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The effect of neurofeedback and somatosensory exercises on balance and physical performance of older adults: a parallel single-blinded randomized controlled trial

Saeedeh Sedighi Darijani[1], Mansour Sahebozamani[1]✉, Mahin Eslami[2], Shima Babakhanian[3], Mohammad Alimoradi[1] & Mojtaba Iranmanesh[1]

This study examines the effects of a 5-week program of neurofeedback combined with somatosensory exercises on balance and physical performance in older adults, with the goal of addressing age-related declines in sensory processing and motor function. Sixty older adult men with balance disorders were randomly assigned to one of three groups: neurofeedback combined with somatosensory training, somatosensory training alone, or a control group. The interventions were administered over 5 weeks, with participants attending three sessions per week. Assessments were conducted both before and after the intervention period, including measurements of static balance using the Stork test, dynamic balance using the Timed Up and Go (TUG) test, and physical performance using the Continuous Scale Physical Functional Performance-10 (CS-PFP-10) test. The findings revealed significant improvements in balance and physical performance among participants who received either neurofeedback combined with somatosensory training or somatosensory training alone. Specifically, the Stork test (with both open and closed eyes) showed significant increases in duration, while the TUG test indicated reductions in completion times for both intervention groups ($p = 0.001$), suggesting enhanced balance and mobility. Additionally, the CS-PFP-10 test results demonstrated a significant difference following the interventions ($p = 0.001$). These findings suggest that incorporating neurofeedback training into somatosensory exercises may provide additional benefits for older adults in improving balance and mobility.

Keywords Neurofeedback exercises, Somatosensory exercises, Balance, Older adults

The global age distribution is shifting, with a growing number of older adults and a concurrent decline in the younger population[1]. This demographic change has sparked scientific interest in aging, particularly in promoting successful aging strategies. As a result, numerous interventions have been developed to enhance the physical and psychosocial well-being of older adults[2]. Among the health challenges faced by this population, balance impairment and the associated high prevalence of falls remain critical concerns. Approximately one in three individuals over the age of 65 experiences a fall each year, often resulting in serious consequences such as injuries, disabilities, loss of independence, and even death[3]. Regular physical activity is recognized for its positive effects on the physical health of older adults, functioning as both a preventive and rehabilitative strategy against various health risks. Functional assessments, including measures of physical performance like walking speed, standing balance, and muscle strength, are essential for evaluating physical capabilities and predicting outcomes such as falls and mortality[4,5]. Maintaining balance requires the central integration of sensory systems and appropriate neuromuscular responses. Conditions such as unilateral peripheral vestibular disorder (UPVD) can significantly disrupt this stability, thereby increasing the risk of falls[6]. International guidelines recommend

[1]Department of Sports Injuries and Corrective Exercises, Faculty of Sports Sciences, Shahid Bahonar University, Kerman, Iran. [2]Neuroscience Research Center, Institute of Neuropharmacology and Department of Psychiatry, Afzalipour School of Medicine, Kerman University of Medical Sciences, Kerman, Iran. [3]Department of Health and Sport Medicine, Faculty of Physical Education and Sport Sciences, University of Tehran, Tehran, Iran. ✉email: sahebozamani@uk.ac.ir

vestibular rehabilitation as a primary treatment for balance issues; however, its effectiveness may be limited by the degree of vestibular damage and the patient's capacity to perform the exercises correctly[7]. To address these limitations, advanced training approaches have been developed[8]. These methods often incorporate biofeedback, which provides immediate sensory input to enhance balance control. Biofeedback devices, which deliver real-time visual, auditory, electrotactile, and vibratory feedback, have demonstrated effectiveness in improving both static and dynamic balance in healthy older adults and those with balance disorders[9].

