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Impact of Whole-Body Vibration Combined with Heat Therapy on Muscle Strength, Flexibility, and Balance in Older Adults

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Abstract

Whole-body vibration (WBV) represents an innovative training approach that enhances muscular power, range of motion, and postural control in older adults. The practicality and effectiveness of thermotherapy sessions lasting 20–30 minutes—achieved by wrapping a 73 °C heat source in several towel layers to reduce skin contact temperature to 40–43 °C—are increasingly supported by practical uses and research evidence. Research indicates that such thermal applications improve the extensibility of tendons and ligaments. Yet, research has not explored the combined effects of applying heat before and after exercise over an extended training period. Accordingly, this research examines how WBV combined with thermal treatment influences muscular power, range of motion, and postural control in older populations. A total of 80 middle-aged and older adults lacking consistent physical activity routines participated. They were allocated randomly into four categories: a WBV-only category, a combined WBV and thermotherapy category, a thermotherapy-only category, and a non-intervention category. Those in WBV categories completed 5-minute sessions with a consistent amplitude of 4 mm, three times per week for three months using a vibration platform. Postural control was assessed via the limits of stability (LOS) evaluation on a specialized balance platform. Knee extension and flexion power before and after the intervention were evaluated with an isokinetic dynamometer for lower limbs. Range of motion variations pre- and post-intervention were determined through the sit-and-reach assessment. The WBV and combined WBV-thermotherapy categories exhibited markedly greater pre- to post-intervention gains in range of motion and muscular power. Integrating thermotherapy with WBV yielded the most substantial gains in range of motion.

Keywords: Whole-body vibration, Heating pad, Middle-aged and older individuals, Balance training, Flexibility training

Introduction

According to the Population Reference Bureau (PRB), people aged over 65 constituted 8% of the global population of 7.06 billion in 2012, with 35% residing in affluent countries. In nations such as Japan, Monaco, Germany, and Italy, one in four or five residents falls into this age group, highlighting aging as a global trend [1]. Modern societies feature extended lifespans. By 2050, the worldwide share of people aged over 60 is projected to double from present levels [2, 3]. Data from the American Centers for Disease Control and Prevention (CDC) in 2010 reveal that 30% of those over 65 experience at least one fall annually, rising above 50% for those over 80 [4].

Compromised postural control is a key contributor to fall risks. Age-linked declines in sensory processing, central integration, and neuromuscular pathways for power and movement coordination lead to diminished stability [5]. Extensive evidence confirms that physical activity improves functional capabilities in older adults. Numerous interventions for bettering postural control in this group target enhancements in muscular power, range of motion, endurance [6, 7], visual cue-based exercises [8], rhythmic aerobic activities [9], and stability ball workouts [10]. Nonetheless, research indicates that about half of adults over 60 remain sedentary [11]. Thus,

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motivating older individuals to engage in suitable and effective physical activities is essential. Certain investigations found no benefits from resistance exercises on postural control [12–14]. These inconsistencies might stem from key vibration parameters like frequency [15]. In contrast, Messier *et al*.'s (2000) extended research indicated that resistance exercises improve stability [16, 17]. Consequently, consistent and efficient training approaches are vital for advancing postural control in older adults [8, 18].

Whole-body vibration (WBV) training is an emerging technique involving a platform that produces ongoing oscillatory movements transferred from the lower limbs throughout the body, activating sensory receptors and inducing adaptive responses. Initial records of vibration showed it alleviating hypertonia in muscles [19]. Later 1990s research revealed vibration aiding elite athletes in building explosiveness and boosting athletic output [19]. Recent animal and human trials have evidenced WBV's advantages for bone mineralization and lower-limb circulation [20, 21]. Regarding neuromuscular outcomes, evidence demonstrates WBV boosting muscular power [22], range of motion [23], and athletic capabilities in both competitors and general populations [24]. WBV also serves as an efficient pre-activity warm-up and mitigates soreness from delayed muscle onset [25]. Multiple investigations have confirmed WBV's favorable impacts on postural control and overall function in older adults, while offering a secure and accessible training option [26]. It has been incorporated into rehabilitation for individuals with neurological conditions like stroke and multiple sclerosis [27, 28].

