadmill cognitive dual-task training where participants walked while performing increasingly challenging mental tasks and showed significant gains in gait speed, stride length, and symmetry under both single and dual-task conditions relative to conventional treadmill training, indicating that the nervous system can be trained to manage cognitive-motor interference more efficiently [13]. Baek et al extended this approach in a randomized trial of chronic stroke survivors, comparing treadmill gait training delivered simultaneously with a cognitive task versus the same gait and cognitive components administered in separate blocks; only the simultaneous dual-task group achieved superior improvements in dual-task gait speed, stride length, variability, and dual-task cost, together with enhanced fall efficacy, implying that temporal co-occurrence of motor and cognitive demands is a critical ingredient for transfer to complex walking [14].

Other RCTs have emphasised overground and visually mediated dual-task paradigms, reinforcing the generalisability of these benefits across task formats. In a trial of visual cognitive dual-task training, Lee and colleagues asked chronic stroke patients to perform visual attention tasks while standing and walking with virtual reality, demonstrating improvements in balance and gait measures, including Timed Up and Go and Berg Balance Test, beyond those seen with conventional balance training, suggesting that targeting visuospatial attention during locomotion may be particularly relevant for obstacle negotiation in the community [54]. More recent randomized studies have embedded dual-task elements within broader multi-component rehabilitation programmes. Zhang et al evaluated a structured cognitive-motor dual-task training regimen in subacute and chronic stroke, reporting improvements in lower-limb motor scores and functional mobility that exceeded those of conventional therapy, with secondary analyses indicating favourable changes in gait speed and balance under challenging conditions [7]. Liang and colleagues tested multi-task balance training that combined stepping, postural transitions, and concurrent cognitive tasks in ambulatory stroke survivors, finding that this approach improved dual-task walking performance and dynamic balance more than balance exercises alone, which supports the notion that coupling postural control with concurrent information processing is essential for preparing patients for real-world ambulation [15].

Not all RCTs, however, demonstrate clear superiority of dual-task training over well-dosed single-task interventions, underscoring the importance of training intensity and patient selection. In a single-blind randomized clinical trial, Maeneja and colleagues compared a 12-week dual-task cognitive-gait programme with an aerobic exercise protocol (treadmill, cycling, and pedal exerciser) in people with subacute to chronic stroke; while both groups trained three times per week, aerobic exercise produced greater gains in cognitive attention and perceived exertion than dual-task walking, suggesting that when overall dose and cardiovascular load are high, generic aerobic training may match or exceed dual-task protocols for some outcomes [16]. Taken together, the RCT evidence indicates that dual-task training can improve walking performance, especially gait speed, step length, cadence, and dual-task cost after stroke, but its advantage over intensity-matched single-task or aerobic programmes is not uniform and appears to depend on task design, training dose, and the baseline level of cognitive-motor interference in the target population.

## 3. Conclusion, Limitation and Future Directions

### *3.1 Conclusion & Limitations*

Dual-task training holds profound promise for restoring functional independence after a stroke; however, the field currently stands at a crossroads. Despite growing evidence supporting dual-task training for post-stroke rehabilitation, several methodological limitations continue to constrain the interpretation and clinical translation of current findings. Considerable heterogeneity exists across studies in intervention protocols, task characteristics, training intensity, session duration, and outcome measures. Recurrent limitations include small sample sizes, inadequate blinding, and insufficiently powered subgroup analyses, which reduce the certainty and generalizability of the available evidence. In addition, follow-up periods are generally short, limiting understanding of the long-term sustainability of improvements in gait and cognition, as well as their impact on community mobility and fall prevention.

### *3.2 Future Directions*

Future studies should prioritize greater methodological standardization to improve comparability across trials and facilitate high-quality evidence synthesis. The development of standardized intervention protocols and core outcome sets would strengthen future meta-analyses and support the translation of research into clinical practice. Large, multicenter randomized controlled trials with adequate statistical power are also needed to evaluate treatment effects across clinically relevant subgroups, including stroke stage, lesion characteristics, and baseline functional impairment. Advances in neuroimaging and computational approaches may further enable a more individualized rehabilitation strategy. Integration of structural and functional neuroimaging modalities, including diffusion MRI, mobile functional near-infrared spectroscopy (fNIRS), and high-density electroencephalography (EEG), with machine-learning approaches may improve patient stratification according to lesion topology, white matter integrity, and network dysfunction. Such approaches have the potential to identify patients who are most likely to benefit from specific dual-task interventions. Technology-assisted rehabilitation, including virtual reality and exergaming, represents another promising direction by enabling ecologically relevant and progressively challenging cognitive-motor training. Integrating these technologies with personalized neuroimaging-based prediction models may facilitate precision rehabilitation, tailoring interventions to individual neurological profiles while improving long-term functional recovery and community participation.

