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Review Article

Exploring the Impact of EMG Biofeedback Training on Postural Stability in the Elderly: A Scoping Review

Kanika Wadhwa, Anand Kumar Singh*, Radhika Gupta, Shalini Singh, Vishwajeet Trivedi, Ankush Sharma and Sheetal Malhan

Department of Physiotherapy, Goenka University Gurugram, Haryana, India

Abstract

Postural stability is critical for preventing falls in the elderly, a population particularly vulnerable to injury, morbidity, and mortality from falls. Electromyography (EMG) biofeedback training has emerged as a potential intervention, offering real-time muscle activity feedback to improve neuromuscular control, proprioception, and muscle activation patterns. Despite promising results in various clinical populations, the application of EMG biofeedback for enhancing postural stability in the elderly remains underexplored. This scoping review aims to explore the impact of EMG biofeedback training on postural stability among older adults, evaluating its effectiveness, underlying mechanisms, and clinical implications for fall prevention. A scoping review methodology was employed to comprehensively analyze peer-reviewed literature published from 2010 to 2024. Studies were sourced from PubMed, CINAHL, Cochrane Library, Scopus, and Web of Science. The review focused on randomized controlled trials, quasi-experimental, and observational studies examining the use of EMG biofeedback to enhance postural stability in elderly populations. Key variables such as intervention protocols, participant demographics, and outcomes were extracted and synthesized thematically. The review identified significant improvements in static and dynamic balance through EMG biofeedback training, with studies demonstrating enhanced muscle activation, reduced postural sway, and improved functional mobility. Notably, personalized biofeedback protocols showed superior outcomes, suggesting tailored interventions could optimize therapeutic effectiveness. While short-term benefits were evident, further research is needed to evaluate the long-term sustainability of these effects. Overall, EMG biofeedback presents a promising tool for improving postural stability and reducing fall risk in older adults.

Keywords: Accidental falls, Aged, Biofeedback, Demography, Electromyography, Feedback, Humans, Muscles, Proprioception, Psychology

*** Corresponding author**

Anand Kumar Singh, PhD
Department of Physiotherapy, Goenka University Gurugram, Haryana, India
Tel: +91 8607370746
Email: anand01physio@gmail.com

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Introduction

Postural stability is essential for maintaining balance and preventing falls, especially in the elderly population. Falls are a significant global public health issue, contributing to increased morbidity, reduced quality of life, heightened healthcare costs, and elevated mortality rates among older adults (1-3). The World Health Organization (WHO) identifies falls as the second leading cause of unintentional injury-related deaths globally, particularly affecting individuals aged 65 and older (4). With a steadily aging population, the urgency to develop interventions that effectively reduce fall risks and enhance postural stability has never been greater (5,6).

One promising intervention is Electromyography (EMG) biofeedback training, which offers real-time feedback on muscle activity to facilitate neuromuscular re-education and improve motor control (7,8). This therapeutic approach has been widely utilized to address various conditions, including motor impairments in stroke survivors (9,10), musculoskeletal disorders (11), and neurological dysfunctions (12). By providing visual or auditory feedback, EMG biofeedback allows individuals to better understand and modulate their muscle activation patterns, leading to improved movement efficiency and motor learning (13).

Emerging research indicates that EMG biofeedback may hold potential for improving postural stability among older adults. This is achieved by enhancing proprioceptive feedback mechanisms, reducing excessive muscle co-contractions, and fostering optimal muscle activation patterns (14,15). Studies have shown that balance and postural control are influenced by the interaction between visual, vestibular, and somatosensory systems, all of which can be augmented through targeted training with biofeedback (16). However, despite these promising findings, the application of EMG biofeedback for fall prevention and balance improvement in the elderly remains underexplored and fragmented across studies (17).

Existing literature highlights improvements in static and dynamic balance through EMG biofeedback, particularly in clinical populations (18,19). Yet, the evidence specific to older adults is sparse, necessitating a comprehensive synthesis to identify key trends, outcomes, and gaps in knowledge (20). This scoping review aims to systematically explore the impact of EMG biofeedback training on postural stability among the elderly, focusing on its effectiveness, mechanisms of action, and practical implications for clinical practice.

By consolidating and analyzing the current body of evidence, this review seeks to guide future research, inform clinical decision-making, and assist policymakers in designing evidence-based interventions for fall prevention in the aging population. Ultimately, the findings will contribute to developing sustainable and effective strategies for improving postural stability and enhancing the quality of life for older adults (21).

Materials and Methods

A scoping review was chosen as the methodological approach for this study to provide a comprehensive overview of existing literature on the impact of EMG biofeedback training on postural stability in the elderly. Scoping reviews are particularly suited for exploring broad or emerging research areas, enabling the identification of key concepts, research gaps, and available evidence (22,23). Unlike systematic reviews, which aim to answer specific research questions with precise conclusions, scoping reviews adopt a broader lens, accommodating diverse study designs and methodologies (24,25).

