

Alternative to traditional stretching methods for flexibility enhancement in well-trained combat athletes: local vibration versus whole-body vibration

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ABSTRACT: This study aimed to compare the effect of local vibration (LV) and whole body vibration (WBV) on lower body flexibility and to assess whether vibration treatments were more effective than traditionally used static and dynamic stretching methods. Twenty-four well-trained male combat athletes (age: 22.7 ± 3.3 years) performed four exercise protocols – LV (30 Hz, 4 mm), WBV (30 Hz, 4 mm), static stretching (SS), and dynamic stretching (DS) – in four sessions of equal duration 48 hours apart in a randomized, balanced order. During a 15-minute recovery after each protocol, subjects performed the stand and reach test (S&R) at the 15th second and the 2nd, 4th, 6th, 8th, 10th and 15th minute. There was a similar change pattern in S&R scores across the 15-minute recovery after each protocol ($p = 0.572$), remaining significantly elevated throughout the recovery. A significant main protocol effect was found for absolute change in S&R scores relative to baseline ($p = 0.015$). These changes were statistically greater in LV than WBV and DS. Changes in SS were not significantly different from LV, but were consistently lower than LV with almost moderate effect sizes. After LV, a greater percentage of subjects increased flexibility above the minimum detectable change compared to other protocols. Subjects with high flexibility ($n = 12$) benefited more from LV compared with other methods (effect size ≥ 0.862). In conclusion, LV was an effective alternative exercise modality to acutely increase lower extremity flexibility for well-trained athletes compared with WBV and traditional stretching exercises.

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INTRODUCTION

Flexibility is generally defined as the ability of muscles and tendons to elongate and is one of the main athletic components to achieve efficient movements and perform sports-specific skills effectively [1,2]. A high level of flexibility is a prerequisite for athletic success in some sports such as gymnastics, trampolining, figure skating, diving, synchronized swimming, and combat sports, since these sports require relatively large ranges of motion and extreme limb positions [3].

Stretching is a common warm-up method that competitive and recreational athletes routinely use to prepare their bodies for intense muscular efforts [4]. Stretching exercises are generally performed immediately after aerobic warm-up activities and constitute a basic component of the warm-up process [4,5]. Stretching improves flexibility and reduces muscular soreness and injury [6].

One of the most common injuries that competitive athletes encounter is a hamstring strain, which is mainly caused by decreased hamstring flexibility. Therefore, athletes routinely use hamstring stretching exercises to prevent these injuries. Hamstring and lower back flexibility plays a critical role in physical performance dependent upon lower body explosive strength [4,5,7].

In combat sports such as judo, tae kwon do, and karate, static stretching (SS) is predominantly used as part of the warm-up process. It is also used at the end of training sessions to improve and/or maintain flexibility. However, some research indicates that SS may have detrimental effects on explosive strength (i.e. vertical jump), maximum strength, speed, and agility if used before muscular activity including these biomotor abilities [4,5]. To overcome the negative effects of SS, it has been recommended to replace static stretching with dynamic stretching (DS) in the warm-up period. DS has no detrimental effects and may have positive effects on subsequent muscular activity [5,8]. On the other hand, DS is not as effective as SS at improving flexibility [5,8].

Whole body vibration (WBV) is another training modality used to enhance flexibility [1,9-13]. Since SS has detrimental effects on explosive activities and DS is less effective than SS at increasing flexibility, WBV may be a better alternative to these traditional stretching methods for enhancing acute flexibility prior to sporting activities. In WBV, a mechanical stimulus with an oscillatory motion is applied to the whole body via a vibrating platform. Frequency, amplitude, acceleration, and duration are the main variables constituting the

vibratory load [14-16]. The amount of vibratory load transmitted to body parts depends on musculoskeletal stiffness, dampening of the vibrations by tissues and body fluids [17], and distance between the vibration source and target muscles [15].

In general, WBV studies use standing and squatting exercises. In these exercises, the vibratory stimulus is indirectly transmitted through the body tissues via the feet [18-20]. During transmission, vibration energy is absorbed by the soft tissues, thus reducing the vibratory stimulus to the muscles distal to the vibration source. Therefore, these muscles may be exposed to an insufficient vibration load to elicit performance enhancement [10,15,18]. In contrast, local vibration (LV) directly applied to target muscles reduces dissipation of vibratory energy [18]. Hence, LV may more intensely affect target muscles than WBV [19].

In the literature, LV [3,7,19,21,22] and WBV [1,9,10,23-26] are both suggested to effectively increase acute flexibility. However, to date, no study has compared the effects of LV and WBV on lower extremity flexibility. WBV relies on indirect effects whereas LV relies on direct effects of the vibratory stimulus on the related body region. Therefore, LV could be as effective as WBV – even more effective if similar vibratory loads are used – in enhancement of lower body flexibility [19]. Accordingly, the present study aimed to compare the effects of WBV and LV on lower body flexibility levels using well-trained combat athletes. It also aimed to assess whether vibration treatments were superior to traditionally used static and dynamic stretching methods regarding lower body flexibility enhancement.

MATERIALS AND METHODS

Experimental Approach to the Problem. The primary hypothesis of the present study was that LV would be more effective than WBV in enhancing lower extremity flexibility. The secondary hypothesis was that both LV and WBV treatment would be at least as effective as traditional stretching methods in enhancing lower extremity flexibility.

The study consisted of four sessions separated by 48 hours. All tests were performed by the same researcher at the same time of day (13:00 to 16:00) to avoid the effect of circadian rhythms on the study results.