Neurofeedback, a specialized form of biofeedback, involves the self-regulation of brain functions through real-time monitoring of brain wave activity. It enables individuals to consciously modify brain wave patterns to achieve desired cognitive states[10]. During neurofeedback therapy, electroencephalography (EEG) is recorded, and its various components are extracted and presented to participants through an online feedback loop in the form of auditory, visual, or combined stimuli. Positive or negative feedback is provided based on the presence of favorable or unfavorable brain activities, respectively. Neurofeedback has been investigated for several decades and is recognized as a complementary and alternative treatment for numerous brain disorders[11,12]. Maintaining effective balance in daily activities is crucial for preserving independence and quality of life in older adults[13]. Somatosensory training, which utilizes the brain's capacity to "re-weight" sensory inputs, is an accessible strategy for maintaining and enhancing balance. This form of training engages both the sensory and motor functions of the brain, promoting neuroplasticity and enhancing the central nervous system's ability to integrate sensory information[14,15]. By specifically targeting and challenging the somatosensory, visual, and vestibular systems, somatosensory exercises aim to improve overall balance and reduce the risk of falls.

Despite extensive research in this area, there remains a gap in understanding the combined effects of neurofeedback and somatosensory exercises on balance and physical performance in older adults with balance disorders. Previous studies have predominantly examined neurofeedback or somatosensory training separately. This study aims to assess the impact of somatosensory exercises on balance and physical performance and to investigate the combined effects of neurofeedback and somatosensory exercises. We hypothesize that integrating neurofeedback with somatosensory exercises will lead to greater improvements in balance and physical performance compared to somatosensory training alone. By addressing this gap, our study seeks to contribute to the development of more effective intervention strategies for enhancing balance and reducing fall risk among older adults.

Results

The baseline descriptive characteristics of participants across the experimental groups are presented in Table 1. The study was conducted from June 4, 2023, to July 20, 2023. All participants completed the interventions as well as the follow-up assessments, and their post-test results were recorded (Fig. 1). Notably, no adverse events were reported in either of the intervention groups.

The variables were normally distributed ($p > 0.05$). Table 2 presents the mean and standard deviation of the dependent variables before and after the intervention. The results of the mixed ANOVA, also shown in Table 2, reveal significant effects for time ($p < 0.05$), group ($p < 0.05$), and the group-time interaction ($p < 0.05$) for the stork test under both open and closed conditions, the TUG, and the CS-PFP test.

Based on the results of the Tukey test (Table 3), significant differences ($p < 0.05$) were observed between the NFT + SST group and the CO group, as well as between the SST group and the CO group, in the Stork test

Variable	Group	Mean (SD)	*p*
Age (year)	NFT + SST	65.30 (3.62)	0.836
	SST	65.15 (3.64)	
	CO	65.80 (3.48)	
Height (cm)	NFT + SST	165.56 (3.98)	0.910
	SST	165.00 (6.10)	
	CO	164.91 (5.01)	
Mass (kg)	NFT + SST	69.12 (4.85)	0.477
	SST	69.72 (2.97)	
	CO	69.10 (6.12)	
BMI (kg/m^2)	NFT + SST	25.26 (2.24)	0.528
	SST	26.00 (1.94)	
	CO	25.69 (1.70)	
GHQ-28 test (score)	NFT + SST	5.36 (0.67)	0.065
	SST	5.81 (0.76)	
	CO	5.85 (0.71)	
MMSE test (score)	NFT + SST	28.75 (0.63)	0.498
	SST	28.70 (0.92)	
	CO	28.95 (0.0.60)	

Table 1. Baseline descriptive characteristics of participants. NFT neurofeedback training, SST somatosensory training, CO control, GHQ general health questionnaire, MMSE mini-mental state examination.

