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Original Research

Acute effects of stochastic whole-body vibration on executive function and balance in young healthy adults: a randomized controlled trial

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Abstract

Falls represent a major public health concern, leading to injuries and loss of independence, while also imposing substantial financial burden of millions of Swiss francs annually in Switzerland. Modifiable protective factors against falls include good cognitive abilities and good physical balance. The present study investigates the impact of stochastic whole-body vibration training (SR-WBV) on executive functions and balance and thus indirectly on fall prevention. To this end, 62 participants were randomly assigned to either an intervention or a control group. Both groups completed one training session of SR-WBV, with the intervention group exposed to 5 Hz and the control group to 2 Hz. The training on an SRT Zeptor® Medical plus noise device consisted of three one-minute intervals of vibration, separated by one-minute rest periods. Data on executive functions (updating, shifting, inhibition) and balance were collected before and after the intervention, complemented by subjective assessments of concentration and balance through questionnaires. Although most descriptive patterns were consistent with the hypothesized effects, none of the interaction terms reached statistical significance, suggesting that the difference in dose between the intervention and control conditions may have been insufficient to elicit measurable changes in young healthy adults. Future studies could increase contrasts from experimental to control conditions by slightly increasing the frequency in the experimental group or reducing it in the control group in order to test acute effects. The effects of varying frequency, amplitude, and other platform parameters also require more rigorous and systematic examination.

Keywords: stochastic whole-body vibration, training, balance, executive functions

1. Introduction

1.1 Falls, balance, and cognition

According to the World Health Organization, falls represent the second leading cause of unintentional injuries and fatalities worldwide (1). Similarly, in Switzerland, slips, trips, and falls occur frequently and account for a substantial proportion of injury-related healthcare costs each year (2). Direct healthcare expenditures for injuries exceeded five billion Swiss francs in 2011 (3).

The occurrence of falls is closely linked to proprioception, broadly defined as the perception of joint position and movement (4), and to overall balance control. Both factors are interrelated and can be successfully improved through targeted training interventions (5).

Research shows that executive functions are consistently associated with both static and dynamic balance (6). Evidence further suggests that age-related reductions in executive functioning often occur in parallel with decreases in balance capacity (7), highlighting the cognitive underpinnings of postural control.

Especially poor executive functioning has been linked to a higher incidence of falls and more severe fall-related injuries (8–14). According to Miyake *et al.* (15), executive functions, primarily localized in the prefrontal cortex, can be subdivided into three core dimensions: updating, hence the process of refreshing and monitoring working memory contents (16), shifting, the ability to switch between mental sets or tasks (17), and inhibition, which includes the suppression of automatic responses (18).

In particular, impairments in inhibition and shifting have been identified as key factors contributing to an increased risk of falls. (19–21). Supporting this, performance on the Stroop Color-Word Test (inhibition) and the Trail Making Test Part B (shifting) has been shown to

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predict risk of falls in older adults (21). These findings align with a recent review emphasizing inhibitory control as essential for maintaining balance under complex conditions (22). Moreover, shifting appears particularly crucial for balance and fall prevention (23). For instance, Ble *et al*. (24), demonstrated already two decades ago that individuals with poor Trail Making Test performance performed significantly worse on a seven-meter obstacle run compared to those with higher shifting ability. Thus, studies indicate that at least two of the three executive function components proposed by Miyake *et al*. (15) are associated with balance.

1.2 Whole-body vibration as a practical intervention

Both acute and habitual exercise interventions have been shown to improve executive functions, with small effects on inhibition and cognitive flexibility but moderate effects on working memory (25). These findings suggest that even short bouts of physical activity can elicit measurable cognitive benefits. Recent evidence further indicates that low-intensity physical activity acutely enhances prefrontal activation (26–28), a neural mechanism closely linked to executive functioning. This increased activation has been associated with improved performance on tasks requiring inhibitory control, such as the Stroop test.

Interestingly, Johnson *et al*. (29) found that low-intensity, but not moderate or vigorous, physical activity was positively associated with set-shifting performance in community-dwelling older adults, underscoring the particular relevance of low-intensity exercise for executive processes. Taken together, these findings support the view that physical activity, even at low-intensity, can acutely modulate prefrontal function and thereby enhance executive performance (30).

Whole-body vibration (WBV) involves standing, sitting, or exercising on a platform that delivers mechanical vibrations to the body. It can be seen as a low-intensity physical activity and represents a convenient form of exercise, requiring minimal time and no change of clothing. This makes it feasible to integrate into daily routines and results in high compliance (31–33).

In the literature, different types of WBV are distinguished based on the direction and pattern of oscillation. The most common forms are vertical vibration, where the platform moves predominantly in a synchronous up and down motion, and side-alternating vibration, which mimics a see-saw motion around a central axis (34,35). Both, vertical and side-alternating WBV are typically applied in a sinusoidal modality (SS-WBV), in which the vibration frequency and amplitude remain constant. More recently, these classical forms of SS-WBV have been extended by the introduction of stochastic resonance WBV (SR-WBV). In contrast to SS-WBV, the direction and force-time characteristics of the vibrations in SR-WBV are unpredictable, continuously challenging the body to adapt muscle responses. This dynamic adjustment may result in effective training for the sensorimotor system (36). Moreover, while SS-WBV operates at a fixed frequency, SR-WBV features continuous fluctuations in vibration frequency within a predefined low-frequency range, maintaining an overall stochastic but controlled stimulation pattern (32).

Overall, WBV appears to be an effective low-intensity intervention with broad physiological and functional benefits, as shown for both SS-WBV *e.g.* (37–40) and SR-WBV modalities *e.g.* (31,32,41–44).

Regarding balance, long-term sinusoidal SS-WBV training has not reliably improved balance in healthy working-age adults (33). Although a single SS-WBV session showed short-term balance improvements (37), both the experimental and sham/control group improved similarly, indicating nonspecific effects such as arousal or familiarization. In contrast, stochastic SR-WBV has shown group-specific long-term adaptations (experimental > control) after 4 weeks (42) and after 28 days at 5-6 Hz (45). Acute, single-session standing stochastic WBV has shown improvements in postural control in older or clinical groups (46–48). In contrast, little is known about the acute effects of SR-WBV on balance in healthy young adults. To the best of our knowledge, the only robust significant single-session balance effect in this population stems from a seated partial-body stochastic vibration design (45). Finally, current evidence suggests that while single-session stochastic vibration can temporarily modulate postural performance, stable, vibration-specific balance adaptations are more consistently demonstrated in multi-week stochastic training, rather than after isolated exposures, especially in non-clinical adult populations (44).

