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Original Article

Effects of Static vs. Dynamic Whole-Body Vibration Training on Neuromuscular Activation, Activities of Daily Living, and Functional Movement in Older Sedentary Adults: A Preliminary Study

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Abstract

Objectives: This preliminary study compared static vs. dynamic whole-body vibration (WBV) on neuromuscular activation, activities of daily living (ADLs), and functional movement in sedentary older adults. **Methods**: Ten adults completed a six-week static or dynamic WBV intervention three times per week. Electromyography (EMG), ADLs, and functional movements including sit-to-stand (STS), timed-up-and-go (TUG), STEPs, functional reach (FR), and a Functional Movement Screen (FMS) composite score were recorded at PRE and POST intervention. EMG was recorded from the vastus lateralis (VL) and biceps femoris (BF) and analyzed for root-mean-square (RMS) and mean power frequency (MPF). The hamstring:quadriceps (H:Q) ratio was calculated using RMS as BF/VL. **Results**: RMS: VL and MPF: VL were significantly greater at POST compared to PRE ($p < 0.05$), while the H:Q ratio was lower at POST ($p < 0.001$). Significant improvements were observed in STS, STEPs, TUG, FR, and FMS composite score ($p < 0.05$). No differences were observed between interventions. **Conclusion**: Improvements in RMS and MPF of the VL, ADLs, and functional movement were observed following six weeks of static and dynamic WBV. These preliminary findings suggest that WBV may elicit positive adaptations, providing a low-impact alternative for older adults unable to perform traditional exercise.

Keywords: Activities of Daily Living, Electromyography, Functional Movement Screen, Mean Power Frequency, Root Mean Square

Introduction

Age-related declines in neuromuscular activation, which can be assessed via electromyography (EMG), are associated with decreased functional ability and deficits in performing activities of daily living (ADLs)[1]. Root mean square (RMS), an index of EMG amplitude and neuromuscular activation, and mean power frequency (MPF), a frequency-domain EMG measure reflecting nerve conduction-related properties, can serve as indirect estimators of motor unit recruitment (MUR) and muscle fiber conduction velocity (MFCV), respectively[2], which have been identified as major contributors to reduced ADL performance, increased fall risk, and functional decline in older adults[3]. Neuromuscular activation of the quadriceps and hamstrings is particularly important for ADLs, including rising from a chair, climbing stairs, and maintaining balance, and may predict functional ability[3–5]. Specifically, previous research indicates that greater MUR of the vastus lateralis (VL) during closed-kinetic-chain (CKC) movements is associated with better performance in ADLs such as sit-to-stand (STS) and stair climbing[6], whereas increased MUR of the biceps femoris (BF), relative to the VL during CKCs, resulting in a higher hamstring: quadriceps (H:Q) ratio, has been linked to reduced functional performance[7,8]. Importantly, neuromuscular activation of the quadriceps declines more

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rapidly with age compared to the hamstrings and is related to reduced functional independence[9]. Additionally, the rate of force development (RFD) of the quadriceps declines at a faster rate than muscular strength, with previous research suggesting that the ability to activate the quadriceps rapidly, indirectly reflected in part by higher MPF and associated increases in MFCV[10], is a significant determinant of functional ability and is linked to superior ADL performance, particularly in tasks requiring rapid movements, such as rising from a chair[5].

Age-related declines in physical activity (PA) are closely associated with impaired neuromuscular activation, including reductions in MUR and MFCV, as well as decreased performance in ADLs, all of which contribute to an increased risk of functional limitations and falls in sedentary older adults[1]. Furthermore, previous research demonstrates that these age-related declines in functional ability, ADL performance, and neuromuscular activation may be preventable or delayed through properly prescribed exercise interventions[2,3]. Despite these findings, total daily PA declines rapidly with increasing age[1] as physical limitations, such as decreased mobility, joint pain, reduced range of motion (ROM), and fear of falling, may prevent older adults from participating in traditional resistance training exercises.

Whole-body vibration (WBV) training, which promotes involuntary muscle contractions via reflex activation of muscle spindles[11], has emerged as a promising alternative or supplemental exercise modality that may improve neuromuscular activation, functional ability, and ADL performance[11]. WBV can be performed dynamically, involving lower-limb CKC exercises, or statically, with no lower-limb joint movement. While prior studies have demonstrated improvements in indirect neuromuscular performance measures, such as strength, power, and force production following dynamic WBV training programs[12,13], as well as increases in neuromuscular activation of the VL when measured during a single dynamic WBV session[14], to our knowledge, little to no prior research has examined the effects of longer-term dynamic WBV training programs on neuromuscular activation via RMS specifically. Prior literature examining the effects of static WBV training programs on RMS is also limited. However, Lienhard et al[15] examined the effects of a single bout of static WBV on lower-limb muscle activity in young and older adults and concluded that older adults may benefit more from acute static WBV exposure than their younger counterparts[15]. Similarly, Mikhael et al[16] observed significant gains in lower-leg strength in older adults who stood with their knees locked during WBV, suggesting that knee-flexed postures may not be necessary to elicit positive adaptations in older adults[16]. More research is needed to investigate the long-term effects of static WBV training interventions on neuromuscular activation via RMS in older adults and to compare the effectiveness to dynamic WBV training programs. In addition, although previous research has demonstrated either increased[17] or decreased[18] MFCV during acute dynamic WBV exposure, to our knowledge, no prior studies have investigated the effects of static or dynamic WBV training programs on EMG MPF or MFCV in older adults.