Thermal treatment is intimately linked to physical activity [29] owing to its impacts on tissue metabolism, vascular flow, neuromuscular activity, and connective tissue properties [30]. Application of heat elevates metabolic activity, promotes vessel dilation and perfusion, relaxes muscles, and enhances tissue pliability, aiding recovery and alleviating discomfort by raising pain tolerance [31, 32]. Evidence supports heat inducing muscle growth [33] and elevating athletic output [34]. A recent investigation noted strong links between muscular temperature and effort capacity. Depending on contraction type and velocity, a 1 °C rise in muscle temperature can boost subsequent performance by 2% to 5% [35]. Additionally, alterations in muscle temperature correlate positively with movement speed [35]. Currently, most heat-related research emphasizes muscular power and intense activities. Limited work addresses its influence on endurance in older adults [35]. Furthermore, there is scant evidence on prolonged WBV paired with thermal treatment in middle-aged and older populations. This investigation thus aimed to explore the impacts of WBV and heating pads on muscular power, postural control, and range of motion in older adults. Findings may inform future explorations of synergies between WBV and thermal applications.

Materials and Methods

The present investigation utilized a single-blind randomized controlled trial approach to ensure that assessors remained unaware of whether participants were in an intervention or control arm. Ethical approval was granted by the institutional review board of the hospital (Ministry of Health and Welfare Tsaotun Psychiatric Center IRB104056), and the trial was registered clinically (Registration Number ChiCTR-IOR-16008059). Prior to participation, all individuals received comprehensive information about the study procedures and provided written informed consent.

A total of 80 middle-aged and older adults were recruited for this research. Inclusion requirements included: (1) Age exceeding 45 years, with no consistent physical activity routines or prior formal exercise guidance. Based on the most recent Taiwan Social Change Survey (TSCS), individuals reporting exercise frequency of “several times a week” or “daily” were not included, as this indicated established habits [36]. (2) Capability to maintain independent standing without support. Exclusion requirements comprised: (1) Use of medications affecting musculoskeletal metabolism; (2) Recent bone fractures or surgical procedures within the preceding three months; (3) Prior episodes of vertigo.

Intervention protocols: Qualifying subjects were allocated randomly to three intervention arms and one control arm. The vibration device employed was a professional whole-body vibration platform (LV-1000, X-trend, Taiwan). Random assignment resulted in a WBV-only arm (20 Hz, n = 20), a combined WBV and thermotherapy arm (20 Hz + heat, n = 22), a thermotherapy-only arm (n = 21), and a non-intervention control arm (n = 17). Vibration was delivered via consistent sinusoidal oscillations (amplitude: 0–4 mm). Sessions involved five minutes of standing in a relaxed, natural stance. Individuals assigned to WBV performed sessions on the platform three times per week over three successive months **(Figure 1)**. For those receiving thermotherapy, a post-vibration session was incorporated, involving 20-minute placement of the posterior lower limbs (hamstrings and gastrocnemius muscles) on a circulating-water heating pad set to 40 °C (CW89 WiPOS, Taiwan) **(Figure 2)** [37, 38]. The control arm participated solely in assessment procedures and monitoring of physical activity patterns.

Figure 1. A participant standing on the WBV machine.

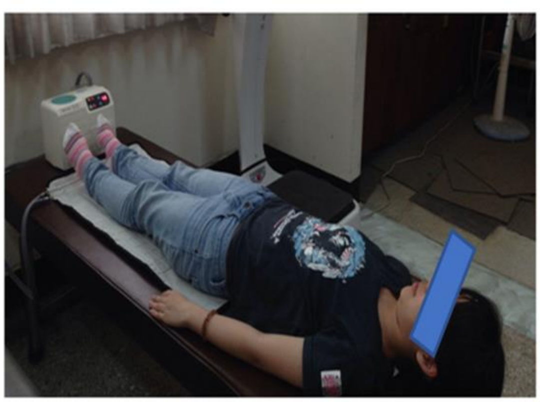

Figure 2. A heating pad warming a participant's lower extremities.