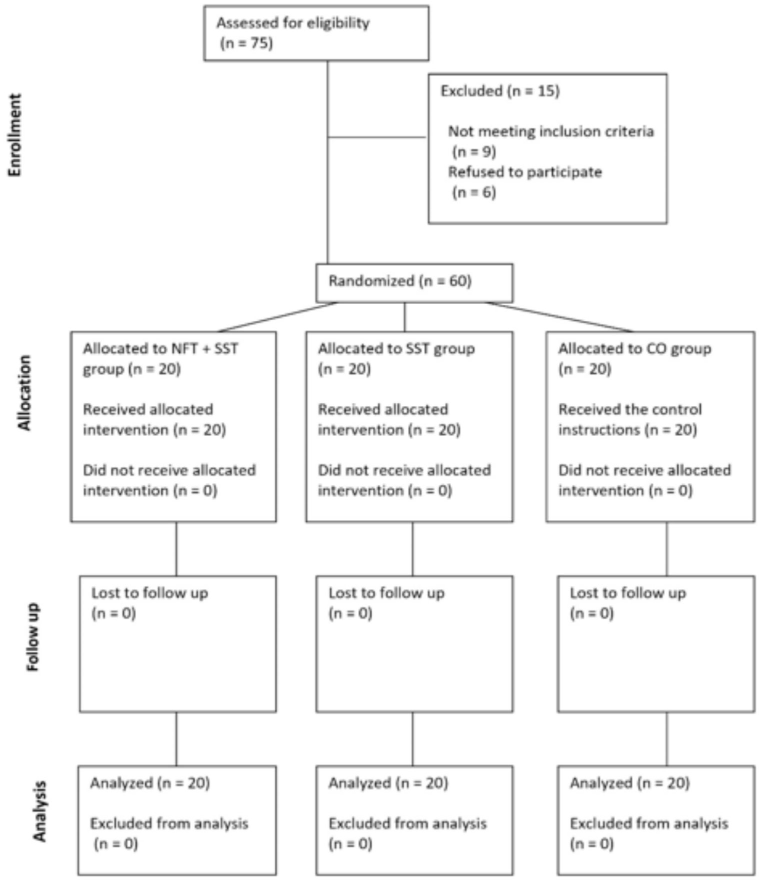

Fig. 1. CONSORT flow diagram.

	Group								
	NFT + SST Mean (SD)		SST Mean (SD)		CO Mean (SD)				
Variable	**Pre-test**	**Post-test**	**Pre-test**	**Post-test**	**Pre-test**	**Post-test**	**Time effect**	**Group effect**	**Time × group interaction**
Stork test with open–eyes (s)	40.19(11.15)	62.84(16.52)	38.90(9.95)	55.12(16.28)	39.45(8.01)	39.65(8.42)	F = 59.45 *P* = 0.001 ES = 0.64	F = 11.49 *P* = 0.001 ES = 0.41	F = 19.33 *P* = 0.001 ES = 0.54
Within-group results	*P* = < 0.001 MD = 22.65 % change = ↑ 56.35% 95% CI: − 31.39 to − 13.91		*P* = < 0.001 MD = 16.22 % change = ↑ 41.69% 95% CI: − 24.85 to − 7.58		*P* = 0.84 MD = 0.2 % change = ↑ 0.50% 95% CI: − 5.45 to 5.05				
Stork test with closed–eyes (s)	3.08(0.94)	5.10(0.86)	3.28 (1.43)	4.53 (1.06)	3.62(1.36)	3.61(1.24)	F = 98.11 *P* = 0.001 ES = 0.74	F = 10.44 *P* = 0.001 ES = 0.38	F = 38.57 *P* = 0.001 ES = 0.70
Within-group results	*P* = < 0.001 MD = 2.52 % change = ↑ 65.58% 95% CI: -2.59 to − 1.44		*P* = < 0.001 MD = 1.25 % change = ↑ 38.10% 95% CI: − 2.05 to − 0.44		P = 0.94 MD = − 0.01 % change = ↓ 0.27% 95% CI: − 0.82 to 0.84				
TUG (s)	14.97(0.96)	11.88(0.59)	15.11(1.10)	13.73(1.44)	14.85(0.83)	14.68(0.87)	F = 113.60 P = 0.001 ES = 0.77	F = 31.50 *P* = 0.001 ES = 0.65	F = 29.27 *P* = 0.001 ES = 0.64
Within-group results	*P* = < 0.001 MD = − 3.09 % change = ↓ 20.64% 95% CI: 2.57 to 3.60		*P* = < 0.001 MD = − 1.38 % change = ↓ 9.13% 95% CI: 0.55 to 2.20		*P* = 0.43 MD = − 0.17 % change = ↓ 1.14% 95% CI: − 0.47 to 0.61				
CS-PFP (score)	50.11(13.56)	63.85(9.34)	51.23(10.66)	60.76(10.02)	50.16(8.13)	48.38(5.19)	F = 47.22 *P* = 0.001 ES = 0.45	F = 5.54 *P* = 0.006 ES = 0.16	F = 17.90 *P* = 0.001 ES = 0.38
Within-group results	*P* = < 0.001 MD = 13.74 % change = ↑ 27.41% 95% CI: − 17.79 to − 8.37		*P* = < 0.001 MD = 9.53 % change = ↑ 18.60% 95% CI: − 13.36 to − 5.43		*P* = 0.23 MD = − 1.78 % change = ↓ 3.54% 95% CI: − 0.95 to 3.66				