Subjects performed one of four different exercise protocols (LV, WBV, SS, DS) for an equal duration in each session in a randomized, balanced order. During a 15-minute recovery period after the end of each exercise protocol, subjects performed the stand and reach test (S&R) seven times: at the 15th second and the 2nd, 4th, 6th, 8th, 10th and 15th minute of the recovery period.

Subjects

Twenty-four well-trained male combat athletes (age: 22.7 ± 3.3 years, height: 1.77 ± 0.06 m, mass: 76.1 ± 10.9 kg, training experience: 11.8 ± 4.8 years, training volume: 8.26 ± 2.28 hours/week, S&R score: 16.9 ± 4.8 cm) competing in judo, karate, taekwon do, and Muay Thai volunteered to participate in the present study.

Subjects had no health problems that would prohibit participation (diabetes, epilepsy, metabolic or neuromuscular diseases, or prostheses). They were required to refrain from vigorous physical activity, consumption of alcohol, and any food or drinks containing caffeine or other stimulants at least 24 hours prior to the testing session. All subjects were instructed about the procedures, purpose, and risks of the study in detail, and they signed an informed written consent form. Approval was granted from the medical ethics committee of the medical faculty of the local university (protocol number: 2013/39) in accordance with the Declaration of Helsinki.

Procedures

At the beginning of each session, subjects warmed up for five minutes on a cycle ergometer (834 E, Monark, Vansbro, Sweden) at 60–80 rpm and a resistance of 50 W. After two minutes, they performed S&R using a Standing Trunk Flexion Meter (Takei Physical Fitness Test, TKK 5103, made in China) to assess the baseline S&R score. During the test, subjects held one hand exactly on the other one and flexed their trunk slowly. Measurements were based on the maximum distance reached and held for two seconds. Each subject performed two trials separated by a 30-second rest interval. The highest score was recorded as the baseline flexibility score.

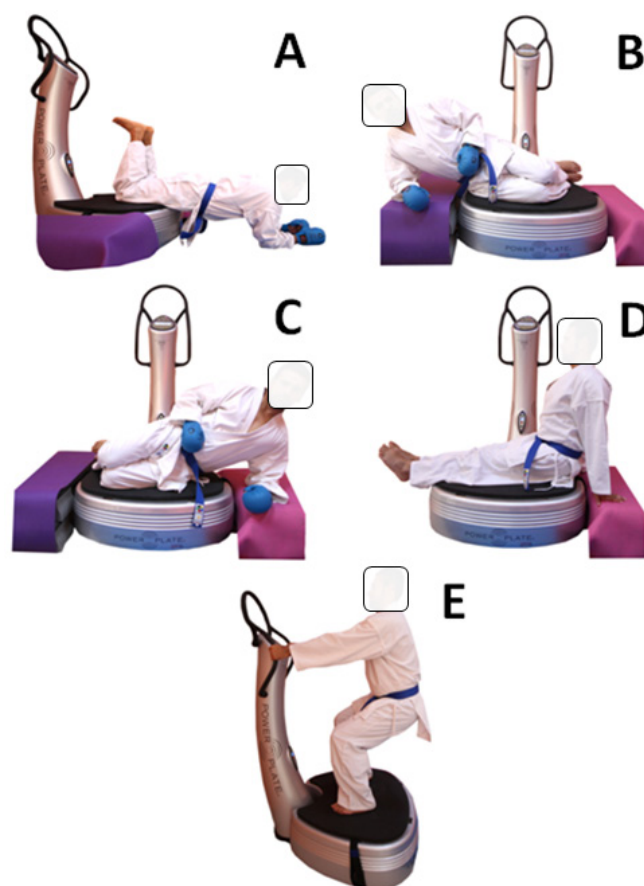


FIG. 1. Exercises used in local vibration (A, B, C, and D, respectively) and whole body vibration (E).

TABLE 1. Static stretching exercises used in the study.

Hamstring Stretch	Sit on the ground. Legs are straight out in front. Bend forward. Keep the back straight.
Standing Quadriceps Stretch	Bend your knee. Pull your foot up behind you. Feel the stretch at your thigh.
Standing Groin Stretch	Stand with your feet apart and facing in the same direction. Lean away from one side. Feel the stretch at your groin.
Kneeling Hip Flexor Stretch	Kneel on right knee with toes down. Place left foot flat on the floor in front of you. Knee is bent and aligned with ankle. Place hands on left thigh. Press hips forward. Feel tension at your right thigh.
Standing Soleus Stretch	Take a half step forward. Slowly bend the knees and sink down toward the ground. Keep the heels on the ground. Feel the stretch just above the heel.
Eagle Straddle	Sit on the ground. Legs are spread and extended straight out. Slowly lower your torso down and forward. Try to touch your nose to the floor in front of you.

TABLE 2. Dynamic stretching exercises used in the study.

Light High Knee	Stand with feet hip width apart. Drive knee up towards chest and quickly place the foot back on the ground. Drive other knee up in a moderate jog.
Side to Side Kick	Face a wall with your hands on the wall. Swing your right leg out to the side and back in front and across your body. Increase your range with each leg swing.
Light Skip	Drive your right leg into the air and push the ground with the left foot so that both feet are off the ground. Upon landing, repeat it with opposite leg/foot. Swing arms back and forth during the motion.
Lateral Shuffle	Move laterally facing sideways. Step with your lead foot and then bring your trail foot up toward your lead foot. Do not rotate the body.
Standing Rhythm Hamstring Kick	Stand sideways onto the wall. Keep your left hand on the wall for balance. Swing your right leg forward and backward. Repeat it with opposite leg.
Walking Lunge	Take a big step forward. Lower your hips and bend your knee until your lead thigh is parallel to the ground. Keep your shin straight vertically. Trail leg is as straight as possible. Step forward again and repeat it with the other leg. Keep your upper body upright.
Walking Lateral Lunge	Take a big side step. Bend the knee of your lead leg and lower your hip, resulting in a 90° knee joint angle. Trail leg is as straight as possible. Repeat it three or four times successively, and then perform it similarly in the other direction.
Walking Hamstring Kick	Kick leg up then out straight in front of you as high as possible. Try to touch the toe with the contralateral hand. Then, perform it with the other leg.

