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The Effects of Localized Vibration on the Flexibility of the Spine and Lower Extremities: A Randomized Controlled Study [Version 2]

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Abstract

Study Design: A randomized control study.

Level of Evidence: Therapy, level 1b

Objectives: Assess if localized vibration (LV) affects spinal flexibility, the sit-and-reach test, or lower extremity (LE) range of motion (ROM) measurements among LV group when compared to controls. Determine if effects were specific to the site of LV application and if changes persisted between the follow-up visits.

Background: Vibration is a potential mechanism for increasing flexibility. Most of the literature has investigated whole body vibration (WBV) and the few studies that examined LV did not include specific measurements for the spine or dorsiflexion.

Methods: Forty-three college students were randomized into an experimental or control group. All participants underwent the same procedures and positioning except the LV device was activated for the experimental group. Nine flexibility measurements were taken at the beginning and end of each of three visits. An experienced therapist took all the measurements. A repeated measures analysis of variance (ANOVA) was used with mixed modeling. P-values are associated with Wald $\chi 2$ tests. SAS 9.2 was used.

Results: Statistically significant changes in flexibility after the application of LV at each visit for all measures (<0.0016) except the sit-and-reach test (p=0.1477) were observed. No between-visit or carryover effects of vibration were found.

Conclusion: Immediate gains in flexibility occurred with LV in all but one measurement. No between visit changes in ROM measurements occurred. Further research is needed to verify the physiological reasons for these changes and if they are similar to those noted with WBV.

Keywords
Segmental Vibration; Stretching; Range of Motion (ROM); Inclinometer; Goniometer; Sit-and-Reach; Tape Measurement

Introduction

Vibration exercise (VE) has become increasingly popular as a form of exercise for training amateur, college, and professional levels. Athletes, rehabilitation professionals, and the general consumer use VE to increase strength, flexibility, circulation, balance, coordination, and bone mineral density and to reduce muscle soreness. Manufacturers and information available to consumers on the internet claim that VE can improve training recovery time and reduce injury and pain [1]. Although much of the research focuses on the use of VE to enhance muscle and sport performance [2], it has also been investigated among patients with balance deficits [3,4], proprioception deficits [5-7], Parkinson disease [5,8-11], multiple sclerosis [12,13], cerebral palsy [14], and stroke [4,15].

VE devices can be categorized into whole-body-vibration (WBV) or localized (focused) vibration (LV) formats. WBV devices are typically oscillating platforms on which a person stands [16] and LV devices are applied to individual body segments like the hand, low back, or foot. These devices are sometimes used to transmit vibration through the distal segment of a limb. WBV and LV devices have not been compared and cannot be considered similar without further investigation.

The preponderance of the research has studied WBV, whereas fewer studies have examined the application of LV. Several review articles support positive effects of vibration, citing varying levels of evidence from well-constructed randomized controlled trials (RCT) to case reports [2,16-19], Many of these studies were small or lacked control groups, and used a variety of treatment parameters. Currently there is no agreement among VE users concerning the method of application, duration of treatment, amplitude and vibration frequency of device being used or how to appropriately incorporate it into a training regime [2,17].

Three studies have investigated the effects of vibration on young gymnasts in the forward split stretching position by applying vibration either to the distal end of the limb and/or directly to muscle itself [20-22]. All three studies revealed that vibration enhanced flexibility. In one of the studies, Sands et al.,[21] examined the acute and long-term effects of vibration applied directly to the muscle and the distal segment of the limb on the forward and rear. They noticed significant acute gains in flexibility for each of the forward legs when in the split position, but only the right rear leg in the split position demonstrated long-term changes in flexibility for the experimental group (n=5) when compared to the control (n=5). In a later study in 10 young healthy male gymnasts, Sands et al.,[22] demonstrated significant improvement in the forward split range of motion (ROM) when vibrating the limb compared to the limb that did not receive vibration. The third study on young gymnasts (n=22) demonstrated that vibration was more effective at increasing flexibility in the split leg stretch position than stretching alone and the addition of stretching during vibration had favorable results [20].

Multiple mechanisms including muscle 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 [18-23]. Although pain perception to pressure has been investigated with LV, it did not appear to alter the perception of pain to pressure when compared to the control [22].

This RCT is unique because it used targeted measures of spinal flexibility, while previous studies have used LV to either examine the effects of vibration on the flexibility of the lower extremities [20-22,24,25] or general flexibility measures like the sit-and-reach test [26]. The primary purpose of this RCT was to determine if the application of LV has an effect on the flexibility of the spine, the sit-and-reach test, and the LE ROM measurements when compared to a control group. The secondary aims were to determine 1) if any of the effects were specific to the site of application and 2) if any effects persisted over the course of several treatments.