Table 2. The results of the groups under study were collected before and after the interventions. NFT neurofeedback training, SST somatosensory training, CO control, ES effect size, CI confidence interval, TUG timed up and go, CS-PFP continuous-scale physical functional performance. ↑ indicates increase, ↓ indicates decrease. Significant level set as $p < 0.05$.

Variables	Groups	*P*	95% CI
Stork test with open–eyes (s)	NFT + SST - CO	< 0.001*	15.08 to 31.30
	NFT + SST - SST	0.16	- 2.42 to 17.86
	SST - CO	< 0.001*	23.50 to 7.44
Stork test with closed–eyes (s)	NFT + SST - CO	< 0.001*	0.83 to 2.15
	NFT + SST - SST	0.09	- 0.03 to 1.17
	SST - CO	< 0.001*	0.20 to 1.63
TUG (s)	NFT + SST - CO	< 0.001*	- 3.26 to – 2.34
	NFT + SST - SST	0.01*	- 2.53 to – 1.17
	SST - CO	< 0.001*	- 1.68 to – 0.21
CS-PFP (score)	NFT + SST - CO	0.01*	1.48 to 15.22
	NFT + SST - SST	0.99	- 6.50 to 7.23
	SST - CO	0.01*	1.11 to 14.85

Table 3. Comparison of the investigated variable among the three groups after the interventions. NFT neurofeedback training, SST somatosensory training, CO control, MD mean difference, CI confidence interval, TUG timed up and go, CS-PFP continuous-scale physical functional performance. Significant level set as $p < 0.05$.

with both open and closed eyes, and in the Timed Up and Go (TUG) test. For the CS-PFP-10 test, significant differences were also found between the NFT + SST group and the CO group, and between the SST group and the CO group. However, no significant differences were detected between the NFT + SST and SST groups in the Stork test with open eyes, the Stork test with closed eyes, or the CS-PFP-10 test.

Discussion

The present study examined the efficacy of neurofeedback training (NFT) combined with somatosensory training (SST) on various physical and cognitive performance measures, in comparison to SST alone and a control (CO) group. The findings demonstrated greater improvements in the NFT + SST group compared to the SST group across several outcome variables, including the Stork test (in both open and closed conditions), the Timed Up and Go (TUG) test, and the Continuous Scale Physical Functional Performance (CS-PFP) test. These results underscore the potential benefits of integrating neurofeedback with somatosensory interventions.

