Research Paper

Cortical Activity During Postural Recovery Under Dual-task Conditions: A Quantitative EEG Study

Ehsan Sinaei[1,2], Mohammad Nami[3], Zahra Saadat[4,5*]

1. Department of Rehabilitation Sciences, MGH Institute of Health Professions, Boston, United States.
2. Shiraz Geriatric Research Center, Shiraz University of Medical Sciences, Shiraz, Iran.
3. Cognitive Neuroscience Unit, Department of Social Sciences, Faculty of Communication, Arts and Science, Canadian University Dubai, Dubai, United Arab Emirates.
4. Cardiovascular Research Center, Hormozgan University of Medical Sciences, Bandar Abbas, Iran.
5. Department of Physical Therapy, School of Rehabilitation Sciences, Shiraz University of Medical Sciences, Shiraz, Iran.

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ABSTRACT

Introduction: This study aimed to investigate the cortical activity differences between healthy older adults and younger individuals during postural adjustments in response to external perturbations under both single-task (ST) and dual-task (DT) conditions.

Methods: Nineteen young adults (mean age: 24.25±3.15) and 20 older adults (mean age: 65.55±4.67 years) were recruited. Participants stood barefoot while a load (3% body weight) was unpredictably released, inducing postural perturbations. In DT trials, participants performed a cognitive task (counting backward) while maintaining balance. Quantitative electroencephalography was recorded from 32 channels, focusing on cortical regions involved in postural control (e.g. motor and sensorimotor cortices). Alpha (8–12 Hz) and beta (12.5–25 Hz) absolute power in specific brain regions (C3, C4, Fz, Cz, Pz) were analyzed using a 3-way mixed-design analysis of variance.

Results: Older adults exhibited significantly higher alpha power in sensorimotor areas (C4, Pz) during DT conditions, compared to younger adults. Group×condition interactions revealed greater beta power in the frontal and central regions (F4, C4) in older adults under DT conditions. Post hoc analysis indicated significantly greater beta power in older adults during DT than in younger individuals.

Conclusion: These findings suggest that older adults rely more on cortical resources for postural recovery, particularly under cognitively demanding DT conditions. The increased alpha and beta power in cortical regions reflects a shift towards compensatory cortical strategies, likely due to age-related declines in automatic postural control mechanisms. Understanding these neural changes can inform fall prevention strategies targeting both cognitive and motor functions in older adults.

*** Corresponding Author:**
Zahra Saadat, Assistant Professor.
Address: *Cardiovascular Research Center, Hormozgan University of Medical Sciences, Bandar Abbas, Iran.*
Tel: *+98 (917) 7302237*
E-mail: *saadat.zahra@gmail.com*

Highlights

- Older adults rely more on cortical resources during postural recovery.
- DT conditions increase brain activity related to balance in older adults.
- Compensatory cortical strategies support balance control with aging.

Plain Language Summary

As people grow older, keeping balance becomes more difficult, and the risk of falling increases. While we know that muscle weakness and slower reflexes contribute to this balance problem, less is known about the brain activity changes when older adults try to regain balance, especially when they are distracted by another task. In this study, we compared younger adults in their 20s with older adults in their 60s and 70s. We asked participants to stand while facing small, unexpected pushes to their balance. Sometimes they focused only on keeping their balance, and other times they had to do a mental task (counting backward) at the same time. During these tests, we measured their EEG activity. We found that older adults used more brain power than younger adults when trying to recover their balance, especially when they were also doing the mental task. This suggests that their balance control depends less on automatic body responses and more on conscious, effortful brain activity. These findings are important because they help explain why older adults may struggle more when walking in real-life situations, such as talking while walking or avoiding obstacles in a busy street. Understanding how the brain compensates for age-related changes in balance can guide new training and prevention strategies to reduce the risk of falling and help older adults maintain independence longer.