In addition to neuromuscular improvements, WBV training has been proposed as a safe and effective intervention to improve functional movement in older adults. Previous studies have observed improvements in functional outcomes, such as balance and timed-up-and-go (TUG), following six weeks of static WBV[19], while others have reported improvements in stability and STS performance following eight weeks of dynamic WBV[20]. While limited research has compared the effectiveness of dynamic vs. static WBV, Rees et al[21] found that only dynamic WBV improved functional performance after an 8-week intervention, with no improvements observed following static WBV in adults aged 65 and older[21]. Despite these conflicting results, WBV may be an effective modality for reducing fall risk and maintaining independence in older adults, and more research is needed to compare the effects of dynamic and static WBV on functional performance and ADLs[22].

As many older adults face mobility restrictions, joint pain, and fear of falling that may limit their ability to safely engage in traditional strength training with free weights or machines, the effects of static vs. dynamic WBV training on neuromuscular and functional outcomes are of interest. To our knowledge, little to no research has compared the effects of static vs. dynamic WBV training on EMG measures such as RMS and MPF, and only limited research has compared the effects of these modalities on functional performance and ADLs in older adults. Additionally, no prior research has investigated changes in the H:Q ratio and its relationship to functional and ADL performance following dynamic vs. static WBV in older adults. Therefore, the primary purpose of this study was to examine the effects of static vs. dynamic WBV on RMS and MPF of the VL and BF, functional ability, and ADLs. A second purpose of the study was to examine the effects of static vs. dynamic WBV on the H:Q ratio and its relationship to functional ability and ADL performance.

Materials and Methods

Participants

Ten community-dwelling adults aged 55 or older volunteered for this preliminary matched-pair randomized two-arm pretest-posttest intervention study comparing static and dynamic WBV. To control for the potential confounding effects of age, participants volunteered and were sequentially assigned to five matched pairs based on chronological age. Within each matched pair, participants were then randomly allocated via a coin flip to either the static WBV group (n = 5; 2 male, 3 female; 65.2 + 2.1yrs) or the dynamic WBV group (n = 5; 3 male, 2 female; 67.5 + 3.4yrs). The present study did not include a non-WBV

Table 1. Whole-Body Vibration (WBV) Protocol.

Week	Frequency	Bout Duration	# of Bouts	Total Vibration Time	Total WBV Session Time
1 - 2	30 Hz	45 sec.	10	7.5 min	17.5 min
3 - 4	35 Hz	60 sec.	10	10 min	20 min
5 - 6	40 Hz	90 sec.	10	15 min	25 min

control group. Exclusion criteria, determined by a medical history questionnaire, included lower-limb fractures and joint replacements within the past year, musculoskeletal injuries limiting exercise, neurological disorders, cardiovascular conditions or uncontrolled hypertension, severe cognitive impairment, or other contraindications to WBV. Participants were included only if they were considered sedentary according to the American College of Sports Medicine (ACSM)[23] and were instructed to refrain from initiating any new exercise programs throughout the study. Each participant provided informed consent prior to participating in this study, and the Institutional Review Board at Ripon College approved the research protocol in accordance with the ethical standards set by the Declaration of Helsinki.

Protocol

Participants reported to the Exercise Science Laboratory for their initial session, during which baseline (PRE) assessments were completed, including maximal voluntary isometric contractions (MVICs), CKCs, ADLs, and functional assessments. Following baseline testing, participants were allocated to a six-week static or dynamic WBV intervention consisting of three supervised sessions per week. MVICs, CKCs, functional assessments, and ADLs were evaluated again after the six-week intervention (POST).

Intervention

All participants attended three supervised training sessions per week over a six-week period, consistent with previous literature demonstrating measurable improvements in functional outcomes following WBV training[24,25]. The WBV intervention was delivered using a Power Plate Pro5 vibration platform. Each session included a progressive WBV protocol (Table 1). Both groups followed the same 6-week progression for vibration frequency, bout duration, number of bouts, total vibration time, and total WBV session time (Table 1). Additionally, the amplitude was set at 4 mm and a protocol was in place to adjust the amplitude individually based on participant tolerance, as determined by a Borg RPE scale; if the participant reported >13 (somewhat hard) after a bout, the amplitude was reduced by 1mm for the remainder of that session[11,19]. No adverse events, discomfort, dizziness, musculoskeletal pain, or protocol intolerance were reported throughout the 6-week intervention. Additionally, no participants withdrew from the study, and all participants completed the 18 sessions within a six-week timeframe.

Static WBV Intervention: The static WBV group stood upright on the vibration platform with minimal knee flexion, maintaining minimal joint movement to isolate the passive mechanical effects of vibration[11,15,16]. The knee joint angle did not change throughout the WBV intervention.

Dynamic WBV Intervention: The dynamic WBV group performed lower-limb body-weight exercises during vibration exposure to elicit active muscular contractions. These exercises included narrow-leg squats at 45 degrees of knee flexion, wide-leg squats at 45 degrees of knee flexion, alternating front lunges at 45 degrees of knee flexion, and heel raises[21]. Participants completed two sets of 12 repetitions of each exercise during weeks 1-2, two sets of 15 repetitions during weeks 3-4, and two sets of 18 repetitions during weeks 5-6. All sets were performed when WBV was being applied. If the set was completed before the vibration bout ended, participants maintained a static standing position on the platform. Additionally, participants remained in a static standing position during the first and final vibration bouts of each session. No exercises were performed during the 1-minute rest intervals.

