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Original Article

Comparison of Active versus Passive Whole-Body Vibration Training on Neuromuscular Activation of Deep Trunk Muscles and Dynamic Postural Stability: A Pilot Study

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Abstract

Objectives: This pilot study compared the effects of Active Vibration Exercise (AVE) involving dynamic movements and static Whole-Body Vibration Exercise (WBVE) on deep trunk muscle activation, dynamic balance, and peripheral circulation in healthy adults. **Methods**: Ten participants were randomly assigned to AVE or WBVE groups (n=5 each) for two weeks of twice-daily 5-minute sessions. Primary outcomes measured deep trunk muscle (internal oblique [IO] and multifidus) activation via surface electromyography. Secondary outcomes assessed dynamic balance, peripheral circulation, grip strength, and flexibility. **Results**: Within-group comparisons indicated no significant pre-to-post changes for either group. However, between-group change score analysis showed a statistically significant difference in left IO activation (p=0.032, effect size r=0.694), favoring the AVE group. Both groups showed non-significant numerical improvements in skin temperature, balance, and flexibility. **Conclusions**: These preliminary findings suggest that integrating dynamic movements with vibration (AVE) may be more effective for specific deep trunk muscle activation than static WBVE. Further large-scale trials are needed to confirm AVE's therapeutic value for core stabilization due to this study's limited sample size.

Keywords: Active Vibration Exercise, Core Stabilization, Postural Stability, Trunk Muscle Activation, Whole-Body Vibration

Introduction

The physical build of university students in their 20s has been significantly improving compared to the past; however, their physical strength and levels of physical activity are continuously declining due to excessive internet use and a reduction in physical education hours. Furthermore, studies on university freshmen have reported a high necessity for physical activity promotion, as they spend a considerable amount of time in sedentary behaviors[1]. Despite clear evidence that increased physical activity provides numerous physical benefits, the current level of physical activity among adults remains insufficient[2]. In fact, compared to the 45.5% rate of regular moderate-intensity exercise participation among American university students[3], the rate for Korean university students and young adults remains significantly lower, reported at approximately 20%[4].

Improper lifestyle habits resulting from a lack of exercise lead to external postural changes and internal pain[5,6]. Such muscular imbalances can cause musculoskeletal issues, including disc herniation, arthritis, and postural alteration[7]. A narrowed base of support increases injury rates due to decreased coordination, balance, and postural maintenance abilities, and induces continuous contraction of surrounding muscles, leading to muscle fatigue and

Minyong Eom is an employee of FineM Co., Ltd. The remaining authors have nothing to declare.

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Table 1. General characteristics of participants.

Characteristics	AVE[a] (n=5)	WBVE[b] (n=5)
Sex (male/female)	2/3	4/1
Age (yrs)	22.40±1.14	22.00±0.71
Height (cm)	162.90±7.60	172.60±3.21
Weight (kg)	56.94±11.67	64.30±10.01

[a]*active vibration exercise,* [b]*whole-body vibration exercise*

impaired balance[8]. Additionally, weakening of core muscles and decreased stability have been observed[9]. Furthermore, such physical inactivity can negatively impact peripheral microcirculation and autonomic thermoregulation, physiological responses that are increasingly monitored using infrared thermography during clinical and exercise assessments[10].

To counteract these functional declines, innovative modalities such as vibration exercise have been widely investigated for their potential to effectively enhance neuromuscular performance[11]. As a critical period of significant physical, mental, and social changes, opportunities for physical training during this time serve as a driving force for a happy life[12]. In this regard, regular exercise for university students is a vital factor in their growth as healthy members of future society and in maintaining a healthy life beyond adulthood[13].

Recently, Whole-Body Vibration (WBV) equipment has been actively utilized as a new training tool[14]. The effects of vibration exercise are attributed to the 'tonic vibration reflex,' which induces tissue deformation through physical vibration. Vibrations of 30–100 Hz activate receptors in the skin, tendons, and muscle spindles, thereby inducing muscle contractions, activating reflex nerves, and alleviating muscle stiffness[15]. WBV is a form of exercise where vibration is applied to the entire body while standing on a vibration plate. It is a novel exercise method that elicits neuromuscular responses and adaptations by providing mechanical stimulation to sensory receptors, such as muscle spindles, through various frequency stimulations[11].

As research has shown that the effects on muscle and bone metabolism positively influence exercise performance and health promotion, WBV has emerged as a new exercise-training modality[16,17]. Cardinale and Wakeling[18] suggested that WBV acts as a mechanical stimulus capable of enhancing neuromuscular performance, particularly when the vibration frequency reaches the resonant frequencies of the target tissues (typically ranging from 10 to 50 Hz).