1.3 Acute effects of WBV on executive functions

Prior research on the short-term cognitive effects of WBV has primarily employed SS-WBV either in a vertical mode (49,50) or using side-alternating platforms (37,51,52), with vibration frequencies typically ranging from 20-60 Hz for vertical and 10-28 Hz for side-alternating WBV.

Regterschot *et al*. (50) demonstrated that two minutes of passive vertical SS-WBV significantly improved performance in the Color-Word Interference Test and the Stroop Difference Score in healthy young adults. The small effects were short-lived and only detectable when cognitive tests were administered immediately after vertical SS-WBV exposure. Similarly, Fuermaier *et al*. (49) confirmed beneficial effects of two minutes of passive vertical SS-WBV on attentional performance – specifically inhibitory control, with a small effect size in healthy adults and an even larger, medium effect in adults with attention-deficit/hyperactivity disorder (ADHD).

Arenales Arauz *et al*. (51) reported that side-alternating SS-WBV significantly improved selective attention and inhibition only in a seated posture with small effect sizes, whereas no cognitive enhancement was observed in the standing condition. In contrast, more recent work by Hamer *et al.* (52) using side-alternating SS-WBV found significant improvements in Color-Word Interference Test performance in both seated and standing conditions. Notably, Hamer *et al.* (52) also measured cortical activation patterns and observed that oxyhemoglobin (HbO_2) levels in the dorsolateral prefrontal cortex were reduced during side-alternating SS-WBV relative to control but increased immediately afterward during cognitive testing, an effect interpreted as enhanced cognitive readiness.

Given the crucial role of executive functions in balance and fall prevention, and the feasibility of WBV as an intervention, this study investigates the acute effects of SR-WBV on the three core executive function domains: inhibition, updating, and shifting in a young and healthy cohort. The present study extends previous work by examining whether SR-WBV delivered at lower frequencies can, similar to the effects observed in both vertical and side-alternating SS-WBV, elicit short-term improvements in executive functioning. To our knowledge, no study to date has examined the short-term effects of SR-WBV on executive functions, underscoring the novelty of the present investigation. The sham SR-WBV condition was set at a frequency of 2 Hz, which is assumed to be too low to induce meaningful neuromuscular or cognitive stimulation and therefore serves as an appropriate control condition (53,54).

We therefore hypothesize that (H1) SR-WBV at 5 Hz, compared to a control condition at 2 Hz, will lead to immediate significant improvements across all three executive function domains, and that (H2) SR-WBV at 5 Hz will result in immediate significant improvements in balance.

2 Material and Methods

2.1 Design

The study employed a 2×2 mixed factorial design, with group allocation (intervention *vs*. control) as the between-subjects factor and time (pre *vs*. post) as the within-subjects factor. Although participants were blinded to their group allocation, it was not feasible to blind the examiners. The independent variable was the type of training administered, whereas the dependent variables included various questionnaires, cognitive tests measuring the three dimensions of executive functions and balance. Balance ability was assessed using the Modified Star Excursion Balance Test.

2.2 Ethical aspects

This randomized controlled trial was registered at ClinicalTrials.gov (identifier: NCT06629298). The registration was performed via the ClinicalTrials.gov Protocol Registration and Results System (PRS) through the University of Bern. Moreover, the study was approved by the Ethics Committee of the Faculty of Human Sciences at the University of Bern (approval number 2019-07-00005).

2.3 Participants

The sample consisted of 62 German-speaking undergraduate psychology students (German language proficiency ≥ C1), who were randomly assigned to either the intervention group (n=31) or the control group (n=31). Inclusion and exclusion criteria followed Faes *et al*. (37). Exclusion criteria comprised pregnancy, osteosynthetic material (e.g., screws, plates, wires), joint or musculoskeletal problems, disc herniation, rheumatism, cardiovascular disease, balance disorders, or red-green color blindness. Participants were asked to refrain from intensive physical activity 24 hours prior to testing and to avoid any medication affecting the central nervous system.

Each participant received a performance credit equivalent to one and a half participant hours, which is required for the Psychology program. All participants received a informed consent form via email at least 24 hours before their study session, which was signed on-site on the day of the study. Moreover, participants retained the right to withdraw from the study at any time without providing a reason. All data was treated confidentially. Upon arrival, participants generated an individual ID, which was linked to their identity in a password-protected file for two weeks, during which they could request data deletion. After this period, the link was permanently removed, ensuring full anonymity.

None of the participants reported any previous experience with WBV. No acute, short-term, or long-term side effects were observed or reported following the sessions.

2.4 Procedures

The description of the WBV procedure follows the Reporting Guidelines for Whole-Body Vibration Studies in Humans, Animals and Cell Cultures by van Heuvelen *et al.* (34), to ensure transparent, complete, and consistent reporting of WBV-specific parameters.

Both the intervention and control groups performed the training on a *SRT Zeptor® Medical plus noise* device (Frei Swiss AG, Zurich, Switzerland). This platform uses two independently oscillating footplates that produce SR-WBV. The footplates move in a vertical (up-down) direction with a 3-mm amplitude and have additional passive degrees of freedom (forward-backward and lateral). They can also tilt medially and laterally, leading to a pluridimensional movement. No additional equipment such as chairs or external attachments was mounted on the platform.

The mean vibration frequency for the intervention group was set at 5 Hz, while the control group trained at 2 Hz. As typical for SR-WBV, both frequency and magnitude varied stochastically within a defined range around the set value. Vibration parameters were not independently verified with external accelerometers; the manufacturer's specifications were used.

Participants stood centrally on the respective platform plates with both feet, distributing their body weight evenly across the whole foot. Participants maintained an upright, static posture with knees slightly bent, arms relaxed alongside the body, and their gaze directed forward fixating a point on the wall. No tools or aids (e.g., dumbbells or resistance bands) were used.

A handrail was available but not used by any participant. Each session consisted of three bouts of one minute of vibration, interspersed with one-minute rest intervals.

All SR-WBV sessions were conducted in a laboratory room at the University of Bern. Participants could register for measurement slots scheduled between 8:00 a.m. and 8:00 p.m. An experimenter supervised all sessions, providing standardized instructions and ensuring participant safety. No warm-up was performed apart from the pre-test balance measurement (mSEBT). The training was performed without shoes; participants wore socks during all sessions.