Outcome Measures: Prior to the formal assessments, participants completed two practice trials (each lasting 10 seconds) for familiarization. Evaluations were conducted at three time points: before WBV training, immediately after the 3-month WBV intervention, and at a 6-month follow-up after WBV completion. These assessments covered balance abilities, muscle strength, and the incidence of falls over the subsequent year for all participants.

Balance abilities were evaluated using the Limits of Stability (LOS) test on a computerized balance platform (Biodex Balance System, Shirley, NY, USA). The LOS test primarily assesses an individual's capacity to shift their center of gravity while maintaining stability within their base of support. During the test, participants were directed to move their center of gravity toward randomly indicated targets displayed on the screen and then return to the neutral starting position. This measure reflects the ability to voluntarily control center-of-gravity movements in multiple directions.

Data Processing: Before testing, each participant's age, height, and stability level were entered into the system. Results were reported as percentages, calculated from the ratio of actual center-of-pressure displacement to the theoretical maximum distance to the target: (actual distance to target / theoretical distance to target) × 100%. The system has established reliability, with intraclass correlation coefficients ranging from 0.60 to 0.95 [39, 40].

Muscle strength was assessed with an isokinetic dynamometer for the lower extremities (Biodex System IV Pro, Shirley, NY, USA). Pre- and post-intervention measurements included knee extensor and flexor strength, testing both concentric and eccentric isokinetic contractions at an angular velocity of 60°/s.

Following a warm-up, participants were seated on the dynamometer with their trunk, pelvis, right thigh, and ankles securely strapped to minimize compensatory movements. Seat and dynamometer positions were adjusted so that the axis of rotation aligned with the lateral malleolus of the tibia at the knee joint. Gravity correction for the lower leg was applied prior to testing. Concentric contractions at 60°/s were performed, with each participant completing three repetitions separated by 1-minute rest periods.

Flexibility was determined using the sit-and-reach test, which evaluates the range of motion in the lower back and posterior lower-limb musculature. Participants sat barefoot on the floor or mat with legs extended, knees straight, feet shoulder-width apart, and toes pointed upward. A measuring tape was positioned between the legs, with the 25-cm mark aligned at the heels. With palms facing downward and middle fingers overlapped, participants reached forward along the tape and held the farthest position for two seconds. The distance (in cm) was recorded; the first attempt served as practice, and the best of the subsequent two trials was used as the final score [41].

Fall incidence over the past year was determined via telephone interviews and written questionnaires inquiring about any medical treatment received for falls.

Participant demographic data and outcome variables were summarized using descriptive statistics. Group differences at baseline were examined with chi-squared tests and one-way ANOVA. Changes over time in LOS, muscle strength, and flexibility were analyzed using repeated-measures ANOVA. All statistical analyses were conducted with SPSS version 14.0, with significance set at $\alpha = 0.05$. Significant interactions or main effects were followed by post-hoc comparisons using the Scheffé test.

Results and Discussion

As illustrated in **Figure 3**, the study included 80 middle-aged and older adults. Participants were randomly allocated to four groups: a whole-body vibration training group (20 Hz, n = 20), a combined whole-body vibration and heat therapy group (20 Hz + heat, n = 22), a heat therapy-only group (n = 21), and a control group (n = 17).

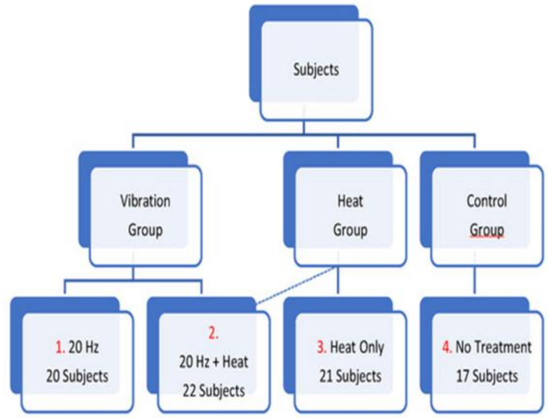

Figure 3. Allocation of participants to groups.