Pre- and Post-Testing

Participants reported to the Exercise Science Laboratory for PRE and POST testing. A standardized 10-minute treadmill warm-up at a self-selected pace preceded all pre- and post-testing procedures. Participants were instructed to refrain from strenuous exercise, alcohol, and caffeine for at least 24 hours before testing sessions to ensure measurement accuracy and reduce fatigue-related effects. Pre-test and post-test measures were administered by a single, unblinded assessor who underwent training for standardized testing procedures and scoring criteria to minimize inter- and intra-rater variability.

EMG: Surface EMG was recorded from the VL and BF from the dominant limb (MP160; Biopac System, Santa Barbara, CA, USA). To minimize skin impedance and enhance the signal-to-noise ratio, the skin area was shaved, abraded, and cleaned with an isopropyl alcohol pad before electrode placement. Bipolar surface EMG electrodes were placed according to SENIAM recommendations. Raw EMG recordings were sampled at 1,000Hz, and EMG signals were band-pass filtered between 10 and 500 Hz. EMG data were collected during MVICs and CKCs and analyzed for RMS and MPF.

MVICs: MVICs were performed on a leg extension or flexion machine, with the participant seated upright and the knee flexed to 60 degrees. Participants were asked to perform two 5-second MVICs against an immovable mass on the dominant limb for both leg extension and flexion, with a 3-minute rest between repetitions[26]. Participants were given verbal encouragement and instructed to produce maximal force as quickly as possible, maintain consistent force throughout the 5-second contraction, and then relax as quickly as possible. RMS and MPF for the VL and BF were determined for the five-second epoch[26].

CKCs: Participants performed two exercises on a stable surface: a forward lunge (FL) and a bilateral squat (BLSQ)[26], selected as functional CKC movements that closely replicate common ADLs and effectively elicit neuromuscular activation of the VL and BF. The FL was performed on the dominant limb, with the knee angle set at 60 degrees of flexion. Participants were instructed to keep their knees over their toes and to place as much weight as possible on their dominant leg. During the BLSQ, participants were asked to maintain balance on both limbs, with the knee joint angle set at 45 degrees of flexion. All testing procedures were explained to the participant before testing, and each participant was able to perform a trial movement to familiarize themselves with the movement and the desired joint angle. A digital goniometer (Baseline, Aurora, IL, USA) was used to determine the knee joint angle before and during the CKCs. Participants were instructed to hold the knee position for 15 seconds, with a 1-minute rest interval between exercises. RMS and MPF of the middle five seconds for each exercise were normalized to the MVICs. The average of the four trials, expressed as % MVIC, was used for the data analysis, and H:Q ratios were calculated using RMS as BF/VL[4,24,27,28].

ADLs: Participants completed two ADLs: STS and ascending and descending stairs (STEPs).

STS: Participants performed one 30-second STS evaluation on a standardized armless chair. On a verbal cue, participants performed as many STS repetitions as possible, beginning seated with their buttocks touching the chair and arms crossed over their chests, then moving to a fully standing position with arms still crossed over their chests. The number of fully completed STS repetitions was counted and recorded. A repetition counted if the buttocks fully touched the chair during the movement.

STEPS: Participants performed the Step Test Evaluation of Performance on Stairs (STEPS), which is a well-established instrument with documented reliability and validity in prior literature for evaluating stair performance in older adults[4,29]. The test was performed on a standard set of 8 stairs with one handrail. Participants were instructed to climb the stairs as they normally would, avoiding using the handrail if possible. Once participants reached the top of the stairs, they were instructed to turn around, face the steps, and come down as they normally would[4,29]. For safety, a research assistant remained beside the participant throughout each stair ascent and descent trial to provide stabilization or assistance in the event of a loss of balance. The STEPs evaluation tool consists of 8 items, each scored on a 0-1 or 1-2 scale during the ascent and descent phases, with a maximum possible score of 20[4,29].

Functional Assessments: Participants completed three functional assessments: FMS, TUG, and FR.

Lower-Body FMS Composite Score: While the FMS (Functional Movement Systems, Chatham, VA) consists of seven movements, only three lower-body movements were included for the purpose of this study, including the deep squat (DSQ), hurdle step (HS), and in-line lunge (IL)[4,30]. The same researcher scored all FMS tests. Participants were given two attempts to perform the movement as described by the researcher, and the lower of the two scores was used. For unilateral movements, including HS and IL, the lower of the right and left limb scores was recorded. From these results, a lower-body movement composite score was calculated by summing the DSQ, HS, and IL scores, consistent with prior literature that uses movement-based FMS subscores to assess lower-body mobility and stability[31]. The maximum possible movement composite score was 9. Each movement was scored from 0 to 3, with 0 indicating pain during the movement, 1 indicating inability to perform the movement, 2 indicating completion with compensation, and 3 indicating successful completion without compensation. The lower-body FMS composite score was used for data analysis.

TUG: Functional mobility and balance were assessed using the TUG test, which has demonstrated excellent reliability and validity for assessing functional ability and fall risk in older adults[32,33]. Participants stood up from a chair, walked 3m, turned, returned to the chair, and sat down. Time to complete the task was recorded in seconds, with shorter times indicating better performance.

