

Improving Post-Stroke Cognitive Impairment via Cognitive and Motor Dual Task Gait Training: Potential Mechanisms and Clinical Value

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Abstract: Post-stroke cognitive impairment (PSCI) severely impacts patients' quality of life and functional recovery, with its incidence rising alongside global population aging. Cognitive-walking dual-task training, which integrates cognitive and motor elements, has emerged as a key focus in rehabilitation research in recent years. This review summarizes its value and neural mechanisms in improving PSCI. By integrating randomized controlled trials and functional imaging studies, it assesses the training's effects on cognitive and motor functions and reveals the association between brain region activation and cognitive recovery. The training can enhance cognitive abilities such as attention and executive function, improve motor functions including gait and balance, and boost quality of life. It promotes neuroplasticity, strengthens activation and connectivity of key brain regions like the prefrontal cortex, and regulates Brain-derived neurotrophic factor (BDNF) expression. Technologies such as Functional Near-Infrared Spectroscopy (fNIRS) and Functional magnetic resonance imaging (fMRI) confirm its role in brain function remodeling, and it outperforms traditional training and aerobic exercise alone in enhancing dual-task performance. This training provides a basis for PSCI rehabilitation. Future research should optimize individualized protocols, verify long-term efficacy, and advance the application of multimodal imaging and intelligent platforms to refine rehabilitation strategies.

Keywords: dual task training, walking rehabilitation, stroke, cognitive impairment, neural mechanisms

Introduction

Post-stroke cognitive impairment (PSCI) is a prevalent sequela affecting a substantial number of patients globally. As the global population ages, the incidence of stroke and associated cognitive impairments is projected to rise steadily, with older adults being disproportionately affected. Research indicates that stroke not only induces significant motor dysfunction but also markedly elevates the risk of cognitive impairment. Such cognitive decline exerts a profound impact on patients' quality of life.^{1,2} Studies have shown that the incidence of cognitive impairment in stroke patients is as high as 83.8%, with an even greater prevalence among elderly patients. This has heightened attention within healthcare systems toward post-stroke cognitive recovery and spurred clinicians to pursue effective interventions and rehabilitation strategies.²

Cognitive impairment presents with diverse manifestations, typically involving deficits in attention, memory, and executive function. These impairments not only diminish patients' capacity for self-care but may also result in reduced social participation, thereby exacerbating feelings of isolation and depression.³ For instance, one study observed that approximately 40% of stroke patients present with varying degrees of cognitive impairment during rehabilitation, which directly impairs their activities of daily living and social interaction skills.⁴ Therefore, understanding and mitigating the impact of PSCI is crucial for enhancing patients' quality of life and social participation.

Traditional rehabilitation approaches have inherent limitations, particularly in addressing multi-tasking demands and complex cognitive activities. Many rehabilitation programs focus predominantly on physical function recovery, often overlooking the assessment and intervention of cognitive function.⁵ Emerging rehabilitation research has acknowledged that dual task training, which integrates cognitive training with physical rehabilitation, may yield significant improvements in both cognitive and motor functions among stroke patients. By embedding cognitive tasks into walking or other physical activities, dual task training facilitates neural adaptation and enhances cognitive flexibility, highlighting the potential advantages of integrating cognitive and motor training in rehabilitation.^{6,7}

However, there remain multiple gaps in current research. First, there is no consensus on the priority of impairments in different cognitive domains (eg, attention, executive function) after stroke and their mutual influence mechanisms, making it difficult to target training priorities. Second, there is a lack of standardized protocols for the optimal combination mode of cognitive and motor tasks in dual-task training, as well as for setting difficulty gradients, leading to significant variations in training effects across studies. Third, for the high-risk group of elderly stroke patients, research data on balancing training intensity to ensure both safety and effectiveness remain insufficient. Fourth, there are few studies comparing the long-term effects of traditional rehabilitation and dual task training on cognitive function recovery, making it hard to clarify the long-term clinical value of dual-task training.

In summary, the epidemiological characteristics of post-stroke cognitive impairment and the quality-of-life needs of patients necessitate enhanced assessment and intervention of cognitive function during rehabilitation. The limitations of traditional rehabilitation methods and gaps in existing research have driven the exploration of more effective rehabilitation strategies. Based on this, this study aims to systematically review the potential value of Cognitive and motor dual task gait training in improving post-stroke cognitive function, deeply explore its impact on brain function activation and underlying neural mechanisms, and provide a more comprehensive theoretical basis and practical guidance for stroke patient rehabilitation. Meanwhile, it seeks to clarify directions for future research, facilitating the optimization of rehabilitation strategies and improvement of patients' quality of life.

Mechanisms of Stroke-Induced Cognitive Impairment

The mechanisms underlying stroke-induced cognitive dysfunction are multifaceted, with ischemic injury driving neuronal loss and synaptic impairment as pivotal factors. Following a stroke, neurons within the ischemic region undergo necrosis or apoptosis due to hypoxia and nutrient deprivation, disrupting the integrity of neural networks and precipitating cognitive decline.⁸ Additionally, ischemia impairs synaptic transmission between neurons, diminishing information processing capacity and further exacerbating cognitive impairment.⁹ Studies have demonstrated that patients with ischemic stroke exhibit marked impairments in cognitive functions, including deficits in attention, memory, and executive function.