Exercise protocols were as follows:

- i) Local Vibration (LV):* In LV, the WBV device (Power Plate Next Generation PRO 5, 2x1A, 2010, USA) was used as the LV source for lower extremity muscle groups. Subjects positioned their muscles on the WBV platform in four different body postures (Figure 1 A–D) and received vertical WBV of 30 Hz frequency and 4 mm amplitude. Vibration lasted for one minute for each body posture, and subjects rested for 45 seconds between successive vibration exposures.
- ii) Whole Body Vibration (WBV):* In WBV, subjects received four sets of WBV (30 Hz, 4 mm) separated by 45-second rest intervals during an isometric squat with a 90° knee joint angle and the torso erect on the same vibration platform used in LV (Figure 1 E). Knee joint angle was controlled with a plastic goniometer (Lafayette Instrument Europe, Richardson Products, INC., Sammons Preston J00240, 12-inch) throughout each set. A standard dampening mat of 2-cm thickness (Power Plate) was used during the local and WBV protocol.
- iii) Static Stretching (SS):* In SS, subjects performed six different SS exercises (Table 1). Each exercise was performed for each limb for 20 seconds. Subjects rested for 20 seconds between exercises.

iv) Dynamic Stretching (DS): In DS, subjects performed eight different DS exercises (Table 2). Each exercise lasted for 15 seconds and was performed as two sets with 30-second inter-set and inter-exercise rest intervals.

SS and DS exercises were chosen among exercises that subjects regularly use in their training sessions.

Statistical Analysis

Data were analyzed using the IBM SPSS Statistics for Windows version 20 software (IBM Corp., 2011, Armonk, NY). A Shapiro-Wilk test was performed, and skewness-kurtosis values were checked for normality. A priori power analysis demonstrated that a sample size of 22 was sufficient for the current study (mean effect size = 0.56 [7,26], alpha = 0.05, power = 0.80). Protocol (LV, WBV, SS, DS), and Time (Baseline, 15 s, 2 min, 4 min, 6 min, 8 min, 10 min, 15 min) were the within-subject factors. Main and interaction effects of Protocol and Time on the S&R score were investigated using a 4 × 8 (Protocol × Time) two-factor repeated measures analysis of variance (ANOVA). Intra-protocol comparisons were performed using one-factor within-subject ANOVA with a post-hoc Fisher's LSD test. Afterwards, the study sample was separated into two groups: a high flexibility group (HFG) and a low flexibility group (LFG). Subjects

having baseline S&R scores (mean of baseline scores obtained in each testing session) higher and lower than the median value (15.6 cm) of the S&R scores of the whole sample constituted the HFG ($n = 12$, S&R score = 20.6 ± 3.8) and LFG ($n = 12$, S&R score = 13.2 ± 1.8), respectively. The difference between baseline S&R scores and S&R scores obtained at each time point following the exercise protocols were investigated using a $2 \times 4 \times 7$ (Group \times Protocol \times Time) three-factor mixed design ANOVA. The homogeneity of variance assumption was checked by Levene's test. Intra-protocol and inter-group comparisons were performed using a one-factor within-subject design and one-factor between subject design ANOVA, respectively, with a post-hoc Fisher's LSD test. Statistical significance level was not corrected for multiple pairwise comparisons to avoid loss of statistical power and was set at $p \leq 0.05$ for all analyses [27,28].

Even small changes in the performance measures of well-trained athletes might have a substantial impact [29]. Therefore, the percent-

age of subjects having S&R score changes greater than the minimum detectable change with 90% confidence (MDC_{90}) and smallest worthwhile change (SWC) value ($0.2 \times$ pooled standard deviation) were considered as the critical limit. Changes greater than MDC_{90} and SWC values were regarded as "real change" and "practically important change" in the S&R scores, respectively. MDC_{90} was calculated using the following equation:

$$MDC_{90} = SEM \times 1.65 \times \sqrt{2} \quad [1]$$

where SEM is the standard error of measurement, 1.65 is the z score of the 90% confidence level, and $\sqrt{2}$ is the variance of two measurements. MDC_{90} and SWC values were calculated for each set of paired protocols (six pairs), and the mean of these values was used for further analysis.

Test-retest reliability of baseline S&R scores was estimated using intra-class correlation coefficients (ICC) and 95% confidence intervals computed by two-factor mixed-effects single-measure reliability with absolute agreement.