1. Introduction

Postural instability and falls are among the most common problems in older adults. The changes in sensory, motor, and cognitive components of postural control can reduce older individuals' postural adjustment in response to external distresses, such as slips and trips (Kanekar & Aruin, 2014; Pai et al., 2003), thus increasing the risk of falling. These changes include decreased visual, vestibular, and somatosensory inputs, reduced muscle mass, power, and torque, altered spinal reflexes, diminished attentional capacity, and functional and structural changes in the brain (Melzer et al., 2001; Reid & Fielding, 2012; Woollacott et al., 1986). Age-associated impairments in brain structures such as the supplementary motor area and the foot area of the sensorimotor cortex may also be responsible for postural instability in old age (Slobounov et al., 2005), when the postural control is less automated (Laessoe & Voigt, 2008). Hence, older adults are more reliant on cognitive input and cortical information processing during motor tasks, as shown by additional activations of sensorimotor cortical areas (Heuninckx et al., 2005; Heuninckx et al., 2008; Venkatraman et al., 2010). Postural control in older adults is attentionally demanding, and the cerebral cortex, particularly the primary motor area and premotor and prefrontal cortex, shows high activity, playing a key role in maintaining balance following perturbations (Jacobs & Horak, 2007; Papegaaij et al., 2014; Smith et al., 2012).

Neurological studies have shown that retaining postural balance against external perturbations activates cognitive processes that are also involved in complicated mental activities such as attention, concentration, perception, and learning. These cognitive tasks, therefore, share a common cognitive source with postural control tasks, which reside mostly in the frontal and parietal lobes and might undergo atrophy during aging (Fraizer & Mitra, 2008; Lacour et al., 2008; Ohsugi et al., 2013). This common capacity even assumes greater importance when one tries to control balance while concomitantly performing a cognitive task. In this condition, known as dual-task (DT), the total attentional demand is escalated. However, the attentional capacity of the brain is limited, and the increased cognitive load would reduce attentional resources for postural control (Lacour et al., 2008). Evidence suggests that older people are more susceptible than younger people during postural recovery under DT conditions (Brown et al., 1999). Incurring external perturbations while performing a cognitive task is expected to challenge the postural stability of older adults. Meanwhile, earlier research has not evaluated the cortical neurodynamic features of such an enhanced susceptibility. Therefore, this study was designed to compare the cortical activity of healthy older adults versus young individuals during postural adjustment in response to external perturbations under single-task (ST) and DT conditions.

2. Materials and Methods

Study design and setting

Volunteers who met the eligibility criteria signed a written consent form after being debriefed about the trial. Having met the ethical code standard measures as per the Declaration of Helsinki, the experiment was approved by the Institutional Review Board of Shiraz University of Medical Sciences, Shiraz, Iran. The present research also followed the strengthening the reporting of observational studies in epidemiology (STROBE) guidelines.

Asymptomatic young and older individuals were recruited through a convenience sampling method. Participants stood barefoot with their feet 24 cm apart and a load massing about 3% of their body weight attached to a belt worn at their sternum level. To induce perturbations, the examiner could release the load at random time intervals of 5 s to 15 s between trials while the participants tried to maintain their postural balance. The experiment consisted of 15 ST and 15 DT trials. For the DT assessment, the individuals were asked to perform the same test while counting backward by 3s beginning from a random two-digit number. To prevent the risk of falling, an examiner stood by the participant during all experiments.

Study participants

Twenty older adults, aged over 65 years (mean age: 65.55±4.67 years), were recruited from Jahandidegan Day-Care Center for senior citizens (Shiraz, Iran), and 19 young students between 20 and 35 years old (mean age: 24.25±3.15 years) volunteered from Shiraz University of Medical Sciences, through flyers. Older adults could stand independently without using assistive devices. Further inclusion criteria for older adults included scores of ≥24 out of 30 in the mini-mental state examination (MMSE), <7 out of 15 in the geriatric depression scale (GDS), and ≥25 out of 40 in the Fullerton advanced balance (FAB) scale. Participants were excluded if they had any history of serious neuromuscular or musculoskeletal disorders (e.g. lower extremities surgeries or fractures, neuropathy, and arthritis), uncorrected vision impairments, vestibular deficits, auditory dysfunctions, severe pain or deformity in the trunk or lower extremities (e.g. scoliosis or kyphosis), or if they had taken any medication potentially affecting their balance within the past 24 hours. Pregnant young adults and individuals with a BMI >30 kg/m^2 were also excluded. This dataset was previously utilized in a separate study that investigated cortical responses to predictable and unpredictable perturbations (Saadat et al., 2021).