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## Author Contributions

Farida Arisanti: Conceptualization, methodology, literature search, formal analysis, investigation, data curation, writing - original draft, writing - review and editing. Bejo Ropii: Literature search, writing - original draft. Yunia Sribudiani: Supervision, writing - review and editing. Lisda Amalia: Supervision, writing - review and editing. Julia Patrick Engkasan: Supervision, writing - review and editing. Vitriana Biben: Supervision, writing - review and editing. All authors have read and approved the published version of the manuscript.

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## Competing Interests

The authors have declared that no competing interests exist.

**Data Availability Statement**

The data supporting the findings of this study are available within the article. No new datasets were generated or analyzed during this study.

**AI-Assisted Technologies Statement**

Artificial intelligence (AI) tools were limited to basic grammar correction and language refinement in the preparation of this manuscript. Specifically, Gemini AI was used to improve the readability and structural signposting of the English text. These tools were used as rephrasing and copy-editing assistants and did not contribute to the generation of research data, scientific interpretation or the derivation of conclusions. All scientific content was developed independently by the authors. We have carefully revised and edited the AI text to ensure its accuracy, reliability and compliance with the publication's criteria. The authors accept full responsibility for the content of the manuscript.

**References**

1. Buvarp D, Rafsten L, Sunnerhagen KS. Predicting longitudinal progression in functional mobility after stroke: A prospective cohort study. Stroke. 2020; 51: 2179-2187.
2. Khan F, Chevidikunnan MF, González-Bernal J, Soto-Cámara R. Prevalence of balance impairment and factors associated with balance among patients with stroke. A cross sectional retrospective case control study. Healthcare. 2021; 9: 320.
3. Rössler R, Bridenbaugh SA, Engelter ST, Weibel R, Infanger D, Giannouli E, et al. Recovery of mobility function and life-space mobility after ischemic stroke: The MOBITEC-Stroke study protocol. BMC Neurol. 2020; 20: 348.
4. Klotzbier TJ, Schott N. Cognitive-motor interference during walking in older adults with probable mild cognitive impairment. Front Aging Neurosci. 2017; 9: 350.
5. Deblock-Bellamy A, Lamontagne A, Blanchette AK. Cognitive-locomotor dual-task interference in stroke survivors and the influence of the tasks: A systematic review. Front Neurol. 2020; 11: 882.
6. Tao W, Chen J, Peng J, Xiao W. Comparing the effectiveness of dual-task and single-task training on walking function in stroke recovery: A systematic review and meta-analysis. Medicine. 2025; 104: e41776.
7. Zhang L, Ma J, Liu X, Jin A, Wang K, Yin X. Cognitive-motor dual-task training on gait and balance in stroke patients: Meta-analytic report and trial sequential analysis of randomized clinical trials. J Neuroeng Rehabil. 2024; 21: 227.
8. Shu Y, Bi MM, Zhou TT, Liu L, Zhang C. Effect of dual-task training on gait and balance in stroke patients: An updated meta-analysis. Am J Phys Med Rehabil. 2022; 101: 1148-1155.
9. Gasull T, Arboix A. Molecular mechanisms and pathophysiology of acute stroke: Emphasis on biomarkers in the different stroke subtypes. Int J Mol Sci. 2022; 23: 9476.
10. Liu YC, Yang YR, Tsai YA, Wang RY. Cognitive and motor dual task gait training improve dual task gait performance after stroke-A randomized controlled pilot trial. Sci Rep. 2017; 7: 4070.
11. Zhou Q, Yang H, Zhou Q, Pan H. Effects of cognitive motor dual-task training on stroke patients: A RCT-based meta-analysis. J Clin Neurosci. 2021; 92: 175-182.

