# Motor-cognitive synergism in health and disease

## Motor-cognitive interactions: the neural mechanism underlying function

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**Abstract:** Gait is a complex task requiring balance, sensation and muscle strength but also cognition. Studies have shown that the motor and cognitive systems work synchronously and synergistically to allow movement. This lecture will focus on the interplay between these systems through performance paradigms, neural mechanisms and clinical implications in aging and neurodegeneration.

**Keywords:** Motor-cognitive, fNIRS, fMRI, TMS-EEG, virtual-reality

### Introduction

Traditionally, walking was considered an automatic motor behavior requiring minimal cognitive involvement. However, contemporary research has fundamentally challenged this view, revealing that gait is a complex task that demands significant cognitive resources, particularly when performed under challenging conditions or when combined with concurrent cognitive activities [1]. Real-world walking environments constantly present simultaneous cognitive challenges: navigating crowded spaces while maintaining conversation, walking in a new and unfamiliar environment, or traversing uneven terrain while carrying groceries. These everyday scenarios highlight the ecological relevance of motor cognitive research and its implications for functional mobility and safety [2]. This lecture will explore the fascinating interplay between motor and cognitive functions through performance paradigms, neural mechanisms underlying these interactions and their clinical implications in aging and neurodegeneration. Specifically the presentation will focus on evidence in four different domains to summarize work by the author and published work and provide a better understanding on how the brain orchestrates complex motor-cognitive behaviors and how these processes are altered in disease states.

**1) Gait as a complex task: the dual-task paradigm**

The dual-task paradigm has emerged as a powerful framework for understanding motor-cognitive interaction. When individuals walk while simultaneously performing cognitive tasks such as talking, calculating, or remembering—both motor and cognitive performance can be compromised [2]. This dual-task interference demonstrates the shared neural resources between motor and cognitive systems. The magnitude of this interference varies depending on task complexity, individual capacity, and the specific cognitive demands involved. The ability to successfully manage dual-task walking is crucial for independent living and quality of life, making it a critical area of investigation for understanding human movement and cognition. Evidence will be shared on validated methods to quantify dual-task performance and the dual-task costs. Dual-task assessment provides insight into the strategies individuals employ to manage competing task demands. Evidence on the impact of endogenous and exogenous factors on dual-task will also be provided.

**2) Neural mechanisms of dual-task performance, evidence from studies using advanced neuroimaging techniques.**

Advanced neuroimaging techniques such as functional near-infrared spectroscopy (fNIRS) and functional magnetic resonance imaging (fMRI) have revolutionized our understanding of the brain networks involved in dual-task walking. fNIRS has been particularly valuable due to its portability and tolerance for movement artifacts, enabling the direct measures of brain activity during actual walking tasks. Our studies using fNIRS have demonstrated increased activation in the prefrontal cortex during dual-task walking compared to single-task conditions in healthy adults [3,4]. This frontal activation is represents the cognitive load associated with motor-cognitive integration. The prefrontal cortex, particularly the dorsolateral and medial regions, appear to serve as a crucial hub for coordinating motor and cognitive demands during complex walking tasks.

fMRI research provided complementary insights into the broader neural networks involved in motor-cognitive interaction, revealing activation in multiple brain regions such as the supplementary motor area, anterior cingulate cortex, and parietal regions during dual-task conditions [5]. The pattern of activation suggests that dual-task walking engages executive control networks responsible for attention allocation, conflict monitoring, and task switching. Connectivity analyses have further revealed how different brain regions communicate during dual-task walking, showing increased functional connectivity between frontal regions and motor areas, suggesting enhanced coordination between cognitive control centers and motor execution networks when task demands are high [6].

3) **Motor-Cognitive interaction in neurodegeneration and aging**

Healthy aging is associated with increased reliance on cognitive resources for motor control with greater dual-task costs in older adults. This increased susceptibility to dual-task interference was associated with higher fall risk and with changes in white matter integrity, processing speed, and executive function [7] . Evidence will be presented from imaging studies showing greater prefrontal activation in older adults during walking compared to younger adults, even during single-task conditions [3]. This increased activation likely represents a compensatory mechanism to maintain gait stability in the face of age-related changes in sensory, motor, and cognitive systems.

Similar findings are also observed in neurodegenerative diseases. Parkinson's disease (PD) provides a particularly compelling model for understanding motor-cognitive interaction due to its effects on both the motor and cognitive systems. Patients with PD show altered patterns of brain activation during dual-task walking, with the prefrontal cortex playing an increasingly important compensatory role as the disease progresses and associated reduced motor automaticity due to further basal ganglia dysfunction. Neuroimaging studies have revealed that PD patients show different patterns of brain activation compared to healthy controls during dual-task walking, with altered connectivity between frontal regions and motor areas. These changes may represent both compensatory mechanisms and pathological alterations in neural network function [8,9].