Among cognition-related brain regions, infarctions in the right parietal lobe, left frontotemporal lobe, and left thalamus exhibit the strongest predictive power for PSCI. Following a stroke, damage to these regions directly causes patients to develop cognitive dysfunctions.¹⁰ Meanwhile, studies have found that injuries to the bilateral anterior cingulate cortex and left anterior temporal lobe in the human brain are associated with certain impairments in language and cognition. These injuries affect spatial localization ability and motor execution ability, thereby undermining the independence of individuals in their daily lives.¹¹

Neural network reorganization is closely associated with cognitive recovery. During post-stroke rehabilitation, the brain engages in self-repair via neuroplasticity, reconfiguring neuronal connections to partially restore cognitive function.¹² Research demonstrates that active rehabilitation training facilitates such reorganization, thereby enhancing cognitive abilities. Elucidating the relationship between post-stroke neural network alterations and cognitive recovery aids in developing more effective rehabilitation strategies and provides insights for future therapeutic interventions.¹³

In summary, stroke impairs cognitive function primarily through ischemic injury-mediated neuronal loss, synaptic dysfunction, and damage to cognition-related brain regions. Exploring the link between neural network reorganization and cognitive recovery provides novel perspectives for advancing stroke rehabilitation.

Neural Interaction Mechanisms Between Motor and Cognitive Functions

Accumulating studies confirm that exercise enhances cognitive function, with the underlying neurobiological mechanisms involving neuroplasticity, neurotrophic factor release, and cerebral energy metabolism. Firstly, exercise upregulates the expression of brain-derived neurotrophic factor (BDNF), which supports neuronal survival, development, and synaptic plasticity—thereby facilitating improvements in learning and memory.¹⁴ Additionally, exercise strengthens neuronal connectivity and brain network functionality, thereby enhancing overall cognitive performance.

Exercise improves cerebral energy metabolism, augments cerebral blood flow, and facilitates the delivery of oxygen and nutrients—processes critical for sustaining cognitive function. Cardiovascular adaptations (eg, improved heart rate regulation and blood pressure control) further enhance cerebral perfusion, which in turn boosts cognitive function.¹⁵ For instance, a study demonstrated that aerobic exercise significantly increased cerebral artery blood flow velocity, which correlated with improvements in cognitive ability.¹⁴ Exercise safeguards brain health through inhibiting inflammation and exerting antioxidant effects. Research has shown that physical activity reduces levels of inflammatory markers, thereby mitigating neuropathological changes associated with cognitive decline.¹⁴ Collectively, these mechanisms constitute the neurobiological basis for exercise-induced cognitive enhancement, suggesting that appropriate exercise interventions can effectively improve cognitive function—particularly in older adults and stroke patients.

Exercise not only modulates the biological substrates of cognition but also promotes cognitive recovery by altering patterns of brain region activation. In stroke patients, motor training effectively reshapes brain functional networks, thereby strengthening the neural support for specific cognitive tasks. For example, one study demonstrated that stroke patients who underwent motor training exhibited increased activation in relevant brain regions (eg, the prefrontal lobes) during cognitive tasks, indicating functional improvements in these areas.¹⁶ Moreover, these effects extend beyond single-region interactions to inter-regional coordination. Following exercise, stroke patients exhibit altered activation patterns in memory-associated cognitive networks, which are closely linked to cognitive improvement.¹⁷ This plasticity underscores the brain's capacity for adaptive reorganization in response to injury. Regular motor training not only

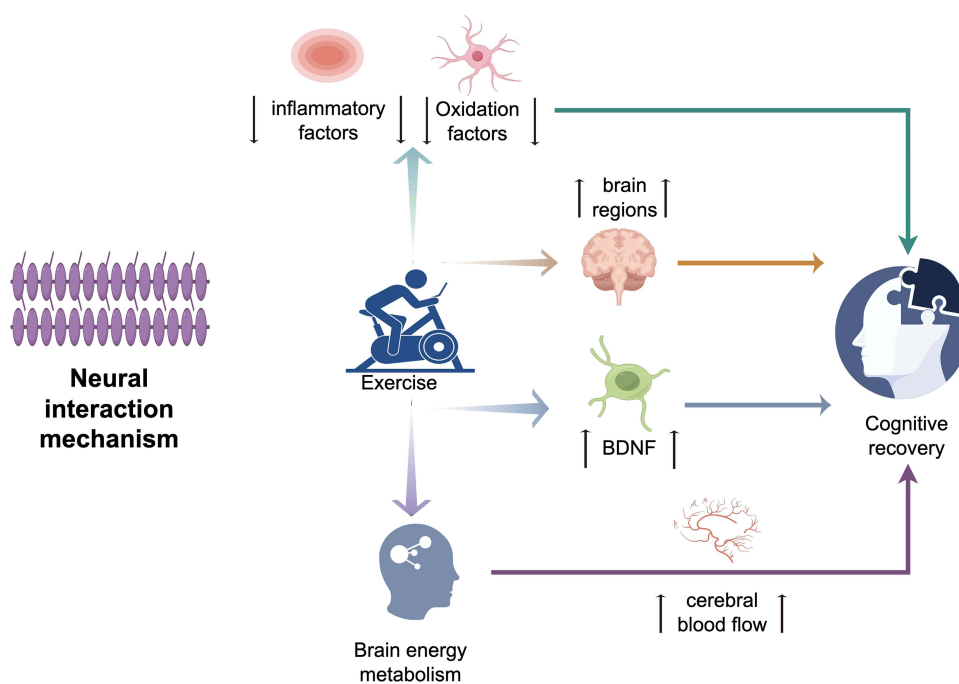


Figure 1 This diagram depicts the neural interaction mechanism underlying the effect of exercise on cognitive recovery. As the initiating factor, exercise exerts multiple impacts: it inhibits inflammation and exerts antioxidant effects; promotes increased production of brain-derived neurotrophic factor (BDNF); modulates brain energy metabolism processes and enhances cerebral blood flow; and activates specific brain regions. These collective effects ultimately contribute to the recovery of cognitive function (by Figdraw).

