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Localized vibration: effects on flexibility

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Abstract

Background. Flexibility is an important component of physical conditioning used to improve performance and prevent injury. The application of vibration is one method that has been reported to increase flexibility. The preponderance of the literature reports the effects of whole-body vibration; fewer studies have investigated the effects of local vibration (LV) therapy.

Aims. To assess if LV affects spinal flexibility, the sit-and-reach test, or lower extremity range of motion measurements when compared to controls. To determine if the effects were specific to the site of LV application and if changes persisted between the follow-up visits.

Methods. Forty-three college students (age range 21-40 years) responded to an email advertisement sent to a college of health professions. All participants underwent the same procedures and positioning but the vibration device was activated for the experimental group participants only. Nine flexibility measurements were obtained at the beginning and end of each of three visits.

Results. Changes in flexibility were statistically significant after LV at each visit except for the sit-and-reach test. No between visit effects or carry-over were observed.

Conclusion. The addition of LV to a training regime can improve flexibility immediately after its application. Although the persistence of the effect is unknown, no long-term effects were observed.

Keywords: local vibration, segmental vibration, stretching, range of motion, flexibility

Introduction

Vibration exercise (VE) is used at all levels of athlete training from amateur through professional ranks. Various reports claim increases in strength, flexibility, circulation, balance and coordination (Alam et al., 2018; Dabbs & Svoboda, 2016; Games et al., 2015; Osawa & Oguma, 2013). There are reports that VE can improve training recovery time and reduce injury and pain (Marin et al., 2012).

Although much of the research focuses on the use of VE to enhance muscle and sport performance (Lapole & Perot, 2012; Manzi et al., 2020), it has also been investigated among patients with balance deficits (Gusi et al., 2010), Parkinson disease (Dincher et al., 2019), multiple sclerosis (Broekmans et al., 2010), cerebral palsy (Rutovic et al., 2019), and stroke (Leplaideur et al., 2016). Furthermore, it has been evaluated to aid in improving recovery following knee surgery (Bily et al., 2016).

VE devices can deliver whole-body-vibration (WBV) or localized (focused) vibration (LV). WBV devices are typically oscillating platforms on which a person stands (Rittweger, 2010), while LV devices are positioned to focus the vibration on individual body segments. Although LV focuses on a body segment, its effects are likely transmitted to adjoining segments at attenuated levels.

The preponderance of the research has studied WBV, while fewer studies have examined the application of LV. Further study is needed to determine if WBV and LV devices produce similar effects (Germann et al., 2018). Additionally, optimal parameters regarding the method of application or the benefits over volitional exercises are unknown (Germann et al., 2018; Rittweger, 2010).

Hypothesis

Multiple studies support enhanced flexibility after vibration in athletes (Annino et al., 2017; Cochrane, 2013; Manzi et al., 2020). Multiple mechanisms including muscle

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relaxation, changes in musculotendinous stiffness, changes in proprioception, increased temperature and circulation, changes in reflexes, and alterations in the pain threshold have been proposed for the changes in flexibility due to vibration (Cochrane, 2013; Lapole & Perot, 2011; Lapole & Perot, 2012; Osawa & Oguma, 2013).

The primary objective of this RCT was to determine if the application of LV to the musculotendinous unit in a non-stretched position has an effect on the flexibility of the spine, the sit-and-reach test, and the lower extremities range of motion (ROM) measurements when compared to a control group.

Material and methods

Research protocol

The University of Oklahoma Health Sciences Center (OUHSC) Institutional Review Board (IRB) approved this study (IRB# 15037). All participants were fully informed of why this study was being done, the procedures involved in the study, and any known potential benefits or harm from LV. Each subject signed an informed consent form approved by the IRB.

a) *Period and place of research*

This randomized controlled study was conducted in the research lab of the OUHSC College of Allied Health in Tulsa, Oklahoma, United States of America between January 2010 and July 2013. All data were collected and stored in accordance with IRB guidelines.

b) *Subjects and groups*

An email advertisement was sent to all local students within a college of health professions seeking volunteers to participate in the study. Participants were eligible if they were college students between the ages of 18 and 60 years. Participants were excluded if they met any of the exclusion criteria in Table I or if the investigator determined, upon review of their medical histories, that participation was not in their best interest.