As presented in **Table 1**, baseline characteristics of the participants—including age, height, weight, body mass index (BMI), flexibility, muscle strength, and balance abilities—showed no statistically significant differences across groups ($p > 0.05$).

Table 1. ANOVA results.

		Sum of Squares	df	Mean Square	F	Significance
Age	Between groups	31.015	3	10.338	0.110	0.954
	Within groups	7110.872	76	93.564		
	Total	7141.888	79			
Height	Between groups	162.125	3	54.042	0.956	0.418
	Within groups	4294.074	76	56.501		
	Total	4456.199	79			
Weight	Between groups	79.823	3	26.608	0.249	0.862
	Within groups	8108.659	76	106.693		
	Total	8188.482	79			
BMI	Between groups	1.356	3	0.452	0.044	0.988
	Within groups	777.319	76	10.228		
	Total	778.676	79			
Pre-test flexibility	Between groups	52.464	3	17.488	0.299	0.826
	Within groups	4446.933	76	58.512		
	Total	4499.397	79			
Pre-test muscle strength	Between groups	3146.558	3	1048.853	1.079	0.363
	Within groups	73,854.242	76	971.766		
	Total	77,000.800	79			
Pre-test LOS	Between groups	734.882	3	244.961	1.509	0.219

	Within groups	12,334.606	76	162.297	
	Total	13,069.488	79		

Regarding flexibility, notable pre- to post-intervention differences were found in both the WBV group and the WBV combined with heat therapy group. The extent of improvement in the combined group was significantly greater than that observed in the other 3 groups after 3 months (p = 0.007) **(Figure 4 and Table 2)**.

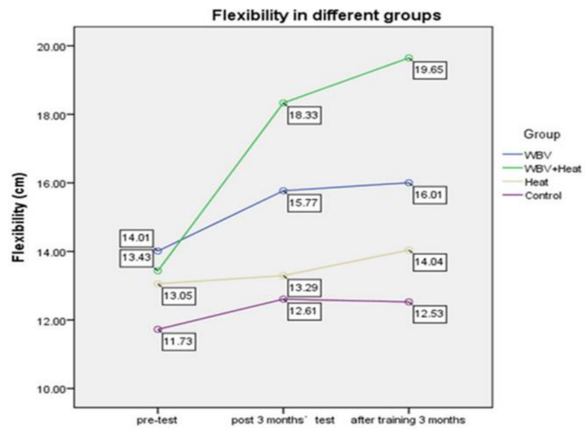

Figure 4. Flexibility outcomes across groups at the six-month mark.

Table 2. Comparison of the training effect on flexibility in six months.

Group	1. before Training	2. after Training for 3 Months	3. after Training for 6 Months	Time 1 vs. 2 p; Time 1 vs. 3 p
WBV	14.0 ± 8.92	15.7 ± 8.81	16.0 ± 8.74	0.024 *; 0.015 *
WBV + Heat	13.4 ± 7.08	18.3 ± 6.84	19.6 ± 10.11	0.000 *; 0.001 *
Heat	12.0 ± 6.89	13.2 ± 5.70	14.0 ± 6.28	0.877; 0.536
Control	11.7 ± 7.36	12.6 ± 8.21	12.5 ± 7.25	0.398; 0.389
WBV + Heat	13.4 ± 7.08	18.3 ± 6.84	19.6 ± 10.11	0.000 *; 0.001 *

A significant effect of time on flexibility performance was observed (p = 0.000) as well as an interaction between groups and time (p = 0.009). In the posthoc comparison, the WBV + Heat group was significantly better than the control group (p = 0.046). * p < 0.05; the values are given as mean (95% confidence interval).

