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Effects of Different Neuromuscular Training Modalities on Balance Performance in Older Adults: A Systematic Review and Network Meta-Analysis

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INTRODUCTION

Review question / Objective This systematic review and network meta-analysis aims to evaluate and compare the effectiveness of different neuromuscular training modalities in improving balance performance among older adults. The study is structured according to the PICOS framework as follows:
Population (P): Community-dwelling or clinically stable older adults aged 60 years and above, including those with chronic conditions (e.g., Parkinson's disease, osteoporosis, post-surgical recovery, or diabetic peripheral neuropathy), who are capable of participating in exercise-based interventions.
Intervention (I): The interventions of interest include four types of neuromuscular training modalities: sensorimotor training (ST), neurofunctional training (NT), whole-body vibration training (WBVT), and balance training (BT). Each modality is designed to enhance neuromuscular control, proprioceptive feedback, postural stability, and motor coordination through different mechanisms and training protocols.
Comparison (C): Comparators include either no intervention, standard care, or routine exercise programs. These may encompass general physical activity, resistance or strength training, Tai Chi, conventional balance exercises, health education, or hydrotherapy.
Outcomes (O): The primary outcome is dynamic balance performance measured by the Timed Up and Go Test (TUGT). Secondary outcomes include the Walk Test (WT) for dynamic balance, and two static balance indicators: the Berg Balance Scale (BBS) and the One-Leg Standing Test (OLST).
Study Design (S):Only randomized controlled trials (RCTs) are eligible for inclusion to ensure methodological rigor and minimize bias in effect estimation.
Objective: To determine the relative efficacy of different neuromuscular training modalities in improving both dynamic and static balance among older adults and to identify the most effective intervention for fall prevention and functional mobility enhancement. By applying network meta-analysis, the study aims to generate comprehensive comparative evidence that can

inform clinical rehabilitation strategies and public health decision-making.

Condition being studied Age-related balance impairment and increased fall risk constitute a significant global public health concern, particularly in aging societies. Epidemiological data suggest that nearly one-third of individuals aged 65 years and older experience at least one fall annually, often resulting in serious injuries such as fractures, head trauma, and prolonged functional decline. These incidents not only compromise physical health and quality of life but also place a substantial burden on healthcare systems worldwide. Falls are among the leading causes of injury-related mortality and morbidity in older adults, with the highest fall-related death rates observed in populations aged 60 and above.
The progressive deterioration of neuromuscular control, proprioceptive function, and postural stability due to aging is a major contributor to these outcomes. Impairments in sensory-motor integration and decreased lower-limb strength further exacerbate instability and movement dysfunction in this population. To address these challenges, a variety of neuromuscular training modalities have been developed, including sensorimotor training, neurofunctional training, whole-body vibration training, and traditional balance training. These interventions aim to enhance neuromuscular coordination, improve proprioceptive feedback, and restore postural control mechanisms.
Given the heterogeneity of intervention designs and outcomes in current randomized controlled trials (RCTs), there is a growing need to systematically compare the relative effectiveness of these training approaches. This study focuses on evaluating the impact of different neuromuscular training modalities on balance performance in older adults, with the ultimate goal of informing clinical decision-making and fall prevention strategies through robust evidence synthesis.

METHODS

Participant or population Population (P): The target population comprises older adults, typically aged 60 years or above, who are capable of participating in routine exercise interventions or rehabilitation programs. Participants with varying health statuses are eligible, provided they do not have severe medical conditions that would preclude physical activity.

Intervention Intervention (I): Eligible studies must include an intervention group receiving one of the following neuromuscular training modalities: sensorimotor training, whole-body vibration training, neurofunctional training, or balance training. These interventions aim to enhance postural control, proprioception, and neuromuscular coordination in older adults.

Comparator Comparison (C): Control conditions may include either no specific intervention or routine physical activity/standard care protocols. These can consist of general physical exercise, resistance or strength training, traditional balance exercises, Tai Chi, health education, or hydrotherapy, among others.

Study designs to be included Study Design (S): Only randomized controlled trials (RCTs) will be considered for inclusion to ensure methodological rigor and minimize bias.Study Design (S):Only randomized controlled trials (RCTs) will be considered for inclusion to ensure methodological rigor and minimize bias.