Outcome measures were assessed before and after the WBV session. The pre-test sequence included (1) general questionnaires, (2) pre-session questionnaires, (3) Running Span (updating), (4) Trail Making Test B (shifting), (5) Stroop Color-Word Task (inhibition), and (6) modified Star Excursion Balance Test (mSEBT). Following the intervention, the post-test sequence included (1) Running Span, (2) TMT-B, (3) Stroop Color-Word Task, (4) mSEBT, and (5) post-session questionnaires. A graphical representation of the entire procedure is provided in Figure 1.

2.5 Measures

To assess the three dimensions of executive functions, all cognitive tests were administered using computer-based methods (55) (Inquisit 5 Lab software, Millisecond Software, LLC, Seattle, USA).

The Running Span Task was used to measure the updating dimension of executive functions (56). Participants were presented with a series of letters of varying lengths (3 to 8 letters). At the end of each series, they were asked to recall and repeat the last *n* letters of the list, where *n* ranged from 3 to 6. Participants did not know in advance the length of the series; they only knew how many items they needed to recall. The items to be recalled were termed “target items”, whereas the remaining ones in the series were considered “distractors”. The entire series consisted of both target items and distractors.

This study used a slow presentation rate with intervals of fixation (500 ms), blank (500 ms), letter (300 ms), and blank (2200 ms), with a total duration of about 8 minutes.

For each participant, the total Running Span (sum of all correctly recalled target items) and the Running Span Score (sum of correctly recalled target items from sets containing at least one distractor) were calculated, with maximum possible scores of 54 and 36, respectively. Higher scores indicate better working memory performance.

The Trail Making Test (TMT) includes two parts: TMT-A (numbers only) and TMT-B (numbers and letters). TMT-B specifically measures the ability for mental flexibility, or "shifting" of attention (57). In the computerized version of the TMT, participants completed Parts A and B using a computer mouse to select numbers and letters in the correct order. Each part was preceded by a brief practice trial to ensure task familiarity. In TMT-A, participants connected numbered circles in ascending order as quickly as possible (practice: 6 circles; main test: 24 circles). In TMT-B, circles contained both numbers and letters, which had to be selected alternately in ascending order (e.g., 1–A–2–B–3–C; practice: 6 circles; main test: 24 circles).

In this study, the completion time of TMT-B was used as the measure of shifting, following Piepmeier *et al*. (58). The total testing duration was approximately three minutes.

Using the Stroop Test, cognitive interference, a subcomponent of inhibition, was assessed (59). Participants were presented with color words on the screen, written in red, green, blue, or black. They were instructed to identify the color of the word (not its meaning) by pressing the corresponding key on the keyboard as quickly and accurately as possible. Following a test trial, the experimental session began, consisting of 84 randomized items. These items included congruent trials (e.g., the word "blue" written in blue), incongruent trials (e.g., the word "red" written in green), and neutral elements (rectangles in red, green, blue, or black). Reaction times were recorded from the onset of the stimuli, with an interstimulus interval of 200 milliseconds (ms), and the total test duration was approximately two minutes.

Cognitive interference can be described as the difference between incongruent elements and a control condition, which may include congruent, neutral, or non-lexical conditions (60). In this study, cognitive interference was computed for congruent conditions. Specifically, the mean reaction time of correctly answered congruent items was subtracted from the mean reaction time of correctly answered incongruent items. Higher cognitive interference indicates poorer inhibitory control (61).

Furthermore, participants were asked to self-assess mental aspects before and after the SR-WBV using a shortened version of the questionnaire from Burger *et al*. (41). Participants rated the extent to which they felt distracted and experienced mind-wandering on a scale from 0 to 100 at that moment, using whole-number steps (e.g., increments of 1). Lower scores indicated less distraction and fewer episodes of mind-wandering.

Balance data were collected using the Modified Star Excursion Balance Test (mSEBT) as described by Hertel *et al*. (62). In this balance test, participants stand on one leg, while the range of motion of the other leg is measured in eight directions: anterolateral, anterior, anteromedial, medial, posteromedial, posterior, posterolateral, and lateral. Research has shown that simplifying the procedure by measuring only three directions – anterior, posteromedial, and posterolateral, does not significantly impact the reliability of the test (63-65). This modified approach, known as mSEBT, has demonstrated excellent intra- and inter-rater reliability (66-73).

To determine the dominant leg, participants stood with their back to the experimenter, who then gave them a slight push. The leg that moved to maintain balance was identified as the dominant leg. The revised recommendations for conducting the mSEBT, as outlined in the review by Picot *et al*. (74), served as a guideline.

In addition to the mSEBT, participants' immediate sense of balance and foot stability were assessed using a questionnaire. They rated their balance and stability on a scale from 0 to 100, using whole-number steps (i.e., increments of 1), with higher values indicating a better perception of balance and greater foot stability.

2.6 Statistical Analysis

The data were analyzed using R (version 4.2.2) and RStudio (version 2025.9.1.401; R Core Team, 2022). Prior to statistical analysis, all measures were examined for outliers. Potential outliers were identified through visual inspection of Q-Q plots and were removed when they showed clear deviations from distributional assumptions. To verify that there were no significant pre-intervention differences between groups in demographic characteristics or baseline measures, independent-samples t-tests were performed (two-sided *p*-values, $\alpha = .05$). In addition, correlations among baseline variables were examined.

To examine the effects of the intervention on executive function, balance, and self-reported outcomes, linear mixed-effects models (LMMs) were conducted with Group (Intervention vs. Control) and Time (Pre vs. Post) as fixed factors, and the respective baseline score included as a covariate. Participant ID was entered as a random intercept to account for within-subject variability.

The models were estimated using the lme4 (75) and lmerTest (76) packages in R. For outcomes with non-singular random effects (e.g., behavioral measures), denominator degrees of freedom were based on the random-intercept variance at the participant level.