Regarding muscle strength, the heat therapy-only group and the control group exhibited no notable pre- to post-intervention changes. In contrast, significant enhancements in muscle strength were evident in both the WBV group and the WBV combined with heat therapy group. The magnitude of improvement in the combined group was markedly greater than that seen in the remaining 3 groups **(Figure 5 and Table 3)**.

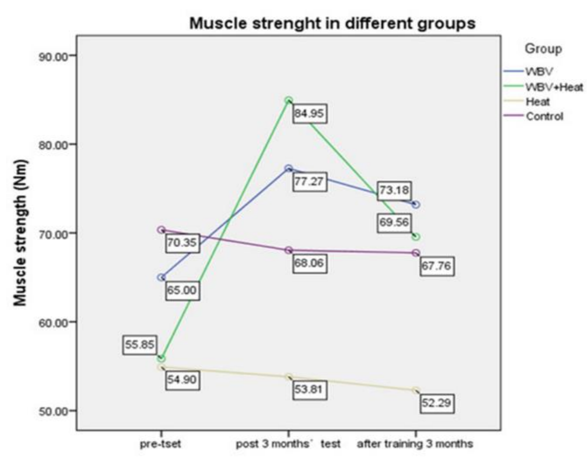

Figure 5. Muscle strength outcomes across groups at the six-month follow-up.

Table 3. Comparison of the training effect on muscle strength in six months.

Group	1. before Training	2. after Training for 3 Months	3. after Training for 6 Months	Time 1 vs. 2 p; Time 1 vs. 3 p
WBV	65.0 ± 28.93	77.2 ± 37.24	73.1 ± 35.75	0.013 *; 0.066
WBV + Heat	55.8 ± 32.30	84.9 ± 36.22	69.5 ± 35.13	0.000 *; 0.000 *
Heat	54.9 ± 32.02	53.8 ± 34.14	52.2 ± 31.72	0.723; 0.456
Control	70.3 ± 31.55	68.0 ± 31.45	67.7 ± 32.26	0.510; 0.463

The factor of time had a significant effect on muscle strength ($p = 0.000$) and there was also an interaction between different groups and time ($p = 0.000$). * $p < 0.05$; the values are given as mean (95% confidence interval).

Regarding balance abilities, the heat therapy-only group and the control group showed no significant pre- to post-intervention changes. In contrast, significant enhancements in balance abilities were found in both the WBV group and the WBV combined with heat therapy group **(Figure 6 and Table 4)**.

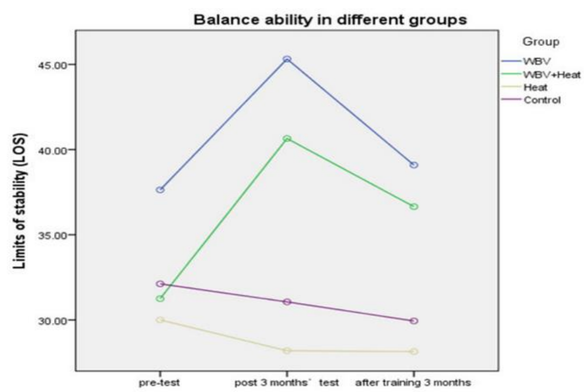

Figure 6. Six-month balance outcomes across different groups

Table 4. Comparison of the training effect on balance performance in six months.

Group	1. before Training	2. after Training for 3 Months	3. after Training for 6 Months	Time 1 vs. 2 p; Time 1 vs 3. p
WBV	37.6 ± 11.24	45.3 ± 13.98	39.0 ± 12.63	0.010 *; 0.068
WBV + Heat	31.2 ± 11.87	40.6 ± 13.96	36.6 ± 15.06	0.011 *; 0.193
Heat	30.0 ± 15.80	28.1 ± 11.76	28.1 ± 11.32	0.480; 0.480
Control	32.1 ± 9.77	31.0 ± 16.84	29.9 ± 13.96	0.715; 0.715

In balance performance, time had a significant effect on equilibrium ($p = 0.016$), and there was also an interaction between different groups and time ($p = 0.009$). * $p < 0.05$; the values are given as mean (95% confidence interval).