A total of 43 volunteers (37 females, 6 males, ranging in age from 21 to 40 years old) were eligible to participate in the study. All qualified individuals were randomized at the time of consent to either an experimental or control group. Table II summarizes the characteristics of the sample by treatment group. The groups did not differ significantly by any of the demographic variables.

The forty-three subjects were seen over a period of six days for a total of 3 visits each. Nine flexibility measurements (see Tests applied section) were taken at the beginning and end of each visit. After pre-LV flexibility measurements were recorded at the beginning of each session, the experimental group underwent LV therapy

Table I
Exclusion criteria.

Current use of the following medications	Acute conditions	Medical history of:
- nonsteroidal anti-inflammatory drugs (NSAIDS) - muscle relaxants - pain medication or - regular use of a controlled substance for pain	- recent (< 4 weeks) low back or lower extremity sprain or strain - acute inflammation or disease - acute hernia - current migraine - deep vein thrombosis in the past 3 months - recent sutures - currently pregnant	- advanced stage osteoporosis - cardiovascular or circulatory disease - epilepsy - cardiac pacemaker - retinal disease - spinal pathology - two or more hospitalizations in the past 6 months - any medical condition which potentially placed subject at risk for harm (e.g., cancer)

Table II
Demographics.

Variable	All (n=43)	Control Group (n=22)	Treatment Group (n=21)
Mean Age (SD)	25.7 (4.3)	26.3 (4.8)	25.1 (3.7)
Ethnicity	n (%)	n (%)	n (%)
White	36 (84)	18 (81)	18 (85)
Native American	4 (10)	2 (9)	2 (10)
African American	1 (2)	--	1 (5)
Hispanic	1 (2)	1 (5)	--
Asian	1 (2)	1 (5)	--
Gender			
Female	37 (83)	19 (86)	18 (86)
Male	6 (14)	3 (14)	3 (14)
Level of Education			
Some Graduate/Professional	40 (93)	20 (91)	20 (95)
MS/MA Degree	3 (7)	2 (9)	1 (5)
Regular Exercise Program			
Yes	27 (63)	13 (59)	14 (66)
No	15 (35)	9 (41)	6 (29)
Unknown	1 (2)	--	1 (5)
Self-Reported Health Rating			
Average	2 (5)	1 (5)	1 (5)
Good	22 (51)	11 (50)	11 (52)
Excellent	19 (44)	10 (45)	9 (43)

using a BMR 2000 vibration drum manufactured by Swiss Therapeutic Training Products (SwissTTP; Cincinnati, OH). Vibration was applied for 2 minutes at a constant amplitude of 4 mm and 26 hertz at three sites and positions, according to the manufacturer's guidelines. The sites and positions used for this experiment were (Figure 1): Position 1 at the gluteal line and posterior thigh muscles in a standing position as participants leaned against the vibration drum; Position 2 at the lumbar spine in a seated position as participants rested the lumbar spine against the vibration drum, and Position 3 at the popliteal fossa with hamstring muscles and triceps surae resting against the vibration drum in a modified hook-lying position. These positions were chosen to avoid elongating the targeted muscles, thereby minimizing potential effects from a static stretch.

Position 1 – Gluteal Line

Position 2 – Lumbar Spine

Position 3 – Popliteal Fossa

Fig. 1 – Positions used for control and experimental groups.

In accordance with the manufacturer's recommendations, each subject was asked to contract the muscle groups positioned against the vibration drum for 5-10 seconds with equal rest periods during the two-minute sessions at each of the three sites (6 minutes of total treatment time per visit). Participants in the control group were positioned in the same manner against the LV device and were asked to perform the same sequence of muscle contractions and rest for the same amount of time except the vibration drum was turned off. All subjects were monitored continuously to ensure protocol compliance. See Figure 2 for study flow design.