enhances cognitive abilities but also strengthens resilience against future cognitive decline through the reshaping of brain function. These findings provide theoretical and practical support for exercise as a non-pharmacological intervention for PSCI (Figure 1).

Cognitive Load Theory in Dual Task Training

Cognitive load theory elucidates how cognitive and motor tasks influence performance by focusing on the allocation of cognitive resources. When executing dual tasks, individuals must distribute limited cognitive resources to effectively complete both tasks. Research underscores the pivotal role of executive functions—including attention control, task switching, and working memory—in dual task performance. Elevated cognitive load may disrupt executive functions, resulting in diminished task performance. For instance, one study demonstrated that higher cognitive load significantly impaired dual task performance in older adults, particularly in scenarios with high attentional demands.¹⁸

Individuals with reduced cognitive capacity—such as older adults—may experience greater burden and diminished executive function during dual tasks, underscoring the significance of resource allocation in dual task training. Elucidating these mechanisms facilitates the design of more effective training protocols to enhance cognitive and motor functions in stroke patients.^{18,19}

Cognitive-motor interference refers to the adverse impact of cognitive load on motor performance during physical tasks, particularly in complex dual task scenarios. Research has demonstrated that cognitive interference significantly impairs motor function—for example, older adults exhibit reduced gait speed and coordination while engaging in cognitive tasks.

Training adaptation refers to diminished sensitivity to cognitive-motor interference following training, resulting in enhanced adaptability. For instance, older adults who completed cognitive-motor dual task training showed improved management of cognitive load and motor performance, with heightened cognitive accuracy and motor coordination. Appropriate dual task training enhances adaptability in both cognitive and motor domains, thereby mitigating cognitive interference.¹⁹ To achieve this, training protocols must be designed to enhance motor ability while effectively integrating cognitive function. For instance, utilizing virtual reality for cognitive-motor interference training provides realistic, complex environments that facilitate the real-world integration of cognitive and motor processes.²⁰

Neuroplasticity Mechanisms in Cognitive Walking Training

Cognitive Walking training is an effective intervention that enhances motor function and exerts positive effects on brain function. It strengthens and reorganizes the activity of functional brain regions through neuroplasticity, thereby facilitating the reconstruction of damaged neural networks. Research demonstrates that robot-assisted gait training improves gait ability in older adults and patients with gait disorders while modulating cognitive function and neuroplasticity.²¹ This high-intensity, task-specific training augments activity across multiple brain regions—particularly those subserving motor and cognitive functions (eg, the prefrontal and motor cortices).

Cognitive Walking training enhances brain connectivity in stroke patients. Functional magnetic resonance imaging (fMRI) has revealed strengthened functional connectivity between the left occipital lobe and posterior cingulate cortex, as well as improved connectivity in the right parietal lobe—findings that suggest enhanced inter-regional coordination and improved overall cognitive and motor performance.²²

Neuroplasticity plays a pivotal role in cognitive training. Research demonstrates that cognitive training induces structural adaptations—such as neuronal regeneration and synaptic remodeling—to enhance learning and memory processes.²³ In patients undergoing Cognitive Walking training, improved cognitive function correlates with altered patterns of brain region activation, reflecting functional reorganization. Overall, Cognitive Walking training promotes neuroplasticity by enhancing the activation and reorganization of functional brain regions, with substantial clinical implications for stroke rehabilitation.

Cognitive Walking training facilitates cognitive recovery by strengthening neural network connectivity. Gait training not only improves gait ability but also enhances brain network connectivity—a factor critical for cognitive recovery. For instance, one study demonstrated that mixed Motor Cognitive training significantly increased resting-state functional connectivity in stroke patients, particularly between regions associated with cognitive control and motor execution.²² This enhanced connectivity benefits both motor function and cognitive ability. Cognitive Walking training facilitates inter-regional information transmission and integration, particularly during complex cognitive tasks. Dual task gait training—which combines

walking with cognitive tasks—strengthens connectivity in brain regions associated with attention and executive function. This improvement enhances patients' capacity to perform complex daily activities, thereby reducing fall risks and accidental injuries.²⁴

Additionally, Cognitive Walking training substantially improves emotional and psychological states in stroke patients, which may be linked to enhanced neural network connectivity. Strengthened connectivity enables patients to better regulate emotions and manage cognitive stress—thereby improving quality of life and functional independence.²¹ By enhancing neural network connectivity, Cognitive Walking training supports both motor and cognitive recovery, thereby contributing to comprehensive stroke rehabilitation.