Tsopani et al.[19] reported that WBV significantly improved flexibility, balance, and muscle strength in rhythmic gymnasts. Kerschan-Schindl et al.[20] observed that short-term vibration stimulation nearly doubled blood flow velocity, and Maikala et al.[21] found that oxygen consumption and blood flow were highest at 4.5 Hz when testing frequencies of 3, 4.5, and 6 Hz. According to a recent meta-analysis[22], while WBV can lead to a statistically significant reduction in body fat mass in overweight and obese populations, these changes appear to lack clinical significance, and WBV alone is insufficient to significantly modify body weight or BMI.

However, despite these beneficial effects, certain limitations related to the mechanical design of WBV devices have been reported, including a restricted degree of freedom in some models[23].

While previous research has extensively explored the benefits of Whole-Body Vibration Exercise (WBVE) in passive or static conditions, there is a limited understanding of how integrating active, multi-planar dynamic movements—such as those performed with Smovey rings (Active Vibration Exercise, AVE)—compares to conventional static vibration protocols. Unlike static WBVE, which relies primarily on reflexive muscle responses, AVE may offer additional neuromuscular demands by combining mechanical vibration with coordinated voluntary movement. Therefore, comparing these two modalities is essential to determine their respective roles in core stabilization and peripheral physiological responses.

The primary aim of this pilot study was to compare the preliminary effects of a 2-week intervention of AVE and static WBVE on deep trunk muscle activation (Internal Oblique and Multifidus). The secondary aim was to explore their associated trends in dynamic balance, peripheral circulation, functional strength, and flexibility. This exploratory study seeks to provide feasibility data and generate hypotheses for future large-scale clinical trials.

Methods

Participants and Study Design

Ten healthy young adults in their 20s were recruited for this pilot study. Participants were randomly assigned to either the AVE group (n=5) or the WBVE group (n=5).

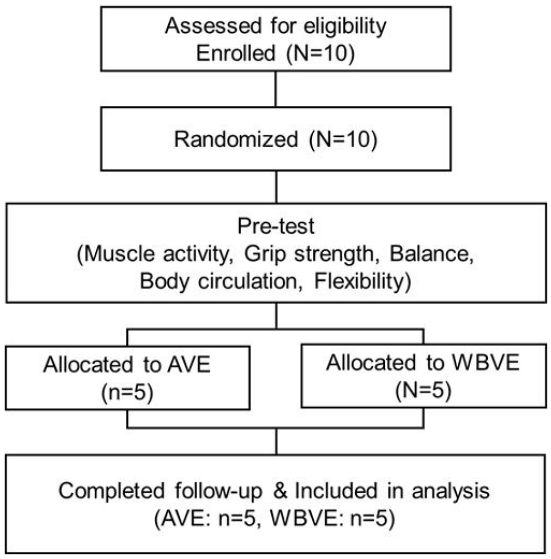

Figure 1. CONSORT participant flow diagram and experimental procedure.

The study protocol was approved by the Institutional Review Board (IRB) of Konyang University (Approval No.: 2025-05-023-001), and all participants provided written informed consent prior to enrollment.

Selection criteria were as follows: (1) individuals who provided consent and had no history of back or pelvic pain within the last three months; (2) those without orthopedic diseases or medical issues such as thrombosis, diabetes, or cardiovascular disease; (3) those without balance issues related to vestibular damage or visual impairment; and (4) those who agreed not to engage in any other exercises that could influence the study results during the experimental period. The general characteristics of the participants are presented in Table 1.

This study was designed as a pilot randomized parallel-group trial to evaluate the feasibility and preliminary effects of two different vibration exercise modalities. A total of 10 eligible healthy adults were screened, enrolled, and randomly assigned to either the AVE group (n=5) or the WBVE group (n=5). Randomization was performed using a computer-generated random number sequence. To ensure allocation concealment, assignments were enclosed in sequentially numbered, opaque, sealed envelopes. An independent researcher, who was not involved in the recruitment or assessment process, generated the random allocation sequence and assigned the participants to their respective groups. Due to the intervention type, participants and therapists could not be blinded; however, outcome assessors and statisticians were strictly blinded to group allocation. Adherence was 100%, and all 10 participants completed the entire 2-week intervention and post-intervention assessments with no dropouts.

Pre-tests were conducted for both groups to assess abdominal muscle activity, grip strength, balance, blood circulation, and flexibility prior to the intervention. Participants then performed either WBVE using the Galileo device or AVE using the Smovey, during both morning and afternoon sessions daily. Figure 1 illustrates the experimental procedures of this study.

Due to the physical nature of the exercise interventions, it was not possible to blind the participants or the therapists providing the intervention. However, to minimize detection and performance bias, all outcome assessors and the statistician who performed the data analyses were strictly blinded to the participants' group allocations. To preserve blinding, the outcome assessor conducted all measurements in a separate laboratory space completely isolated from the intervention area. Furthermore, to ensure the statistician remained blind to group allocation, the final dataset was de-identified and numerically coded by an independent researcher prior to statistical analysis.