Search strategy

A systematic search of peer-reviewed literature was conducted in the databases PubMed, CINAHL, Cochrane Library, Scopus, and Web of Science. The search targeted studies published between 2010 and 2024 to ensure the inclusion of contemporary research. The following keywords and Boolean operators were utilized to refine search results: *"EMG biofeedback"*, *"postural stability"*, *"elderly"*, *"fall prevention"*, and *"neuromuscular control"*. Boolean operators such as *"AND"* and *"OR"* were employed to combine search terms effectively. A manual review of reference lists from relevant articles was also performed to identify additional studies.

Inclusion and exclusion criteria

The review incorporated studies that examined the use of EMG biofeedback training to enhance postural stability in elderly populations aged 60 years or older. Eligible studies were required to report either quantitative or qualitative outcomes related to balance, postural control, fall risk, or neuromuscular function. Included studies encompassed Randomized Controlled Trials (RCTs), quasi-experimental studies, or observational research published in English. Furthermore, studies needed to provide detailed information on intervention protocols, including specifics about EMG biofeedback settings, duration, and frequency of training sessions.

Conversely, studies were excluded if they focused on populations other than the elderly or explored interventions unrelated to EMG biofeedback, such as pharmacological treatments or traditional physical therapy without a biofeedback component. Additionally, review articles, editorials, opinion pieces, and conference abstracts were not considered. Studies lacking sufficient outcome data or detailed methodological descriptions relevant to postural stability were also excluded to maintain the rigor and relevance of the review.

Study selection process

All identified records were imported into reference management software (EndNote X9) to remove duplicates. Titles and abstracts were screened independently by two reviewers for relevance. Full-text articles were subsequently reviewed to determine eligibility based on the inclusion and exclusion criteria. Discrepancies between reviewers were resolved through discussion, with a third reviewer consulted if necessary (26).

Data extraction and synthesis

Data from included studies were extracted using a standardized form. Key variables included study characteristics (author, year, country, design), participant demographics (age, gender, health status), intervention details (EMG biofeedback protocol, duration, and frequency), and reported outcomes (balance measures, muscle activation patterns, fall risk). To ensure reliability, data extraction was performed by two independent reviewers, and discrepancies were resolved through consensus (27,28).

Risk of bias assessment

Although scoping reviews do not typically assess the quality of included studies, potential biases were critically examined. Particular attention was given to studies funded by EMG device manufacturers, with a focus on identifying methodological flaws, such as lack of blinding, inadequate controls, or selective reporting of positive outcomes (29,30). A summary of the key characteristics and potential sources of bias in the included studies is presented in table 1.

Analysis and reporting

Findings were synthesized thematically to identify trends, research gaps, and areas for further investigation. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines were followed to ensure methodological rigor and transparency (31).

Results

The article selection process is depicted in the PRISMA flow diagram (Figure 1), which outlines the identification, screening, and inclusion stages. A total of 14 studies met the eligibility criteria and were included in this scoping review. Comprehensive details regarding each study's design, sample size, intervention protocols, measured outcomes, and key findings are presented in table 2.

Across the included studies, there was consistent evidence supporting the effectiveness of EMG biofeedback training in enhancing postural stability among older adults. Improvements were observed across several key indicators, including reduced postural sway, enhanced center of pressure control, and improved functional mobility (Table 2; *e.g.*, Vieira *et al*, 2022; Zhang *et al*, 2023). Notably, participants exhibited better performance in dynamic functional tasks such as gait, sit-to-stand transitions, and reactive balance responses—critical components for reducing fall risk in geriatric populations.

A subset of studies implemented individualized EMG biofeedback protocols, adjusting training parameters based on participants' neuromuscular profiles. These personalized interventions consistently led to superior balance outcomes compared to standardized protocols (Table 2; Brauer *et al*, 2024), aligning with