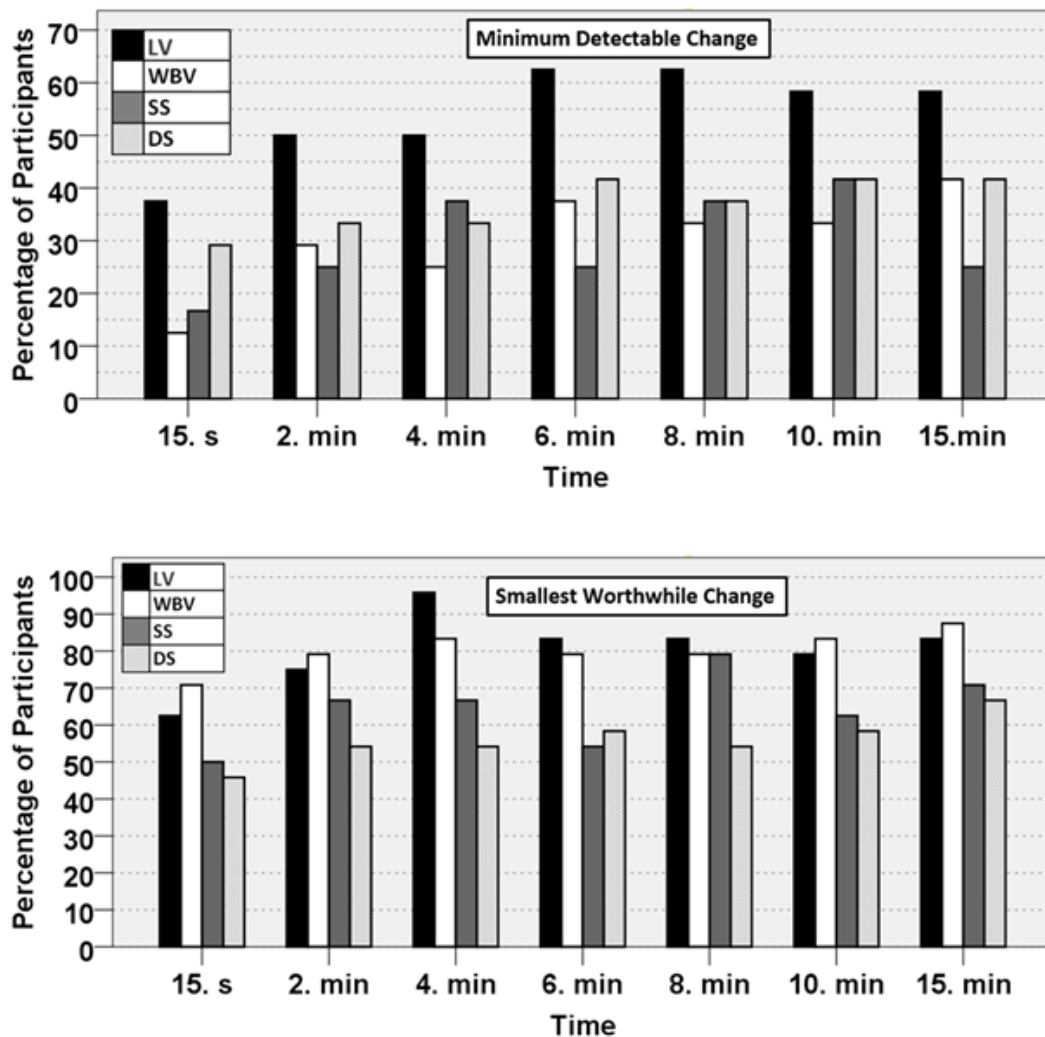


FIG. 2. Percentage of subjects improving the S&R score more than the minimum detectable change score with 90% confidence ($MDC_{90} = 2.55$ cm) and more than the smallest worthwhile change score ($SWC = 0.97$ cm) at different time points after the acute exercise protocols. DS = dynamic stretching, LV = local vibration, S&R = stand and reach test, SS = static stretching, WBV = whole body vibration.

TABLE 3. Critical limits (MDC90 and SWC) for increase in S&R score and reliability results for S&R based on pairwise comparisons between baseline S&R scores obtained in different exercise protocol sessions.

Paired Protocols	MDC90 (cm)	SWC (cm)	ICC	95% CIs of ICC
LV – WBV	2.61	0.981	0.953	0.894 – 0.979
LV – SS	3.01	0.978	0.937	0.861 – 0.972
LV – DS	2.94	0.985	0.940	0.867 – 0.974
WBV – SS	1.73	0.958	0.979	0.951 – 0.991
WBV – DS	2.34	0.956	0.961	0.912 – 0.983
SS – DS	2.72	0.962	0.947	0.883 – 0.977
Mean	2.55	0.970	—	—

Note: CI = confidence interval, DS = dynamic stretching, ICC = intraclass correlation coefficient, LV = local vibration, MDC₉₀ = minimum detectable change score with 90% confidence, S&R = stand and reach test, SS = static stretching, SWC = smallest worthwhile change, WBV = whole body vibration.

RESULTS

Test-retest reliability for S&R (ICC ≥ 0.937) was high, and mean MDC₉₀ and SWC values were 2.55 cm and 0.970 cm, respectively (Table 3). After LV, a greater percentage of subjects increased flexibility above MDC₉₀ compared to other exercise protocols at each specified testing time point – without exception – in the 15-minute recovery period. These percentage scores exceeded 60% at the 6th and 8th minutes of the recovery period. This percentage did not exceed