Advances in Functional Near-Infrared Spectroscopy (fNIRS) Research

Functional near-infrared spectroscopy (fNIRS) is a non-invasive neuroimaging technique that monitors real-time changes in cerebral oxygenation, rendering it valuable for studying cognitive impairment in stroke patients. Key brain regions involved in executive function, motor control, and visuospatial processing—including the prefrontal cortex, premotor area, and parietal lobe—exhibit significant changes in oxygenated hemoglobin concentration during Cognitive and motor dual task gait training, reflecting activation under elevated cognitive load.²⁵ Patients with PSCI typically exhibit reduced oxyhemoglobin responses in the left dorsolateral prefrontal cortex, which indicates that this region plays a crucial role in cognitive control and decision-making processes.²⁶ The premotor cortex is closely associated with motor planning and control, and fNIRS data indicate that it also exhibits significant activation during walking tasks. Meanwhile, studies have shown that the left prefrontal cortex is thought to be modulated by the left parietal lobe, which may result from the functional compensation of the left parietal lobe.²⁷ These findings provide novel insights into the mechanisms of PSCI and inform future interventions.

In fNIRS studies, task difficulty significantly modulates brain activation. As task difficulty increases, activation in key regions—the prefrontal cortex, premotor area, and parietal lobe—intensifies. For instance, basic walking tasks induce low-level activation, while the addition of complex cognitive tasks (eg, arithmetic or language processing) significantly elevates oxygenated hemoglobin levels in the prefrontal cortex, indicating its deeper involvement in cognitive load processing.²⁵ The premotor area also exhibits stronger activation during high-difficulty tasks, underscoring its role in complex motor coordination and planning.²⁸ Parietal activation during perceptual and spatial attention tasks correlates with task difficulty, underscoring its role in information integration. These findings highlight the significance of task design in brain function research, facilitating the development of effective rehabilitation programs for stroke patients.

Correlation Analysis Between Brain Activation and Cognitive/Motor Abilities

Studies on brain activation patterns in individuals with high cognitive function have revealed unique characteristics. Using fMRI, researchers observed enhanced activity in the left dorsolateral prefrontal cortex and right medial prefrontal cortex during working memory tasks—regions critical for cognitive control and attention allocation. This suggests efficient mobilization of cognitive resources during complex tasks. Additionally, EEG studies demonstrated reduced brain activity in individuals with high spatial-visual ability during spatial rotation tasks, which aligns with the neural efficiency hypothesis: individuals with high cognitive ability utilize resources more efficiently, thereby minimizing unnecessary activation.^{29,30} These differences in activation patterns reflect cognitive differences and elucidate the neural basis of cognition.

For patients with motor disorders, complex interactions characterize the relationship between activation patterns in specific brain regions and the severity of motor impairment. Studies have demonstrated that activation patterns in the prefrontal and motor cortices during dual task training are correlated with motor performance outcomes. For instance, patients with poor motor function exhibit increased prefrontal activation while performing simultaneous walking and cognitive tasks, which serves to compensate for motor deficits. Patients with severe impairment also exhibit enhanced activation in the contralateral motor cortex during complex tasks, suggesting increased interhemispheric coordination to support balance and motor control.^{16,31} These interactions inform clinical interventions, emphasizing the need to consider cognitive load and brain activation patterns when designing rehabilitation programs for motor-impaired patients.

The above analysis highlights the dynamic relationships between brain activation patterns in high-cognitive-function individuals and motor-impaired patients, revealing complex interactions between cognitive and motor abilities and providing a theoretical foundation for future rehabilitation research.

Evidence of Cognitive Function Improvement

Recent studies confirm that Cognitive and motor dual task gait training effectively enhances attention, executive function, and memory in stroke patients. By requiring the simultaneous performance of walking and cognitive tasks, this training promotes brain plasticity and facilitates cognitive recovery. For instance, stroke patients who completed dual task training achieved significantly higher scores on attention and executive function assessments compared to control groups.³² Additionally, dual task training enhances short-term and working memory—cognitive capacities critical for daily cognitive functioning.³³

The mechanism involves strengthening neural connections, particularly between the prefrontal cortex and other relevant brain regions. Following training, stroke patients exhibit altered brain activity patterns during cognitive tasks, with increased prefrontal activation correlating with cognitive improvement.¹⁶ Dual task training also alleviates cognitive task burden, thereby enhancing overall performance.³⁴

The Mini-Mental State Examination (MMSE) and Montreal Cognitive Assessment (MoCA) are key tools for evaluating cognitive function. Following training, patients exhibit significant improvements in MMSE and MoCA scores.³⁵ In addition, the Korean versions of the Executive Function Performance Task and Instrumental Activities of Daily Living Scale—both used as tools for assessing cognitive function—have also shown that patients undergoing dual task training exhibit significant improvements in executive function.³⁶

Cognitive and motor dual task gait training enhances attention, executive function, and memory, demonstrating potential for ameliorating PSCI. These findings underscore the significance of comprehensive training in stroke rehabilitation. Cognitive assessment tools are pivotal for evaluating such improvements. The MMSE and MoCA effectively assess domains including orientation, attention, memory, and language. Studies show post-training score increases—with the MMSE reflecting global cognitive improvement and the MoCA detailing gains in executive function and short-term memory. As a specialized tool for assessing attention and concentration, the D2 Test has also been utilized in research. By evaluating participants' performance under dual task conditions, researchers can observe patients' attentional stability and rapid response ability when executing cognitive tasks. The results indicated that performance on the D2 task was significantly associated with all measures of attention and executive function, providing evidence of good convergent validity.³⁷ Notably, patients with initially poor cognitive function exhibit greater improvement, suggesting that dual task training should be prioritized for this subgroup.^{36,38}

In summary, tools such as the MMSE, MoCA, and d2 are vital for quantifying cognitive improvements in stroke patients, thereby guiding clinical decision-making and rehabilitation adjustments.