Table 1. Cochrane risk of bias table of included studies

Author, year	Eligibility Criteria	Random Allocation	Concealed Allocation	Similar Baseline	Subject Blinding	Therapist Blinding	Assessors Blinding	Adequate follow-up	Intention to treat analysis	Between group comparison	Point estimates & variability	Score
Thomaz Nogueira Burke, 2010	Yes	Yes	No	Yes	?	?	Yes	Yes	Yes	Yes	Yes	8
Chang Ho Song, 2012	Yes	Yes	Yes	Yes	Yes	?	Yes	No	Yes	Yes	Yes	9
Thomaz Nogueira Burke, 2012	Yes	Yes	No	Yes	?	?	?	Yes	Yes	Yes	Yes	7
Kathleen H. Sienko, 2012	Yes	Yes	No	Yes	?	?	?	No	Yes	No	Yes	5
Koutatsu Nagai, 2012	Yes	Yes	No	Yes	?	?	?	No	Yes	Yes	Yes	6
Kwon-Young Kang, 2013	Yes	Yes	No	Yes	?	?	?	Yes	Yes	Yes	Yes	7
Marcio R. de Oliveira, 2014	Yes	Yes	Yes	Yes	?	Yes	Yes	No	Yes	Yes	Yes	9
Jungwon Yoon, 2016	Yes	Yes	No	Yes	?	?	?	No	Yes	No	Yes	5
Tadayoshi Asaka, 2017	Yes	Yes	Yes	No	?	?	?	No	Yes	Yes	Yes	6
Ji-Soo Jeong, 2021	Yes	Yes	No	Yes	?	?	?	Yes	Yes	Yes	Yes	7
Leonardo Araujo Vieira, 2022	Yes	Yes	No	Yes	?	?	?	No	Yes	Yes	Yes	6
Anren Zhang, 2023	Yes	Yes	Yes	Yes	?	?	Yes	Yes	Yes	Yes	Yes	9
Sharon M. Henry, 2024	Yes	Yes	No	Yes	?	?	?	No	Yes	No	Yes	5
Sandra G. Brauer, 2024	Yes	Yes	No	No	?	?	?	No	Yes	Yes	Yes	5

current trends in precision rehabilitation.

Furthermore, studies that integrated multimodal biofeedback mechanisms—combining EMG with visual and auditory cues—reported heightened user engagement, enhanced neuroplastic adaptation, and improved compliance with training regimens (Table 2; Jeong *et al*, 2021; Sienko *et al*, 2012). These results highlight the potential for multisensory feedback systems to amplify therapeutic effects and promote lasting balance improvements.

Although the majority of studies emphasized short- to mid-term outcomes, a few (*e.g.*, Vieira *et al*, 2022; Henry *et al*, 2024) provided preliminary evidence of long-term retention of postural improvements. Nevertheless, inconsistencies in follow-up periods, assessment tools, and intervention protocols indicate the need for standardized methodologies and extended longitudinal trials to better evaluate sustained efficacy.

In summary, findings presented in table 2 reinforce the clinical utility of EMG biofeedback as an effective, adaptable, and non-invasive intervention for improving both static and dynamic postural control in older adults. These results also advocate for the integration of EMG biofeedback into comprehensive fall-prevention programs in both clinical and community-based settings.

Discussion

This scoping review provides an integrated synthesis of current evidence regarding the impact