Intervention Methods

Active Vibration Exercise (AVE)

For active vibration exercise, Smovey® (smovey Med, Switzerland) was utilized as a small exercise tool. The Smovey is a swing-ring system designed for dynamic movement, consisting of a spiral tube with four freely moving steel balls inside. While the static weight of each ring is approximately 1 lb, the centrifugal force generated during swinging motions can increase the perceived resistance to nearly 12 lbs. When a user performs a forward stroke followed immediately by a reciprocal backward movement, the four steel balls roll along the interior of the tube, generating pulsatory vibrations in the user's hands. The movement of the balls against the corrugated interior induces vibrations of 50–60 Hz, which are transmitted through the palms to provide a dynamic upper-body workout.

The AVE group performed 5-minute sessions twice daily (morning and afternoon) for a total of 20 sessions over two weeks. During the exercise sessions, five pieces of music with an appropriate tempo were selected and played. Regarding intervention adherence, all participants demonstrated 100% compliance. Every participant successfully completed the prescribed 20 sessions (twice daily for two weeks) without any reported adverse events, side effects, or protocol deviations.

Whole-Body Vibration Exercise (WBVE)

As research has demonstrated the beneficial effects of vibration exercise on neuromuscular activation and muscle performance, WBV has emerged as a promising

Table 2. Electrode placement for EMG.

Muscle	Electrode Placement
Internal Oblique	Medial to the anterior superior iliac spine (ASIS), approximately 2/3 of the way along the line connecting the ASIS.
Multifidus	At the level of the L3 spinous process, two finger-widths lateral to the spinal midline.

training modality[11,14]. Previous studies have reported that WBV enhances endurance and power output[18], and induces physiological responses such as increased blood flow velocity[20] and elevated oxygen consumption[21]. Furthermore, systematic reviews have highlighted its positive effects on body composition and neuromuscular recruitment[22]. In terms of functional outcomes, improvements in flexibility, balance, and muscle strength have been observed in athletic populations[19]. However, certain limitations related to biomechanical constraints and device characteristics have also been reported[23]. Therefore, in this study, the vibration frequency was set as the treatment variable at 20 Hz. Previous studies utilizing side-alternating vibration devices, such as the Galileo® system (Novotec Medical GmbH, Germany), have demonstrated that frequencies around 20 Hz optimally elicit neuromuscular activation and significantly improve mean force, mean power, and mean velocity[14,16,18].

The duration and posture for WBVE have varied across previous studies. In this study, based on the research by Jacobs et al.[24], the WBVE protocol was established as maintaining a squat posture for 5 minutes. The WBVE group performed 5-minute sessions twice daily (morning and afternoon) for a total of 20 sessions over a two-week period.

To ensure intervention fidelity, all sessions were directly supervised by a licensed physical therapist. For the WBVE group, participants maintained a static squat posture on the vibration plate with a knee flexion angle of 30°, verified using a goniometer. For the AVE group, participants performed a dynamic squat while swinging Smovey rings in a coordinated multi-planar motion according to a standardized protocol. Compliance was monitored through individual exercise logs, and any protocol deviations were recorded.

Measurement

The primary outcome of this study was the change in deep trunk muscle activation (Internal Oblique and Multifidus). The secondary outcomes included dynamic balance (SEBT), peripheral circulation (skin temperature), functional strength (grip strength), and flexibility. To ensure standardization, all assessments were conducted by a single trained physical therapist who received specific training on the testing protocols. Baseline pre-testing was conducted 24 hours prior to the first intervention session, and post-testing was performed 24 hours after the final session to capture the sustained effects of the 2-week intervention.

Electromyography (EMG)

A wireless surface electromyography (sEMG) system (TeleMyo 2400T, Noraxon Inc., USA) was used to measure muscle activity. Four wireless electrodes were attached to the bilateral internal oblique (IO) and multifidus (MF) muscles. For the internal oblique, muscle activity during contraction and Maximal Voluntary Isometric Contraction (MVIC) were measured while participants were in a supine position with knees flexed at 90 degrees. For the multifidus, measurements were taken in a prone position. The collected sEMG amplitude data were normalized to each participant's MVIC and expressed as a percentage (%MVIC). The specific electrode placement for each muscle followed the guidelines of Moraes et al.[25], as detailed in Table 2.