Improvements in Motor Function and Gait Performance

Enhancing motor function and gait performance is critical for stroke rehabilitation. Studies demonstrate that Cognitive and motor dual task gait training improves balance, gait speed, and adaptability. Increased gait speed is essential for regaining independent ambulation. Research indicates that motor training enhances step length, frequency, and speed.³⁹ Meanwhile, studies have shown that during dual-task level-ground walking and obstacle-crossing training, the type and complexity of cognitive tasks exert a moderate-to-large interactive effect on cognitive performance. Among all cognitive tasks, serial subtraction induces the strongest interference effect on both cognitive and motor performance. Consequently, “motor interference” defined as a decrease in walking distance without a corresponding decline in cognitive performance emerges as the most common pattern of dual-task effects.⁴⁰ Gait adaptability is enhanced, enabling better stability when traversing uneven surfaces or navigating obstacles.⁴¹

Functional tests such as the 10-Meter Walk Test (10MWT) and Timed-Up-and-Go (TUG) assess motor function and gait. Following training, patients exhibit significant improvements in these tests, particularly in walking speed and TUG completion time.⁴² In a trial involving adult stroke patients, 34 participants received an 8-week sedentary behavior intervention. The results indicated that after 8 weeks of the intervention aimed at reducing sedentary behavior, the baseline composition of

movement-related behaviors was significantly correlated with changes in the TUG test and gait speed. This further confirms that movement-related behaviors are strongly associated with post-stroke functional outcomes.⁴³ 10MWT results confirmed clinically meaningful improvements in walking speed, validating the value of the training.⁴⁴

Improvements in Quality of Life and Daily Functioning

Post-stroke, patients often experience reduced self-care ability and social participation, which significantly impacts quality of life. Research demonstrates that Cognitive and motor dual task gait training enhances these aspects, improving daily independence and social engagement. For instance, dual task training improves upper limb function, increasing scores on the Barthel Index and Functional Independence Measure (FIM).⁴⁵ Cognitive interventions also foster mental health, enhancing social interaction and life satisfaction.⁴⁶

Long-term follow-up studies indicate sustained improvements in quality of life, including social interaction and life satisfaction. Many patients maintain these gains post-training, suggesting lasting benefits for functional recovery and quality of life.⁴⁶

Trained patients retain improvements in self-care and social participation, with recovery remaining stable during follow-up. For instance, a 12-week dual task training program led to sustained functional independence and quality of life 6 months later.⁴⁶ Enhanced cognitive ability and social interaction facilitate patients' adaptation to life changes, supporting long-term independence and participation.⁴⁶ This provides a viable rehabilitation pathway, emphasizing cognitive training for functional recovery.

Cognitive and motor dual task gait training effectively enhances self-care and social participation in stroke patients, with lasting benefits. These findings underscore its clinical value and offer new rehabilitation approaches.

Comparison Between Aerobic Exercise and Cognitive and Motor Dual Task Gait Training

Cognitive and motor dual task gait training and aerobic exercise differ significantly in their impacts on cognitive recovery. Dual task training uniquely improves executive function and attention, reducing task-switching costs and enhancing real-world multi-tasking abilities in older adults. While beneficial for overall cognitive health, aerobic exercise shows limited effectiveness in improving dual task performance—particularly under complex cognitive loads.^{47,48}

Dual task training improves both cognitive function and cognitive-motor coordination during physical activity. While aerobic exercise benefits specific cognitive domains, it lacks efficacy in dual task execution. Thus, Cognitive and motor dual task gait training is more effective for older adults requiring simultaneous physical and cognitive engagement. Training intensity and duration also influence outcomes.⁴⁹ Moderate-to-high-intensity aerobic exercise better enhances cognition in older adults, with effects correlating with frequency and duration.⁴⁸

In dual task training, patient adherence is critical. Comprehensive cognitive-physical training often increases participation due to greater engagement, thereby enhancing self-efficacy.⁴⁸ Studies demonstrate that longer training periods (eg, 12 weeks) significantly enhance cognition, whereas short-term training may not yield such effects.⁴⁸ Combining aerobic and dual task training addresses diverse patient needs, particularly those requiring cognitive support for complex tasks. Optimizing intensity, duration, and adherence will be pivotal in future research.

Traditional Walking Training vs Virtual Reality-Based Cognitive Motor Training

Traditional walking training and virtual reality (VR)-based cognitive-motor training differ significantly in engagement and motivation. Traditional training is often monotonous, reducing long-term adherence. In contrast, VR training integrates cognitive tasks with movement, leveraging immersion to boost interest. Studies demonstrate that VR training enhances motivation through interactivity and gamification—for example, patients reported greater enjoyment in completing cognitive tasks in virtual environments, which increased adherence.⁵⁰ VR's adaptability enables personalized task selection, further enhancing engagement. Virtual reality-based training can boost participants' enthusiasm through instant feedback and reward mechanisms. For instance, when participants complete a specific task in a virtual environment, they receive immediate visual or auditory feedback—this not only enhances their sense of achievement but also encourages them to maintain higher

concentration and participation in training. VR training leverages immediate feedback and rewards (eg, visual/audio cues) to sustain motivation and focus.⁵¹ Social interaction features (eg, group training) foster support networks, thereby providing psychological encouragement. VR training's diversity and interactivity enhance enjoyment and motivation, whereas traditional training lacks such engagement.⁵² VR-based cognitive-motor training exhibits more significant long-term effects on motor and cognitive function. Traditional training effects diminish without ongoing practice. VR's interactivity encourages sustained participation, thereby maintaining training gains. A 12-week VR training study found greater cognitive improvements compared to traditional methods, with effects persisting long term.⁵³