The Stork test results demonstrated substantial improvements in balance for the NFT + SST group, with participants achieving a 56.35% improvement in the open-eyes condition and a 65.58% improvement in the closed-eyes condition. These improvements were greater than those observed in the SST group, which saw gains of 41.69% and 38.10%, respectively. These findings underscore the added value of combining NFT with SST. Additionally, the TUG test results further validate the efficacy of the NFT + SST intervention, as the NFT + SST group exhibited a 20.64% reduction in completion time, compared to a 9.13% reduction in the SST group. These results suggest that while both NFT and SST are effective in improving TUG performance, the combined NFT + SST intervention yields superior outcomes. The findings of this study are consistent with previous research demonstrating the effectiveness of both NFT + SST and SST exercises in improving balance and reducing fall risk among older adults. For instance, Azarpeikan and Torbati (2018) found that healthy older adults participating in neurofeedback sessions exhibited better balance than those in the control group[16]. Two potential interpretations for these results are worth considering. First, the placement of electrodes significantly influences the data used to assess balance[17]. In this study, the electrode positions "O1–O2" are located near key brain regions involved in balance regulation, such as the occipital lobe, substantia nigra, basal ganglia, and cerebellum[18]. According to Halder et al. (2013), the superior fronto-occipital fasciculus plays a role in evaluating individual performance when using a sensorimotor rhythm (SMR) brain-computer interface [19]. The choice of electrode placement (O1–O2) in our study is crucial due to the involvement of the posterior corona radiata in SMR activity. Another possible explanation is that the method used to reduce theta activity and enhance SMR activity is vital for maintaining balance. Theta brainwave activity, typically observed in young children, tends to occur during meditative, drowsy, or sleep states in older children and adults[20]. In contrast, SMR waves are primarily seen during normal waking states when an individual is focused and engaged in cognitive tasks. In this study, older adults were able to learn how to decrease theta activity and increase SMR power through neurofeedback training, potentially by engaging in various cognitive activities unrelated to the task at hand to maintain balance. During the Stork and TUG tests, participants in the NFT + SST group achieved better scores than those in the control and SST groups, suggesting effective brainwave regulation even under novel conditions. This indicates that the learning process for static balance occurred in individuals receiving the NFT + SST intervention, further enhancing the benefits of SST. Regarding the effects of somatosensory exercises in the SST group, previous studies have also demonstrated positive impacts on balance in older adults[21,22]. For example, Freire and Seixas (2023) showed that sensorimotor exercises led to balance gains and increased confidence among older adults[21]. Similarly, Mohammad Ali Nasab Firouzjah and Farnian (2023) reported that their fall-proof intervention improved both static and dynamic balance and reduced fear of falling in older women[22]. Walking on patterned surfaces can effectively stimulate the mechanical and pressure receptors in the soles of the feet, part of the lower limb sensory-motor system, thereby improving balance[16]. Such exercises enhance balance by utilizing more sensory information, which improves the older adults' ability to reintegrate proprioceptive inputs. Additionally, prominences on the soles aid in transmitting cutaneous information related to the body's vertical position, enhancing body awareness and spatial representation, and optimizing the distribution of pressure on the soles[23]. This enhanced utilization of sensory information may explain the observed improvements in balance in both the NFT + SST and SST groups.

The results of the current study indicated significant improvements in physical performance, as measured by the CS-PFP-10 test, in both the NFT + SST group (27.41%) and the SST group (18.60%). This finding provides substantial support for the effectiveness of the provided exercises in enhancing physical performance among older adults. Neurofeedback exercises, by modulating brain wave activity and providing the desired range to the central nervous system (CNS), are recommended to improve older adults' control over this system and their ability to maintain balance[24]. Essentially, delivering biological feedback to an individual's CNS through neurofeedback and adjusting the wavelength to an optimal range can unconsciously enhance the CNS's capacity to manage fluctuations due to illness or aging, thereby improving postural control[25]. Furthermore, walking on patterned surfaces and utilizing sensory information has been shown to enhance balance. Performing exercises on these surfaces can positively affect the proprioceptive and vestibular sensory systems, which interact in the occipital lobe[16]. As aging is an irreversible process, it is often associated with a decline in physical performance, and physical inactivity can accelerate this decline. However, research indicates that engaging in physical activity can slow the decline in physical performance and mitigate the decrease in physiological capacity related to aging[26,27]. For example, Bischof et al. (2021) found that a multi-component training program significantly improved the physical performance of women in nursing homes after 16 weeks of intervention[26]. Similarly, Zacharia et al. (2015) reported that an 8-week yoga intervention effectively enhanced physical performance, as measured by the CS-PFP-10 test, in middle-aged women[27]. To maintain physical performance and promote quality of life in older adults, encouraging participation in physical activity programs is crucial. Our study's findings align with this research, demonstrating that both SST and NFT + SST interventions can significantly enhance physical performance in older adults. The implications of these findings extend to real-world applications. Integrating NFT + SST into community programs and rehabilitation centers could help address the growing prevalence of balance disorders in older adults. The enhanced balance and mobility observed in the NFT + SST group suggest that such combined interventions could reduce fall risk and improve daily functioning, ultimately supporting older adults in maintaining independence and enhancing their overall quality of life.