Handgrip Strength

A digital dynamometer (EH-101, Camry®, China) was used to measure handgrip strength, which serves as an indicator of hand function and its associated task performance capabilities. Participants were instructed to stand upright in an attention posture, with the testing arm extended and positioned at approximately 15 degrees from the torso. The dynamometer was adjusted so that the second joint of the fingers formed a right angle when gripped. Participants were asked to squeeze the dynamometer with maximal effort, with measurements taken for the left hand followed by the right. The highest value from two trials was recorded in kilograms (kg). During measurement, care was taken to ensure the device did not touch any other objects and that the participant's torso remained upright without bending[26].

Dynamic Balance (Star Excursion Balance Test, SEBT)

The Star Excursion Balance Test (SEBT) was employed to assess dynamic balance. Participants stood on one leg at the center of a grid and reached as far as possible along eight designated lines (anterior, anteromedial, medial, posteromedial, posterior, posterolateral, lateral, and anterolateral) (Figure. 2). The absolute reach distance for each direction was recorded in centimeters (cm). A composite score was calculated by averaging the reach distances of all eight directions for the right and left legs separately. As noted in the limitations, the absolute reach distances (cm) were analyzed directly and were not normalized to the participants' lower limb lengths. Each measurement was performed three times, and the mean values were used for analysis.

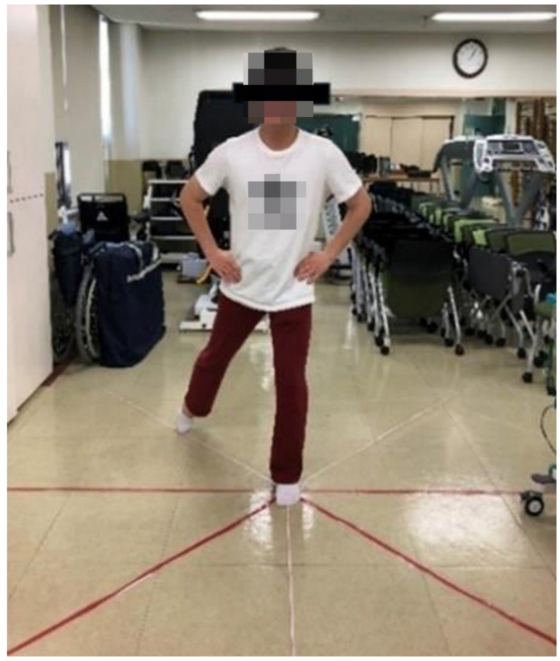

Figure 2. Dynamic balance ability test (SEBT).

Digital Infrared Thermal Imaging (DITI)

Digital Infrared Thermal Imaging (DITI) (T-1000HD, Mesh Co., Korea) was used to measure skin temperature as an established, non-invasive proxy for peripheral microvascular circulation, since local vasodilation directly increases regional surface temperature[27]. Prior to imaging, participants underwent a strict 15-minute acclimation period with the target areas exposed in a temperature-controlled room (maintained at 22–24°C, with humidity at roughly 50%) protected from external light and drafts, in accordance with standard thermographic protocols[28]. The thermal camera was positioned precisely 1 meter away from the participant at a perpendicular angle to the skin surface. The Regions of Interest (ROIs) were standardized as the anterior mid-forearm for the upper extremity and the anterior mid-patella for the lower extremity. In this study, the device categorized surface temperatures into eight colors: red (40.00–38.41°C), orange (38.40–36.81°C), amber (35.22–33.63°C), yellow (33.00–32.03°C), green (30.44–27.25°C), blue (25.66–22.47°C), purple (22.47–16.00°C), and black (below 14.5°C)[29].

Flexibility

Participants sat with their feet flat against the vertical surface of the testing device and knees fully extended. They then leaned forward to push the scale indicator as far as possible. Measurements were taken three times before and after the exercise, and the average values were recorded (Figure 3).

Figure 3. Sit-and-reach test.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 25.0 (IBM Corp., Armonk, NY, USA). Due to the small sample size (n=5 per group), normality of the data distribution could not be assumed; therefore, non-parametric tests were employed to ensure the validity of the results. All descriptive statistics are presented as mean ± standard deviation (SD), with the level of statistical significance set at $\alpha < 0.05$ for all tests. To evaluate the effects of the interventions, the Wilcoxon signed-rank test was first conducted to assess within-group changes from pre- to post-intervention in muscle activity, grip strength, dynamic balance, peripheral circulation, and flexibility. Subsequently, the Mann-Whitney U test was utilized to compare the relative effectiveness between the two groups. This analysis focused on the magnitude of change, calculated as the delta score (Δ: post-test value minus pre-test value), to determine if significant differences existed between the Active Vibration Exercise

Table 3. Comparison of muscle activity between groups. (Unit: %MVIC).

