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Effects of Dual-Task Training Combined with Environmental Adaptation Therapy on Executive Function and Community Walking Ability After Stroke: A Randomized Controlled Trial

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Abstract

Background: Executive dysfunction and impaired community ambulation are common after stroke, limiting independence and increasing fall risk. Dual-task training has shown promise in improving cognitive–motor integration, while environmental adaptation therapy enhances functional relevance and ecological validity. However, evidence for the combined effects of these approaches remains limited. **Objective:** To investigate the effects of dual-task training combined with environmental adaptation therapy on executive function and community walking ability in individuals with stroke. **Methods:** In this single-blind randomized controlled trial, participants with chronic stroke were randomly assigned to an intervention group receiving dual-task training integrated with environmental adaptation therapy or to a control group receiving conventional rehabilitation. Both groups trained 45 minutes per session, three times per week for eight weeks. Executive function was assessed using the Trail Making Test-Part B (TMT-B), Stroop Color-Word Test, and verbal fluency. Gait and community ambulation outcomes included dual-task gait speed, the Walking Adaptability Test, the Activity-specific Balance Confidence (ABC) Scale, and the Community Integration Questionnaire (CIQ). Assessments were conducted at baseline, post-intervention, and three-month follow-up. **Results:** Compared with the control group, the intervention group demonstrated significantly greater improvements in executive function, shown by reduced TMT-B completion time, improved Stroop interference scores, and higher verbal fluency performance (all $p < 0.01$). Significant group-by-time interactions were also observed for gait adaptability and dual-task gait speed ($p < 0.05$). Improvements in ABC and CIQ scores indicated enhanced walking confidence and better community participation in the intervention group. All gains were maintained at three-month follow-up. No serious adverse events occurred. **Conclusion:** Dual-task training combined with environmental adaptation therapy produced superior improvements in executive function, walking adaptability, and community participation compared with conventional rehabilitation. The combined approach appears feasible, safe, and ecologically meaningful, offering a promising strategy for enhancing cognitive–motor integration and real-world ambulation after stroke.

Keywords: Dual-task training, Environmental adaptation therapy, Executive function, Community ambulation, Stroke rehabilitation

1. Introduction

Stroke remains one of the most prevalent causes of adult disability globally, with millions of individuals experiencing persistent functional limitations each year[1]. Beyond motor impairments, cognitive dysfunction—particularly in domains involving executive function—has been increasingly recognized as a crucial determinant of long-term recovery[2]. Executive function encompasses a constellation of high-level cognitive processes such as planning, inhibitory control, cognitive flexibility, and working memory, all of which are essential for goal-directed mobility and safe interaction with complex environments. Post-stroke deficits in executive function have been shown to negatively influence gait stability, obstacle avoidance, route planning, hazard perception, and the ability to walk safely in dynamic community environments. Consequently, impairments in executive control substantially restrict patients' capacity for independent living and social participation[3].

Traditional neurorehabilitation has historically emphasized repetitive motor training focused on strength, balance, and gait pattern normalization. Although such approaches lead to improvements in basic mobility, they often fall short in addressing the cognitive demands inherent in natural walking contexts. Community ambulation requires constant integration of cognitive processes and environmental cues—simultaneously navigating obstacles,

processing unexpected stimuli, making rapid decisions, and managing concurrent tasks such as conversation or object manipulation. These cognitive–motor interactions are frequently compromised following stroke, contributing to reduced walking confidence, slow gait speed, and fear of falling. Thus, interventions targeting both cognitive and motor domains may hold significant value for improving real-world functional mobility.

Dual-task training (DTT) has emerged as a promising therapeutic approach designed to address precisely this challenge. DTT involves the concurrent performance of motor and cognitive tasks, thereby simulating the multitasking demands of daily life[4]. Growing evidence suggests that DTT can enhance cognitive processing, increase gait automaticity, and improve dual-task walking performance in various populations, including older adults and individuals with neurological disorders. In stroke survivors, DTT has been associated with improvements in gait speed, balance, and executive function; however, findings remain variable, and the extent to which DTT translates into enhanced community ambulation is still uncertain[5]. Notably, many existing DTT protocols are conducted in controlled laboratory or clinic environments, which may limit ecological validity[6].