Quantitative electroencephalography (QEEG) measures

Thirty-two silver-chloride surface electrodes (Medico Electrodes International Ltd., Uttar Pradesh, India) mounted on an electrocap were used for EEG signal recording based on the international 10-20 system. In this study, a 32-channel NrSign 3840 EEG amplifier (NrSign Inc., Vancouver, Canada) was used to collect the EEG data at a sampling rate of 500 Hz with a 2–120 Hz band-pass filter. The impedance of skin under the electrodes was kept below 5 kΩ using conductive gel, and the FPz electrode was regarded as the reference point in a monopolar montage.

Data processing

The EEG recordings were initially preprocessed for denoising using the EEGLab plugin in MATLAB software, then transformed into ASCII format to be further analyzed using the NeuroGuide Software (version 2.5.5, Applied Neuroscience, St. Petersburg, FL, USA). The synchronization of EEG data with the load release onset was achieved using a mechanical pedal system operated by the by-standing examiner. At the exact moment the load was released, the pedal generated a sharp electrical signal recorded as an event marker on a dedicated EEG channel, serving as the temporal reference (T0) for precise alignment of EEG data and perturbation onset. This marker was visually inspected during preprocessing to ensure accuracy. The analysis focused on two distinct periods: T1 (-1000 to -500 ms before T0) and T2 (-500 ms to the moment of T0) (Figure 1). For each group of 15 experimental trials, the alpha (8–12 Hz) and beta (12.5–25 Hz) powers were first computed for each trial individually. Then, they averaged across the 15 trials to determine the mean absolute power, expressed in square microvolts (μV^2).

The EEG data recorded over bihemispheric sensorimotor and primary motor areas (C3 and C4) were scrutinized. Additionally, a power spectral analysis was conducted on the frontal (Fz, F3, F4), central (Cz), and parietal (Pz) regions to elucidate the EEG signals' characteristics further.

Statistical analyses

The normality of data distribution was confirmed with the Shapiro–Wilk test (P>0.05), and descriptive statistics were used to present the demographic characteristics of the two groups. The QEEG data were analyzed with SPSS software, version 22 through a 3-way mixed de-

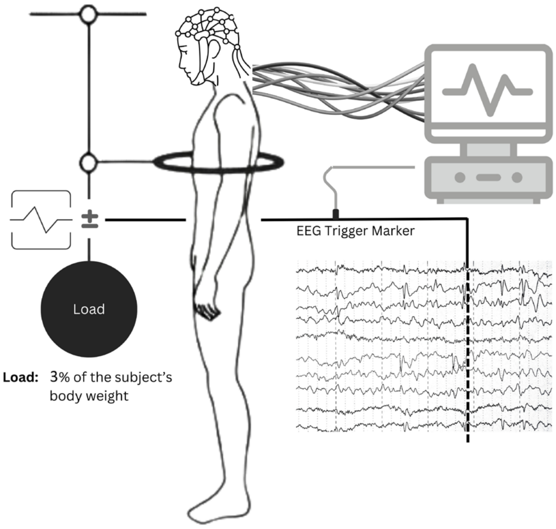

Figure 1. Experimental setup illustrating EEG recording during postural balance perturbation

Note: Participants stood barefoot with feet 24 cm apart, with a load massing 3% of body weight attached to a belt at sternum level. EEG data were recorded with 32 electrodes while an examiner released the load at random intervals, marking the time of release (T0) on the EEG trace.

sign analysis of variance to assess the absolute power z-scores in alpha and beta frequency bands, with one 'between-subject factor' (group: Older vs young adults), and two 'within-subject factors' including condition (ST vs DT) and time (T1 and T2). A P<0.05 was established a priori to determine statistical significance.

3. Results

Demographic characteristics and baseline values of 39 participants are reported in Table 1.

As outlined in Table 2, the group×time interaction was significant for alpha power across the derivations. Also, the main effect of the condition was significant for alpha power in the C4 and PZ regions. In addition, the post hoc analysis of conditions revealed that the power was significantly greater under the DT condition in C4 and PZ (Table 2).

For the beta power, the group×condition interaction was significant in F4 and C4 regions, and post hoc analyses demonstrated significantly greater beta power values in older adults during dual tasks compared to the younger group (Table 3). Findings on the group×condition for beta absolute power in F4 and C4 cortical regions are summarized in Figures 2 and 3.