Muscle	Group	Pre	Post	p_1	p_2 (r)
Rt. multifidus	AVE	74.35 ± 15.11	79.82 ± 23.45	0.625	1.000 (0.033)
	WBVE	97.94 ± 25.36	103.46 ± 10.25	0.625	
Lt. multifidus	AVE	72.04 ± 14.29	79.58 ± 18.52	0.313	0.222 (0.429)
	WBVE	91.32 ± 22.83	108.42 ± 19.54	0.063	
Rt. internal oblique	AVE	73.88 ± 47.59	101.88 ± 52.98	0.625	0.421 (0.297)
	WBVE	120.42 ± 104.08	99.16 ± 99.95	0.625	
Lt. internal oblique	AVE	47.18 ± 28.11	89.48 ± 79.49	0.125	**0.032*** **(0.694)**
	WBVE	110.39 ± 73.90	68.32 ± 64.60	0.125	

*p_1: Within-group comparison (Pre vs. Post by Wilcoxon signed-rank test), p_2 (r): Between-group comparison (Change scores by Mann-Whitney U test) and its corresponding effect size (r). The level of significance was set at * p < 0.05, ** p < 0.01, *** p < 0.001.*

(AVE) group and the Whole-Body Vibration Exercise (WBVE) group for each dependent variable.

Given the exploratory and hypothesis-generating nature of this pilot study, no adjustments for multiple comparisons (e.g., Bonferroni correction) were applied. Consequently, all inferential statistical tests should be interpreted as exploratory, and any isolated significant p-values were evaluated alongside their corresponding effect sizes rather than relying solely on null-hypothesis significance testing. To account for the small sample size and to provide a measure of the magnitude of the intervention effects, effect sizes (r) were calculated for all non-parametric tests. Effect sizes (r) of 0.1, 0.3, and 0.5 were interpreted as medium, and large, respectively.

Results

A total of 10 participants were enrolled and randomized (n=5 per group). All participants completed the 2-week intervention and follow-up assessments, demonstrating 100% adherence to the 20-session protocol. There were no dropouts or adverse events reported during the study period. Regarding harms and safety monitoring, no adverse events or negative side effects were reported by any participants in either the AVE or WBVE groups during or after the 2-week intervention period.

Changes in Muscle Activity

The changes in the activation of the multifidus (MF) and internal oblique (IO) muscles following the 2-week intervention are summarized in Table 3. The AVE group showed a consistent upward trend in muscle activity for both the MF (Right: 74.35 ± 15.11 to 79.82 ± 23.45; Left: 72.04 ± 14.29 to 79.58 ± 18.52) and IO muscles (Right: 73.88 ± 47.59 to 101.88 ± 52.98; Left: 47.18 ± 28.11 to 89.48 ± 79.49). In contrast, the WBVE group exhibited a decrease in IO muscle activity (Right: 120.42 ± 104.08 to 99.16 ± 99.95 Left: 110.39 ± 73.90 to 68.32 ± 64.60), despite a numerical increase in the MF. Statistical analysis using the Wilcoxon signed-rank test indicated that these within-group changes did not reach statistical significance for either group ($P > 0.05$). However, a significant between-group difference was observed in the change scores for the left internal oblique muscle (p=0.032, effect size r=0.694). This indicates that the AVE group's tendency toward increased IO activation was statistically superior to the decrease observed in the WBVE group, highlighting a distinct response pattern between the two vibration protocols.

Changes in Grip Strength

The changes in handgrip strength, utilized as an indicator of hand function, are presented in Table 4. For the AVE group, no notable differences were observed in either hand, with the right-hand strength shifting minimally from 35.92 ± 9.66 kg to 35.86 ± 9.94 kg. In the WBVE group, right-hand grip strength showed a slight increase from 45.22 ± 12.15 kg to 46.04 ± 13.85 kg, while left-hand strength decreased from 43.30 ± 10.63 kg to 41.62 ± 12.95 kg.

Changes in Dynamic Balance

Improvements in dynamic balance were observed in both groups through the Star Excursion Balance Test (SEBT). In the AVE group, the reach distance increased from 85.05 ± 8.34 cm to 92.41 ± 9.44 cm on the right side, and from 86.45 ± 15.72 cm to 89.27 ± 12.11 cm on the left side. Similarly, the WBVE group showed increases on the right (80.69 ± 9.37 cm to 91.07 ± 11.80 cm) and left sides (80.13 ± 17.46 cm to 89.27 ± 11.84 cm) (Table 4). However, according to the Wilcoxon signed-rank test, these within-group improvements were not statistically significant ($p > 0.05$). Furthermore, the Mann-Whitney U test revealed no significant between-group differences in

Table 4. Comparison of grip strength, dynamic balance, and flexibility.