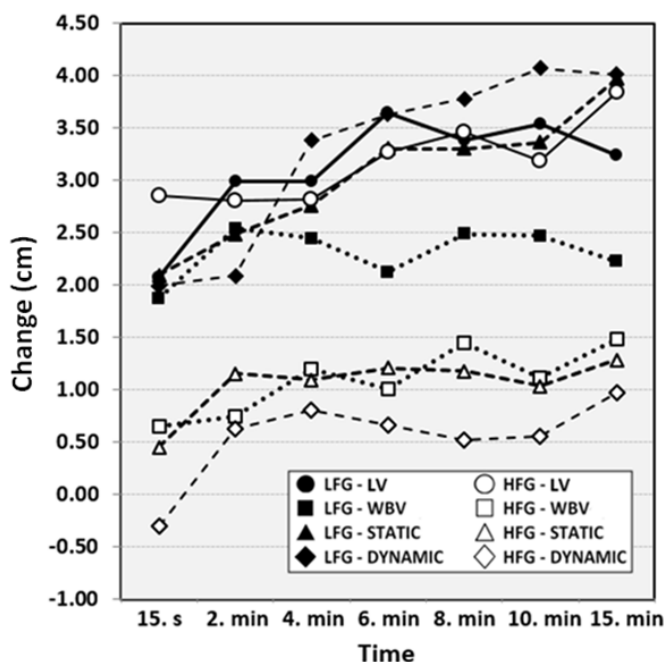


FIG. 3. Changes in S&R scores relative to baseline at the specified testing time points in the low flexibility group (LFG) and high flexibility group (HFG). To avoid confusion, no symbol representing statistical significance was used. Error bars indicate standard deviation. LV = local vibration, WBV = whole body vibration, S&R = stand and reach test. Red and blue horizontal lines indicate minimum detectable change score with 90% confidence (MDC90 = 2.55 cm) and the smallest worthwhile change score (SWC = 0.97 cm), respectively.

TABLE 4. Statistical results related to differences in S&R scores between the specified testing time points after the acute exercise protocols

	LV (n = 24)					WBV (n = 24)				
	Δ (cm)	95% CIs of Δ	p	d	95% CIs of d	Δ (cm)	95% CIs of Δ	p	d	95% CIs of d
15. s - Base	1.55	0.750 - 2.34	<0.001*	0.304	0.130 - 0.479	1.26	0.634 - 1.89	<0.001*	0.277	0.134 - 0.421
2. min - Base	1.98	0.978 - 2.98	<0.001*	0.384	0.167 - 0.601	1.64	0.900 - 2.38	<0.001*	0.352	0.171 - 0.532
4. min - Base	1.98	0.967 - 3.00	<0.001*	0.387	0.165 - 0.608	1.82	1.07 - 2.57	<0.001*	0.388	0.201 - 0.576
6. min - Base	2.54	1.56 - 3.52	<0.001*	0.508	0.269 - 0.746	1.57	0.831 - 2.30	<0.001*	0.327	0.152 - 0.503
8. min - Base	2.50	1.28 - 3.73	<0.001*	0.483	0.216 - 0.750	1.97	1.25 - 2.68	<0.001*	0.427	0.240 - 0.614
10. min - Base	2.45	0.963 - 3.93	0.002*	0.465	0.163 - 0.768	1.79	1.05 - 2.53	<0.001*	0.394	0.211 - 0.577
15. min - Base	2.63	1.76 - 3.49	<0.001*	0.541	0.311 - 0.771	1.85	1.12 - 2.59	<0.001*	0.396	0.213 - 0.580

	Static Stretching (n = 24)					Dynamic Stretching (n = 24)				
	Δ (cm)	95% CIs of Δ	p	d	95% CIs of d	Δ (cm)	95% CIs of Δ	p	d	95% CIs of d
15. s - Base	1.23	0.591 - 1.87	<0.001*	0.252	0.107 - 0.396	0.846	-0.045 - 1.74	0.062*	0.189	0.008 - 0.370
2. min - Base	1.78	1.29 - 2.26	<0.001*	0.368	0.226 - 0.511	1.36	0.457 - 2.26	0.005*	0.295	0.096 - 0.494
4. min - Base	1.88	1.35 - 2.41	<0.001*	0.390	0.236 - 0.543	2.09	1.01 - 3.17	<0.001*	0.471	0.216 - 0.727
6. min - Base	2.21	1.60 - 2.83	<0.001*	0.475	0.294 - 0.656	2.15	1.06 - 3.24	<0.001*	0.493	0.234 - 0.752
8. min - Base	2.20	1.57 - 2.82	<0.001*	0.458	0.277 - 0.640	2.15	1.15 - 3.15	<0.001*	0.501	0.264 - 0.738
10. min - Base	2.15	1.50 - 2.81	<0.001*	0.456	0.272 - 0.641	2.31	1.07 - 3.55	<0.001*	0.530	0.234 - 0.826
15. min - Base	2.58	1.79 - 3.38	<0.001*	0.563	0.338 - 0.788	2.49	1.38 - 3.60	<0.001*	0.576	0.301 - 0.851

Note: *p < 0.05, Δ = mean increase in S&R score, Base = baseline, d = unbiased effect size of the difference (Hedge's d; d < 0.2 trivial, 0.2 ≤ d < 0.5 small, 0.5 ≤ d ≤ 0.8 moderate, d > 0.8 large effect size), CIs = confidence intervals, LV = local vibration, S&R = stand and reach test, WBV = whole body vibration.

TABLE 5. Inter-protocol comparison of absolute change in S&R scores relative to baseline at the specified testing time points after the acute exercise protocols.

	LV - WBV (n = 24)					LV - SS (n = 24)				
	Δ (cm)	95% CIs of Δ	p	d	95% CIs of d	Δ (cm)	95% CIs of Δ	p	d	95% CIs of d
15. s	1.20	0.117 - 2.28	0.031*	0.545	0.063 - 1.03	1.19	-0.645 - 3.03	0.193	0.453	-0.233 - 1.14
2. min	1.25	0.049 - 2.46	0.042*	0.598	0.018 - 1.18	1.08	-0.192 - 2.35	0.092	0.499	-0.086 - 1.08
4. min	1.08	0.191 - 1.97	0.019*	0.563	0.089 - 1.04	0.975	-0.163 - 2.11	0.090	0.474	-0.076 - 1.03
6. min	1.89	0.775 - 3.00	0.002*	0.936	0.340 - 1.53	1.20	-0.052 - 2.45	0.059	0.527	-0.024 - 1.08
8. min	1.45	0.209 - 2.70	0.024*	0.653	0.085 - 1.22	1.18	-0.241 - 2.61	0.099	0.486	-0.095 - 1.07
10. min	1.58	0.237 - 2.91	0.023*	0.664	0.090 - 1.24	1.17	-0.376 - 2.71	0.131	0.439	-0.134 - 1.01
15. min	1.69	0.371 - 3.00	0.014*	0.669	0.141 - 1.20	0.917	-0.821 - 2.65	0.286	0.308	-0.262 - 0.879