Functional Reach (FR): The FR test was used as a reliable and valid measure of dynamic balance[34]. Participants stood upright and reached forward as far as possible without stepping, and the maximum reach distance (cm) was recorded; greater distances indicated better balance[34].

Statistical Analysis

Prior to data analysis, all data were assessed for normal distribution, homogeneity of variance, and sphericity. If the assumption of sphericity was violated, a Greenhouse-Geisser correction was applied. An a priori power analysis was conducted for a two-way repeated-measures ANOVA

Table 2. Average Root Mean Square (RMS) and Mean Power Frequency (MPF) of the Vastus Lateralis (VL) and Biceps Femoris (BF) during closed-kinetic-chain (CKC) movements at PRE and POST intervention.

Dependent Variable	Group	Sample size (n)	Pre-Test M (SD)	Post-Test M (SD)	Source of Variation	F	*p*	η^2
RMS:VL	Static	n = 5	60.92 (7.35)	65.11 (6.39)	Group (static vs. dynamic)	0.885	0.374	0.100
	Dynamic	n = 5	63.64 (6.42)	70.90 (5.17)	Time (pre vs. post)	21.322	0.002	0.727
	All Participants	n = 10	62.28 (6.66)	68.01 (8.05) *	Time x Group	1.536	0.250	0.161
MPF:VL	Static	n = 5	73.0 (8.76)	79.44 (6.76)	Group	1.034	0.339	0.114
	Dynamic	n = 5	69.06 (2.74)	75.71 (5.98)	Time	18.420	0.003	0.697
	All Participants	n = 10	71.03 (6.46)	77.58 (6.33) *	Time x Group	0.005	0.948	0.001
RMS:BF	Static	n = 5	48.31 (2.55)	46.31 (2.34)	Group	1.687	0.23	0.174
	Dynamic	n = 5	49.32 (3.13)	48.12 (3.10)	Time	1.306	0.286	0.140
	All Participants	n = 10	48.81 (2.74)	47.21 (2.76)	Time x Group	0.082	0.782	0.010
MPF:BF	Static	n = 5	83.38 (5.78)	84.06 (5.09)	Group	0.511	0.495	0.060
	Dynamic	n = 5	79.27 (5.97)	80.81 (6.68)	Time	1.576	0.245	0.165
	All Participants	n = 10	81.33 (7.98)	82.43 (8.06)	Time x Group	0.238	0.639	0.029
H:Q	Static	n = 5	0.789 (0.163)	0.694 (0.181)	Group	0.023	0.883	0.003
	Dynamic	n = 5	0.780 (0.131)	0.674 (0.156)	Time	12.015	0.008	0.600
	All Participants	n = 10	0.785 (0.140)	0.684 (0.159) *	Time x Group	0.034	0.858	0.004

*Data presented as mean ± SD. *Significant main effect of time.*

using G*Power 3.1. Based on a previous study[35] reporting a partial eta-squared of 0.327, an effect size of 0.697 was calculated. To achieve a power (1 - β) of 0.80, with two groups and two repeated measures and an α of 0.05, assuming a correlation among repeated measures of 0.5 and a non-sphericity correction of 1, a total sample size of 8 participants was required.

A series of independent-samples t-tests was conducted on all baseline data to determine differences between groups. Because no differences were observed in any of the PRE testing variables ($p > 0.05$), repeated measures mixed design ANOVAs (two-group; static and dynamic WBV, and two time-point; PRE and POST) were used to analyze differences in RMS and MPF of the VL and BF, H:Q ratio, FMS, FR, STS, TUG, and STEPs. Significant interactions were further analyzed using a two-time-point repeated-measures ANOVA, splitting the data file by group (static, dynamic). Significant main effects for time were further analyzed using post hoc pairwise comparisons with a Bonferroni correction.

Additionally, to quantify the magnitude of participant improvement, raw difference scores were calculated by subtracting pre-test scores from post-test scores. Pearson's product correlation (r = 0.4-0.59, moderate correlation; 0.6-0.79 = moderately high correlation; > 0.8 = high correlation) was subsequently used to determine associations between the magnitude of change in RMS, MPF, and H:Q, and performance on ADLs and functional assessments. An alpha level of $p < 0.05$ was used to determine statistical significance. All data are reported as mean ± SD. Effect size was reported as partial eta squared (η^2) and was interpreted as = ~0.01 small effect, ~0.06= moderate effect, and ≥ 0.14 = large effect. Data were analyzed using SPSS (SPSS v.31.0, IBM, Somers, NY).

Results

Root Mean Square

VL: No significant time x group interaction ($F(1,8) = 1.536$, $p = 0.250$, $\eta^2 = 0.161$) or main effect of group ($F(1,8) = 0.885$, $p = 0.374$, $\eta^2 = 0.100$) was observed for average RMS of the VL during the CKCs. A main effect of time ($F(1,8) = 21.322$, $p = 0.002$, $\eta^2 = 0.727$) was observed with significantly greater RMS of the VL at POST (68.01 ± 8.05) compared to PRE (62.28 ± 6.66) (Table 2).

BF: No significant time x group interaction ($F(1,8) = 0.082$, $p = 0.782$, $\eta^2 = 0.010$), main effect of group ($F(1,8) = 1.687$, $p = 0.230$, $\eta^2 = 0.174$), or main effect of time ($F(1,8) = 1.306$, $p = 0.286$, $\eta^2 = 0.140$) was observed for average RMS of the BF during CKCs (Table 2).