Several limitations should be considered when interpreting the findings of this study. Firstly, the study's duration was relatively short, with interventions conducted over a five-week period. Longer-term follow-up assessments are necessary to determine the sustainability of the observed improvements in balance and physical performance. Additionally, the lack of long-term follow-up data limits our ability to assess the maintenance effects of the interventions beyond the immediate post-intervention period. Moreover, the study exclusively involved older adult men, which may limit the generalizability of the findings to older adult women or other demographic groups. Finally, the study did not assess the fear of falling, a critical factor that could influence the effectiveness of interventions aimed at improving balance and physical performance in older adults.

Conclusion

In conclusion, our study underscores the potential of neurofeedback, somatosensory exercises, and their combination in enhancing balance and physical performance in older adults with balance disorders. These interventions could play a significant role in reducing the risk of falls and improving the quality of life for older adults. To translate these findings into practice, healthcare providers should consider incorporating these interventions into rehabilitation programs and community initiatives, thereby promoting healthy aging and independence. Future research should aim to refine these interventions and develop strategies for their broader implementation, effectively bridging the gap between research and practical application for the benefit of the older adult population.

Methods

Ethics

The participants were orally informed about the study procedures and provided written informed consent. All experimental conditions adhered to the Declaration of Helsinki and were approved by the Ethical Committee of Shahid Bahonar University of Kerman, Iran (Code: IR.UK.VETMED.REC.1398.025). The study followed the Consolidated Standards of Reporting Trials (CONSORT) guidelines to ensure high-quality reporting[28]. Additionally, the study was registered with the Iranian Registry of Clinical Trials (Registration Number: IRCT20191201045568N1, Date: 06/05/2020).

Participants

The present study was a balanced randomization [1:1], parallel, single-blinded randomized controlled trial involving 60 older adult men aged 60–70 years with balance disorders. The study aimed to evaluate preventive measures for balance disorders and was conducted at Shahid Beheshti Hospital in Kerman. Participants were recruited through notifications distributed to all retirement centers in Kerman City. The sample size was determined using G*Power software (version 3.1.9.4; University of Kiel, Kiel, Germany), with an effect size of 0.36, an alpha level of 0.05, and a statistical power of 80%. Participants were randomly assigned to one of three groups using the simple randomization method at Random.org with a permuted block technique (block size of 6): somatosensory training (SST; n = 20), neurofeedback + somatosensory training (NFT + SST; n = 20), and a control group (CO; n = 20). The randomization process was conducted by hospital staff, ensuring researchers were unaware of group assignments. Inclusion criteria required participants to exceed a 14-s threshold in the Timed Up and Go (TUG) test to identify balance deficits[29], and to have refrained from any balance or somatosensory exercises for at least the previous 6 months. Participants were also required to complete the General Health Questionnaire (GHQ-28), with a score of ≥ 9 indicating suitability for participation[30]. Brief evaluations of attention and calculation, memory, language, ability to execute simple commands, and temporal and spatial orientation were performed using the Mini-Mental State Examination (MMSE). A score of ≤ 24 on the MMSE was considered suitable for inclusion[25]. Exclusion criteria included refusal to cooperate, pain during the procedure, diminished mental state, cardiovascular instability, metabolic disorders, recent unrepaired fractures, a life expectancy of less than one-year, excessive alcohol use, and difficulty speaking[16,25]. To adhere to research ethics, participants were thoroughly informed about the study's objectives, procedures, and safety considerations related to neurofeedback usage. They were assured of data confidentiality and informed that all information would be used solely for research purposes. Written consent forms were signed by all participants.