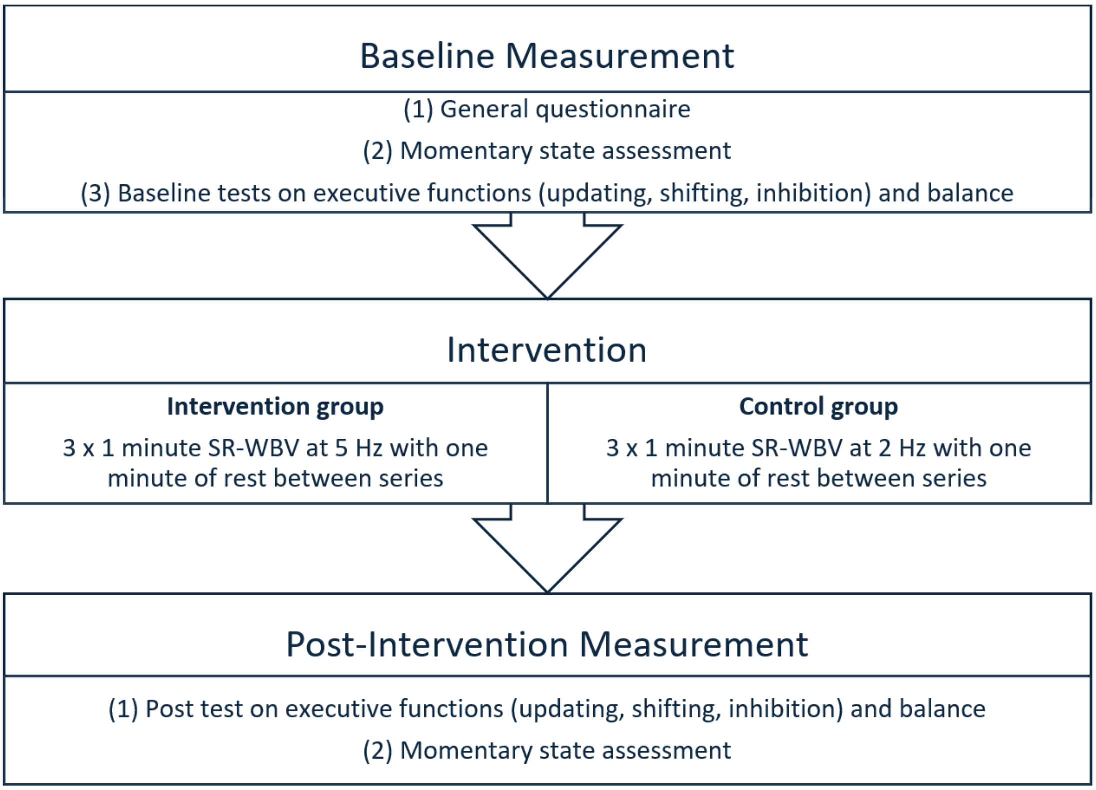

Figure 1. Intervention Procedure

Note. The sequence of procedures was fixed: participants first completed a general questionnaire, then a momentary state assessment, followed by baseline tests of executive functions (in the order of updating, shifting, and inhibition) and balance (modified Star Excursion Balance Test, mSEBT). Next, they underwent three 1-minute sessions of stochastic whole-body vibration (SR-WBV) training with 1-minute breaks. After training, executive functions and balance (in the same order: updating, shifting, inhibition, and balance) were reassessed, and at the end, participants completed a final questionnaire.

For self-report outcomes where the random intercept variance was estimated as zero (singular fits), *p*-values and degrees of freedom were computed using the Satterthwaite approximation as implemented in lmerTest.

Effect sizes were expressed as marginal and conditional R^2 following Nakagawa and Schielzeth (77) representing the variance explained by the fixed effects alone and by the full model including random effects, respectively.

3. Results

A total of 62 participants took part in the study (gender: male = 18, female = 43, not specified = 1; age in years: M = 23.5, SD = 3.4). As shown in Table 1, no significant differences emerged between the intervention and control groups in demographics or baseline cognitive, balance, or self-report measures. Thus, the groups were comparable prior to the intervention.

Four participants were excluded from the cognitive interference analysis due to outlier performance on the Stroop test, and two were excluded from the shifting analysis because of outlier scores in the TMT-B. No substantial outliers were observed in the Running Span or mSEBT data. After exclusion of outliers, all necessary assumptions for the subsequent analyses were met.

A series of linear mixed models was conducted to examine the effects of Group (Intervention vs. Control) and Time (Pre vs. Post) on updating (Running Span; Figures 2 and 3), shifting (TMT-B; Figure 4), inhibition (Stroop interference; Figure 5), balance performance (mSEBT; Figure 6), and subjective perceptions (sense of balance, surefootedness, distractibility, and mind wandering). All models controlled for baseline performance, and Participant ID was included as a random intercept to account for within-subject variance.

As can be seen in Table 2, across all executive function measures a consistent pattern emerged, showing significant improvements from pre- to post-test in both groups, with no evidence of a differential intervention effect of the 5 Hz condition compared to the 2 Hz control condition. Similar patterns were found for balance performance (Table 3).

Across all self-report outcomes, no differential effects of the intervention were observed. The covariate consistently predicted post-test performance, indicating strong stability over time. The only significant time-related change was observed for sense of balance, suggesting a general improvement in perceived balance across both groups (Table 3).

Table 1. Descriptive and inferential statistics of baseline group differences.

Variable	Intervention Group 5 Hz (n = 31)			Control Group 2 Hz (n = 31)			χ^2 / *t* / *U*	*p*
	M	*SD*	n	*M*	*SD*	n		
sex (m/f)[1]	10/20			8/23			0.42	.519
age (years)	23.16	3.53		23.81	3.32		393.5	.219
Sport								
- Never			0			0		
- Less than once a month			1			1		
- About once a month			1			2		
- About once a week			6			6		
- Several times a week			13			15		
- Once a day			6			6		
- More than once a day			3			1		
Education level								
- Compulsory school			0			0		
- Vocational school			0			0		
- High school or equivalent			26			24		
- Higher vocational education			0			1		
- University or college			4			6		
BL Sense of Balance	50.23	7.91		48.16	8.21		467.50	.844
BL Surefootedness	49.87	7.95		47.39	10.31		397.50	.220
BL Distractibility	34.48	25.36		34.55	21.32		460.00	.778
BL Mind Wandering	36.68	31.63		30.97	23.89		335.50	.627
BL Balance dominant leg (cm)	85.65	6.66		86.86	6.87		-0.70	.486
BL Balance non-dominant leg (cm)	85.56	6.99		86.58	7.93		-0.54	.593
BL Time TMT-B (sec)[2]	43.10	12.00		51.41	18.94		356.00	.081
BL Running Span Total	40.42	7.98		37.58	5.74		374.00	.135
BL Running Span Score	24.39	6.86		22.03	5.46		391.50	.211
BL CIE congruent[3]	156.47	137.12		169.99	165.61		-0.340	.736

Note. All *p*-values are two-tailed with an α-level of 5%. BL = Baseline. Baseline measures included balance perception and stability on a 100-point scale, where 0 indicated "worse than usual" and 100 indicated "better than usual." Distractibility and mind wandering were also measured on a 100-point scale, with 0 representing "not at all" and 100 representing "completely." The Cognitive Interference Effect (CIE) was assessed using the Stroop task. CIE was calculated by subtracting the mean reaction time of correctly answered congruent items from the mean reaction time of correctly answered incongruent items. Higher CIE values indicate higher cognitive interference and therefore worse performance (i.e. inhibitory control).