	LV - DS (n = 24)					WBV - SS (n = 24)				
	Δ (cm)	95% CIs of Δ	p	d	95% CIs of d	Δ (cm)	95% CIs of Δ	p	d	95% CIs of d
15. s	1.62	0.202 - 3.03	0.027*	0.659	0.072 - 1.25	-0.008	-1.25 - 1.22	0.989	-0.004	-0.577 - 0.569
2. min	1.54	0.454 - 2.62	0.007*	0.677	0.178 - 1.18	-0.175	-0.997 - 0.647	0.664	-0.094	-0.520 - 0.332
4. min	0.813	-0.162 - 1.79	0.098*	0.349	-0.061 - 0.759	-0.104	-0.985 - 0.776	0.809	-0.053	-0.487 - 0.380
6. min	1.31	0.256 - 2.36	0.017*	0.536	0.095 - 0.978	-0.688	-1.59 - 0.216	0.129	-0.333	-0.760 - 0.093
8. min	1.27	0.085 - 2.46	0.037*	0.503	0.029 - 0.977	-0.271	-1.28 - 0.743	0.586	-0.136	-0.627 - 0.355
10. min	1.05	-0.224 - 2.33	0.101*	0.362	-0.073 - 0.797	-0.408	-1.40 - 0.586	0.404	-0.191	-0.634 - 0.253
15. min	1.05	-0.383 - 2.48	0.143*	0.364	-0.125 - 0.852	-0.771	-1.96 - 0.423	0.195	-0.325	-0.809 - 0.159

Note: *p < 0.05, Δ = mean increase in S&R score, Base = baseline d = unbiased effect size of the difference (Hedge's d; d < 0.2 trivial, 0.2 ≤ d < 0.5 small, 0.5 ≤ d ≤ 0.8 moderate, d > 0.8 large effect size), CIs = confidence intervals, LV = local vibration, S&R = stand and reach test, WBV = whole body vibration.

TABLE 6. Inter-protocol comparison of absolute change in S&R scores relative to baseline at the specified testing time points after the acute exercise protocols (b)

	WBV - DS (n = 24)					SS - DS (n = 24)				
	Δ (cm)	95% CIs of Δ	p	d	95% CIs of d	Δ (cm)	95% CIs of Δ	p	d	95% CIs of d
15. s	0.417	-0.288 - 1.12	0.234	0.225	-0.131 - 0.580	-0.425	-0.784 - 1.63	0.474	-0.181	-0.317 - 0.680
2. min	0.283	-0.690 - 1.26	0.553	0.143	-0.329 - 0.614	-0.458	-0.540 - 1.46	0.352	-0.223	-0.249 - 0.695
4. min	-0.267	-1.22 - 0.688	0.569	-0.119	-0.520 - 0.281	-0.163	-1.25 - 0.923	0.760	-0.069	-0.510 - 0.372
6. min	-0.579	-1.61 - 0.450	0.256	-0.259	-0.696 - 0.179	-0.108	-0.907 - 1.12	0.827	-0.044	-0.350 - 0.437
8. min	-0.183	-1.16 - 0.797	0.702	-0.087	-0.530 - 0.356	-0.09	-0.855 - 1.03	0.849	-0.038	-0.353 - 0.429
10. min	-0.520	-1.76 - 0.723	0.395	-0.212	-0.693 - 0.269	-0.113	-1.27 - 1.05	0.842	-0.041	-0.446 - 0.364
15. min	-0.638	-1.69 - 0.417	0.224	-0.281	-0.726 - 0.163	-0.133	-1.09 - 1.36	0.824	-0.048	-0.379 - 0.476

Note: Δ = difference in mean change scores between protocols, Base = baseline flexibility score, CIs = confidence intervals, d = unbiased effect size of the difference (Hedge's d; d < 0.2 trivial, 0.2 ≤ d < 0.5 small, 0.5 ≤ d ≤ 0.8 moderate, d > 0.8 large effect size), DS = dynamic stretching, S&R = stand and reach test, SS = static stretching, WBV = whole body vibration..

TABLE 7. Inter-protocol comparison of mean change in S&R scores across the 15-minute recovery period after the acute exercise protocols in high (S&R score = 20.6 ± 3.8 cm) and low (S&R score = 13.2 ± 1.8 cm) flexibility groups

	High Flexibility Group (n = 12)					Low Flexibility Group (n = 12)				
	Δ (cm)	95% CIs of Δ	p	d	95% CIs of d	Δ (cm)	95% CIs of Δ	p	d	95% CIs of d
LV - WBV	2.08	0.478 - 3.69	0.016*	0.983	0.211 - 1.754	0.814	-0.263 - 1.89	0.124	0.518	-0.150 - 1.186
LV - SS	2.12	-0.318 - 4.55	0.082*	0.862	-0.124 - 1.848	0.086	-1.25 - 1.43	0.891	0.046	-0.586 - 0.678
LV - DS	2.62	1.18 - 4.07	0.002*	1.217	0.466 - 1.968	-0.156	-1.36 - 1.05	0.782	-0.076	-0.593 - 0.440
WBV - SS	0.036	-1.16 - 1.23	0.949*	0.020	-0.595 - 0.635	-0.729	-2.18 - 0.725	0.294	-0.402	-1.158 - 0.354
WBV - DS	0.545	-0.239 - 1.33	0.154*	0.439	-0.171 - 1.049	-0.970	-2.42 - 0.482	0.169	-0.484	-1.164 - 0.197
SS - DS	0.510	-1.12 - 2.14	0.505*	0.291	-0.580 - 1.161	-0.242	-2.62 - 1.14	0.707	-0.108	-0.672 - 0.456