4. Discussion

This observational study investigated the cortical activity of young and older adults during postural adjustments following external perturbations under both ST and DT conditions. Our results revealed that older adults exhibited increased frontoparietal alpha power during the late phase of recovery from external perturbations, particularly during DT execution. These findings align with previous research, which suggests that aging is accompanied by compensatory neural mechanisms to maintain postural control despite age-related declines in sensory and motor function (Chang et al., 2016; Papegaaij et al., 2014).

We selected the alpha and beta frequency bands due to their well-established relevance in postural control and cognitive-motor interactions. Alpha activity reflects attentional engagement and cortical involvement, while beta activity is associated with motor planning and sensorimotor integration, both critical for balance recovery. The chosen channels also target cortical regions implicated in postural control, such as the sensorimotor, primary motor, and supplementary motor areas. This focused approach allowed us to assess the neural dynamics most directly involved in maintaining stability under ST and DT conditions (Ghosn et al., 2020; Protzak & Gramann, 2021).

Table 1. Demographic characteristics of participants

Variables	Mean±SD	
	Older Adults (n=20)	Young Adults (n=19)
Age (y)	65.55±4.67	24.25±3.15
Weight (kg)	57.96±7.15	55.77±7.88
Height (cm)	163±4.86	162.51±4.21
MMSE (0–30)	27.79±1.81	NA
GDS (0–15)	1.84±1.53	NA
FAB (0–40)	35.58±2.75	NA

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Abbreviations: MMSE: Mini-mental state examination; GDS: Geriatric depression scale; FAB: Fullerton advanced balance scale; NA: Not applicable.

Table 2. Alpha absolute power in ST and DT conditions

Electrode	Group		Condition		Time		Group×Condition		Group×Time		Condition×Time		Group×Condition×Time	
	F Ratio	P	F Ratio	P	F Ratio	P	F Ratio	P	F Ratio	P	F Ratio	P	F Ratio	P
Fz	15.7	<0.001*	0.782	0.387	35.69	<0.001*	1.34	0.278	7.69	0.001*	0.93	0.911	0.405	0.668
F3	17.33	<0.001*	0.277	0.599	31.08	<0.001*	0.297	0.578	6.58	0.002*	0.615	0.542	0.373	0.689
F4	35.41	<0.001*	0.291	0.590	40.77	<0.001*	0.798	0.373	8.084	<0.001*	0.236	0.790	0.255	0.799
Cz	16.73	<0.001*	0.429	0.484	33.69	<0.001*	0.443	0.506	11.25	<0.001*	0.912	0.403	0.14	0.869
C3	22.61	<0.001*	3.69	0.068	26.55	<0.001*	0.29	0.591	11.58	<0.001*	0.04	0.961	0.291	0.748
C4	19.17	<0.001*	5.44	0.021*	12.27	<0.001*	0.048	0.827	15.84	<0.001*	0.052	0.949	0.391	0.677
Pz	1.69	0.194	5.76	0.017*	9.33	0.194	0.446	0.505	8.52	<0.001*	0.808	0.447	1.016	0.364

*Statistically significance.

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Table 3. Beta absolute power in single-task and DT conditions

Electrode	Group		Condition		Time		Group×Condition		Group×Time		Condition×Time		Group×Condition×Time	
	F Ratio	P	F Ratio	P	F Ratio	P	F Ratio	P	F Ratio	P	F Ratio	P	F Ratio	P
Fz	33.61	<0.001*	1.73	0.190	0.53	0.944	0.52	0.47	1.13	0.32	0.16	0.84	0.46	0.95
F3	91.77	<0.001*	0.053	0.819	0.19	0.082	0.19	0.66	1.09	0.33	0.34	0.71	0.02	0.97
F4	105.11	<0.001*	3.126	0.078	0.115	0.891	3.97	0.047*	0.67	0.513	0.006	0.994	0.02	0.980
Cz	40.75	<0.001*	0.61	0.436	2.45	0.089	0.008	0.927	2.04	0.132	0.343	0.710	0.215	0.807
C3	65.56	<0.001*	1.16	0.281	0.194	0.824	1.97	0.162	0.815	0.444	0.114	0.892	0.109	0.896
C4	79.52	<0.001*	4.97	0.027*	1.28	0.279	3.99	0.047*	2.78	0.064	0.033	0.967	0.154	0.857
Pz	8.18	0.005*	2.22	0.137	1.01	0.364	0.011	0.916	0.274	0.761	0.914	0.402	0.58	0.561

*Statistically significance.