4. Discussion

This randomized controlled trial examined the acute effects of SR-WBV on executive functions and balance in young, healthy adults. Contrary to our hypotheses, no significant Group × Time interactions were observed for any cognitive or motor outcomes. Although both the 5 Hz intervention and 2 Hz control groups showed improvements from pre- to post-test, these changes likely reflect general practice or test-retest effects rather than specific SR-WBV-induced benefits.

Interestingly, the control group also exhibited performance gains across sessions. This pattern is consistent with well-documented practice effects in repeated assessments of executive functions, where increased familiarity with task demands, response strategies, and testing procedures can lead to apparent improvement without genuine cognitive change (78,79). Such effects are particularly pronounced in the TMT, where participants typically become faster due to enhanced visual search and motor efficiency, whereas the Stroop Test appears somewhat less susceptible to learning effects (80).

The overall findings are broadly consistent with the wider WBV literature, which generally reports only small and short-lived cognitive effects following brief vibration exposure. In this sense, the present results align with previous studies, even though several investigations have nonetheless demonstrated statistically significant – albeit modest – improvements in specific executive domains. For instance, studies employing SS-WBV at higher frequencies (20-30 Hz) have reported acute enhancements in attention and inhibition when cognitive assessments were conducted immediately after vibration exposure (49–51).

[1] One participant in the intervention group selected "no answer".
[2] Exclusion of 2 individuals identified as strong outliers based on the Q-Q plot.
[3] Exclusion of 4 individuals identified as strong outliers based on the Q-Q plot.

Table 2. Group results for executive functions.

Variable	Intervention Group 5 Hz (n = 31)		Control Group 2 Hz (n = 31)		LMM Results				
	BL ($M \pm SD$)	Post ($M \pm SD$)	BL ($M \pm SD$)	Post ($M \pm SD$)	Time (F, p)	Group (F, p)	Interaction (F, p)	R^2_{marg}	R^2_{cong}
TMT-B (s)	43.10 ± 12.01	36.84 ± 14.73	51.41 ± 18.94	40.44 ± 13.92	20.64, < .001***	4.95, .030*	<0.01, .975	.149	.406
Running Span Total	40.42 ± 7.98	42.71 ± 6.69	37.58 ± 5.74	40.61 ± 8.06	9.76, .003**	2.34, .131	0.19, .665	.061	.590
Running Span Score	24.39 ± 6.86	26.35 ± 5.22	22.03 ± 6.42	24.71 ± 6.59	8.73, .004**	2.27, .137	0.20, .653	.061	.513
CIE (ms)	156.47 ± 137.12	107.56 ± 91.68	169.99 ± 165.61	120.82 ± 112.98	4.94, .030*	0.27, .610	<0.01, .995	.037	.188

Note. LLM = linear mixed-effects models. BL = Baseline. Shifting was measured using Trail Making Test (TMT) B. Total Running Span and Running Span Score reflect correct recall of target items. The Cognitive Interference Effect (CIE) was assessed using the Stroop task. CIE was calculated by subtracting the mean reaction time of correctly answered congruent items from the mean reaction time of correctly answered incongruent items. Higher CIE values indicate higher cognitive interference and therefore worse performance (i.e. inhibitory control). * $p < .05$. ** $p < .01$. *** $p < .001$.

Table 3. Group results for balance and subjective assessments.

Variable	Intervention Group 5 Hz (n = 31)		Control Group 2 Hz (n = 31)		LMM Results				
	BL ($M \pm SD$)	Post ($M \pm SD$)	BL ($M \pm SD$)	Post ($M \pm SD$)	Time (F, p)	Group (F, p)	Interaction (F, p)	R^2_{marg}	R^2_{cong}
Balance – Dominant Leg (cm)	85.65 ± 6.66	87.86 ± 8.69	86.86 ± 6.87	87.24 ± 7.43	3.14, .081	0.03, .868	1.55, .218	.012	.704
Sense of Balance	50.23 ± 7.91	55.35 ± 13.70	48.16 ± 8.21	49.61 ± 13.77	4.40, .038*	1.71, .193	1.37, .244	.429	-
Surefootedness	49.87 ± 7.95	53.55 ± 14.71	47.39 ± 10.31	47.55 ± 12.23	1.91, .172	1.95, .168	1.78, .187	.590	-
Distractibility	34.48 ± 7.95	28.35 ± 22.56	34.55 ± 21.32	34.16 ± 21.63	1.67, .198	1.31, .254	1.30, .257	.621	-
Mind Wandering	36.68 ± 31.63	28.74 ± 27.16	30.97 ± 23.89	33.13 ± 27.04	0.85, .358	1.24, .268	2.61, .109	.579	-

Note. LLM = linear mixed-effects models. BL = Baseline. Sense of Balance, Surefootedness, Distractibility, and Mind Wandering were rated on a 100-point scale. Balance was assessed with the modified Star Excursion Balance Test (mSEBT). For models showing a singular fit, conditional R^2 values were not computed. * $p < .05$. ** $p < .01$. *** $p < .001$.

However, Arenales Arauz *et al*. (51) found no cognitive benefits when participants performed SS-WBV in a standing position compared to those who were seated. The authors attributed the absence of significant cognitive improvements in the standing group to differences in posture, suggesting that body position may critically modulate both the mechanical transmission of vibration and the subsequent central processing of the stimuli. The absence of effects in the present study may therefore be attributable to the low-frequency stochastic stimulus applied in a standing position. Furthermore, frequencies around 30 Hz are believed to activate Meissner corpuscles and other rapidly adapting mechanoreceptors implicated in prefrontal activation and sensorimotor integration (81). Given that the highest density of these receptors is found in the hands (82), the absence of hand contact with the vibrating platform may have further limited cortical stimulation.

Nevertheless, as the current evidence base remains inconclusive, an alternative explanation should also be considered. Performing SR-WBV without hand contact may in fact increase cognitive engagement, as standing freely on the platform imposes greater demands on postural control and sensorimotor coordination. From this perspective, the cognitive stimulation could even be enhanced relative to conditions where the hands stabilize the body, suggesting that the decisive factor may lie not solely in vibration frequency but also in the interaction between mechanical and coordinative demands. Overall, it must be stated that the study of cognitive effects of vibration exercises is still relatively new, and the underlying mechanisms are not yet fully understood. Improvements in executive functions such as inhibitory control have been linked to functional connections between sensory brain regions and the prefrontal cortex, leading to increased neurotransmission in prefrontal areas in response to sensory stimulation (83,84).