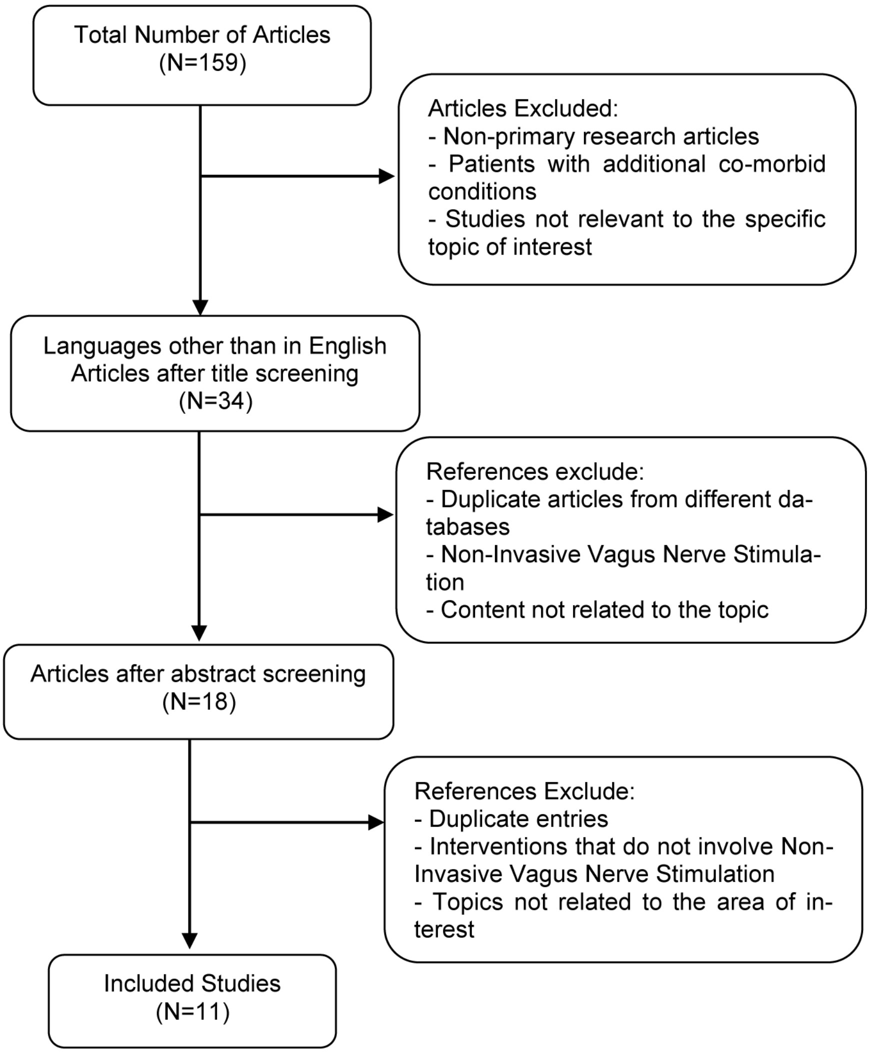

Figure 1. PRISMA flow diagram for selection of articles.

Table 2. Characteristics of the included studies

Author & year	Study design	Control group (Group I)	Experimental group (Group II)	(Group III)	Outcome variables (assessment tools)	Result
Thomaz Nogueira Burke, 2010	Randomized controlled study	The sample comprised 33 women diagnosed with osteoporosis, who were randomly assigned to two groups: the Control group, which consisted of 16 women (age 74.4±3.7 years) who did not engage in exercise	The intervention group (n=17, age 72.8±3.6 years) underwent an 8-week program consisting of exercises aimed at enhancing balance and strengthening the lower limbs	-	Postural control was evaluated with a force plate (Balance Master, Neurocom), while muscular strength in ankle dorsiflexion, knee extension, and knee flexion was measured using a dynamometer	The program adherence rate was 82%. In comparison to the control group, participants in the intervention group showed significant improvements in various outcomes: center of pressure velocity (p<0.02) in the modified clinical test of sensory interaction for balance, center of pressure velocity (p<0.01) and directional control (p<0.01) in the limits of stability test, and isometric force during ankle dorsiflexion (p<0.01), knee extension (p<0.01), and knee flexion (p<0.01)

Contd. table 2.

Chang Ho Song, 2012	Randomized controlled study	A total of 41 participants were chosen from a fall prevention class and randomly assigned to two separate groups. 21 participants were placed in the control group (mean age: 81.29±6.19 years). Individuals in this group did not undergo any form of training	The experimental group, with a mean age of 81.72±7.24 years, participated in biofeedback-based balance training combined with cognitive tasks. The training was conducted for 50 *min* per session, three times a week, over a period of 8 weeks	-	In this study, the BioRescue program was employed to detect motion using sensors attached to a platform. The GAITRite system was utilized to assess changes in temporal and spatial parameters, as well as gait stability. To examine the normal distribution of all parameters, the Shapiro-Wilks test was conducted	The experimental group showed significant improvements in all measures
Thomaz Nogueira Burke, 2012	Randomized controlled study	The sample comprised 50 women aged 65 or older, diagnosed with osteoporosis, who were randomly assigned to three groups. The Control group (n=16) did not participate in any activities	The strengthening group (n=17) engaged in balance training combined with muscle strengthening exercises. The intervention lasted for eight weeks, with sessions held twice a week, each lasting 60 *min*	The stretching group (n=17) participated in balance training combined with stretching exercises. The intervention program lasted for eight weeks, with sessions held twice a week, each lasting 60 *min*	Postural control was assessed using the modified Clinical Test of Sensory Interaction for Balance (CTSIBm) and the Limits of Stability Test. Strength was measured with dynamometry, and hamstring shortening was evaluated using goniometry	Compared to the control group, participants in the strengthening group showed notable improvements in dorsiflexion strength, knee flexion strength, as well as center of pressure velocity, directional control, and oscillation velocity (measured by the CTSIBm test). The stretching group demonstrated significant gains in hamstring flexibility, knee flexion strength, center of pressure velocity, and movement amplitude. When compared to the stretching group, the strengthening group exhibited superior knee extension strength and better directional control
Kathleen H. Sienko, 2012	Randomized controlled study	A total of ten older adults (6 males and 4 females), aged between 68 and 80 years (mean age: 74±4.3 years), voluntarily participated in the study. To be eligible, participants had to be free of central neurologic or musculoskeletal disorders and not experience frequent back or lower extremity pain. Exclusion criteria included self-reported hearing loss, nerve damage, foot numbness, severe visual impairment, a history of fainting, or a body mass index exceeding 30 *kg/m²*	-	-	The vibrotactile feedback system included a belt, an inertial measurement unit, four vibrating actuators (referred to as tactors), and a laptop. Two secondary tasks were incorporated into the experiment, where tones of two distinct frequencies were generated by the laptop and played through speakers for a duration of one second. In the first task, which required verbal responses, a microphone was used to capture the subjects' responses. In the second task, hand-held push buttons were employed to collect responses, with the resulting voltage signals being recorded on the laptop. Participants were provided with a set of standard exercise pants and a shirt before wearing the vibrotactile feedback device	The results indicate that when feedback was provided, participants spent significantly more time in the dead zone compared to when no feedback was given, with increases of +13.6% for the verbal secondary task and +10.1% for the push-button secondary task. Additionally, feedback led to a reduction in the root mean square (RMS) of trunk tilt for both tasks (verbal: -0.1298; push-button: -0.1388). However, the response times for both tasks were longer when feedback was provided, with increases of +119 *ms* for the verbal task and +110 *ms* for the push-button task. These findings suggest that while vibrotactile feedback does raise attentional demands in older adults, it remains an effective tool for enhancing postural control in situations of high cognitive load