Note: *p < 0.05, Δ = difference in mean change scores between protocols, Base = baseline flexibility score, CIs = confidence intervals, d = unbiased effect size of the difference (Hedge's d; d < 0.2 trivial, 0.2 ≤ d < 0.5 small, 0.5 ≤ d ≤ 0.8 moderate, d > 0.8 large effect size), DS = dynamic stretching, LV = local vibration, S&R = stand and reach test, SS = static stretching, WBV = whole body vibration.

45% following other protocols at any of the time points (Figure 2). When LV and WBV were compared with SS and DS, a greater percentage of subjects increased flexibility above SWC at each specified testing time point – without exception – in the 15-minute recovery period (Figure 2).

The 4×8 (Protocol \times Time) two-factor repeated measures ANOVA revealed a significant main effect for Protocol and Time on the S&R scores ($F[2.13, 49.0] = 4.46, p = 0.045, \eta_p^2 = 0.102$ and $F[3.06, 70.4] = 27.7, p < 0.001, \eta_p^2 = 0.547$, respectively). However, no significant interaction effect was detected ($F[6.41, 147] = 0.808, p = 0.572, \eta_p^2 = 0.034$ [Table 4]), indicating that S&R scores demonstrated a similar change pattern across the 15-minute recovery period after each exercise protocol.

According to the $2 \times 4 \times 7$ (Group \times Protocol \times Time) three-factor mixed design ANOVA, a statistically significant main effect for Group ($F[1, 22] = 8.52, p = 0.008, \eta_p^2 = 0.279$), Protocol ($F[3, 66] = 3.77, p = 0.015, \eta_p^2 = 0.146$), and Time ($F[3.57, 78.5] = 10.3, p < 0.001, \eta_p^2 = 0.319$), and a significant interaction effect for Group \times Protocol $F[3, 66] = 3.17, p = 0.030, \eta_p^2 = 0.114$) on absolute change in S&R scores relative to baseline were detected. In contrast, no interaction effect was found for Group \times Time ($F[6, 132] = 1.20, p = 0.308, \eta_p^2 = 0.052$), Protocol \times Time ($F[18, 396] = 0.904, p = 0.574, \eta_p^2 = 0.039$), or Group \times Protocol \times Time ($F[18, 396] = 1.31, p = 0.176, \eta_p^2 = 0.056$). Changes in S&R scores relative to baseline after each intervention are shown in Figure 3. Superiority of interventions between one another regarding their flexibility-enhancing effect can be seen in Tables 5, Table 6 and Table 7.

DISCUSSION

To our knowledge, this is the first study comparing the effects of two different types of vibration – LV and WBV – on lower extremity flexibility. In addition, SS and DS were included in the study design as control treatments to reveal whether vibration treatments could serve as better alternatives to these traditionally used stretching methods for enhancing lower extremity flexibility. Well-trained combat athletes were selected for this study to identify whether vibration treatments could improve lower extremity flexibility of these athletes who routinely perform traditional stretching exercises for long periods of time. In the context of LV treatment, a key result of the present study – a flexibility increase of 2.23 cm (range: 1.55–2.63 cm) across a 15-min recovery period with mean ES of 0.44 (range: 0.30–0.54) – was consistent with those of Siegmund et al. [7] (1.6-cm increase in sit and reach test, ES = 0.55), Cronin et al. [21] (1.6–2.1% increase in dynamic range of motion of the hamstring, ES = 1.15–1.77), and Kinser et al. [22] (9.4–9.8% increase in forward split performance, ES = 0.26–0.31).

When the WBV-related results were considered, our results were in line with the results of the sit and reach test as reported by Cochrane and Stannard [10] (~2.5 cm, no ES was indicated), Bunker et al. [9] (8.00 ± 3.37 cm, no ES was indicated), Gerodimos et

al. [25] (~1.8 cm, no ES was indicated), Jacobs and Burns [26] (4.7 cm, ES = 0.57), and Kinser et al. [22] (4.7 cm, ES = 0.25). In contrast, Cardinale and Lim [30] found an insignificant decrease (3.3%) in flexibility performance after a WBV intervention. The differences in the effect sizes and magnitude of changes could be due to several reasons, such as differences in types of exercise, duration of exercise, frequency, amplitude, types of vibration platform, body posture, or baseline flexibility level [25].

Furthermore, the current findings were also consistent with earlier findings demonstrating a flexibility increase after vibration treatment used in combination with SS exercises [1,3,22,23].

Vibration causes agonist muscles to contract through the tonic vibration reflex (TVR) due to stimulation of muscle spindles [7,19,31]. Relaxation of stretched muscles is proposed to be in relation with the flexibility-enhancing effect of vibration. Vibrating motions may affect the stretch reflex loop that has transcortical connections [31] through Ia inhibitory interneurons and also through group II secondary endings if suitable low frequencies are used [31]. This process may alter intramuscular coordination, reducing braking forces around the lower back and hip joints [7,11,25,32–34]. In addition, it has been suggested that a significant reduction in the stretch reflex medium-latency response compared to the short-latency response after vibration at 30 Hz was attributed to inhibition of the group Ia afferent fibres, which, in turn, increased S&R scores [3]. Vibration-mediated rapid changes in muscle length and joint rotation may induce firing of α and γ motor neurons and reduce muscle stiffness. Moreover, stimulation of Golgi tendon organs via the Ib pathway may inhibit contraction of antagonist muscles, resulting in muscle relaxation [25]. The increase in S&R scores after vibration protocols in the current study may be attributed to these mechanisms [11,32–34].