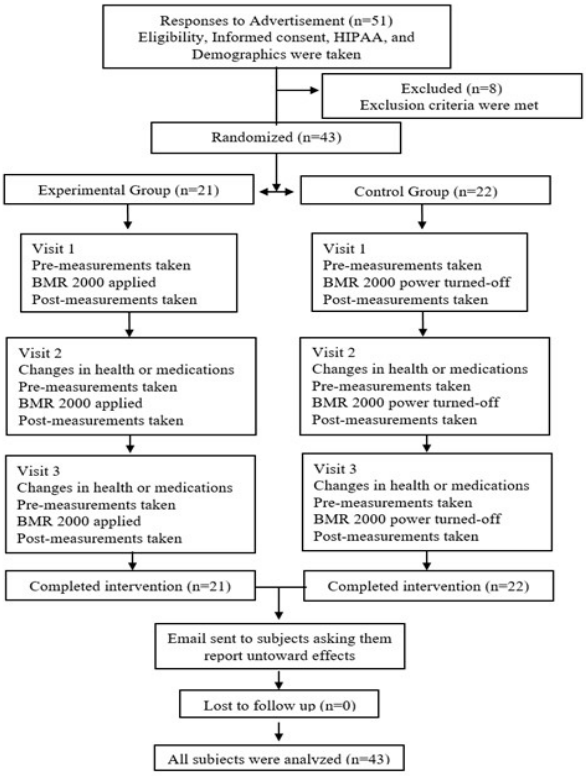

Fig. 2 – Study flow chart.

c) *Applied tests*

All flexibility measurements were taken by one trained examiner with over 15 years of experience teaching flexibility measures to students. Although the examiner was not blinded to group assignments, the recording form was duplexed so the post-treatment measurements were recorded on the backside of the page to prevent the therapist from readily seeing the previously recorded pre-treatment measurements.

Six measures of ROM assessed changes in flexibility and ROM. Pre- and post-intervention flexibility measurements at each visit were obtained in the same order for all subjects: 1) fluid-filled (bubble) double inclinometer method for thoracolumbar spinal flexion with the inclinometers positioned at the spinous process of seventh cervical vertebrae and midway between the posterior superior iliac spines: 2) Modified-Modified Schöber Test (MMST), a tape method for measuring lumbar flexion; and 3) goniometric measurement of passive knee extension with the hip at 90 degrees (popliteal angle measurement for hamstring flexibility) with the contralateral limb resting on the plinth, the knee extended and the hip in neutral rotation (Davis et al., 2008); 4) goniometric measurement of passive ankle dorsiflexion (DF) in the supine position with the knee completely extended (gastrocnemius flexibility) and the heel elevated off the plinth so that the popliteal fossa was not in contact with the table; 5) goniometric measurement of passive ankle dorsiflexion in the prone position with the knee flexed to 90 degrees (soleus flexibility) while the contralateral limb was resting on the plinth with knee extended and the hip in neutral rotation; and 6) Canadian Trunk Forward Flexion (sit-and-reach) test with a flexometer (sit-and-reach box) according to the American College of Sports Medicine's guidelines (Whaley et al., 2006). The better of two repetitions was used for analysis in the sit-and-reach test.

d) *Statistical processing*

We performed separate analyses of variance (ANOVA) on each of the outcome measures. While participants were positioned so they received the vibratory input bilaterally, we determined whether the effects of LV therapy differed for right and left limbs by creating outcome variables to represent the mean difference between right and left hamstring, gastrocnemius, and soleus flexibility measurements. This analysis determined that post-intervention changes in length for the right and left limb measurements did not differ and were unrelated to effects explored in this study. This preliminary analysis justified using the mean of each person's measurements on the left and right limbs to assess the effects of LV. The final analyses were then performed on six measurements for each subject, taken before and after the intervention at each of three visits.

Each outcome, in both the preliminary and the final analyses, was first explored in a separate ANOVA model that included the main effects of intervention (LV versus control); visit (1, 2 or 3); and time of measurement (beginning or end of visit), along with all possible two- and three-factor interactions. The ANOVA provided information about whether LV affected mean flexibility, whether flexibility differed over three visits, whether flexibility changed during a visit, regardless of the treatment provided, and whether these effects were consistent.