Procedure
After assigning participants to study groups, the experiment proceeded as follows: Over a five-week period, participants in both intervention groups (NFT + SST and SST) completed three 60-min sessions per week, amounting to a total of 15 training sessions. In contrast, the control group only participated in pre- and post-tests and continued with their regular daily activities throughout the study period. The training environment was carefully controlled to minimize external sensory factors, such as noise and extreme lighting, which could potentially influence the outcomes. Participants were supervised by two researchers during each session to ensure safety and adherence to the exercise protocol.

Somatosensory training
Each somatosensory training session lasted 60 min and was divided into three segments: a 15-min warm-up phase, a 30-min main walking period on a patterned surface, and a 15-min cool-down phase. During the warm-up, participants engaged in a series of static and dynamic stretches targeting major muscle groups, followed by walking on a smooth, flat surface to gently elevate their heart rate and further prepare muscles and joints. The main walking session involved walking on a specially designed 5-m patterned surface covered with round, stiff plastic prominences spaced approximately 1 cm apart to challenge the somatosensory system. Activities included walking heel to toe (placing one foot directly in front of the other), walking on tiptoes and heels, sideways walking, and walking while simultaneously lifting the opposite leg and arm. Participants performed these activities barefoot to maximize sensory input from the patterned surfaces and wore loose-fitting clothing suitable for physical activity to ensure safety and ease of movement. The cool-down phase involved gradually slowing the walking pace and ceasing arm movement to allow the body to return to a resting state. Participants performed these sessions three times a week for a total of 15 sessions[23].

Neurofeedback and somatosensory training
The NFT + SST intervention combined neurofeedback training with the somatosensory training protocol to provide a comprehensive approach to enhancing participants' neurological and physical performance. For the neurofeedback component, electrode placement adhered to the international 10–20 system, with sensors positioned on the left and right occipital areas (O1, O2) and a reference sensor attached to the left earlobe[18]. Participants underwent 30-min neurofeedback sessions during which they engaged in three specially designed video games: boat sailing, puzzles, and animated sequences, each lasting 10 min. These games were engineered to train participants to increase their beta 1 (12–15 Hz) brainwave activity while decreasing theta (4–7 Hz) activity. The game's difficulty levels were automatically adjusted by the BioGraph Infinity software based on real-time performance, following the 80–20 rule to enhance the desired brainwave frequencies and suppress the undesired ones[18]. The neurofeedback training was conducted using a 10-channel Canadian device (FlexComp Infiniti) equipped with BioGraph Infinity software (Thought Technology Ltd, Canada). Immediately following the neurofeedback session, participants performed the somatosensory training protocol, including a 30-min walking session on a patterned surface as detailed in the SST intervention. This combined intervention of neurofeedback and somatosensory training was conducted three times a week for a total of 15 sessions.

Measurement of outcomes
Standing stork test
To perform the Stork test on the dominant leg, participants were first instructed to stand comfortably on both feet with their hands on their hips. They were then asked to lift one leg and place the toes against the knee of the opposite leg (Fig. 2). Upon command, they raised their heel and stood on their toes. The test was conducted barefoot to ensure maximum proprioceptive feedback. A stopwatch was started when the heel was lifted from the floor and stopped if any of the following occurred: the hands came off the hips, the supporting foot moved in any direction, the non-supporting foot lost contact with the knee, or the heel of the supporting foot touched the floor.The test was conducted under two conditions: eyes-open and eyes-closed. Each participant performed three attempts of the test, and the average duration was recorded for statistical analysis[31]. The Stork test has demonstrated acceptable validity (0.86) and reliability (0.94) for balance assessment[32].

Timed up & go (TUG) test
In the TUG test (Fig. 3), participants wore their regular footwear and were instructed to stand up from a sitting position on a chair approximately 46 cm in height, walk at a normal pace to a marker placed 3 m away, turn around, return to the chair, and sit down again. The time taken to complete this task was measured with a stopwatch to the nearest second[33]. Each participant performed two trials, and the faster time was recorded for

Fig. 2. Static stork test.

analysis. The Intra-Class Correlation coefficients for the TUG test have been reported to range between 0.87 and 0.92, indicating good reliability[34].