4) **Improving motor-cognitive performance: therapeutic interventions and neural plasticity.**

The last part of the presentation will focus on potential interventions to enhance motor-cognitive interaction in aging and neurodegeneration. Research has demonstrated that both motor and cognitive interventions can lead to meaningful improvements in dual-task walking ability [10]. Specific dual-task training programs typically involve progressive practice of walking while performing increasingly challenging cognitive tasks. Treadmill training combined with cognitive tasks or virtual reality have been particularly effective in PD populations, leading to improvements in both motor and cognitive performance [11,12]. Neuroimaging studies have shown that successful interventions are associated with changes in brain activation patterns, often showing a shift towards more efficient neural processing or enhanced connectivity between relevant brain regions reflecting brain plasticity and increased capacity or reserve [13,14]. Evidence will be presented showing that individuals with greater neural resources or more efficient processing strategies may be more resilient to age and disease-related changes in motor-cognitive function. Understanding these protective factors may inform the development of preventive interventions.

## Conclusions

The study of motor-cognitive interaction during dual-task walking has revealed the complex and dynamic relationship between movement and cognition, far from being automatic. Advanced neuroimaging techniques have identified the prefrontal cortex as a key player in motor-cognitive integration, with altered activation patterns observed in aging and neurodegeneration. However, recent work by our group and others has shown that targeted interventions could enhance capacity and promote beneficial neural changes. The ultimate goal is that such research can translate into practical application and interventions to improve quality of life and maintain mobility and independence across the lifespan.

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## References

[1] KZH. Li et al., “Cognitive Involvement in Balance, Gait and Dual-Tasking in Aging: A Focused Review From a Neuroscience of Aging Perspective”. Front Neurol. 2018 Oct 29;9:913.
[2] I. Hillel et al., “Is every-day walking in older adults more analogous to dual-task walking or to usual walking? Elucidating the gaps between gait performance in the lab and during 24/7 monitoring”. Eur Rev Aging Phys Act. 2019 May 3;16:6.
[3] A. Mirelman et al., “Effects of aging on prefrontal brain activation during challenging walking conditions”. Brain Cogn. 2017 Jul;115:41-46.
[4] F. Nieuwhof et al., “Impaired dual tasking in Parkinson's disease is associated with reduced focusing of cortico-striatal activity”. Brain. 2017 May 1;140(5):1384-1398.
[5] A. Droby et al., “Effects of aging on cognitive and brain inter-network integration patterns underlying usual and dual-task gait performance”. Front Aging Neurosci. 2022 Sep 28;14.
[6] M. Kahya et al, “Brain activity during dual-task standing in older adults”. J Neuroeng Rehabil. 2022 Nov 11;19(1):123.
[7] A. Mirelman et al., “Executive function and falls in older adults: new findings from a five-year prospective study link fall risk to cognition”. PLoS One. 2012;7(6):e40297.
[8] I. Maidan et al., “Neural Variability in the Prefrontal Cortex as a Reflection of Neural Flexibility and Stability in Patients With Parkinson Disease”. Neurology. 2022 Feb 22;98(8):e839-e847.
[9] D. Possti et al., “Changes in the EEG spectral power during dual-task walking with aging and Parkinson's disease: initial findings using Event-Related Spectral Perturbation analysis”. J Neurol. 2021 Jan;268(1):161-168.
[10]DA. Wajda et al., “Intervention modalities for targeting cognitive-motor interference in individuals with neurodegenerative disease: a systematic review.” Expert Rev Neurother. 2017 Mar;17(3):251-261.
[11] M. Dorfman et al., “Dual-task training on a treadmill to improve gait and cognitive function in elderly idiopathic fallers”. J Neurol Phys Ther. 2014 Oct;38(4):246-53. 2.
[12] A. Mirelman et al., “Addition of a non-immersive virtual reality component to treadmill training to reduce fall risk in older adults (V-TIME): a randomised controlled tria”l. Lancet. 2016 Sep 17;388(10050):1170-82
[13] I. Maidan et al., “Evidence for Differential Effects of 2 Forms of Exercise on Prefrontal Plasticity During Walking in Parkinson's Disease”. Neurorehabil Neural Repair. 2018 Mar;32(3):200-208.
[14] A. Droby A et al., “Distinct Effects of Motor Training on Resting-State Functional Networks of the Brain in Parkinson's Disease”. Neurorehabil Neural Repair. 2020 Sep;34(9):795-803.