SAS PROC MIXED (v9.2) was used for all analyses to fit linear models to account for correlation among the repeated measures of length over time without making assumptions about the correlation or covariance structure among those repeated measures. The REPEATED statement in PROC MIXED was used to delineate that there were 6 measurements for each subject and that they were measured before and after LV treatment at three different visits.

Type III F test was used to assess the significance of each effect and interaction term ($\alpha=0.05$). Using backward elimination, a non-significant three factor interaction, and then two-factor, the interaction terms with the highest non-significant p-values were removed, one at a time, until only significant interaction terms remained in the model or until all the last non-significant interaction terms were removed. If no interactions were found, the final models contained the three main effects described previously.

Results

Table III summarizes the results for each of the 6 measurements below.

Table III

Predicted mean differences between experimental and control groups (95% confidence intervals) in PRE-POST measurements from mixed models.

Measurements	Parameter Estimate (95% CI)	Standard Error	Wald c^2 p-value
Thoracolumbar Flexion (DI Method)[1]	10.1° (4.8, 15.4)	2.62	0.0004
Lumbar Flexion (MMST Method)[2]	0.3 cm (0.1, 0.5)	0.10	0.0016
Popliteal Angle	12.7° (9.0, 16.3)	1.74	<0.0001
Supine Dorsiflexion	3.7° (2.2, 5.1)	0.68	<0.0001
Prone Dorsiflexion	3.1° (1.2, 4.9)	0.91	0.0028
Sit-and-Reach Test	2.5 cm (-0.9, 5.9)	1.71	0.1477

[1]DI = Double Inclinometer; [2]MMST = Modified-Modified Schöber Test.

Effect of LV on Thoracolumbar Flexion (DI Method)

Significant interaction (p=0.004) was found between treatment and time of measurement (PRE-POST), indicating that changes in mean spinal flexion, at any visit, differed between the experimental and the control group (Figure 3). The post-treatment mean spinal flexion of study participants who underwent LV was 10.1 (95% CI, 4.8-15.4) degrees higher than the control group. The absence of interactions involving the date of visit, along with the no significant effect for visit (p=0.2275), suggested that mean spinal flexion did not differ between visits in either group. These results suggest that although no long-term changes in mean spinal flexion resulted from LV, within-visit spinal flexion increased consistently between the pre and post measurements among participants who underwent LV and not for the control group.

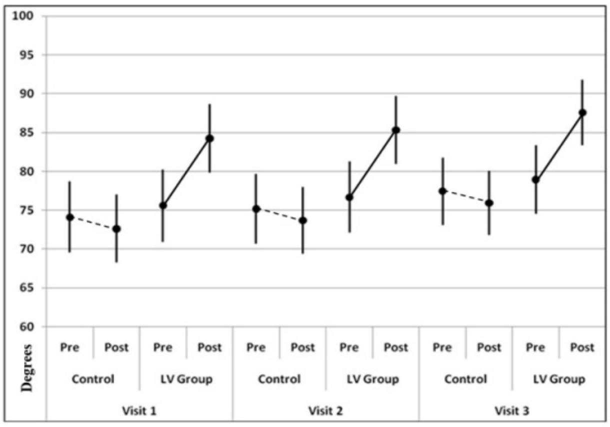

Fig. 3 – Mean differences and 95% confidence intervals for PRE and POST double inclinometer thoracolumbar flexion measurements across three study visits.

Effect of LV on Lumbar Flexion (MMST)

The effects of vibration on lumbar flexion were similar to those for thoracolumbar flexion but smaller.

Interaction was observed between the treatment and PRE-POST effects but not with the VISIT effect indicating that changes in mean lumbar flexibility after LV treatment were consistent within each visit. The mean increase in lumbar flexibility was estimated to be 0.3 centimeters (95% CI, 0.1 cm, 0.5 cm) larger in the experimental group than in the control group; indicating LV had a small effect on mean lumbar flexion.