Eligibility criteria In addition to the standard PICOS framework, the following inclusion and exclusion criteria were applied to ensure the methodological quality and clinical relevance of the included studies:
Additional Inclusion Criteria:
Participants had to be older adults (typically aged 60 years or above) who were physically able to engage in exercise-based interventions or rehabilitation programs, regardless of underlying health conditions, provided they were free of medical contraindications to physical activity.
The intervention had to include a single, clearly defined neuromuscular training modality—sensorimotor training (ST), whole-body vibration training (WBVT), neurofunctional training (NT), or balance training (BT).
Control groups were required to receive either no intervention, standard care, or conventional forms of exercise (e.g., resistance training, general physical activity, Tai Chi, health education, hydrotherapy).
The study must report at least one objectively measured balance-related outcome (e.g., TUGT, OLST, BBS, WT) with sufficient statistical data (mean and standard deviation) available for meta-analysis.
Exclusion Criteria:
Non-original research publications such as reviews, conference abstracts, dissertations, and editorials. Studies lacking any relevant balance performance outcome measures. Duplicate publications or secondary analyses of previously published trials (in such cases, the most recent or methodologically superior version was retained).

Studies for which the full text could not be retrieved or accessed. Articles written in languages other than English. Studies that did not report sufficient statistical data (mean and SD), and where such data could not be retrieved or imputed from the manuscript or corresponding author. Trials employing non-randomized or quasi-experimental designs. Studies that were not formally published in peer-reviewed journals at the time of data extraction. These criteria were rigorously applied to ensure the inclusion of high-quality randomized controlled trials (RCTs), thereby enhancing the validity and reliability of the synthesized findings.

Information sources A comprehensive and systematic literature search was conducted across five major electronic databases: PubMed, EBSCOhost, Embase, Cochrane Library, and Web of Science. The aim was to identify randomized controlled trials (RCTs) investigating the effects of various neuromuscular training modalities—including sensorimotor training, whole-body vibration training, neurofunctional training, and balance training—on balance performance in older adults. The search encompassed all records published from the inception of each database up to January 21, 2025.

Main outcome(s) This review focuses on evaluating the effects of four distinct neuromuscular training modalities—sensorimotor training (ST), neurofunctional training (NT), whole-body vibration training (WBVT), and balance training (BT)—on balance performance in older adults. The outcomes of interest are categorized into dynamic and static balance domains and assessed using well-validated functional measures.

The primary outcome is dynamic balance, measured by the Timed Up and Go Test (TUGT), which evaluates functional mobility and postural transitions. TUGT is sensitive to detecting changes in initiation, gait, and turning ability, with lower scores indicating better performance.

Secondary dynamic balance is assessed using the Walk Test (WT), which quantifies walking capacity over a fixed time or distance and indirectly reflects balance-related gait stability and lower-limb endurance.

Static balance is evaluated through two indicators: the Berg Balance Scale (BBS) and the One-Leg Standing Test (OLST). The BBS consists of 14 functional tasks relevant to postural control in daily life, while the OLST measures the ability to maintain single-leg stance, reflecting proprioceptive control and vestibular function.

All outcomes are treated as continuous variables. Effect estimates include either mean differences (MD) or standardized mean differences (SMD), depending on the consistency of measurement units across studies. Where applicable, 95% confidence intervals are reported to assess statistical significance. The timing of outcome assessment varies from post-intervention (immediate effect) to mid-term follow-up periods (e.g., 8 to 24 weeks), depending on the original study designs.

Quality assessment / Risk of bias analysis The methodological quality of the included randomized controlled trials (RCTs) was assessed using the Revised Cochrane Risk of Bias Tool for Randomized Trials (RoB 2.0). Two independent reviewers conducted the risk of bias assessment across five key domains:

(1) bias arising from the randomization process, (2) bias due to deviations from intended interventions, (3) bias due to missing outcome data, (4) bias in measurement of the outcome, and (5) bias in selection of the reported result. Each study was classified as having "low risk," "some concerns," or "high risk" based on domain-level judgments. A study was rated overall as low risk if all five domains were judged as low risk; "some concerns" if at least one domain raised concerns but none were high risk; and "high risk" if any domain was judged to be high risk. Disagreements between reviewers were resolved through discussion or adjudication by a third reviewer when necessary.