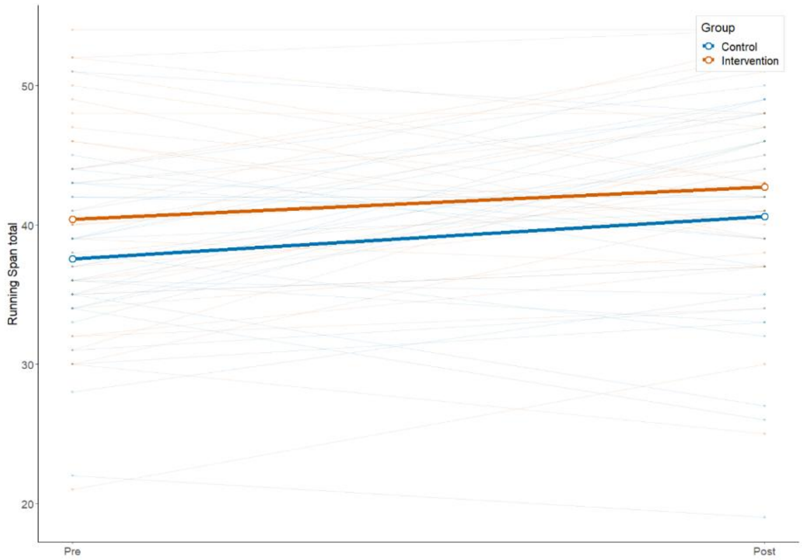

Figure 2. Pre-Post Change in Running Span total by Group

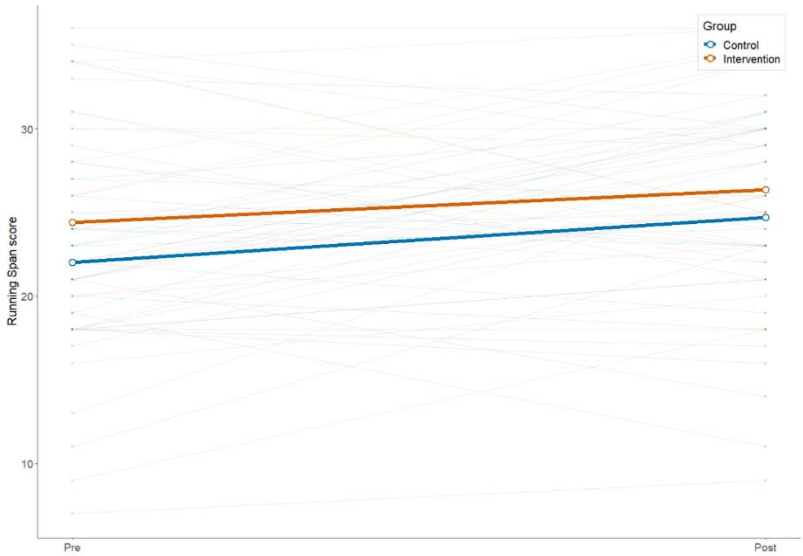

Figure 3. Pre-Post Change in Running Span score by Group

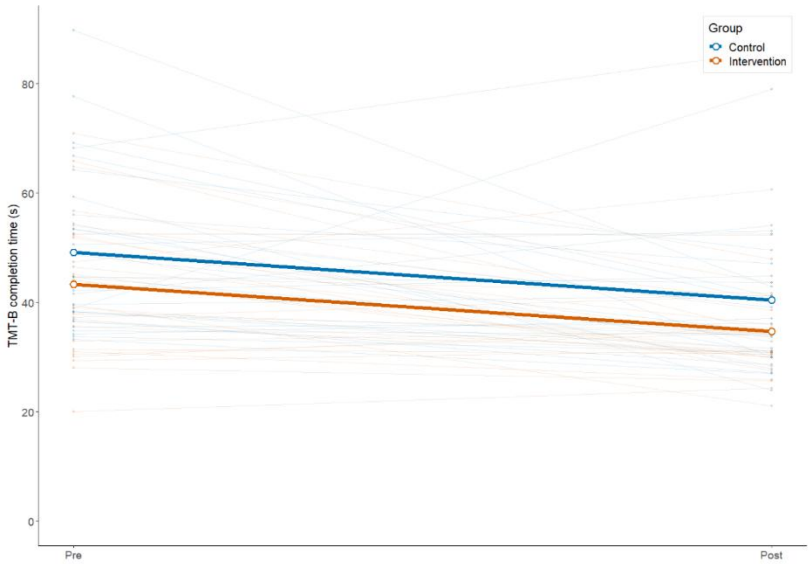

Figure 4. Pre-Post Change in TMT-B Completion Time by Group

Moreover, early animal studies have demonstrated that whole-body vibration can induce neuronal activation in selective brain regions and exert beneficial effects on neurotransmitter systems and cognition in both mice and humans (85).

A further explanation relates to the dose-response relationship of WBV interventions. Evidence from exercise and cognitive neuroscience indicates that brief, low-intensity stimulation preferentially enhances inhibitory control, whereas longer or progressively intensified interventions are required to affect working memory and cognitive flexibility (86). Consequently, the single, brief SR-WBV session applied here likely provided an insufficient total stimulus to induce measurable changes in executive functioning or balance.

Furthermore, participant characteristics may have influenced the results, even though previous studies reporting significant improvements likewise included young participants in their samples. The sample consisted of young, healthy adults with high baseline performance levels in both motor and cognitive domains. Since executive functions typically peak in early adulthood (87-90), ceiling effects are plausible, leaving limited potential for measurable enhancement. In contrast, greater improvements have been observed in individuals with lower baseline capacity, such as those with ADHD (49) or older adults with balance deficits (44). SR-WBV may therefore be most effective in populations with reduced functional reserves.

The sequence of task administration might also have influenced the results. Inhibition was assessed last among the three executive domains, increasing the likelihood that any transient cognitive effects of SR-WBV had dissipated by that point. This interpretation aligns with findings from Regterschot *et al*. (50), who observed acute WBV benefits on inhibition but not on working memory, and Vasconcelos *et al*. (81), who attributed minor performance changes to general learning rather than vibration effects. Collectively, these findings suggest that any WBV-related cognitive facilitation is likely task-specific, short-lived, and sensitive to the timing of assessment.