12. Yang YR, Wang RY, Chen YC, Kao MJ. Dual-task exercise improves walking ability in chronic stroke: A randomized controlled trial. Arch Phys Med Rehabil. 2007; 88: 1236-1240.
13. Kim KJ, Kim KH. Progressive treadmill cognitive dual-task gait training on the gait ability in patients with chronic stroke. J Exerc Rehabil. 2018; 14: 821-828.
14. Baek CY, Chang WN, Park BY, Lee KB, Kang KY, Choi MR. Effects of dual-task gait treadmill training on gait ability, dual-task interference, and fall efficacy in people with stroke: A randomized controlled trial. Phys Ther. 2021; 101: pzab067.
15. Lai LC, Hsu AL, Hu GC, Ou YC, Chen AC, Chuang LL. Cognitive and motor multi-task balance training improves dual-task walking performance in ambulatory patients after stroke: A randomized controlled trial. Disabil Rehabil. 2026; 48: 1617-1635.
16. Maeneja R, Silva CR, Ferreira IS, Abreu AM. Aerobic physical exercise versus dual-task cognitive walking in cognitive rehabilitation of people with stroke: A randomized clinical trial. Front Psychol. 2023; 14: 1258262.
17. Awosika OO, Garver A, Drury C, Sucharew HJ, Boyne P, Schwab SM, et al. Insufficiencies in sensory systems reweighting is associated with walking impairment severity in chronic stroke: An observational cohort study. Front Neurol. 2023; 14: 1244657.
18. Kochman M, Kasprzak M, Kielar A. The impact of proprioception impairment on gait function in stroke survivors: A comprehensive review. Front Neurol. 2025; 16: 1577919.
19. VanGilder JL, Hooyman A, Peterson DS, Schaefer SY. Post-stroke cognitive impairments and responsiveness to motor rehabilitation: A review. Curr Phys Med Rehabil Rep. 2020; 8: 461-468.
20. Yogev-Seligmann G, Hausdorff JM, Giladi N. The role of executive function and attention in gait. Mov Disord. 2008; 23: 329-342.
21. Plummer P, Zukowski LA, Feld JA, Najafi B. Cognitive-motor dual-task gait training within 3 years after stroke: A randomized controlled trial. Physiother Theory Pract. 2022; 38: 1329-1344.
22. Pashler H. Dual-task interference in simple tasks: Data and theory. Psychol Bull. 1994; 116: 220-244.
23. Tombu M, Jolicoeur P. A central capacity sharing model of dual-task performance. J Exp Psychol Hum Percept Perform. 2003; 29: 3-18.
24. Al-Yahya E, Johansen-Berg H, Kischka U, Zarei M, Cockburn J, Dawes H. Prefrontal cortex activation while walking under dual-task conditions in stroke: A multimodal imaging study. Neurorehabil Neural Repair. 2016; 30: 591-599.
25. Fraser SA, Dupuy O, Pouliot P, Lesage F, Bherer L. Comparable cerebral oxygenation patterns in younger and older adults during dual-task walking with increasing load. Front Aging Neurosci. 2016; 8: 240.
26. Mirelman A, Maidan I, Bernad-Elazari H, Nieuwhof F, Reelick M, Giladi N, et al. Increased frontal brain activation during walking while dual tasking: An fNIRS study in healthy young adults. J Neuroeng Rehabil. 2014; 11: 85.
27. Hawkins KA, Fox EJ, Daly JJ, Rose DK, Christou EA, McGuirk TE, et al. Prefrontal over-activation during walking in people with mobility deficits: Interpretation and functional implications. Hum Mov Sci. 2018; 59: 46-55.
28. Plummer P, Villalobos RM, Vayda MS, Moser M, Johnson E. Feasibility of dual-task gait training for community-dwelling adults after stroke: A case series. Stroke Res Treat. 2014; 2014: 538602.