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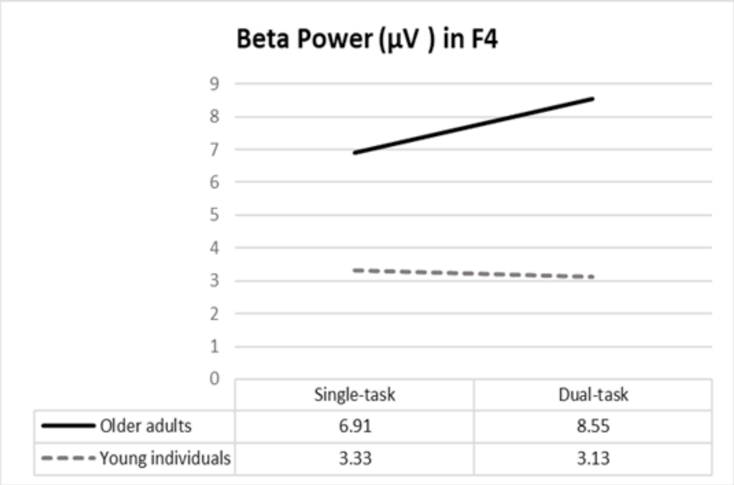

Figure 2. Interaction plot of beta power in the F4 region

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The increased alpha power in the sensorimotor and supplementary motor areas observed in older adults during DT conditions is consistent with evidence that postural control becomes more cognitively demanding with age (Jacobs & Horak, 2007). Motor control in older individuals relies more heavily on cortical regions, including the prefrontal cortex, for compensatory strategies when regaining postural stability following perturbations (Papegaaij et al., 2014). This shift from subcortical to cortical control mechanisms may be attributed to age-related degeneration in somatosensory receptors and reduced conduction velocity, both of which compromise the automaticity of postural control (Papegaaij et al., 2014; Sturnieks et al., 2008).

This study builds upon our previous work, which investigated cortical responses to predictable and unpredictable perturbations using the same dataset (Saadat et al., 2021). While the earlier study highlighted the role of anticipation versus reaction in postural control, the current analysis shifts focus to the cognitive-motor interplay under DT conditions. By examining the influence of an additional cognitive task on cortical activity during postural recovery, this study extends our understanding of DT interference and its implications for fall risk in older adults. The present findings offer actionable insights for fall prevention strategies that integrate both motor and cognitive training, a dimension not explored in the initial analysis.

The cortical overactivation observed as increased power z-scores during DT conditions likely represents an effort to engage additional neural resources to manage the increased attentional demands (Reuter-Lorenz & Cappell, 2008). While this compensatory mechanism supports balance control, it may reduce the availability of cognitive resources for other tasks, explaining the greater DT interference observed in older adults (Palmer et al., 2021).

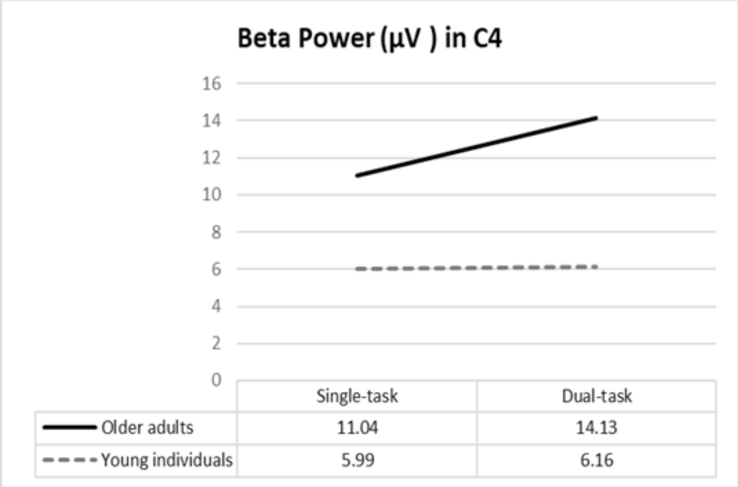

Figure 3. Interaction plot of beta power in the C4 region

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In line with the dedifferentiation theory, the reduced neural specificity seen in older adults may also contribute to this cortical overactivation (Morcom & Henson, 2018). With age, the brain becomes less efficient in segregating neural processes, leading to broader recruitment of cortical areas even for tasks that, in younger adults, are more localized to subcortical regions (Alizadehsaravi et al., 2020). This reduced efficiency in neural processing is particularly evident in DT scenarios, where the cognitive load further strains the brain's limited attentional resources (Lacour et al., 2008).