On the other hand, a muscle relaxation effect of vibration occurring simultaneously with tension induced by TVR is considered paradoxical [3]. However, it has been proposed that the optimal stimulus for primary endings of muscle spindles to induce high levels of muscle tension is very high frequency vibration (i.e., 100 Hz) in conjunction with very low amplitude (i.e., 1 mm) [35]. Accordingly, it is unlikely that vibration of 30 Hz, 4 mm used in the current study might have caused a significant increase in TVR-induced muscle tension and a reduction in the short and medium-latency stretch reflex. Thus, increased S&R scores might have resulted from a high level of relaxation [31].

Another mechanism that may account for the increased S&R scores in the current study is an increase in the pain threshold induced by reduced pain sensation [3,19,25,31]. However, presence of such a mechanism might be debatable since there are contradictory results about the frequency of vibration that leads to reduced pain sensation [3]. Inhibition of pain sensation is attributed to increased proprioceptive impulses, resulting in an unidentified proprioceptive feedback mechanism [25,31]. Indeed, if the current S&R performance enhancement resulted from such a mechanism, this

may be due to reduced phasic and static stretch reflexes. This reduction could result from continuous after-discharge of motor neurons following the cessation of vibration [3].

A local increase in blood flow and local temperature in vibrated muscles might also have led to reduced muscle stiffness and increased S&R scores [3,7,25].

Although both vibration types (LV and WBV) increased S&R scores in the current study, consistent with the meta-analysis of Osawa and Oguma [1] the most crucial finding was that absolute changes in S&R scores relative to baseline were statistically greater (moderate effect sizes) in LV compared with WBV. This effect size was even larger ($d = 0.936$) in the 6th minute of the recovery period. LV has been reported to have a more intense effect on muscles compared with WBV. The superiority of LV over WBV, as well as over DS, is supported not only by the comparison of mean scores obtained in each protocol (Table 5), but also by the individual-based evaluation of the study results (Figure 1). This is likely because direct application of LV to the related muscle groups resulted in lesser dissipation of vibratory energy [18,19]. This direct application may also have increased the duration and magnitude of the neural processes generating inhibitory neuromuscular responses, thus changing S&R scores more than WBV [31]. This difference might also be due to the reduction in vibratory stimulus arriving at muscle groups affecting S&R scores, including erector spinae, hip rotators, hamstrings, and gastrocnemii [37], in WBV. Since these muscle groups were distant from the vibration source in WBV, vibration energy absorbed by the soft tissues might have lessened the vibratory load. Accordingly, stimulation of neural mechanisms might have occurred to a lesser extent compared with LV, thus leading to less flexibility enhancement [10,15,18,38,39]. When LV is compared with SS and DS, the effect sizes of the S&R score differences were higher than the effect sizes of differences when comparing WBV with SS and DS (Tables 5–6). Therefore, LV seemed to be superior to SS and DS for enhancing flexibility compared with WBV. On the other hand, when the number of subjects exceeding SWC, a practical and important change limit, is considered, both LV and WBV improved results compared with SS and DS.

Greater gains in S&R scores in LFG than HFG after each protocol were expected as the subjects in this group had more potential for improvement. An important and interesting finding is that LV led to a greater enhancement in flexibility in HFG than did other protocols (large effect sizes, ≥ 0.862). Although HFG had less improvement potential than LFG, flexibility improvement in HFG seemed to be similar to that in LFG (Figure 3). This is especially important in practical terms since well-trained athletes who already have high levels of flexibility may benefit more from LV than from traditional stretching methods and WBV.

When the group means were considered, the residual effect of each protocol persisted throughout the 15-min recovery period

(Table 3). This finding supports that of Gerodimos et al. [18], who also found a flexibility-enhancing effect of WBV throughout a 15-min recovery period. However, the residual effect of LV in the present study was more pronounced at the 6th and 8th minute of the recovery period, since more subjects benefited more from LV at these time points.

Limitations

No control measurement was performed for the WBV using the same body posture on the WBV device receiving no vibration (0 Hz, 0 mm) to assess any possible potentiating or fatiguing effect of the isometric body posture. However, our previous study [40] showed that a static squat position with no vibration had no effect on lower body flexibility performance. Similarly, no control measurement was performed for the LV, assuming that body positions used in LV were relatively easy to maintain and would be unlikely to cause any potentiating or fatiguing effect.

CONCLUSIONS

The current study shows that LV is an effective exercise modality that acutely increases lower extremity flexibility compared with WBV and traditional stretching exercises. As subjects experienced no negative effects during LV, this protocol could be considered a safe and effective way of enhancing lower extremity flexibility. Since resting on the WBV platform in comfortable body positions is much easier than demanding and strenuous DS and SS, it seems highly practical for athletes to use LV as an alternative flexibility enhancement modality. In addition, athletes having high flexibility levels could benefit from LV as much as athletes with low flexibility levels. It is reasonable for trainers to use a time frame of 6 to 8 minutes after LV to optimize flexibility training gains for athletes if a WBV device is used as a local vibration source during training sessions. As the literature lacks set guidelines for vibration treatment, future studies should investigate the effects of various vibration parameters (types of exercise, duration of exercise, frequency, amplitude, types of vibration platform, body posture, etc.) on lower extremity flexibility. In addition, there is a need to investigate and clarify the underlying neurological mechanisms associated with vibration exercises in which target muscles are in contact with the WBV platform.

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