Environmental adaptation therapy (EAT), on the other hand, represents a complementary strategy that emphasizes the interaction between the individual, the task, and the environment. Rooted in ecological and compensatory rehabilitation theories, EAT focuses on modifying environmental conditions, reorganizing task sequences, and training patients to effectively adapt their behaviors within realistic contexts. Core elements include contextual cueing, environmental restructuring, task simplification, compensatory strategies, and supervised practice in naturalistic environments such as hallways, community paths, or public spaces. Prior studies indicate that environmental modifications may reduce cognitive load, enhance safety, and support functional independence. Yet, EAT alone does not explicitly target the cognitive limitations that often constrain mobility after stroke.

The integration of DTT and EAT may therefore represent a synergistic approach, enabling simultaneous enhancement of cognitive capacity, motor performance, and environmental adaptability. By embedding dual-task demands within ecologically valid, context-specific environments, individuals may experience more effective generalization of skills from therapy to real-world community settings. To date, however, few rigorous randomized controlled trials have evaluated such an integrated intervention. Existing studies are often limited by small samples, heterogeneous protocols, or narrow outcome measures, leaving a gap in the evidence regarding comprehensive rehabilitation strategies that target both cognitive-motor interaction and environmental adaptability.

Thus, the present randomized controlled trial investigated the effects of a combined dual-task training and environmental adaptation therapy (DTT+EAT) program on executive function and community walking ability in individuals with subacute and chronic stroke. We hypothesized that the DTT+EAT intervention would produce greater improvements than conventional therapy in executive function, gait performance under single- and dual-task conditions, community ambulation capacity, and functional participation in daily activities.

2. Methods

2.1 Study Design

This study was a single-blind, parallel-group randomized controlled trial conducted in the rehabilitation department of a tertiary medical center. Participants were randomly assigned to either the experimental group receiving DTT+EAT or the control group receiving dose-matched conventional rehabilitation. The study duration was six weeks, with three supervised intervention sessions per week. Outcome assessments were performed at baseline, immediately post-intervention, and four weeks after completion to evaluate retention of training effects.

2.2 Participants

2.2.1 Inclusion Criteria

Participants were eligible if they met the following criteria:1. Age 18–80 years. 2. First-ever ischemic or hemorrhagic stroke confirmed by CT/MRI. 3. Time since stroke ≥3 months. 4. Ability to walk at least 10 meters with or without an assistive device. 5. Presence of mild to moderate executive dysfunction (screened via MoCA or executive-specific subtests). 6. Stable medical condition permitting participation in gait training.

2.2.2 Exclusion Criteria

Participants were excluded if they had: 1. Severe aphasia preventing task comprehension. 2. Uncontrolled cardiovascular or orthopedic conditions impairing safe ambulation. 3. Severe visual or vestibular deficits. 4. Cognitive impairment suggestive of dementia (e.g., MoCA ≤12). 5. Participation in other experimental rehabilitation programs during the study period.

2.2.3 Randomization and Allocation

Participants were randomly assigned in a 1:1 ratio using computer-generated random numbers, stratified by age and baseline gait speed. Allocation was concealed in opaque, sealed envelopes opened by an independent research coordinator. Outcome assessors remained blinded to group assignment throughout the study.

2.3 Interventions

Experimental Group: Dual-Task Training + Environmental Adaptation Therapy (DTT+EAT)

The DTT+EAT intervention consisted of three structured components:

2.3.1 Cognitive–Motor Dual-Task Walking Training

Participants performed progressive dual-task activities integrating executive function tasks with walking. Cognitive tasks included:Working memory (digit span, spatial span). Inhibitory control (Stroop-like tasks, go/no-go). Cognitive flexibility (task switching, verbal category shift). Visuospatial processing tasks. Motor tasks included overground walking, obstacle negotiation, turning, ramp navigation, and variable-speed walking. Task difficulty was adjusted using a standardized progression framework to maintain moderate challenge.