In contrast to previous studies on acute cognitive effects of whole-body vibration, which predominantly relied on randomized cross-over designs (49–52), the present study employed a parallel two-group design. Cross-over approaches offer the advantage of increased statistical power, as each participant serves as their own control and sequence or practice effects can be counterbalanced. However, such designs also entail an inherent risk of carry-over effects, particularly when experimental and control vibrations are administered within a short timeframe. The two-group design chosen here avoids these potential carry-over influences and enabled a more robust blinding procedure: Participants in the control group received a sham vibration that preserved perceptual plausibility, reducing the likelihood that individuals could infer their group assignment based on the absence of stimulation. Thus, while our between-subjects approach differs from the common cross-over methodology, it provides complementary methodological strengths that align with the study's focus on immediate, condition-specific effects.

Beyond the cognitive outcomes, the absence of immediate interaction effects on balance in the present study is consistent with the limited evidence for acute SR-WBV responses in healthy young adults. Although single SS-WBV sessions have shown short-term improvements, these typically occur in both experimental and sham conditions and are therefore attributed to nonspecific influences such as arousal or familiarization (37). Acute SR-WBV effects on postural control have been demonstrated primarily in older or clinical populations (46–48), whereas the only robust single-session effect in healthy adults stems from a seated, partial-body stochastic vibration protocol (45). Moreover, current evidence suggests that vibration-specific balance adaptations are more reliably observed after multi-week stochastic training (42–44), which aligns with the present study's findings regarding the absence of immediate SR-WBV effects during standing.

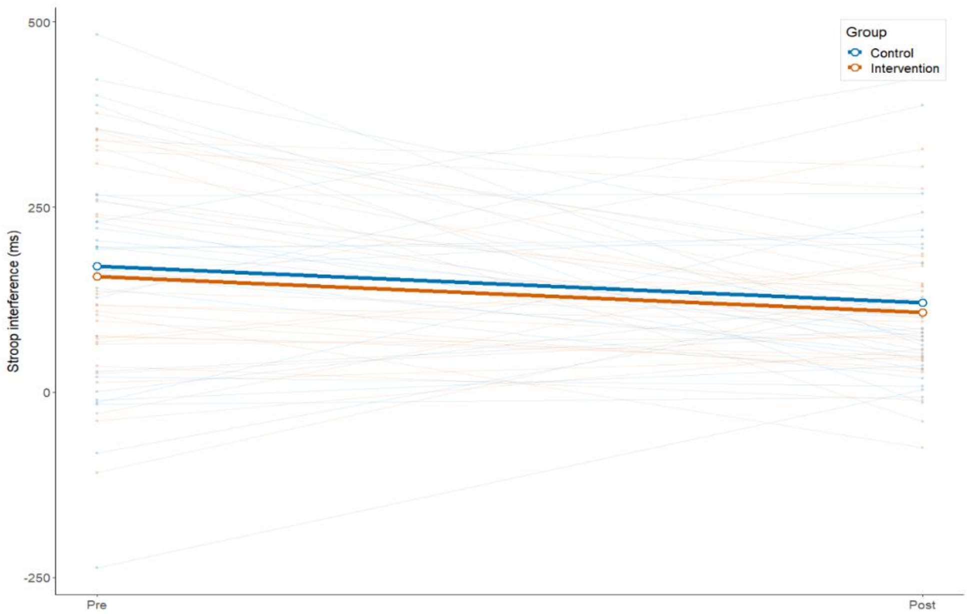

Figure 5. Pre-Post Change in Stroop interference by Group

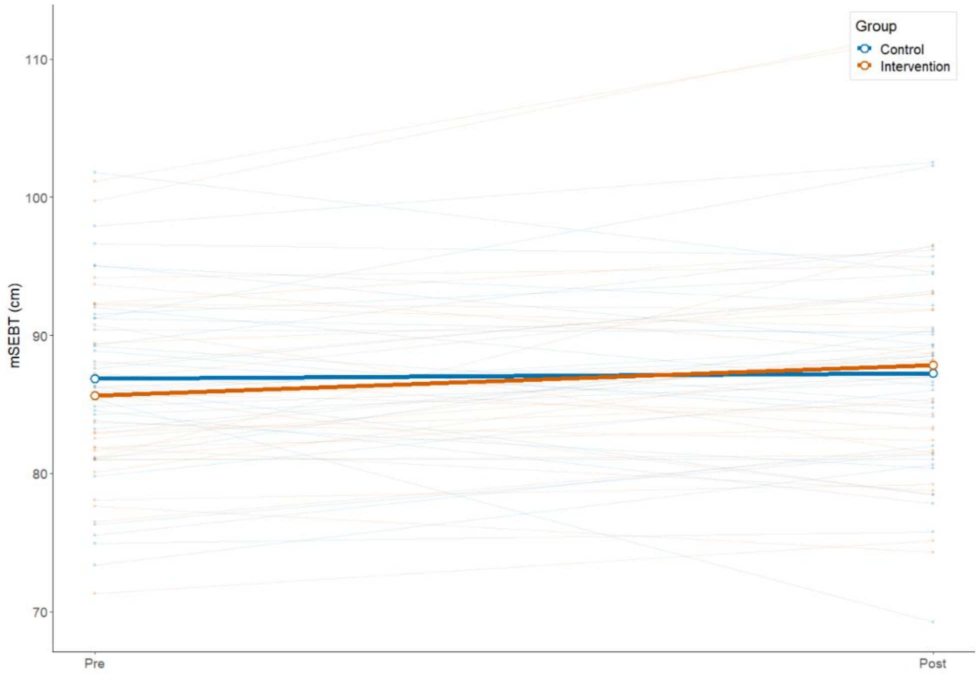

Figure 6. Pre-Post Change in mSEBT by Group

Interestingly, both groups reported small but significant improvements in subjective balance. This finding aligns with Faes *et al.* (37,91), who noted enhanced perceived stability following SR-WBV at comparable frequencies (5-6 Hz). Because subjective ratings are less influenced by test repetition, these improvements may reflect genuine perceptual recalibration. Clinically, even modest gains in perceived stability could be relevant, as they may help reduce fear of falling and enhance confidence during movement, e.g. in older adults.

Finally, methodological aspects of the control condition warrant consideration. The inclusion of an active control group was an intentional design choice aimed at controlling expectancy and sensory stimulation effects, which frequently confound WBV research. Similar approaches have been adopted by Elfering *et al.* (32) and Faes *et al.* (37), who compared different vibration frequencies to ensure comparable somatosensory input across groups. Specifically, Faes *et al.* (37) applied SS-WBV at 8.5 Hz and 6 Hz, while Elfering *et al.* (32) conducted an SR-WBV intervention using 5 Hz for the intervention group and 1.5 Hz for the control group. However, while such active controls enhance internal validity by matching sensory exposure and participant engagement, they concurrently reduce the likelihood of detecting significant between-group differences.