H:Q: No significant time x group interaction (F (1,8) =

Table 3. Activities of daily living (ADL) and functional performance measures, including Timed Up and Go (TUG), Sit-to-Stand (STS), stair performance (STEPs), Functional Reach (FR) and lower-body Functional Movement Screen (FMS) composite score at PRE and POST intervention.

Dependent Variable	Group	Sample size (n)	Pre-Test M (SD)	Post-Test M (SD)	Source of Variation	F	*p*	η^2
STS	Static	n = 5	10.40 (2.51)	13.40 (2.41)	Group	0.784	0.402	0.089
	Dynamic	n = 5	12.0 (2.74)	14.80 (3.27)	Time	52.562	< 0.001	0.868
	All Participants	n = 10	11.20 (2.62)	14.10 (2.81) *	Time x Group	0.063	0.809	0.008
STEPs	Static	n = 5	8.60 (6.66)	11.80 (5.07)	Group	0.800	0.397	0.091
	Dynamic	n = 5	11.60 (6.27)	15.20 (4.76)	Time	28.9	< 0.001	0.783
	All Participants	n = 10	10.10 (6.30)	13.50 (4.97) *	Time x Group	0.100	0.760	0.012
TUG	Static	n = 5	9.43 (4.60)	7.37 (2.37)	Group	0.724	0.419	0.083
	Dynamic	n = 5	7.75 (1.74)	6.19 (1.23)	Time	10.782	0.011	0.574
	All Participants	n = 10	8.59 (3.40)	6.78 (1.89) *	Time x Group	0.209	0.660	0.025
FR	Static	n = 5	12.33 (2.87)	14.59 (3.65)	Group	0.314	0.590	0.038
	Dynamic	n = 5	12.87 (2.44)	15.87 (2.70)	Time	10.304	0.012	0.563
	All Participants	n = 10	12.60 (2.53)	15.23 (2.95) *	Time x Group	0.204	0.664	0.025
FMS	Static	n = 5	1.60 (1.14)	5.40 (0.89)	Group	0.556	0.477	0.065
	Dynamic	n = 5	1.40 (1.14)	4.60 (1.52)	Time	102.083	< 0.001	0.927
	All Participants	n = 10	1.5 (1.08)	5.00 (1.24) *	Time x Group	0.750	0.412	0.086

*Data presented as mean ± SD. *Significant main effect of time.*

0.034, p = 0.858, η^2 = 0.004) or main effect of group (F (1,8) = 0.023, p = 0.883, η^2 = 0.003) was observed for average H:Q Ratio during the CKCs. A main effect of time (F (1,8) = 12.015, p = 0.008, η^2 = 0.600) was observed with significantly lower H:Q ratio at POST (0.684 ± 0.159) compared to PRE (0.785 ± 0.140) (Table 2).

Mean Power Frequency

VL: No significant time x group interaction (F (1,8) = 0.005, p = 0.948, η^2 = 0.001) or main effect of group (F (1,8) = 1.034, p = 0.339, η^2 = 0.114) was observed for average MPF of the VL during the CKCs. A main effect of time (F (1,8) = 18.420, p = 0.003, η^2 = 0.697) was observed with significantly greater MPF of the VL at POST (77.58 + 6.33) compared to PRE (71.03 ± 6.46) (Table 2).

BF: No significant time x group interaction (F (1,8) = 0.238, p = 0.639, η^2 = 0.029), main effect of group (F (1,8) = 0.511, p = 0.495, η^2 = 0.060), or main effect of time (F (1,8) = 1.576, p = 0.245, η^2 = 0.165) was observed for average MPF of the BF during the CKCs (Table 2).

ADLs and Functional Assessment

STS: No significant time x group interaction (F (1,8) = 0.063, p = 0.809, η^2 = 0.008) or main effect of group (F (1,8) = 0.784, p = 0.402, η^2 = 0.089) was observed for STS. A main effect of time (F (1,8) = 52.562, p < 0.001, η^2 = 0.868) was observed with significantly greater STS at POST (14.10 ± 2.81) compared to PRE (11.20 ± 2.62) (Table 3).

STEPs: No significant time x group interaction (F (1,8) = 0.100, p = 0.760, η^2 = 0.012), or main effect of group (F (1,8) = 0.800, p = 0.397, η^2 = 0.091) was observed for STEPs score. A main effect of time (F (1,8) = 28.900, p < 0.001, η^2 = 0.783) was observed with a significantly higher STEPs score at POST (13.50 ± 4.97) compared to PRE (10.10 ± 6.30) (Table 3).

TUG: No significant time x group interaction (F (1,8) = 0.209, p = 0.660, η^2 = 0.025) or main effect of group (F (1,8) = 0.724, p = 0.419, η^2 = 0.083) was observed for TUG. A main effect of time (F (1,8) = 10.782, p = 0.011, η^2 = 0.574) was observed with significantly faster TUG at POST (6.78 ± 1.89) compared to PRE (8.59 ± 3.40) (Table 3).

FR: No significant time x group interaction (F (1,8) = 0.204, p = 0.664, η^2 = 0.025) or main effect of group (F (1,8) = 0.314, p = 0.590, η^2 = 0.038) was observed for FR. A main effect of time (F (1,8) = 10.304, p = 0.012, η^2 = 0.563) was observed, with significantly greater FR at POST (15.23 ± 2.95) compared to PRE (12.60 ± 2.53) (Table 3).