Variable	Group	Pre	Post	p_1	p_2 (r)
Rt. grip strength (kg)	AVE	35.92 ± 9.66	35.86 ± 9.94	0.813	1.000 (0.033)
	WBVE	45.22 ± 12.15	46.04 ± 13.85	0.813	
Lt. grip strength (kg)	AVE	34.36 ± 8.60	35.42 ± 8.80	0.313	0.151 (0.495)
	WBVE	43.30 ± 10.63	41.62 ± 12.95	0.438	
Rt. SEBT (cm)	AVE	85.05 ± 8.34	92.41 ± 9.44	0.250	0.730 (0.165)
	WBVE	80.69 ± 9.37	91.07 ± 11.80	0.125	
Lt. SEBT (cm)	AVE	86.45 ± 15.72	89.27 ± 12.11	0.125	0.905 (0.231)
	WBVE	80.13 ± 17.46	89.27 ± 11.84	0.188	
Flexibility (cm)	AVE	0.26 ± 6.55	4.47 ± 5.01	0.068	0.548 (0.231)
	WBVE	−3.73 ± 11.69	1.95 ± 10.48	0.063	

p_1: Within-group comparison (Pre vs. Post by Wilcoxon signed-rank test), p_2 (r): Between-group comparison (Change scores by Mann-Whitney U test) and its corresponding effect size (r).

Table 5. Comparison of peripheral circulation.

Variable	Group	Pre	Post	p_1	p_2 (r)
Rt. Arm Skin temperature (°C)	AVE	36.76 ± 1.42	38.64 ± 2.11	0.066	0.690 (0.198)
	WBVE	34.97 ± 2.48	35.80 ± 3.17	0.438	
Lt. Arm Skin temperature (°C)	AVE	36.12 ± 1.53	39.08 ± 1.35	0.063	0.690 (0.198)
	WBVE	33.89 ± 1.39	35.14 ± 3.63	0.465	
Rt. Knee Skin temperature (°C)	AVE	27.33 ± 3.04	32.64 ± 5.10	0.188	0.690 (0.165)
	WBVE	28.01 ± 5.11	31.92 ± 5.94	0.125	
Lt. Knee Skin temperature (°C)	AVE	24.97 ± 2.93	32.03 ± 5.44	0.063	0.310 (0.363)
	WBVE	27.35 ± 5.56	31.25 ± 6.45	0.125	

p_1: Within-group comparison (Pre vs. Post by Wilcoxon signed-rank test), p_2 (r): Between-group comparison (Change scores by Mann-Whitney U test) and its corresponding effect size (r).

the change scores for any functional variables, including grip strength and SEBT ($P > 0.05$).

Changes in Flexibility

Regarding flexibility, both the AVE and WBVE groups exhibited improvements in their sit-and-reach test scores following the 2-week intervention period. The AVE group's flexibility improved from an initial baseline of 0.26 ± 6.55 cm to 4.47 ± 5.01 cm. Likewise, the WBVE group's flexibility measurements increased from -3.73 ± 11.69 cm to 1.95 ± 10.48 cm. Nevertheless, these within-group changes were not statistically significant according to the Wilcoxon signed-rank test (AVE p=0.068, WBVE p=0.063). Additionally, there was no significant difference in the flexibility change scores between the two groups (p=0.548) (Table 4).

Changes in Blood Circulation

The evaluation of peripheral circulation using Digital Infrared Thermal Imaging (DITI) revealed a general upward trend in skin temperature for both groups. In the AVE group, numerical increases were observed in the upper extremities (Right: 36.76 ± 1.42°C to 38.64 ± 2.11°C; Left: 36.12 ± 1.53°C to 39.08 ± 1.35°C) and lower extremities (Right knee: 27.33 ± 3.04°C to 32.64 ± 5.10°C; Left knee: 24.97 ± 2.93°C to 32.03 ± 5.44°C). The WBVE group showed a similar trend, with increases in both hand and knee temperatures (Table 5).

However, due to the limited sample size of this pilot study, the Wilcoxon signed-rank test indicated that these within-group changes did not reach statistical significance for either group. Furthermore, between-group comparisons of the temperature change scores (Δ) via the Mann-Whitney U test revealed no significant differences between the AVE