Contd. table 2.

Koutatsu Nagai, 2012	Randomized controlled study	Forty-eight subjects were randomized into two groups. The control group (mean age: 81.6±6.4 years) (n=24) did not receive any intervention	A group of 24 individuals, with an average age of 81.0±6.9 years, participated in an 8-week balance training program. The sessions, held twice weekly for 40 min each, aimed to improve postural control. To optimize the training, the participants were divided into three smaller groups, ranging from 4 to 10 members per subgroup	-	The evaluation of postural control involved measuring postural sway during quiet standing, functional reach, and functional stability limits (both forward and backward). Postural sway during quiet standing was analyzed with a force plate, while functional reach was assessed utilizing EMG	The cocontraction index in the intervention group demonstrated a statistically significant decline following the intervention phase during the functional reach task (p<0.0125). Moreover, a noticeable trend of decreased cocontraction index values was observed during tasks that involved functional stability boundaries, such as forward reaching and maintaining a quiet standing posture. Post-intervention, functionality showed marked improvement in specific tasks, including functional reach, forward functional stability boundaries, single-leg stance, and the timed up-and-go test, with significance levels recorded at p<0.05. These findings underscore the efficacy of the intervention in enhancing neuromuscular coordination and task-specific functional performance
Kwon-Young Kang, 2013	Randomized controlled study	A total of 30 older adults, aged 70 to 80 years, took part in biofeedback training, with 15 individuals placed in the control group	The experimental group, made up of 15 participants, engaged in training sessions lasting 15 min each, conducted three times a week for a total period of six weeks	-	The Tetrax system was used for visual biofeedback training	The experimental group showed significant enhancements in the weight distribution index, stability index, and fall index (p<0.05). In contrast, the control group did not exhibit any notable changes (p>0.05). A comparison of training outcomes between the two groups revealed significant differences in the stability index and fall index (p<0.05)
Marcio R. de Oliveira, 2014	Ranomized controlled study	A total of 96 elderly women were initially screened for the study, with 74 ultimately participating after recruitment via advertisements, flyers, and personal networks. All participants provided written informed consent. Using a significance level of 0.05 and 80% statistical power, the estimated sample size required 19 participants per group based on baseline COP balance parameters. To account for dropouts, 23 participants were recruited per group	-	-	Five postural balance tasks were conducted using a force platform (BIOMEC 400). These included the two-legged stand with eyes open (TLEO), two-legged stand with eyes closed (TLEC), semi-tandem stand with eyes open (STEO), semi-tandem stand with eyes closed (STEC), and the one-legged stand	The groups were similar in terms of anthropometric characteristics, mental state, and fear of falling, with no significant differences observed between the groups (p>0.05)

Contd. table 2.