Lower-Body FMS Composite Score: No significant time x group interaction (F (1,8) = 0.750, p = 0.412, η^2 = 0.086) or main effect of group (F (1,8) = 0.556, p = 0.477, η^2 = 0.065) was observed for FMS composite score. A main effect of time (F (1,8) = 102.083, p < 0.001, η^2 = 0.927) was observed, with significantly greater FMS at POST (5.00 ± 1.24) compared to PRE (1.50 ± 1.08). (Table 3).

Correlations

For the total sample of participants (N = 10), exploratory correlation analyses revealed high and moderately high positive correlations between the change in RMS of the VL during the CKCs and changes in STS (p = 0.002, r = 0.857), change in STEPs (p = 0.003, r = 0.837), and FMS composite score (p = 0.006, r = 0.791). Moderately high negative correlations were observed between the change in H:Q during the CKCs and changes in TUG (p = 0.013, r = - 0.749), STS (p = 0.038, r = -0.659), and STEPs (p = 0.048, r = - 0.635). Additionally, moderately high and high positive correlations were observed between the changes in MPF of the VL during CKCs and STEPs (p = 0.026, r = 0.695) and STS (p = 0.005, r = 0.809). No significant correlations were observed between RMS or MPF of the BF and any ADLs or functional assessments, or between H:Q and FMS.

Discussion

Root Mean Square

WBV training has emerged as a potential intervention to improve neuromuscular activation and functional performance in older adults, particularly among populations with physical limitations that may restrict participation in traditional resistance training[11,19,22]. The present study observed significant increases in neuromuscular activation of the VL following six weeks of static and dynamic WBV training, as evidenced by higher average RMS during CKC movements post-intervention. These findings suggest that WBV training may enhance quadriceps neuromuscular activation in sedentary older adults. Our results contrast with those of Cristi et al[36], who reported no significant increases in VL RMS following a 9-week WBV training intervention in older adults. The discrepancy between findings may be attributed to differences in training protocols, assessment methods, and participants. Specifically, Cristi et al[36] combined static and dynamic movements during WBV at 2 mm amplitude and analyzed RMS only during MVICs, whereas the present study employed either a progressive static or dynamic WBV training protocol at a higher peak 4 mm amplitude and evaluated RMS relative to MVICs during CKC movements, which require greater functional muscle recruitment and may better reflect task-specific neuromuscular adaptations. Additionally, Cristi et al did not include sedentary participants, so the sedentary status of participants in the present study may have increased their responsiveness to both dynamic and static WBV training, thereby eliciting measurable changes in neuromuscular activation. Though the present study utilized RMS as an indirect measure of MUR, findings of the present study are supported by the traditional resistance training literature, which demonstrates increased MUR and neuromuscular activation following training[2], suggesting that WBV may elicit similar neuromuscular responses despite differing mechanical stimuli. However, these results must be interpreted with caution, as, to our knowledge, very little research has investigated the effects of WBV training on direct EMG RMS outcomes, limiting direct comparisons. For example, prior literature primarily demonstrates improvements in broader neuromuscular outcomes, such as lower-body power and strength following dynamic WBV training[12,13], or increased neuromuscular activation when measured during or after a single WBV session[14], rather than training-induced changes in neuromuscular activation. While the present findings are promising, they are not yet definitive, and more research is needed to determine whether the results of the present study are consistent with or contradictory to existing knowledge.

The present study observed improvements in neuromuscular activation of the VL across both training interventions. Although research examining the effects of static WBV training on neuromuscular activation via RMS is limited, the results are somewhat in contrast to studies reporting greater neuromuscular responses following acute exposure to dynamic WBV than to static WBV[12,37]. These contrasting findings suggest that longer-term exposure to WBV is needed to elicit adaptations in neuromuscular performance outcomes. Specifically, the progressive six-week protocol used in the present study, including structured frequency progression, bout duration, and cumulative WBV exposure, may have provided sufficient neuromuscular stimulation for both modalities to elicit adaptation. Additionally, the sedentary status of the present sample may have increased responsiveness to both conditions, thereby minimizing the differences between groups. Despite these conflicting findings, the increase in VL activation observed following static WBV is supported by prior evidence suggesting that vibration alone may provide a sufficient neuromuscular stimulus. Specifically, Lienhard et al[15] examined the effects of acute static WBV on muscle activity of the lower limbs in young and older adults, and concluded that the older population had greater increases in MUR of the VL than their younger counterparts, suggesting that older adults may benefit more from static WBV exposure, while Hazell et al[14] reported increased quadriceps activation during both static and dynamic WBV. Together, these findings suggest that knee-flexed postures may not be necessary to elicit positive adaptations in older adults, and both reflexive activation during static WBV and voluntary muscle contractions during dynamic WBV may contribute to improved neuromuscular function. However, due to the exploratory nature of this study, compounded by the lack of a comparative control group and a small sample size, the present study may not be able to detect between-group differences, and the observed improvements in VL neuromuscular activation following both static and dynamic WBV should be interpreted with caution and validated in larger, controlled studies.