Advances in VR technology have reduced costs, thereby increasing accessibility. Future research should explore its applications across diverse populations and optimize content to maximize long-term effectiveness—offering new therapeutic approaches for PSCI and advancing rehabilitation practices.³⁴

Optimization of Training Frequency, Intensity, and Duration

Stroke patients exhibit distinct rehabilitation needs across recovery stages. Early-phase rehabilitation focuses on foundational motor and self-care skills, with moderate frequency and intensity to prevent fatigue. In the middle phase, as functional independence improves, Cognitive and motor dual task gait training is introduced to enhance cognitive function and motor coordination. Late-stage training prioritizes quality of life, with personalized adjustments to intensity and content.

Personalized plans must account for physiological recovery, cognitive status, and psychological factors. During the early stages, low-intensity motor and cognitive stimulation may be used to build confidence.⁵⁴ In later stages, intensity and complexity are increased to enhance cognitive flexibility.

Cognitive and motor dual task gait training significantly impacts cognitive and motor coordination. An optimal dosage improves outcomes, whereas insufficient or excessive training may cause harm. The recommended frequency is three to five sessions per week, with each session lasting 30 to 60 minutes—this ensures sustained attention and engagement. Safety is paramount, as stroke patients face risks of falls, fatigue, and psychological stress. Physical assessments guide safe, effective training. Gradually increasing intensity adapts to recovery progress, avoiding sudden physical burdens.⁵⁵ Clinicians and therapists must monitor feedback, adjusting programs to maximize benefits while minimizing risks.

In summary, personalized training plans—tailoring frequency, intensity, and duration to individual needs—optimize stroke rehabilitation outcomes and safety, thereby promoting comprehensive recovery.

Impact of Individual Differences in Cognitive and Motor Abilities on Training Effects

Selecting appropriate assessment tools is critical in Cognitive and motor dual task gait training. Due to individual differences in cognition, standardized tools may not reflect actual functional status, necessitating personalized assessment strategies. Research links the effectiveness of cognitive training to baseline cognitive function.⁵⁶ Studies on middle-aged and older patients demonstrate that combined cognitive and physical training delays the progression of mild cognitive impairment (MCI) to dementia, requiring precise assessment and adjustment of training protocols.⁵⁷

Assessment tools should cover key cognitive domains (eg, working memory, executive function). Comparing single-component and multi-component cognitive training modules reveals that the latter better promotes cognitive transfer and improvements in daily function.⁵⁸ Pre-training personalized assessments enhance targeting and effectiveness, thereby supporting overall recovery.

Cognitive reserve significantly influences training outcomes, with strong associations between reserve levels and brain activation patterns. Individuals with high cognitive reserve exhibit greater efficiency and resilience during complex tasks.⁵⁹ A PSCI study found that cognitive training alters brain network connectivity, thereby improving function—with more pronounced effects in high-reserve participants.⁶⁰

Individual differences in brain activation patterns influence training outcomes. Dual task performance involves varying activation patterns, which are linked to baseline cognitive function, training history, and individual traits.⁵⁶ For example, prefrontal and frontal activation correlates with cognitive performance—particularly in individuals with high cognitive reserve.⁵⁷ Understanding cognitive reserve and activation patterns optimizes program design, thereby enhancing training effectiveness.

Functional Recovery of Cognitive Control Networks

Restoring the function of cognitive control networks post-stroke significantly impacts rehabilitation outcomes. Studies highlight the role of activation and connectivity changes in executive function-related regions. For example, stroke patients exhibit altered functional connectivity between the default mode network (DMN) and central executive network (CEN) during recovery—changes that correlate with cognitive improvement.⁶¹ Enhanced DMN connectivity during executive tasks indicates recovery. Another fMRI study found that early reduced connectivity corresponds to later cognitive recovery, suggesting initial impairment followed by gradual restoration through network reorganization.⁶² Studies have also indicated that neuroplasticity plays a crucial role in cognitive recovery. Following a stroke, surviving neurons may compensate for the functions of damaged regions by reconnecting or forming new neural networks. In particular, during tasks involving executive function, patients exhibit significantly increased activation in key brain regions such as the prefrontal cortex and parietal lobe—this reflects that these regions may play an important compensatory role in the recovery process.⁶³ Strengthened connectivity between the prefrontal region and other brain areas improves complex task processing, which correlates with cognitive performance and offers potential biomarkers for clinical intervention.⁶⁴

In summary, cognitive control network recovery depends on activation changes that explain recovery stages. Future research should explore targeted training to promote activation and connectivity, thereby optimizing cognitive recovery.

Adaptive Adjustments of Motor Cognitive Integration Networks

Adaptive adjustments in Motor Cognitive integration networks are vital for post-stroke rehabilitation. Studies reveal complex interactions between motor and cognitive functions, particularly in sensorimotor integration and spatial attention mechanisms. Age influences the relationship between cognition and gait, especially during dual task (DT) walking.⁶⁵ Young adults rely on functional connectivity between motor and sustained attention networks during usual walking (UW), while older adults engage motor and divided attention networks—indicating increased cognitive load with age.