29. Lu CF, Liu YC, Yang YR, Wu YT, Wang RY. Maintaining gait performance by cortical activation during dual-task interference: A functional near-infrared spectroscopy study. PLoS One. 2015; 10: e0129390.
30. Nosaka S, Imada K, Saita K, Okamura H. Prefrontal activation during dual-task seated stepping and walking performed by subacute stroke patients with hemiplegia. Front Neurosci. 2023; 17: 1169744.
31. Asadi B, Khodabakhshi Z, Naimi SS, Herrero P, Ansari NN, Lapuente-Hernandez D. Effect of dual-task training on the number of EEG bands in stroke patients. Physiother Res Int. 2025; 30: e70065.
32. Segura B, Jurado MÁ, Freixenet N, Bargalló N, Junqué C, Arboix A. White matter fractional anisotropy is related to processing speed in metabolic syndrome patients: A case-control study. BMC Neurol. 2010; 10: 64.
33. Mukli P, Detwiler S, Owens CD, Csipo T, Lipecz A, Pinto CB, et al. Gait variability predicts cognitive impairment in older adults with subclinical cerebral small vessel disease. Front Aging Neurosci. 2022; 14: 1052451.
34. Markus HS, Joutel A. The pathogenesis of cerebral small vessel disease and vascular cognitive impairment. Physiol Rev. 2025; 105: 1075-1171.
35. Pieruccini-Faria F, Cornish B, Binns M, Fraser J, Haddad SM, Sunderland K, et al. Association of dual-task gait cost and white matter hyperintensity burden poststroke: Results from the ONDRI. Neurorehabil Neural Repair. 2023; 37: 434-443.
36. Ward N, Menta A, Peach S, White SA, Jaffe S, Kowaleski C, et al. Cognitive motor dual task costs in older adults with motoric cognitive risk syndrome. J Frailty Aging. 2021; 10: 337-342.
37. Arboix A, Massons J, García-Eroles L, Targa C, Comes E, Parra O, et al. Nineteen-year trends in risk factors, clinical characteristics and prognosis in lacunar infarcts. Neuroepidemiology. 2010; 35: 231-236.
38. Beume LA, Hieber M, Kaller CP, Nitschke K, Bardutzky J, Urbach H, et al. Large vessel occlusion in acute stroke. Stroke. 2018; 49: 2323-2329.
39. Cheng B, Knaack C, Forkert ND, Schnabel R, Gerloff C, Thomalla G. Stroke subtype classification by geometrical descriptors of lesion shape. PLoS One. 2017; 12: e0185063.
40. Collett J, Fleming MK, Meester D, Al-Yahya E, Wade DT, Dennis A, et al. Dual-task walking and automaticity after Stroke: Insights from a secondary analysis and imaging sub-study of a randomised controlled trial. Clin Rehabil. 2021; 35: 1599-1610.
41. Plummer-D'Amato P, Altmann LJ, Saracino D, Fox E, Behrman AL, Marsiske M. Interactions between cognitive tasks and gait after stroke: A dual task study. Gait Posture. 2008; 27: 683-688.
42. Yaghi S, Raz E, Yang D, Cutting S, Mac Grory B, Elkind MS, et al. Lacunar stroke: Mechanisms and therapeutic implications. J Neurol Neurosurg Psychiatry. 2021; 92: 823-830.
43. Wollesen B, Wanstrath M, van Schooten KS, Delbaere K. A taxonomy of cognitive tasks to evaluate cognitive-motor interference on spatiotemoporal gait parameters in older people: A systematic review and meta-analysis. Eur Rev Aging Phys Act. 2019; 16: 12.
44. Timmermans C, Roerdink M, Janssen TWJ, Meskers CGM, Beek PJ. Dual-task walking in challenging environments in people with stroke: Cognitive-motor interference and task prioritization. Stroke Res Treat. 2018; 2018: 7928597.

45. Plummer-D'Amato P, Kyvelidou A, Sternad D, Najafi B, Villalobos RM, Zurakowski D. Training dual-task walking in community-dwelling adults within 1 year of stroke: A protocol for a single-blind randomized controlled trial. BMC Neurol. 2012; 12: 129.
46. Zhang X, Wang Q, Li Q, Liu H, Wan X. Comparative effects of arithmetic, speech, and motor dual-task walking on gait in stroke survivors: A cross-sectional study. Front Hum Neurosci. 2025; 19: 1587153.
47. Brustio PR, Rabaglietti E, Formica S, Liubicich ME. Dual-task training in older adults: The effect of additional motor tasks on mobility performance. Arch Gerontol Geriatr. 2018; 75: 119-124.
48. Kaewkaen K, Chueathaeo T, Angart S, Chomkan S, Uttama S, Chaiut W, et al. The interactive effect of cognitive and physical dual task interventions on obstacle negotiation while walking in healthy young, and older, adults. Neurol India. 2021; 69: 883-888.
49. Boyne P, Doren S, Scholl V, Staggs E, Whitesel D, Carl D, et al. Preliminary outcomes of combined treadmill and overground high-intensity interval training in ambulatory chronic stroke. Front Neurol. 2022; 13: 812875.
50. Puh U, Baer GD. A comparison of treadmill walking and overground walking in independently ambulant stroke patients: A pilot study. Disabil Rehabil. 2009; 31: 202-210.
51. Baek CY, Kim HD, Yoo DY, Kang KY, Woo Lee J. Effect of automaticity induced by treadmill walking on prefrontal cortex activation and dual-task performance in older adults. PLoS One. 2023; 18: e0287252.
52. Wrightson JG, Schäfer L, Smeeton NJ. Dual-task prioritization during overground and treadmill walking in healthy adults. Gait Posture. 2020; 75: 109-114.
53. Chau PH, Cheung DS, Kwok JY, Chan WC, Yu DS. Online group-based dual-task training to improve cognitive function of community-dwelling older adults: Randomized controlled feasibility study. JMIR Aging. 2025; 8: e67267.
54. Lee IW, Kim YN, Lee DK. Effect of a virtual reality exercise program accompanied by cognitive tasks on the balance and gait of stroke patients. J Phys Ther Sci. 2015; 27: 2175-2177.