In the present study, no significant changes in neuromuscular activation of the BF were observed, although a significantly reduced H:Q ratio was observed following WBV training. This reduction appears attributable to increased VL activation without a corresponding increase in BF activation, reflecting a shift toward greater quadriceps dominance. These findings are supported by previous literature demonstrating preferential quadriceps activation relative to hamstrings during WBV exposure[14]. These results, combined with the results of the present study, may suggest that WBV primarily targets the quadriceps, which serve as the primary force-producing muscle during CKC movements, rather than the hamstrings, which primarily function as stabilizers, thereby reducing the neuromuscular stimulus following WBV exposure[14]. Importantly, the reduced H:Q ratio may have functional relevance, as prior research has linked greater quadriceps activation relative to hamstrings with improved independence in ADLs and reduced fall risk in older adults[4,7]. These findings are further supported by the negative correlations observed in the present study between the H:Q ratio and STS and STEPs, as well as the positive correlations observed between RMS of the VL and ADLs. While the correlations must be interpreted as exploratory, collectively, these results suggest that increased quadriceps activity relative to hamstring activity may be associated with improved ADL performance. However, the potential for long-term imbalances between agonist and antagonist muscle groups should be considered, as quadriceps dominance may increase injury risk in older adults by increasing knee joint loading[38]. Therefore, future research should be conducted to determine whether combining WBV with targeted hamstring strengthening exercises may further optimize neuromuscular adaptations and associated improvements in functional ability, and mitigate injury risk in older populations.

Mean Power Frequency

The present study demonstrated a significant increase in VL MPF across multiple CKC movements following static and dynamic WBV. As no significant differences were observed between static and dynamic conditions, these findings suggest that both WBV modalities may enhance neuromuscular function in older adults, though definitive between-group differences must be confirmed in larger, controlled trials. While prior studies have demonstrated either increases[17] or decreases[18] in MPF of the VL during acute WBV exposure, to our knowledge, no prior research has directly examined the effects of longer-term static or dynamic WBV training interventions on EMG MPF, which highlights the novelty of the present findings. However, given that age-related declines in MPF, often due to selective atrophy of type II fibers[39], are associated with impaired functional capacity and increased fall risk[3], the observed increase in MPF may represent a meaningful neuromuscular adaptation in older adults. Specifically, increased MPF has been identified as a neuromuscular determinant of the RFD[10], and rapid force production is strongly associated with improved performance in ADLs requiring rapid movements, such as rising from a chair or climbing stairs[10,40,41]. Therefore, it's possible that the increased MPF observed following WBV training may be associated improvements in ADL and functional performance[5], which is supported by the positive correlations observed between MPF of the VL and STS and STEPs performance, though these correlations must be interpreted as exploratory, and more research is needed to confirm the results of the present study. In conclusion, while additional research is needed to clarify the mechanisms underlying these adaptations to WBV training, the present findings suggest that static and dynamic WBV may offer a practical, accessible intervention to improve neuromuscular activity and potentially reduce age-related declines in ADL performance.

In contrast to the VL, no significant changes in MPF were observed in the BF, suggesting a muscle-specific adaptation to WBV that favors the primary agonist muscles involved in force production during functional weight-bearing tasks[14]. Research examining the effects of WBV training on MPF as an indirect frequency-domain EMG indicator is extremely limited; however, some studies have observed increased MPF of the BF when measured during dynamic WBV[42]. It is possible that the static and dynamic WBV protocols used in the present study did not provide a sufficient stimulus to activate the BF and elicit measurable changes. Similarly, MPF was measured post-intervention during CKC movements, in which the quadriceps act as the primary movers and the hamstrings act as stabilizers, with lower activation. Therefore, alternative methodologies that involve greater hamstring activation may be necessary during WBV training protocols and post-intervention measurements to observe adaptations in BF MPF. While significantly more research is needed, these preliminary findings suggest that WBV alone may be insufficient to elicit meaningful adaptations in BF, and that targeted exercises may be necessary to detect enhanced BF neuromuscular function in older adults.

ADLs

In response to six weeks of static and dynamic WBV training, the present study demonstrated significant improvements in STS and STEPs ADL performance, consistent with previous WBV research showing enhanced ADL performance following short-term static and dynamic WBV interventions in older populations[19,22,43]. These improvements in ADL performance may be attributed, in part, to increases in neuromuscular activation of the VL observed in the present study. This interpretation is supported by the preliminary positive correlations between RMS and MPF in the VL and STS, as well as

STEPs performance. Since reduced RMS and decreased MPF directly contribute to age-related declines in ADL performance and independence[5,44], it seems reasonable to suggest that increases in RMS and MPF of the VL may be partly responsible for improvements in ADL performance. However, the authors recognize that improvements in ADL performance and functional ability result from multifactorial interactions, and this is only one acute perspective. Furthermore, while limited research has compared the effectiveness of dynamic vs. static WBV in improving ADL performance, our results contrast with those of Rees et al. (2008), who reported greater improvements in ADL performance following dynamic WBV training compared to static WBV. In Rees et al[21] the static WBV condition may not have provided a sufficient progressive neuromuscular stimulus to elicit functional adaptations, whereas the progressive static protocol used in the present study may have provided a greater cumulative neuromuscular stimulus. Specifically, the progressive increase in vibration frequency (30-40 Hz), bout duration (45-90 s), and total WBV exposure (7.5 - 15 minutes) over 6-weeks in the present study may have contributed to the improvement observed following static WBV, compared to a consistent exposure of 26 Hz frequency throughout an 8-week training program and less total exposure, ranging from 4.5 - 8 minutes in the study by Rees et al[21]. Additionally, the sedentary status of the present sample may have increased responsiveness to both modalities, thereby minimizing the differences between groups. The findings of the present study, in combination with those of Lienhard et al[15], who also demonstrated improvements in ADL performance following static WBV training, suggest that static WBV alone may provide a sufficient neuromuscular stimulus to elicit meaningful improvements in functional performance in older adults.