In the present study, the 2 Hz low-frequency vibration used as a control was likely not physiologically inert, as even subtle oscillations can activate vestibular and proprioceptive pathways (31,32). Consequently, both groups may have received mild sensorimotor stimulation, attenuating the experimental contrast. Future studies should therefore consider including a true sham condition (0 Hz, no vibration) to fully isolate the specific effects of stochastic vibration. Alternatively, a larger separation in vibration frequency between intervention and control groups would enhance experimental sensitivity. Although the 5 Hz versus 2 Hz contrast used here represents a formal difference in stimulation parameters, it was likely too small to produce functionally distinct neurosensory effects.

4.1 Limitations of the study

Several limitations of the present study should be acknowledged. First, the trial investigated only the acute effects of a single SR-WBV session. Consequently, no conclusions can be drawn regarding long-term adaptations or cumulative training effects. Repeated or prolonged interventions may be required to elicit measurable neuroplastic or behavioral changes.

Second, all participants were exposed to a fixed vibration frequency of 5 Hz, without individual adjustment. Previous studies using SS-WBV have demonstrated that personalized frequency tuning can enhance responsiveness and interindividual variability (37). According to established training principles, an adequate and individualized stimulus is essential for adaptation. It is therefore possible that the 5 Hz setting was too low to produce robust improvements in this young, high-functioning cohort and that the three one-minute bouts of SR-WBV provided an insufficient total training dose.

Third, as discussed above, the 2 Hz control condition may not have been physiologically inert. Even low-frequency oscillations can activate vestibular and proprioceptive pathways (31,32), potentially masking between-group effects. Future studies should therefore consider a true sham condition or a wider frequency gap between intervention and control to ensure clearer differentiation.

Fourth, the sample characteristics limit the generalizability of the findings. The participants were young, healthy students – an age group in which executive functions typically peak (87–90). Ceiling effects are therefore likely leaving limited scope for observable improvement. In contrast, more pronounced and consistent effects may emerge in populations with reduced baseline performance, such as older adults or individuals with cognitive or balance impairments. Moreover, the gender distribution in the present study was unbalanced, precluding analysis of potential sex-specific effects.

Finally, several methodological considerations pertain to the cognitive measures employed. The Running Span task, although widely used to assess updating (6,92), has been criticized for potentially engaging short-term storage rather than continuous updating processes (93–95). Similarly, set-shifting is operationalized inconsistently across studies: while the present study used absolute completion times for TMT-B, other researchers compute difference scores between TMT-B and TMT-A (96), which may capture different cognitive aspects. Such methodological variations should be considered when interpreting and comparing results across studies.

4.2 Strengths of the study

Despite these limitations, the present trial exhibits several methodological strengths. It adhered closely to the Reporting Guidelines for Whole-Body Vibration Studies (34), ensuring comprehensive documentation of device characteristics, vibration parameters, and testing procedures. The randomized controlled design, standardized test order, and use of validated cognitive measures (Running Span, TMT-B, Stroop) enhance internal validity and facilitate replication.

Moreover, the inclusion of a stochastic vibration modality broadens the literature beyond classical sinusoidal paradigms and provides valuable reference data on SR-WBV in healthy populations. Importantly, the absence of adverse events underscores the short-term safety and feasibility of SR-WBV. Notably, while low-frequency vibration (≈5 Hz) has occasionally been linked to increased drowsiness and reduced alertness (97), no such effects were observed here, suggesting that the mechanisms underlying SR-WBV may differ from those associated with low-frequency SS-WBV.

A further strength lies in the dual focus on motor and cognitive outcomes. While most WBV research examines either balance or cognition, the present study assessed both domains simultaneously, which is highly relevant given the close interplay of cognitive and motor functions in fall risk (6). Moreover, the analysis of distinct executive domains, shifting, updating, and inhibition, rather than a unitary construct allows more nuanced interpretation and adds novelty to the field.

Given that cognitive impairment, fear of falling, and fall history indirectly contribute to fall risk (19), SR-WBV may have practical utility. Enhancing perceived balance could help reduce fall anxiety and thereby improve both mobility confidence and quality of life, with potential downstream benefits for healthcare costs.

4.3 Perspectives

Future research should pursue several directions. First, as the present study did not reveal significant acute effects of SR-WBV on executive functions or balance, further work is needed to clarify under which stimulation conditions such effects might emerge. In particular, systematic variation of vibration frequency and amplitude should be considered, as higher-frequency stimulation or larger contrasts between intervention and control groups may elicit stronger neurosensory activation and, consequently, more pronounced behavioral effects. Moreover, longitudinal designs with repeated exposure and follow-up assessments are required to determine whether potential short-term adaptations can translate into sustained cognitive and functional benefits (98). Research in older or clinical populations, where executive functioning and balance are typically reduced, appears especially warranted.

Second, the diversity of WBV modalities calls for comparative trials systematically contrasting different vibration types and frequencies (e.g., SR-WBV vs. SS-WBV). To ensure methodological consistency and facilitate cross-study comparison, future studies should adhere to the reporting standards proposed by van Heuvelen *et al*. (34).

Third, multimodal approaches combining SR-WBV with cognitive engagement appear particularly promising. According to the cognitive stimulation hypothesis, interventions that simultaneously challenge physical and cognitive systems yield stronger executive improvements than purely physical training (99–102). Indeed, programs integrating WBV with psychomotor or dual-task components have produced superior outcomes compared to either method alone (101). Similarly, multi-component exercise interventions have been shown to enhance mobility, strength, and fall prevention (102).

Taken together, these perspectives underscore the importance of future research focusing on optimized vibration parameters, long-term intervention effects, diverse target populations, and multimodal training strategies to fully elucidate the cognitive and motor potential of stochastic WBV.

5. Conclusion

In this randomized controlled trial, a single session of stochastic resonance whole-body vibration (SR-WBV) at 5 Hz did not produce specific improvements in executive functions or balance beyond general practice effects in young, healthy adults. The findings suggest that low-frequency SR-WBV may be insufficient to elicit measurable neurocognitive or motor adaptations in high-functioning populations.

Nevertheless, the study provides important methodological insights for optimizing WBV research design. Future investigations should employ higher vibration frequencies, larger contrasts between intervention and control conditions, and repeated-session protocols to determine dose-response relationships and potential long-term effects. Studies in older or clinical populations may further clarify whether SR-WBV can serve as an effective tool to enhance cognitive-motor functioning and balance in individuals with lower baseline capacity.

Conflict of Interest

The authors declare that they have no conflict of interest related to this study.

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