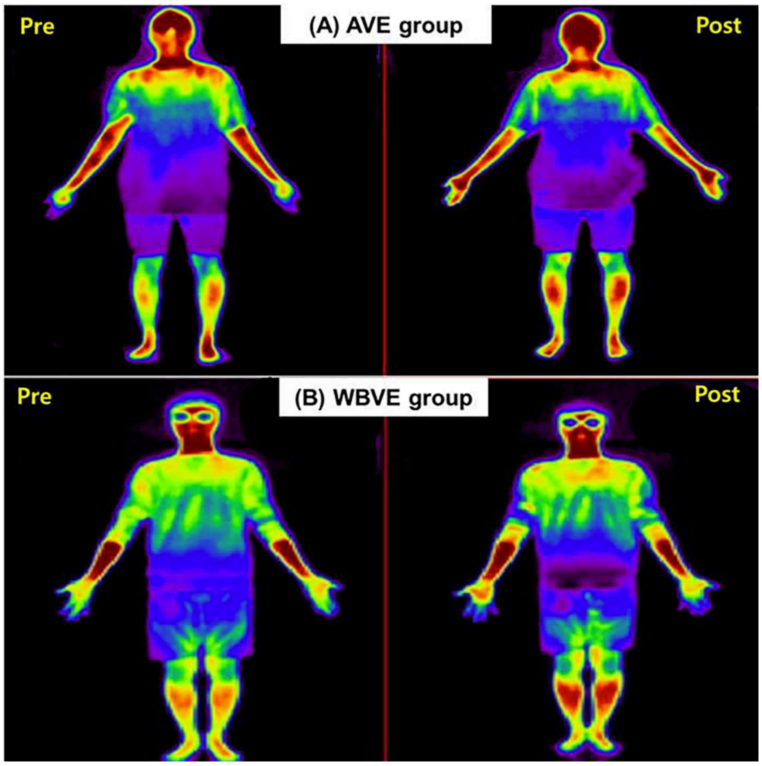

Figure 4. Comparison of digital infrared thermal imaging (DITI) between AVE and WBVE groups. Thermal images illustrate the changes in peripheral skin temperature before and after the 2-week intervention. (A) AVE group showing numerical temperature increase in the upper and lower extremities. (B) WBVE group showing moderate numerical increases. The color scale on the right represents the temperature range from 14.5°C (black) to 40.0°C (red).

and WBVE groups ($P > 0.05$). Regions of Interest (ROIs) for these measurements were defined as the anterior mid-forearm and anterior mid-patella (Figure 4).

Discussion

This pilot study compared the preliminary effects of AVE and WBVE on deep trunk muscle activation and dynamic postural stability. A key finding of this pilot study is the differential response of the internal oblique (IO) muscle between groups. Although the 2-week intervention was insufficient to produce statistically significant within-group adaptations given the limited sample size ($P > 0.05$), the comparison of change scores highlighted a significant advantage for the AVE group in terms of left IO activation ($p=0.032$). This suggests that the multi-planar dynamic demands of AVE may be a more potent stimulus for IO recruitment than the static WBVE posture, even if those changes have yet to reach a threshold of within-group significance in a small pilot cohort.

This discrepancy can be explained by the biomechanical nature of the "static squat" posture used in the WBV protocol. For instance, Marín and Hazell[30] reported that introducing instability or dynamic demands during whole-body vibration significantly increases the electromyographic (EMG) activity of trunk muscles compared to static conditions on a stable platform.

In our study, the static squat primarily demands sagittal plane stability, which predominantly engages the posterior chain muscles like the multifidus (MF) to counteract the flexion moment. In contrast, the internal oblique (IO) functions as a key stabilizer for rotational and multi-planar movements. The AVE protocol, which involves rhythmic swinging of the upper extremities, necessitates continuous neuromuscular control to stabilize the trunk against the oscillating forces, thereby promoting greater recruitment of the IO. Conversely, in the static WBV condition, the lack of voluntary dynamic perturbation likely resulted in a reduced demand for co-contraction of the abdominal obliques, potentially leading to the observed decrease in IO activity as the participants adapted to the static posture over time. This aligns with previous findings by Abercromby et al., which demonstrated that active vibration protocols elicit superior neuromuscular responses by integrating voluntary motor task demands, whereas passive static exposure may lead to habituation or suboptimal recruitment of core stabilizers[31].

Regarding balance and functional performance, both groups demonstrated numerical improvements in the Star Excursion Balance Test (SEBT) and flexibility following the 2-week intervention. Although the WBVE group exhibited slightly larger absolute increases in reach distances compared to the AVE group, these changes did not reach statistical significance within or between groups. These findings align with previous research by Cloak et al.[32], who reported balance improvements following vibration training. While their study utilized a 6-week intervention, our results suggest that even a short-term, 2-week protocol may initiate early neuromuscular adaptations. Such improvements, as supported by Cardinale and Bosco[33], are likely driven by enhanced proprioceptive feedback and the tonic vibration reflex (TVR) rather than structural muscle changes, which typically require longer training periods. However, since this pilot study did not directly measure neural adaptation or motor unit synchronization, the underlying mechanisms remain speculative. These results should be viewed as exploratory, hypothesis-generating signals. Further research with a larger sample size is required to determine whether these numerical trends translate into statistically significant advantages for either active or passive vibration protocols.