Among the 49 included trials, 30 studies (61.2%) were rated as low risk of bias, 13 studies (26.5%) had some concerns, and 6 studies (12.2%) were rated as high risk. The majority of studies described adequate allocation concealment, and most had low attrition rates (<20%) or employed intention-to-treat analysis. Although few studies implemented blinding of participants or outcome assessors, the primary outcomes were objective, performance-based balance measures (e.g., TUGT, BBS), reducing the risk of detection bias.

The RoB 2.0 evaluations were used not only to describe the methodological quality of the evidence but also to inform subsequent sensitivity analyses and aid interpretation of the network meta-analysis results. Overall, the included studies demonstrated acceptable internal validity, supporting the robustness of the synthesized findings.

Strategy of data synthesis Data synthesis was conducted using both RevMan 5.4 and Stata 17.0 software. For the network meta-analysis (NMA), a random-effects model was applied to integrate both direct and indirect comparisons across multiple interventions. Standardized mean

differences (SMD) with corresponding 95% confidence intervals (CIs) were used as effect sizes when outcome units varied across studies; otherwise, weighted mean differences (WMD) were applied.

Network diagrams were constructed to illustrate the structure and strength of direct comparisons. The size of each node was proportional to the cumulative sample size, while the thickness of connecting lines represented the number of direct comparisons available between interventions.

Heterogeneity across studies was evaluated using the Q statistic and the I^2 index. Fixed-effect models were considered when heterogeneity was low (I^2 0.1), and random-effects models were adopted when heterogeneity was substantial ($I^2 > 50\%$, $P <$ 0.1). Inconsistency within the network was assessed through both global (loop inconsistency factor and its 95% CI) and local approaches (node-splitting analysis). If inconsistency was detected ($P \leq 0.05$), further exploration of its sources was undertaken, and sensitivity analyses were performed by removing studies at high risk of bias.

To evaluate the relative ranking of each intervention, Surface Under the Cumulative Ranking Curve (SUCRA) values were calculated. Interventions with higher SUCRA percentages were interpreted as having a greater likelihood of being the most effective in improving balance performance.

Publication bias was examined through funnel plots and statistical tests, including Begg's and Egger's methods. When asymmetry was observed, the trim-and-fill method was employed to estimate the impact of potential small-study effects.

All statistical analyses were independently reviewed by two researchers to ensure methodological rigor and accuracy of interpretation.

Subgroup analysis Although predefined subgroup analyses were not extensively reported, several strategies were planned to explore potential sources of heterogeneity and improve the interpretability of the findings. In cases where substantial between-study heterogeneity was identified ($I^2 > 50\%$ or $p < 0.1$), subgroup analyses or sensitivity analyses were considered to determine whether certain clinical or methodological variables contributed to the inconsistency of effect estimates.

Sensitivity analysis To ensure the robustness and reliability of the synthesized estimates, a series of sensitivity analyses were planned and performed throughout the network meta-analysis process. These analyses were designed to assess the potential influence of methodological heterogeneity, bias, and extreme effect sizes on the overall findings.

Specifically, studies assessed as having a high risk of bias based on the RoB 2.0 tool were sequentially excluded to determine whether their inclusion had a significant impact on the direction or magnitude of effect estimates. This approach was particularly applied in comparisons with high inconsistency or substantial heterogeneity (e.g., $I^2 > 50\%$ or $p < 0.1$), especially in static balance outcomes such as the One-Leg Standing Test (OLST), which demonstrated considerable between-study variability.

In addition, sensitivity analyses were conducted by removing trials with small sample sizes or unclear reporting of key methodological elements (e.g., allocation concealment, dropout rates), as well as studies that contributed disproportionately large effect sizes. These steps were taken to minimize the influence of outliers and increase the internal validity of the pooled results.

Furthermore, inconsistency within closed loops of the network diagram was evaluated using inconsistency factors and node-splitting techniques. If inconsistency was detected ($p \leq 0.05$), sensitivity analyses were used to test whether its resolution could be achieved by excluding particular studies with methodological concerns.

Overall, the results of these sensitivity analyses confirmed that the main findings—particularly the superiority of sensorimotor training (ST) and neurofunctional training (NT) in improving dynamic balance—remained stable and consistent, thereby supporting the robustness of the network estimates.

Country(ies) involved China.

Keywords Older Adults; Neuromuscular Training; Fall Prevention; Balance Performance; Network Meta-Analysis.

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