Functional Movement

The present study demonstrated significant improvements in the FMS and in functional assessments (TUG and FR), with no differences observed between static and dynamic WBV conditions. These results suggest that WBV training, regardless of modality, can improve functional movement quality and mobility in sedentary older adults. The improvements in the lower-body FMS composite score may be attributed, in part, to the observed increases in VL neuromuscular activation following WBV training. Specifically, the positive correlations observed between RMS of the VL and the FMS composite score and TUG suggest that increased quadriceps activation may be associated with improved movement quality during complex, multi-joint movement patterns[2,14]. However, because only two significant correlations were observed between neuromuscular variables and the FMS and functional assessments, this relationship should be interpreted with caution, and more research is needed. Although prior studies have not specifically examined the effects of WBV training on FMS scores in older adults, the present findings are consistent with previous WBV research demonstrating improvements in dynamic balance and functional mobility, including TUG and FR performance[19,21,22,43]. In contrast to studies reporting greater functional improvements following dynamic WBV than static WBV[21], the present study observed no differences between modalities, suggesting that both modalities may provide a sufficient stimulus to improve functional movement quality. These findings align with those of Lienhard et al[15] and may indicate that reflex-driven activation during static WBV can elicit meaningful functional adaptations in sedentary older adults, even in the absence of dynamic movement. Collectively, these findings add to the limited but growing evidence comparing WBV modalities and suggest that both static and dynamic WBV training are effective strategies for improving functional movement quality in older adults.

Limitations

This study is not without limitations. First, the sample size of 10 participants may be considered small, and our observations were limited to sedentary, community-dwelling older adults, which may not generalize to more active older adults, individuals with greater functional impairment, or other age groups. Second, because multiple tests were conducted, there is an increased risk of Type I error, and the results should be interpreted as exploratory and require confirmation in future studies. Additionally, the authors acknowledge that the limited number of existing studies, which often employed different methodologies to examine EMG variables, precludes ample direct comparisons of results and that more research is needed to determine whether the results of the present study are consistent with or contradictory to existing knowledge. Furthermore, the conclusion may not apply to all lower-limb muscle groups, as only EMG data from the VL and BF were considered. Similarly, RMS and MPF were used as indirect indicators of MUR and MFCV and neuromuscular function and may not fully capture the underlying mechanisms. Another limitation is that the present study employed a six-week intervention; longer training durations may be necessary to determine whether these adaptations persist over time or whether differences between static and dynamic WBV conditions emerge. Another limitation is that functional performance was assessed only for selected ADLs and the lower-body FMS composite score; these findings cannot be generalized to all aspects of fall risk or functional abilities. Additionally, researchers isolated three of the seven FMS movements to create a partial, targeted lower-body movement profile, rather than individual FMS scores. Therefore, composite scoring approaches may not fully capture asymmetries between limbs, which may be more clinically meaningful than composite scores alone. Additionally, the authors acknowledge that the lack of assessor blinding to pre- and post-intervention data collection presents an inherent risk of detection bias. Future studies should employ independent, blinded assessors to evaluate outcomes, thereby strengthening internal validity and minimizing observer-related bias. Lastly, the present study lacked a non-WBV control group, which may limit the ability to determine whether the observed improvements are attributable specifically to WBV or to repeated testing, familiarization, or participation in structured activity. Therefore, adequately powered randomized controlled trials with sham or no-WBV control groups are needed to further investigate the effects of static and dynamic WBV.

Conclusions

In conclusion, significant improvements in neuromuscular activation and functional performance were observed in sedentary older adults following six weeks of static and dynamic WBV training. Specifically, increases in VL RMS and MPF, along with improvements in ADL performance and functional movement, suggest that static and dynamic WBV may be associated with improvements in selected EMG and functional outcomes in sedentary older adults; however, efficacy cannot be established without an adequately powered sham or non-WBV control group. While the present study is preliminary and underpowered to detect definitive between-group differences, these preliminary results contribute to a growing body of literature highlighting the potential of WBV as a practical and accessible alternative for individuals with physical limitations who may be unable to participate in dynamic exercise or traditional resistance training. Future research involving adequately powered non-WBV control trials is needed to further investigate the effects of static and dynamic WBV. Future research should also further investigate long-term adaptations in larger, more diverse populations and examine additional neuromuscular and functional variables to better understand the mechanisms underlying WBV-induced neuromuscular adaptations and their role in functional decline in aging populations.

Ethics Approval

Approval was granted by the Ethics Committee of Ripon College (IRB #20252627). This study was performed in line with the principles of the Declaration of Helsinki.

Consent to Participate

Written informed consent was obtained from all individual participants included in the study.

Authors' Contributions

Design and concept: KK, NR, BF, KF, YS; data collection: KK, NR, BF; analysis: KK, BF; drafting of work and revisions: KK, NR, BF, KF, YS; accuracy and integrity: KK, NR, BF, KF, YS. All authors read and approved the final version of the manuscript.

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