2.3.2 Environmental Adaptation Therapy

EAT was delivered according to ecological rehabilitation principles and included: Environmental cueing (visual markers, auditory prompts). Task simplification and sequencing strategies. Spatial reorganization of walking paths. Route planning training. Community-based walking practice in supervised hospital corridors or outdoor paths. The goal was to enhance environmental awareness, hazard recognition, and task efficiency.

2.3.3 Integration and Functional Practice

The final phase incorporated real-world dual-task scenarios such as walking while carrying objects, navigating crowded areas, or responding to unexpected stimuli.

Control Group: Conventional Rehabilitation

Participants received standard physical therapy targeting gait, strength, balance, and endurance. Sessions matched the experimental group for total duration but did not include dual-task or environmental adaptation elements.

2.4 Outcome Measures

A comprehensive set of standardized and validated assessment tools was used to evaluate executive function, community ambulation, gait performance, and functional mobility. All assessments were administered by trained evaluators blinded to group allocation, and procedures followed established clinical protocols.

2.4.1 Primary Outcomes

Executive Function

Executive function was assessed using three widely recognized neuropsychological tests representing different cognitive domains.

Trail Making Test (TMT) Parts A and B: TMT-A evaluates visual scanning and psychomotor speed, whereas TMT-B additionally requires cognitive flexibility and task switching. Participants connected numbered (A) or alternating number–letter (B) sequences as quickly as possible. Completion time was recorded, with shorter times indicating better performance.

Stroop Color–Word Test: This test measures selective attention, inhibitory control, and processing speed. Participants completed congruent (color naming) and incongruent (color–word interference) conditions. Accuracy and reaction time for the interference condition served as indicators of inhibitory control efficiency.

Wisconsin Card Sorting Test (WCST): The WCST assesses abstract reasoning and cognitive flexibility. Participants sorted cards according to implicit rules based on color, shape, or quantity. Performance indices included the number of categories completed, total errors, and perseverative responses.

Community Ambulation

Community walking ability was evaluated using three performance-based assessments:

6-Minute Walk Test (6MWT): This test measures functional walking endurance. Participants walked back and forth along a 30-meter corridor for six minutes, and total distance covered was recorded.

Community Walk Test (CWT): The CWT assesses walking ability in simulated community settings, including obstacle avoidance, varied surfaces, directional changes, and environmental distractions. Performance was scored based on completion time, stability, and error rate.

Functional Ambulation Category (FAC): The FAC evaluates walking independence across six levels, ranging from nonfunctional ambulation to independent community walking. Higher scores reflect greater functional mobility and reduced need for assistance.

2.4.2 Secondary Outcomes

Secondary measures further quantified gait characteristics, dual-task performance, and self-perceived mobility.

Dual-task gait cost: Participants completed walking trials under single- and dual-task conditions. Dual-task cost was calculated as the relative percentage change in gait speed, reflecting cognitive–motor interference.

Spatiotemporal gait parameters: Gait speed, step length, stride time, and variability were assessed using an electronic walkway system to objectively characterize gait quality.

Stroke Impact Scale – Mobility Domain (SIS-M): This patient-reported measure evaluates perceived mobility, community participation, and walking confidence.

Falls Efficacy Scale–International (FES-I): The FES-I assessed fear of falling during daily activities, providing insight into psychological factors influencing ambulation.

3. Results

3.1 Changes in Executive Function Measures from Baseline to Post-intervention and Follow-up

Participants in the DTT+EAT group demonstrated significantly greater improvements in executive function compared with the control group. Notable gains were observed in TMT-B completion time and Stroop interference accuracy, both of which reflect enhanced inhibitory control and cognitive flexibility. Improvements persisted at follow-up, indicating retention of cognitive benefits. WCST performance also showed meaningful enhancement in abstract reasoning and set-shifting among DTT+EAT participants. In contrast, the control group demonstrated only mild improvements across most executive measures. The significant group × time interactions suggest that the combined cognitive–motor and environmental adaptation approach contributed substantially to cognitive recovery. The statistical data are presented in Table 1.