The results indicated notable pretest-to-posttest improvements in flexibility for participants in both the WBV and WBV combined with heat therapy groups, suggesting that these interventions enhanced flexibility, muscle strength, and functional balance. One proposed mechanism is that vibration training may enhance γ-aminobutyric acid neurotransmission and muscle spindle responsiveness, thereby activating additional motor neurons [42]. Participants receiving WBV plus heat therapy showed greater improvements than the other groups, aligning with findings from prior research. Specifically, gains in flexibility and muscle strength were more pronounced in the WBV plus heat therapy group, and these improvements persisted only in this combined intervention group. Previous studies have also suggested that low-intensity resistance exercise paired with heat stress can increase muscle strength and hypertrophy, potentially due to heat-induced expression of heat shock proteins, which augment mechanically induced muscle growth [29]. WBV alone has been shown to elevate intramuscular temperature and provide a warming effect [23], while also improving flexibility [43]. The superior gains observed in the WBV plus heat therapy group may be partly explained by the use of heat therapy as a preparatory strategy prior to exercise [44], which enhances tissue metabolism and primes muscle activity [45], promotes glycogenesis, and supports muscle recovery [45]. Additionally, heat application has been reported to reduce tissue damage by increasing tissue pliability and decreasing the energy cost of muscle contractions through lower internal friction [46].

Conversely, participants in the heat therapy-only and control groups did not show significant gains in muscle strength, which contrasts with some prior studies [33] and may reflect differences in participant age [47]. Nonetheless, other research has noted that active warming protocols induce greater metabolic responses than passive heating, improving readiness for subsequent exercise [35]. Both WBV and WBV plus heat therapy interventions led to significant muscle strength enhancements, consistent with earlier reports that WBV at 41 °C for 60 minutes can boost muscle power [48–50]. As in previous studies, the combined WBV and heat therapy group achieved the highest improvements, potentially due to heat shock protein activation, which supports resistance training adaptations [51]. Elevated temperatures accelerate glycogen breakdown within muscles, and the passive increase of intramuscular temperature can enhance ATP turnover by increasing creatine phosphate (PCr) utilization and stimulating anaerobic glycolysis [52]. The effectiveness of pre-exercise heating may also reflect differences in muscle and ligament temperatures relative to core temperature, with peripheral tissues often being cooler than the core (~37 °C) and skin (~31 °C) [53–55]. Thus, warming these regions is critical for optimal exercise performance [56].

Regarding balance, the heat therapy-only and control groups did not show significant improvements over the six-month period. Prior studies have demonstrated that cessation of training for three to eight weeks leads to a decline in arterial oxygen extraction, mitochondrial ATP production, and VO2max, though short-term training adaptations in non-athletes tend to return to baseline after inactivity [57]. In contrast, WBV and WBV plus heat therapy interventions significantly enhanced balance, corroborating findings that increases in muscle strength support postural control [50, 57]. WBV has been reported to improve joint range of motion and sensitivity, contributing to dynamic stability [57]. However, after six months, balance improvements were no longer significant in these groups, highlighting the importance of ongoing exercise to maintain functional gains [58]. Future research could include participants from broader age ranges or athletes from various sports to further evaluate WBV effects.

This study represents one of the first to investigate the combined impact of WBV and heat therapy, demonstrating that the addition of heat can amplify exercise outcomes. A limitation is the difficulty in sustaining consistent participation among previously inactive individuals, resulting in a relatively small sample size.

Conclusion

The findings indicate that WBV training, particularly when supplemented with heat therapy, effectively enhances muscle strength and flexibility. Incorporating heat treatment, such as a hot compress, may further improve flexibility outcomes. WBV with heat therapy can therefore be recommended as a strategy to optimize these physical parameters. To maintain long-term benefits, continued exercise is advised to preserve gains in muscle strength and functional performance.

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Ethics Statement: None

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