Effect of LV on Hamstring Flexibility (Popliteal angle measurement)

Interaction was found between the treatment and the PRE-POST effects (p=<0.0001) indicating that mean hamstring extensibility changes occurred within each visit for the experimental group. Hamstring length increased 12.7 degrees more in the experimental group than in the control group at each visit (95% CI, 9.0 degrees, 16.3 degrees) (Figure 4). The non-significant parameter estimate for the VISIT effect (p=0.9155) suggests that mean popliteal angle measurement did not differ between visits. These results suggest that while no long-term changes in hamstring extensibility resulted from LV, within-visit hamstring extensibility of the left and right limbs increased among participants who underwent LV and not for the control group.

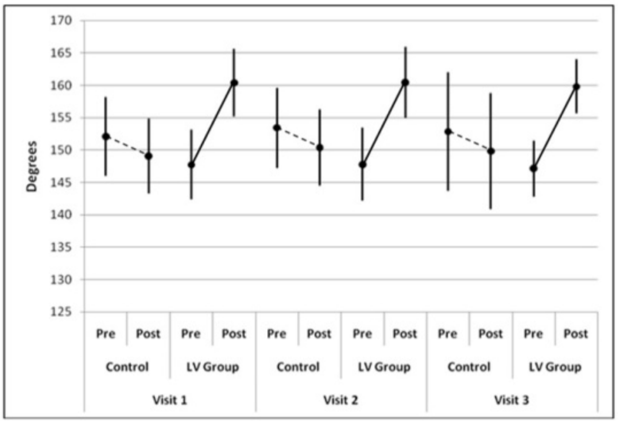

Fig. 4 – Mean differences and 95% confidence intervals for PRE and POST hamstring goniometric popliteal angle measurement across three study visits.

Effect of LV on Gastrocnemius Flexibility (Supine DF with knee fully extended)

The effect of LV on gastrocnemius flexibility was similar to the effects of LV on hamstring flexibility in that interaction was found between treatment and time of measurement (PRE-POST). Among the controls, mean gastrocnemius lengths did not differ between (p=0.7138) or within visits (p=0.0649). However, among those who received LV, mean gastrocnemius lengths increased 3.7 degrees (95% CI, 2.2 degrees, 5.1 degrees) within each visit (p=<0.001). Mean gastrocnemius length did not change between visits (p=0.3304). Results indicate that LV consistently increased mean gastrocnemius lengths within each visit (PRE-POST) for the experimental group and not for the control group.

Effect of LV on Soleus Flexibility (Prone DF with Knee Flexed to 90 degrees)

The effects of LV on soleus length mirrored those found for gastrocnemius flexibility. Interaction was found between the GROUP and PRE-POST effects. No change in soleus length was seen for the control group between (p=0.6513) or within visits (p=0.7033). Among participants who underwent LV, the change in mean soleus length increase was estimated to be 3.1 degrees higher when compared to the control group within each visit (p=0.0028) but there was no change between visits (p=0.3786).

Effect of LV on the Sit-and-Reach test

No interaction was found, and no effects were found to be related to the sit-and reach test for the experimental or control groups. This indicates that LV did not have an effect on overall posterior flexibility within or between visits.

Adverse Effects

Participants in both the experimental and control groups were asked to report adverse effects experienced from the previous visit and recent changes to their health or medications. No changes in health status or enduring effects were reported. Approximately two days after the final visit, an email was sent to all participants asking them again to report any adverse effects. One subject reported a transient case (resolved that evening) of "dizziness" after the initial visit, but reported that it did not occur with subsequent visits. The subject was asked why it was not reported after the first visit and she did not feel it was significant. No other subjects in the experimental or control group reported any adverse effects. All subjects completed the study.

Discussion

Flexibility is a component of an exercise regime that is used to enhance performance, help reduce the potential for injury and to treat various conditions. Not only has VE been used with the intent to affect flexibility (Alam et al., 2018; Jacobs & Burns, 2009; Manzi et al., 2020; Osawa & Oguma, 2013), it has been investigated for its effects to enhance strength and athletic performance (Alam et al., 2018; Dabbs & Svoboda, 2016; Hortobagyi et al., 2015). Although many of the previously cited studies used whole body vibration, the focus of this study was to examine LV and its effect on flexibility.