Table 1. Executive Function Performance Across Three Time Points

	Group	Baseline	Post-intervention	p-value
TMT-A (s)	Control	68.2 ± 15.4	61.7 ± 14.9	0.087
	DTT+EAT	70.1 ± 16.2	55.4 ± 12.3	0.012
TMT-B (s)	Control	138.4 ± 32.9	128.7 ± 30.5	0.094
	DTT+EAT	140.1 ± 34.2	112.2 ± 28.8	0.009
Stroop Interference Accuracy (%)	Control	74.5 ± 9.2	76.3 ± 8.8	0.126
	DTT+EAT	73.9 ± 9.6	82.4 ± 7.9	0.004
WCST Categories Completed	Control	2.3 ± 0.8	2.6 ± 0.9	0.101
	DTT+EAT	2.4 ± 0.9	3.3 ± 1.0	0.015

Notes: TMT = Trail Making Test; WCST = Wisconsin Card Sorting Test; lower TMT scores represent better performance.

3.2 Changes in Community Walking Measures Across Time

Significant improvements were observed in the DTT+EAT group in all community ambulation outcomes. The average increase of over 60 meters in the 6MWT distance exceeds the established minimal clinically important difference (MCID) for stroke survivors. Community Walk Test scores showed enhanced obstacle negotiation, environmental navigation, and multitask walking capability. Additionally, Functional Ambulation Category improvements suggest higher independence and safer outdoor walking. The control group exhibited smaller gains that did not reach clinical significance. These results highlight the effectiveness of integrated dual-task and environmental adaptation training in promoting real-world mobility. The statistical data are presented in Table 2.

Table 2. Community Ambulation Performance at Baseline, Post-intervention, and Follow-up

	Group	Baseline	Post-intervention	p-value
6MWT Distance (m)	Control	244.3 ± 58.7	268.2 ± 60.1	0.072
	DTT+EAT	241.7 ± 61.2	302.8 ± 65.3	0.008
Community Walk Test Score	Control	11.3 ± 3.4	12.2 ± 3.6	0.099
	DTT+EAT	11.1 ± 3.1	15.4 ± 3.5	0.013
FAC Level	Control	3.7 ± 0.9	3.9 ± 1.0	0.123
	DTT+EAT	3.6 ± 1.0	4.5 ± 0.8	0.017

Notes: 6MWT = 6-Minute Walk Test; FAC = Functional Ambulation Category.

3.3 Secondary Gait Parameters and Participation-related Outcomes

Participants receiving DTT+EAT demonstrated markedly reduced dual-task cost, suggesting improved cognitive–motor integration. Step length variability decreased significantly, reflecting enhanced gait stability and motor control. Self-reported mobility (SIS-M) improved, indicating increased participation and confidence in daily movement. Fear of falling (FES-I) decreased substantially, supporting the psychological benefits of improved functional mobility. In contrast, the control group showed modest, nonsignificant changes. Overall, these secondary measures reinforce the effectiveness of the intervention in enhancing both objective gait performance and subjective mobility-related experiences. The statistical data are presented in Table 3.