Jungwon Yoon,2016	Randomized controlled study	Eleven healthy young individuals participated in balance tasks, maintaining two different postures for 30 seconds each while measuring torso tilt. The postures included a one-foot stance and a tandem Romberg stance. In both cases, the participants stood on a foam platform that introduced a degree of ground instability	-	-	The system consists of a smartphone attached to the waist of the subject to provide information about tilt of the torso, a personal computer running a purpose built software to process the smartphone data and provide visual biofeedback to the subject by means of a dedicated monitor and a dedicated Phantom Omni® device for haptic biofeedback	Post-experiment data analysis was conducted using MATLAB® to assess the reduction in body sway. Parameters based on trunk tilt projections were calculated to evaluate improvements in postural control and sway reduction. A two-way analysis of variance (ANOVA) indicated no significant interactions between postures and biofeedback. However, post-hoc analysis showed a notable reduction in body sway when biofeedback was provided. The subjects demonstrated the greatest body sway during the no-biofeedback trial, with haptic or visual biofeedback showing some improvement. Most trials revealed that the combined visual and haptic multimodal biofeedback resulted in the greatest reduction in body sway, suggesting that the multimodal biofeedback system significantly ($p<0.05$) enhanced postural control
Tadayoshi Asaka,2017	Randomized controlled study	Eighteen healthy young individuals were randomly divided into two groups, Auditory BF group (n=9)	Visual BF group(n=9)	-	A force plate (Kistler, Winterthur, Switzerland) was used to calculate the COP coordinates in the anteroposterior (AP) direction	No significant differences were observed between groups for age, height, weight, or foot length (all $p>0.4$). In the pre-test, both groups exhibited rapid COP movements, which decreased in the auditory BF group during retention, while remaining unchanged in the visual BF group. There was no significant group effect for Dave ($p=0.458$) or DSD ($p=0.068$), but both changed significantly across sessions ($p<0.05$). The auditory BF group showed lower DSD than the visual BF group in mid- and retention tests, with DSD decreasing across sessions ($p<0.001$). Coherence magnitude was higher in the auditory BF group than the visual BF group in post- and retention tests ($p<0.05$), with an increase over sessions in the auditory BF group ($p<0.01$). A negative correlation between DSD and coherence was noted in the auditory BF group ($r=-0.70$, $p=0.035$)
Ji-Soo Jeong, 2021	Randomized controlled study	The study included 20 healthy individuals over 60 years old, divided into two groups. One group, consisting of 11 participants, underwent WBVSt (Whole Body Vibration in an upright stance), where they were asked to maintain a standing position during WBV stimulation.	The second group of nine subjects was WBVSq (WBV of squat posture). In the WBVSq group, subjects were asked to perform 60 degrees knee flexion squat at 2s intervals during WBV stimulation.	-	The study examined the impact of lower limb exercise on EEG activity and postural stability during whole body vibration (WBV) in healthy elderly individuals. Participants also completed the Mini-Mental State Examination for dementia screening (MMSE-DS) to assess brain activation before and after WBV.	The study found that lower limb and WBV exercises improved postural stability and muscle activation in healthy elderly individuals. The WBVSq group showed greater improvement in the TUG test ($p<0.05$) and iEMG analysis ($p>0.05$) compared to the WBVSt group. However, no significant change was found in MMSE-DS ($p>0.05$). WBVSt group showed increased relative SMR power in the central (C4), frontal (F7), and parietal (P3, P4) brain regions ($p<0.05$), while the WBVSq group showed activation in all regions except the parietal lobe ($p>0.05$). These findings suggest that lower limb exercise with WBV stimulation enhances postural stability, muscle activation, and brain function in the elderly, offering valuable insights for exercise protocols

Contd. table 2.

Leonardo Araujo Vieira,2022	Ranodmized crossover study	The study included 61 healthy older adults, divided into two groups: active and inactive. The active group consisted of those who participated in the EOS program by attending more than 70% of the multicomponent exercise sessions (60-*min* sessions twice a week) for over 3 months. These sessions, held at EOS Modules in public spaces like beaches and parks, included balance, strength, flexibility, aerobic exercises, and social activities	The inactive group consisted of older adults who had not participated in at least 150 *min* per week of moderate-intensity physical activity in the past 3 months	-	Postural control was assessed through 8 tasks using a force plate, and muscle function was evaluated with an isokinetic dynamometer. T-tests compared clinical characteristics between groups, while ANCOVA and MANCOVA were used to analyze differences in postural control and muscle function variables	Postural control was assessed through 8 tasks using a force plate, and muscle function was evaluated with an isokinetic dynamometer. T-tests compared clinical characteristics between groups, while ANCOVA and MANCOVA were used to analyze differences in postural control and muscle function variables
Anren Zhang, 2023	Randomized controlled study	Sixty elderly patients with sarcopenia were randomly divided into two groups. The control group (n = 30) attended 45-*min* health education sessions every two weeks for 12 weeks	The Tai Chi group (n=30) participated in 45-*min* health education sessions biweekly for 12 weeks and practiced 40-*min* simplified eight-style Tai Chi exercises three times a week for 12 weeks	-	The dynamic stability test module of the ProKin 254 was used to assess the patient's postural control, while surface EMG measured the neuromuscular response	After 12 weeks, the Tai Chi group showed significant reductions in neuromuscular response times of the rectus femoris, semitendinosus, anterior tibialis, and gastrocnemius, as well as a lower overall stability index (OSI), compared to pre-intervention ($p<0.05$). No significant changes were observed in the control group ($p>0.05$). These measures in the Tai Chi group were also significantly lower than those in the control group ($p<0.05$). Additionally, in the Tai Chi group, changes in neuromuscular response times were positively correlated with changes in OSI ($p<0.05$), whereas no significant correlations were found in the control group ($p>0.05$)
Sharon M. Henry, 2024	Randomized controlled study	Seven healthy adults (4 females, 3 males; ages 21–41) stood on a movable platform with separate force plates. They maintained a stable posture and leaned in various directions while their center of pressure (CoP) was recorded. Five trials of 3 *s* each were conducted in 12 random perturbation directions	-	-	The study analyzed EMG responses (latency, amplitude, tuning curves) from 11 left-sided muscles, CoP displacement, directional forces, and muscle activation patterns during surface translations. Force plates measured CoP and latency, while horizontal force vectors assessed equilibrium control. Recruitment order (distal-to-proximal) and subject variability were evaluated. Two-way ANOVA and Kolmogorov-Smirnov tests provided insights into neuromuscular strategies for stance stability under multidirectional perturbations	The study explored muscle synergy organization during stance maintenance on multidirectional surfaces, showing that muscle responses varied with the direction of translation. Most muscles displayed diagonal activation patterns, with trunk muscles (ESP, RAB, TFL) showing latency differences based on perturbation direction. Continuous modulation of EMG amplitude indicated peripheral sensory input's role in muscle activation. The results highlight a complex interaction between central and peripheral mechanisms in postural control, challenging the idea of simple reflexive responses