Continuous scale-physical functional performance-10 (CS-PFP-10) Tt

The CS-PFP-10 test was administered following standardized procedures, which included using a certified test site, trained administrators, and a scripted dialogue, as described in previous studies[35,36]. This assessment consists of 10 daily living activities performed at maximum effort within the individual's perceived safety and comfort

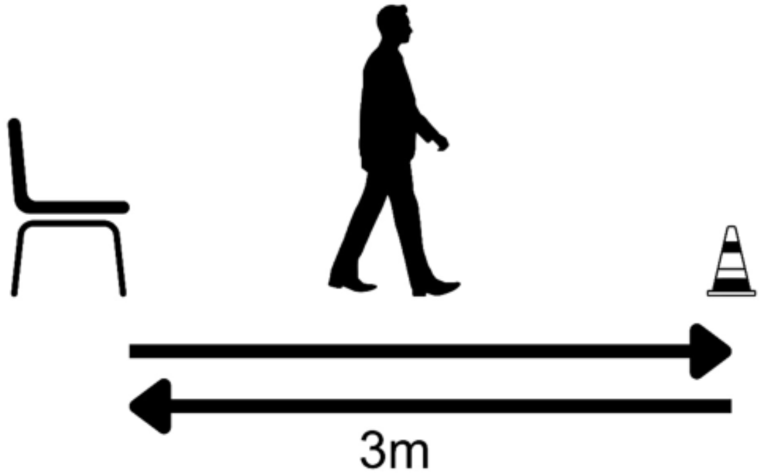

Fig. 3. Sitting on a chair, getting up and walking up to three meters, turning back and sitting on the chair again, TUG test.

limits. The tasks, varying in difficulty from low to high, involve time, distance, and weight components to assess overall physical functional performance. Specifically, the test evaluates performance across five physiological functional domains: upper body strength, upper body flexibility, lower body strength, balance, and endurance. The 10 activities included: carrying a weighted pot, putting on and taking off a jacket, lifting a book onto a shelf, carrying a grocery bag, picking up a penny from the floor, climbing stairs, walking 6 m, putting on and taking off shoes, reaching forward while standing, and standing up from a chair. Raw data such as time, distance, and mass are transformed into a scaled score ranging from 0 to 100 using licensed scoring software, providing both an overall performance score and scores for each of the five functional domains. The total time to complete the CS-PFP-10 test typically ranges from 30 to 40 min[36].

Data analysis
Statistical analyses were performed using SPSS 26.0 software (IBM SPSS, Armonk, NY, USA). The normality of data distribution was assessed with the Shapiro–Wilk test. A mixed-design analysis of variance (ANOVA) was conducted for all variables, incorporating a within-subject factor of time (pre-test and post-test) and a between-subject factor of group (SST, NFT + SST, and CO), as well as examining group-time interaction effects. When significant group effects or interaction effects were identified, Tukey's post hoc test was used to explore any potential differences. Effect sizes (ES, partial η^2) were calculated for all parameters, with partial η^2 values of 0.02, 0.13, and 0.26 representing small, medium, and large effects, respectively. The significance level was set at $p < 0.05$, with a 95% confidence interval.

Data availability
The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Author contributions
Conceptualization, S.S, M.S, and M.E.; Methodology, S.S., M.S., M.E., S.B., M.A. and M.I.; Software, M.A.; Validation, M.S., M.E.; Formal analysis, S.S., M.S., and S.B; Investigation, S.S., S.B., M.A., and M.I.; Resources, M.S., and M.E.; Data curation, S.S. and S.B.; Writing—original draft preparation ,M.A., and M.I. ; Writing—review & editing, M.S., M.E. , and M.A.; Visualization, M.S., and M.E.; Supervision, M.S., and M.E.; Project administration, M.S., and M.E. All authors read and agreed to the published version of the manuscript.

Declarations

Competing interests
The authors declare no competing interests.

Additional information
Correspondence and requests for materials should be addressed to M.S.

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