The results of this study are consistent with the literature (Cochrane, 2013; Houston et al., 2015; Jacobs & Burns, 2009; Lapole & Perot, 2011) with the exception of the sit-and-reach test for which no changes in flexibility were observed. All of the measurements (except the sit-and-reach test) for the experimental group demonstrated a statistically significant increase in ROM immediately after the application of the LV even though the muscles were not placed in a stretched position. These changes were acute and consistent for all three visits, but there was no carry-over between visits. No changes in any of the measurements occurred for the control group within, between, or at the end of the three visits.

Rittweger's comprehensive literature review on vibration examined the physiological changes, uses of vibration as an exercise modality, and discussed some of the potential benefits for specific client populations (Rittweger, 2010). Cochrane's review of the literature supports these results and adds that vibration is a safe and potentially time-saving modality that can be used for flexibility (Cochrane, 2013). Houston et al.'s critical appraisal of the literature using the Centre for Evidence-Based Medicine's model found moderate evidence (Grade B) for WBV ability to improve hamstring flexibility (Houston et al., 2015). More recently, Germann, et al. determined there was "fair" evidence (PEDro score of 5.97/10) regarding LV ability to improve sports performance measures such as muscle activation, strength, power, and flexibility (Germann et al., 2018).

Atha and Wheetley (1976) in a similar study compared LV for 15 minutes at 44 Hz with an amplitude of approximately 0.1 mm to the thighs and lower back of a seated subject to a static stretching program and a control. Both the LV group and static stretching group had similar significant gains in hip flexion ROM when compared to the control. The authors hypothesized that because the tissues for the LV were not in a stretched position, the change in flexibility was likely due to central mediated muscle relaxation and/or a change in tolerance to stretching and/or pain (Atha & Wheatley, 1976).

Multiple neurophysiologic changes have occurred with vibration (Germann et al., 2018; Rittweger, 2010). The stimulation of the muscle spindle through the tonic vibration reflex is frequently cited in the literature (Guang et al., 2018; Hortobagyi et al., 2015) and may be the most controversial to ascribe to the changes in flexibility in this study since both excitatory and inhibitory responses to vibration have been demonstrated in the literature (Barrera-Curiel et al., 2019; Rittweger, 2010).

It is interesting, but not unexpected, that only acute effects were demonstrated in this study. Plastic deformation of the tissues was not expected since the muscles were not placed in a stretched position, and no stretching exercises were given between sessions. Long-term changes in flexibility take time and are likely influenced by the frequency and effort of the individual (Fasen et al., 2009). There are multiple methods of stretching that may create plastic deformation or long-term changes in flexibility (Jenkins & Beazell, 2010).

VE may have produced even greater short-term differences in this study, as well as long-term differences, had the muscles been placed in a stretched position during treatment (Feland et al., 2010) and if the subjects were given regular stretching exercises to perform between sessions. Furthermore, this study was conducted on a healthy population with few to no limitations in range of motion. A patient sample with ROM limitations may have demonstrated more significant gains.

The primary limitation to our study was that the subjects and examiner were not blinded to the treatment, so the Hawthorne effect cannot be excluded. The placebo effect is always a factor especially because simulating a sham VE was not possible (Osawa & Oguma, 2013). In addition, although an attempt was made to prevent the examiner from readily viewing the pre-treatment measurements, it cannot be assumed that the investigator's memory of the measurements did not influence the post-measurements. It may have been better to have a second examiner take the post-measurements, but due to limited resources and the potential for greater inconsistency with measurement since inter-rater reliability is often lower than intra-rater reliability (Norkin & White, 2009), this was not done. Additionally, it is unknown if activities between the three visits influenced the results, since that data was not collected.

Conclusions

1. Participants in the experimental group demonstrated statistically significant gains immediately after the application of the LV on each of the three visits in all but one ROM measurement.
2. These gains in ROM occurred without placing the muscle groups in a stretched position.
3. These short-term changes did not occur in the control group.
4. No long-term or between visit changes in mean ROM measurements for the experimental or control groups were observed.

Conflicts of interests

No conflicts of interests. There were no sources of funding, except for payment of statistical assistance from the College of Allied Health to the OUHSC Department of Biostatistics and Epidemiology.

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