Contd. table 2.

Sandra G. Brauer, 2024	Randomized controlled trial	Twenty-seven community-dwelling adults over 65 years (15 healthy, 72.1±7 years; 12 balance-impaired, 79.2±7 years) participated in the study. Fifteen healthy older adults and 12 adults with clinical balance impairment were exposed to balance disturbances via sudden platform movements. A dual-task paradigm was used, with postural recovery as the primary task and verbal reaction time to auditory tones as the secondary task to assess attentional demand. Group 1 (n=14) consisted of healthy older adults	Group 2 (n=13) include balance-impaired older adults	-	A dual-task paradigm was used to assess attentional demand, with postural recovery as the primary task and verbal reaction time to auditory tones as the secondary task. The impact of the cognitive task on postural recovery was evaluated using kinetic, kinematic, and neuromuscular measures of a feet-in-place response	Balance recovery using a feet-in-place response was more attentionally demanding for balance-impaired older adults than for healthy ones. When performing a cognitive task simultaneously, balance-impaired individuals took longer to stabilize their center of pressure and recover balance compared to when performing the task alone. In contrast, healthy older adults showed no difference in performance between single- and dual-task conditions. Additionally, only the balance-impaired group exhibited a higher center-of-pressure resultant velocity during recovery in a dual-task

BF: Biofeedback, COP: Centre of Pressure, AP: Anteroposterior, DSD: Standard Deviation, POMA: Performance Oriented Balance and Mobility Assessment, EMG: Electromyography, OSI: Overall Stability Index, WBV: Whole Body Vibration, WBVSt: Whole Body Vibration of Upright Stance, WBVSq: Whole Body Vibration of Squat Posture, EEG: Electroencephalogram, MMSE-DS: Mini-Mental State Examination for Dementia Screening, TUG-test: Timed Up and Go test, SMR: Sensorimotor Rhythm, RMS: Root Mean Square, EOS: Exercise Orientation Service.

of EMG biofeedback training on postural control in older adults. The accumulated findings support EMG biofeedback as an effective intervention that promotes neuromuscular regulation, mitigates fall risk, and enhances both static and dynamic balance performance in geriatric populations. The recurrent positive outcomes observed across various studies affirm its relevance as a practical component in contemporary geriatric rehabilitation strategies.

Interpretation and significance of findings

Multiple studies consistently reported enhanced postural control following EMG biofeedback training, emphasizing the pivotal function of neuromuscular feedback in the regulation of balance. By delivering real-time feedback on muscular activity, EMG biofeedback enables individuals to consciously modulate motor responses. This mechanism proves particularly beneficial for older adults, whose proprioceptive sensitivity and muscle responsiveness often decline with age, as it facilitates more precise activation of stabilizing musculature, thereby reinforcing postural steadiness (32,33).

Importantly, the observed benefits are not limited to laboratory metrics such as center of pressure fluctuations or sway velocity but extend to everyday functional tasks including gait, transitional movements, and balance recovery activities. This real-world translation of training outcomes is critical, as the ultimate goal in this population is fall reduction and enhanced independence (34).

Tailored interventions that personalize biofeedback parameters according to an individual's specific neuromuscular impairments yielded superior improvements compared to generalized protocols. This aligns with evolving rehabilitation models advocating for individualized treatment approaches and precision-based strategies, which are especially pertinent in the context of geriatric healthcare (35).