Sensorimotor integration involves coordinated activity in the motor cortex, prefrontal cortex, and cerebellum during complex motor tasks, supporting both basic movement and cognitive processes such as attention and decision-making.⁶⁶ Stroke-induced deficits in integration exacerbate motor impairment, but targeted training reshapes neural pathways, thereby improving overall function.

Motor training induces neuroplasticity, enhancing sensorimotor integration. This improves cognition by strengthening connections between motor and cognitive networks (eg, spatial attention networks).⁶⁷ fMRI studies show that post-training increased connectivity between these networks correlates with cognitive improvement. Optimizing these mechanisms promotes stroke recovery, requiring combined motor and cognitive interventions. Future research should explore training effects across age groups to refine clinical strategies.

Risk Assessment and Management During Training

Stroke patients face a high risk of falls, particularly during Cognitive and motor dual task gait training, necessitating rigorous fall risk assessment and management. Falls are common in older adults and patients with chronic cerebrovascular disease, impairing quality of life and independence.⁶⁸ Assessments utilize tools such as balance tests, gait analysis, and fear-of-fall self-reports. Standardized tests identify dual task risks, thereby guiding the development of personalized programs. Additionally, cognitive-task-integrated walking training improves gait performance and reduces fall incidence while enhancing cognitive function.⁶⁹

Fatigue monitoring is critical—combined physical and cognitive loads increase fatigue, reducing training effectiveness and raising fall risks. Studies show that dual task training elevates cognitive burden, which impairs gait performance.⁷⁰ Trainers and therapists must monitor fatigue levels, adjusting training intensity and content to ensure safety.

Regular assessments and real-time feedback during training facilitate risk management. For instance, signs of fatigue or imbalance warrant immediate rest and supportive measures. Addressing psychological factors (eg, fear of falling) through targeted interventions enhances confidence and improves training adherence.⁷¹ In summary, assessing and

managing fall risks and fatigue ensures safe, effective Cognitive and motor dual task gait training, thereby enhancing stroke rehabilitation outcomes and quality of life.

Patient Subjective Experience and Factors Influencing Adherence

Patient experience and adherence significantly impact Cognitive and motor dual task gait training outcomes. Training difficulty, enjoyment, and social support determine engagement levels. Appropriately challenging tasks enhance motivation—tasks that are too easy breed boredom, while overly difficult ones cause frustration. Gradually increasing difficulty to match individual abilities improves participation and outcomes.⁷²

Enjoyable training enhances interest and adherence. Gamification and social interaction make training more engaging, increasing the time and effort invested. For example, game-based cognitive interventions demonstrate higher adherence rates than traditional methods.⁷³ Designing enjoyable programs enhances participation levels.

Social support—from family, friends, or healthcare teams—provides emotional comfort and confidence, thereby improving adherence. Patients with such support participate more actively and achieve better outcomes.⁷⁴ Support may be emotional (eg, encouragement) or practical (eg, training accompaniment). Building strong support systems is crucial.

This study identifies difficulty, enjoyment, and social support as key factors influencing adherence. Optimizing program design, enhancing enjoyment, and strengthening support improve adherence levels. Future research should explore the interrelationships between these factors to develop more effective interventions.

Combined Application of Multimodal Neuroimaging Techniques

Multimodal neuroimaging—combining fNIRS, fMRI, and EEG—advances PSCI assessment and intervention research. These techniques provide complementary data on brain activity, enhancing understanding of post-stroke neural mechanisms. fNIRS, being non-invasive and real-time, monitors oxygenation and blood flow during motor/cognitive tasks, offering immediate feedback on cognitive load and task difficulty.⁷⁵ fMRI provides high-resolution structural and functional images, identifying brain regions involved in specific cognitive tasks. It clarifies the neural bases of executive function, attention, and memory, thereby guiding clinical interventions.⁷⁶ For example, fMRI distinguishes activity patterns linked to cognitive performance, offering potential biomarkers for the early detection of PSCI.⁷⁷

EEG captures high-temporal-resolution dynamic changes during cognitive tasks, aiding in the analysis of cognitive load and attention allocation during dual task training.⁷⁸ Monitoring EEG patterns during complex tasks reveals cognitive strategies and impairments. Integrating fNIRS, fMRI, and EEG provides multidimensional data on brain function, clarifying the mechanisms of Cognitive and motor dual task gait training in stroke patients. This multimodal approach promises precise, personalized guidance for post-stroke cognitive interventions.

Long-Term Efficacy and Mechanism Tracking Studies

Evaluating long-term efficacy and tracking mechanisms are critical in PSCI research. Follow-up studies assess sustained cognitive improvements from Cognitive and motor dual task gait training through regular assessments and biomarker monitoring. Studies show that dual task training enhances cognitive function—particularly executive function and attention—improving gait performance and cognitive flexibility in complex environments.⁵² Biomarker research is gaining importance, providing biological evidence for cognitive changes. For example, BDNF and Neuron-Specific Enolase (NSE) correlate with cognitive function, showing significant changes after training.⁷⁹ These changes reflect neuroplasticity and regeneration, supporting the effectiveness of training.