Regarding peripheral functional measures, grip strength did not show significant changes in either group after the two-week intervention. This lack of significance, which contrasts with some previous studies, likely stems from two main factors. First, structural adaptations for muscle hypertrophy and strength typically require a longer training period, usually exceeding six to eight weeks. Second, our specific WBVE protocol involved a static squat without holding a vibrating bar, limiting direct mechanical stimulation to the distal upper extremities. This aligns with previous literature suggesting that the effect of vibration on distal strength highly depends on the specific posture, duration, and direct point of contact[14,31]. Consequently, the observed thermal changes in the upper limbs are more likely reflective of autonomic or microvascular responses rather than direct muscular hypertrophy.

In contrast, numerical increases in skin temperature measured via DITI were observed across both groups, although these changes did not reach statistical significance. Vibration-induced shear stress on vascular endothelial cells promotes the release of nitric oxide, leading to vasodilation. The rhythmic oscillating movements in AVE may further assist this process through the skeletal muscle pump effect, potentially offering a more efficient way to improve circulation.

In the present study, passive whole-body vibration at 20 Hz was compared with active vibration exercise using Smovey. Although both interventions share the common feature of vibratory stimulation, they differ substantially in terms of stimulus transmission and motor control requirements. Whole-body vibration predominantly delivers global sensory input via the lower limbs and mainly facilitates static postural control. In contrast, Smovey-based exercise involves rhythmic, voluntary movement of the upper extremities while simultaneously demanding trunk stabilization and anticipatory postural adjustments, which may more directly influence trunk muscle activation and balance control strategies. Furthermore, high-frequency focal vibration has been shown to effectively activate muscle spindle Ia afferents and modulate proprioceptive input, providing a physiological basis for the observed changes in trunk electromyographic activity and balance performance during active vibration exercise. Accordingly, the between-group differences identified in this study should be interpreted not merely as differences in the application of vibration *per se*, but as the result of distinct vibration frequency characteristics, sites of application, levels of voluntary motor engagement, and task-specific neuromotor demands[34-37].

This study is significant for providing a quantitative evaluation of AVE using sEMG, SEBT, and DITI, filling a research gap for this specific modality. However, the small sample size (N=10) and short duration limit the generalizability of the findings. Future studies with larger cohorts and longitudinal designs are warranted to establish optimized AVE protocols. Nevertheless, as noted by Abercromby et al.[31], vibration remains a widely utilized modality for enhancing neuromuscular performance in modern rehabilitation.

Several limitations of this pilot study must be acknowledged. First, the small sample size (N=10) and short 2-week duration limited the statistical power and generalizability of the findings. Due to this small-scale nature, adjusting for covariates through advanced statistical modeling was not methodologically justifiable; therefore, the results should be interpreted as preliminary and exploratory. Second, despite randomized allocation, notable baseline imbalances existed between the groups regarding sex distribution, height, and weight. Specifically, the WBVE group included more male participants and exhibited higher mean height and weight. These anthropometric differences represent potential confounding factors; variations in body mass and stature can affect mechanical vibration transmission, while sex-specific differences in muscle composition and fat thickness may influence sEMG and thermal distribution patterns. Furthermore, for the SEBT, reach distances were analyzed as absolute values (cm) rather than being normalized to lower limb length, which, combined with the height differences, may have affected direct comparability. Third, certain methodological deficiencies were present, including the lack of public trial registration and the omission of blinding for participants and therapists, which may have introduced performance or reporting biases. Additionally, analyzing multiple endpoints without statistical correction for multiplicity increases the risk of false-positive results. Future large-scale, fully powered randomized controlled trials are required to validate these findings by ensuring balanced baseline characteristics, employing normalized outcome measures, and adhering to rigorous clinical trial registration and blinding protocols.

Conclusion

In conclusion, this pilot study provides preliminary feasibility data regarding the use of Active Vibration Exercise (AVE) for deep trunk muscle recruitment. While the integration of dynamic movement with vibration in AVE demonstrated a trend toward greater changes in left internal oblique activation compared to static WBVE, the very small sample size and short intervention period limit any claims of clinical efficacy. These descriptive findings are primarily hypothesis-generating. Fully powered, large-scale randomized controlled trials are required to establish the true therapeutic value and underlying mechanisms of AVE for core stabilization.

Ethics Approval

The Institutional Review Board of Konyang University approved the protocol for this prospective randomized controlled trial (Approval No.: 2025-05-023-001). The study was conducted according to the Declaration of Helsinki 1964 and its later amendments.

Consent to Participate

Written informed consent was obtained from all participants.

Authors' Contributions

HL (Hyunju Lee): Conceptualization, Original draft preparation; JK (Jaehwan Kim): Methodology, Data curation, Formal analysis; HK (Hyelim Kwak) & HL (Hyunah Lee): Investigation, Validation; ME (Minyong Eom): Resources, Software; KT (Kisik Tae): Supervision, Writing - Review & Editing. All authors have read and approved the final version of the manuscript.

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