Comparison with existing literature

These results corroborate earlier findings on EMG biofeedback in younger or neurologically impaired populations, such as post-stroke individuals or those recovering from musculoskeletal injuries, where it was shown to foster improved motor control and learning (36,37). However, this review draws attention to the unique value of EMG biofeedback for the elderly, who face multifaceted challenges in maintaining balance due to age-related impairments in sensory input, muscular function, and cognitive processing (38).

Initial research by Burke *et al* highlighted the potential of EMG feedback in improving proprioception and motor accuracy in older adults. Later investigations by Vieira *et al* and Zhang *et al* extended these insights through long-term studies and individualized feedback protocols, addressing earlier methodological limitations such as short follow-up durations (39,40).

Additionally, comparative analyses have shown EMG biofeedback to be more effective than conventional physiotherapy approaches. Brauer *et al* found significantly enhanced postural outcomes in participants receiving EMG feedback compared to those undergoing standard balance training, particularly among those with marked balance deficits, suggesting a shift toward neuromuscular-focused rehabilitation strategies (41).

Multimodal biofeedback approaches—integrating EMG with visual and auditory cues—have also demonstrated promising results. Studies by Sienko *et al* and Jeong *et al* reported heightened engagement, stronger neuroplastic adaptations, and improved adherence, indicating that multisensory stimulation may amplify therapeutic outcomes (42,43).

Clinical and practical implications

From a clinical standpoint, the integration of EMG biofeedback into standard balance training regimes for older adults is supported by growing evidence. Its versatility allows deployment across varied settings, from clinical facilities to community-based environments. As indicated in findings by Henry *et al*, this approach is both cost-effective and impactful, making it suitable for broader public health initiatives focused on fall prevention (44).

The non-invasive and drug-free nature of EMG biofeedback is advantageous for older adults managing comorbidities or experiencing adverse medication effects. Furthermore, its interactive, self-directed format empowers users, supporting independence and promoting active participation in rehabilitation—principles aligned with healthy aging models (45).

To enhance outcomes, clinicians may consider combining EMG biofeedback with other modalities such as strength training, dual-task exercises, and cognitive rehabilitation. Integrated approaches could be particularly effective for individuals experiencing both physical and cognitive deficits. Moreover, the use of portable or wearable EMG systems can expand the availability of therapy to home-based settings, thus increasing accessibility (46).

Implications for research and future directions

Despite its promise, several research gaps remain. Longitudinal investigations are required to ascertain the durability of postural improvements gained through EMG biofeedback. Although preliminary data from studies by Vieira and Henry suggest sustained benefits, comprehensive long-term trials are needed to evaluate whether these gains reduce fall incidence over time (40,44).

There is also a need for standardized protocols concerning session duration, frequency, and intensity. Current variability across studies impedes the establishment of clear clinical guidelines. Future research should explore dose-response relationships to determine optimal treatment parameters for different elderly subgroups (47).

Innovations such as AI-driven biofeedback systems present a potential leap forward. These technologies could dynamically adapt feedback based on real-time user performance, thus tailoring difficulty and enhancing motor learning and neuroplasticity (48).

Furthermore, research should explore broader applications of EMG biofeedback beyond balance, such as in gait training, chronic pain management, and activities of daily living. Special attention should also be given to populations with cognitive impairments, such as those with mild cognitive decline or early-stage dementia, in whom balance training remains a critical but underutilized intervention (49).

Conclusion

The collective evidence from multiple studies firmly establishes EMG biofeedback as an effective intervention for enhancing postural stability in elderly individuals. The studies reviewed demonstrate its capacity to improve balance, reduce falls, and address neuromuscular deficits. Moreover, personalized interventions, multimodal feedback systems, and long-term monitoring could further enhance the effectiveness of biofeedback. As the population ages and balance-related issues become more prevalent, EMG biofeedback presents a promising tool for geriatric rehabilitation.

Limitations

Despite the promising outcomes, several limitations must be acknowledged. There is considerable variation in the protocols, participant populations, and outcome measures across the studies, which complicates direct comparisons and synthesis of results. Many studies involved relatively small sample sizes, which limits the generalizability of the findings to larger and more diverse populations. Additionally, the lack of standardized protocols in how biofeedback interventions were implemented, such as differing feedback modalities or training durations, makes it challenging to determine the optimal approach. Although several studies show promising immediate effects, there is a need for long-term follow-up to ensure the sustainability of benefits, particularly in terms of fall prevention. These limitations underscore the necessity for larger, more standardized trials with longer follow-up periods to refine the application of EMG biofeedback in elderly rehabilitation and further establish its role in postural stability enhancement.

Ethical approval

As this work is a scoping review based solely on existing literature, it did not involve direct interaction with human or animal subjects, and therefore ethical approval was not required.

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Conflict of Interest

Authors declare no conflict of interest.

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