In specific follow-up study designs, researchers can utilize a variety of assessment tools—such as the MoCA and neuropsychological tests—to comprehensively evaluate different aspects of cognitive function. Meanwhile, integrating imaging techniques like magnetic resonance imaging (MRI) can reveal changes in brain structure and function, providing support for understanding the mechanisms underlying cognitive improvement. For instance, MRI images based on deep learning image segmentation algorithms hold significant application value in the clinical diagnosis and treatment of stroke, as they can effectively enhance the detection of brain region characteristics and psychological status in post-stroke patients.⁸⁰ Long-term studies validate training efficacy and guide personalized interventions, thereby advancing PSCI treatment.

Development of Intelligent, Personalized Rehabilitation Platforms

First, VR technology provides patients with a safe and controllable training setting by simulating real-world environments. In the rehabilitation of patients with PSCI, VR can be designed to create diverse scenarios that help address challenges encountered in daily life—such as completing activities of daily living (ADLs) and participating in social interactions.

Studies have demonstrated that head-mounted displays are a promising technology with wide-ranging applications in neurorehabilitation. Compared to traditional screens, their more natural motion visualization improves movement quality.⁸¹ Telemedicine addresses geographical and resource barriers, enabling real-time communication with professionals to provide personalized guidance, thereby increasing accessibility and improving efficiency.⁸² The introduction of artificial intelligence (AI) provides data support and a decision-making basis for personalized rehabilitation. By collecting patients' movement data and cognitive performance, AI can analyze their rehabilitation progress, identify potential issues, and offer personalized training recommendations. This intelligent analysis not only enhances the accuracy of rehabilitation interventions but also predicts patients' rehabilitation potential, thereby optimizing treatment plans. For instance, studies have shown that AI-integrated healthcare devices can alleviate cognitive impairments, deliver timely and safe medical care to patients via mobile services, and reduce national economic costs.⁸³

These technologies improve rehabilitation experiences and outcomes by tailoring interventions to individual needs. As research and technology advance, future rehabilitation will become increasingly intelligent and personalized, further enhancing the quality of life for PSCI patients.

Construction of Interdisciplinary Team Collaboration Models

Addressing PSCI requires collaboration across disciplines. Integrating neuroscience, rehabilitation medicine, and engineering enables the development of comprehensive, personalized treatments. Neuroscience identifies key factors in cognitive impairment, linking PSCI to mechanisms such as reduced cerebral blood flow, neuronal damage, and neuroinflammation.⁸⁴

Furthermore, the application of engineering can support the rehabilitation process by developing advanced technologies and equipment. For instance, VR technology and AI can be used to design cognitive training programs, thereby enhancing patients' engagement and treatment effectiveness. In recent years, numerous studies have focused on leveraging intelligent devices to monitor patients' rehabilitation progress. The developed systems provide a foundation for AI-driven autonomous rehabilitation systems, integrating automated clinical assessments with quantitative tools and adaptive difficulty algorithms for personalized interventions. These systems are suitable for both clinical and home-based settings.⁸⁵ Interdisciplinary collaboration enhances the efficacy of PSCI treatment by facilitating knowledge sharing and innovation. Integrating diverse expertise enables the development of targeted interventions. This model is applicable to other cognitive disorders, with promising prospects for broader applications. Sustained interdisciplinary collaboration will drive advances in PSCI research and clinical practice.

Conclusion

Cognitive and motor dual task gait training, an innovative stroke rehabilitation strategy, exhibits substantial potential in enhancing both cognitive and motor functions. By integrating cognitive tasks with walking, it enhances rehabilitation experiences and improves daily functional independence and quality of life. Advances in neuroimaging—particularly fNIRS—have deepened our understanding of neural mechanisms, revealing patterns of activation and reorganization in key regions (prefrontal cortex, premotor area, parietal lobe) and guiding training optimization. These activations suggest that cognitive-motor integration promotes functional recovery and neuroplasticity, providing novel insights for rehabilitation strategies. Randomized controlled trials have confirmed its effectiveness in enhancing attention, executive function, gait adaptability, and quality of life. Notably, the training is well tolerated with no significant adverse effects.

However, individualized interventions are of paramount importance, as patients vary in cognitive, motor, and personal needs, thereby limiting the generalizability of a one-size-fits-all approach. Future research should prioritize personalized design, leveraging multimodal neuroimaging to identify optimal training protocols for different patient subgroups.

Validation of long-term efficacy and development of intelligent platforms—integrating technology with clinical practice—will facilitate comprehensive training evaluation and widespread implementation.

Overall, further research will propel the advancement of Cognitive and motor dual task gait training in PSCI rehabilitation, offering effective therapeutic solutions for stroke patients with significant practical value and broad prospects.

Abbreviations

PSCI, Post-stroke cognitive impairment; BDNF, Brain-derived neurotrophic factor; fNIRS, Functional near-infrared spectroscopy; fMRI, Functional magnetic resonance imaging; MMSE, Mini-Mental State Examination; MoCA, Montreal Cognitive Assessment; 10MWT, 10-Meter Walk Test; TUG, Timed-Up-and-Go; FIM, Functional Independence Measure; DMN, Default Mode Network; CEN, Central Executive Network; ADLs, Activities of Daily Living; AI, Artificial Intelligence; VR, Virtual Reality; MCI, Mild Cognitive Impairment; NSE, Neuron-Specific Enolase.

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Disclosure

The authors report no conflicts of interest in this work.

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