Our study also found elevated beta power in the prefrontal and sensorimotor regions during DT conditions, particularly in older adults. Beta oscillations are closely linked to the cognitive aspects of motor control and are indicative of heightened cortical engagement during more demanding tasks (Teasdale & Simoneau, 2001). The increased beta power observed in older adults suggests that they require more cognitive effort to maintain balance under DT conditions, reflecting the additional neural processing required to integrate motor and cognitive tasks simultaneously.

This enhanced cortical activity in older adults may serve as a biomarker for reduced automaticity in balance control (Ghosn et al., 2020). As the task becomes more challenging, the central nervous system recruits higher-level cortical resources to compensate for the loss of subcortical control (Pizzamiglio et al., 2017). This reliance on cortical control could explain the difficulty older adults face in maintaining postural stability while concurrently performing cognitive tasks (Ghosn et al., 2020; Palmer et al., 2021).

Our results support the idea that brain oscillations, particularly in the alpha and beta frequency bands, play a critical role in modulating connectivity between different brain regions during postural tasks (Malcolm et al., 2021). Young and older adults seem to employ different neural strategies when managing DT conditions, with older adults showing less flexibility in reallocating neural resources (Malcolm et al., 2021). The greater engagement of cortical areas in older adults under DT conditions reflects an age-related shift in sensorimotor processing that compensates for the decline in subcortical mechanisms that once governed automatic postural control (Ghosn et al., 2020).

The reliance on these cortical networks may also indicate a lower threshold for eliciting stepping reactions, especially in cognitively demanding situations (Palmer et al., 2021). This condition has important implications for understanding fall risk in older adults, as greater reliance on cortical resources for postural control may lead to slower or less efficient balance recovery (Clark, 2015; Ghosn et al., 2020).

Taken together, our findings suggest the role of task complexity in potentially shaping neural responses during postural adjustments. Accordingly, depending on the cognitive demands, older adults demonstrated heightened challenges in maintaining balance. Such an observation underscores the implication of considering DT scenarios in balance assessments and interventions. Furthermore, the distinction in neural activation patterns between young and older adults proposes that age-related neural adaptations are not merely compensatory and refer to fundamental shifts in how balance is processed within the brain. In other words, since older adults engage more cortical resources in DT perturbations, an increased reliance can lead to a fragile balance system, particularly under complex conditions.

The implications of our findings extend to practical applications in fall prevention strategies. Interventions designed to enhance postural control in older adults could benefit from incorporating cognitive tasks that simulate real-world challenges. Such an approach could help mitigate the neurocognitive burden associated with DT, potentially leading to improved stability and reduced fall risk. Additionally, understanding the specific neural mechanisms underlying balance control in older adults can guide the development of targeted training programs to improve or empower both motor and cognitive functions, leading to a collective approach to maintaining functional independence in aging populations. Future research could expand on these findings by exploring additional cortical regions and frequency bands, including gamma oscillations, to provide a more comprehensive understanding of the neural dynamics underlying balance and DT performance.

5. Conclusion

The findings of this study highlight the significant role of cortical activity in postural adjustments in older adults, particularly during DT conditions. The increased alpha and beta power in the sensorimotor and prefrontal regions points to compensatory mechanisms that enable older adults to maintain balance despite age-related declines in sensorimotor function. These findings contribute to the growing body of evidence that cortical overactivation is a hallmark of aging and suggest that targeted interventions aimed at improving automaticity in balance control could mitigate DT interference and reduce fall risk in older adults.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by Shiraz University of Medical Sciences, Shiraz, Iran (Code: IR.SUMS.REC.1396.26).

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Authors' contributions

Conceptualization, methodology, investigation, review, and editing: All authors; Writing the original draft: Ehsan Sinaei and Zahra Saadat; Funding acquisition and resources: Zahra Saadat and Mohammad Nami; Supervision: Mohammad Nami.

Conflict of interest

The authors declared no conflict of interest.

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