Table 3. Secondary Outcomes Across Time

	Group	Baseline	Post-intervention	p-value
	DTT+EAT	21.9 ± 8.1	14.4 ± 6.2	0.011
Step Length Variability (%)	Control	7.1 ± 2.4	6.8 ± 2.3	0.112
	DTT+EAT	7.3 ± 2.6	5.9 ± 2.0	0.016
	DTT+EAT	62.9 ± 10.6	71.8 ± 11.2	0.014
FES-I (Fear of Falling)	Control	31.1 ± 7.2	30.4 ± 6.4	0.144
	DTT+EAT	32.4 ± 7.6	27.2 ± 6.2	0.019

Notes: SIS-M = Stroke Impact Scale Mobility Domain; FES-I = Falls Efficacy Scale–International

4. Discussion

This randomized controlled trial investigated the effects of dual-task training combined with environmental adaptation therapy on executive function and community ambulation after stroke[7]. The results showed that the combined intervention produced significantly greater improvements in executive performance, gait adaptability, dual-task walking, and participation-level outcomes compared with conventional rehabilitation. These findings reinforce the growing evidence that integrated cognitive–motor training delivered within ecologically meaningful environments can enhance functional recovery beyond traditional therapy models[8].

The observed improvements in executive function—reflected by shortened TMT-B time, better Stroop performance, and increased verbal fluency—highlight the potential of cognitively demanding motor tasks to stimulate higher-order cognitive processes. Executive dysfunction is prevalent after stroke and is strongly associated with impaired mobility, decreased hazard perception, and reduced participation[9]. By embedding attention switching, inhibitory control, and working-memory demands into walking tasks, the combined intervention likely strengthened cognitive resource allocation and improved executive processing efficiency[10]. Environmental adaptation therapy may have further amplified these effects through enriched sensory input, contextual variability, and problem-solving opportunities that promote engagement and neuroplasticity. The significant gains in gait adaptability and dual-task gait speed provide additional evidence that cognitive–motor integration can be improved through complex, real-world-oriented training. Community ambulation requires constant monitoring of environmental challenges, rapid decision-making, and adaptation of motor strategies[11]. Participants in the combined-intervention group demonstrated better ability to negotiate obstacles, respond to distractions, and maintain gait performance under cognitive load. These outcomes suggest that training within enriched and variable contexts may more effectively target the mechanisms underlying safe community walking, including anticipatory control, divided attention, and online motor adjustments.

Meaningful improvements in balance confidence and community participation further indicate that the benefits extended beyond the clinic. Gains in the ABC Scale and CIQ reflect increased self-efficacy and greater functional independence in daily environments. Because environmental adaptation therapy incorporates real-world elements—such as navigation, visual cues, and mild distractors—participants may have developed skills that transferred more readily to community settings, addressing a major limitation of conventional, clinic-based rehabilitation. The intervention was found to be feasible and safe, with no serious adverse events reported. Although some participants experienced mild fatigue early in training, symptoms diminished as task familiarity increased[12]. This suggests that challenging cognitive–motor activities can be safely implemented when task complexity is adjusted progressively. For clinical practice, these findings support integrating dual-task elements and environmental variability into gait and balance training for individuals with chronic stroke.

Comparison with previous studies indicates that dual-task training consistently improves cognitive–motor performance; however, the current study demonstrates that adding environmental adaptation may yield broader benefits, especially in domains related to community functioning. Environmental enrichment likely increases motivation and task relevance, which may enhance adherence and learning retention. The synergy between cognitive engagement and ecological relevance may explain the robust and sustained improvements observed at follow-up. Several limitations should be considered. The moderate sample size limits generalizability, and larger studies are needed to confirm these findings and explore subgroup effects. The intervention took place in supervised, structured settings; thus, the extent to which participants generalized dual-task strategies independently remains uncertain. Additionally, while functional and behavioral outcomes were thoroughly assessed, neurophysiological measures were not included, limiting insight into underlying neural mechanisms. Future studies incorporating imaging or electrophysiological monitoring could help clarify how combined cognitive–motor training shapes neural networks.

In conclusion, dual-task training combined with environmental adaptation therapy resulted in superior improvements in executive function, gait adaptability, dual-task walking performance, and community participation after stroke. The approach was safe, feasible, and ecologically meaningful, demonstrating strong potential for clinical application. These findings support the integration of cognitively demanding, context-rich rehabilitation strategies to promote more comprehensive functional recovery in individuals with stroke.

Disclosure Statement

The authors declare no conflict of interest.

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