Methods

Participants

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 1 or if the investigator determined, upon review of their medical histories, that participation was not in their best interest. Fifty-one potential participants responded to the advertisement, and eight were excluded because they met at least one of the exclusion criteria. A total of 43 volunteers (females, n=37; males, n=6; age range 21-40 years) were eligible to participate in the study. Table 2 summarizes the characteristics of the sample by treatment group. The groups did not differ significantly by any of the demographic variables. The University's Institutional Review Board (IRB) approved this study. All participants signed an informed consent form approved by the IRB.

Table 1: 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	• advance 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 investigator which potential placed subject at risk for harm (e.g., cancer)

Table 2: 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)

Procedures

Forty-three individuals were randomized at the time of consent to either an experimental or control group, and all were seen over a period of six days for a total of 3 visits. Nine flexibility measurements (see measurement section) were taken at the beginning and end of each visit. After pre-LV flexibility measurements were recorded, the experimental group underwent LV therapy using a BMR 2000 vibration drum manufactured by Swiss Therapeutic Training Products (SwissTTP; Cincinnati, OH) device at a constant amplitude of 4 mm and 26 hertz (recommended by SwissTTP for flexibility) for two minutes in each of the following sites and positions (Figure 1): Position 1) gluteal line and posterior thigh muscles in a standing position leaning against the vibration drum, Position 2) lumbar spine in a seated position with the lumbar spine against the vibration drum, and Position 3) popliteal fossa with hamstring muscles and triceps surae resting against the vibration drum in a modified hook-lying position. These positions were chosen to minimize any potential stretch effect from the muscles being in an elongated position. According to 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 muscle contractions for the same amount of time except the vibration drum was turned off. All subjects were monitored continuously to ensure protocol compliance.

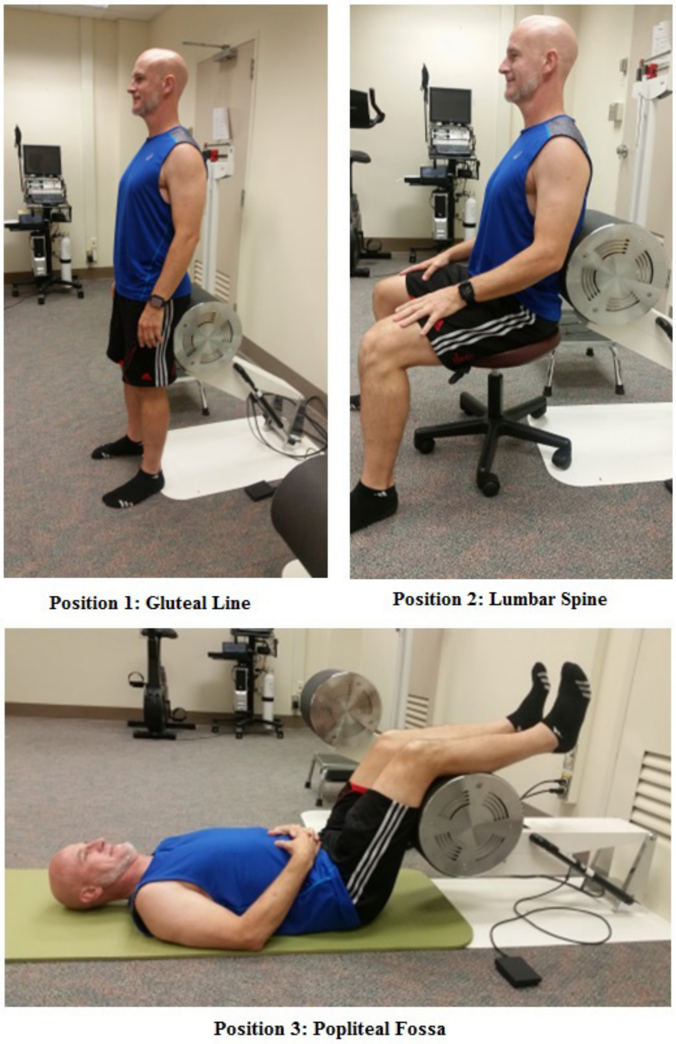

Figure 1: Positions used for control and experimental groups.

Measurements

All flexibility measurements were taken by one trained examiner with over 25 years of experience as a licensed physical therapist and who has also taught these measurements to entry-level students for over 15 years. In addition, prior to the beginning of the study, the examiner reviewed the recommended procedures for each measurement. 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 measurements.

Six measures of ROM assessed changes in overall flexibility and ROM in the lower extremities (LE). Three of the measurements were repeated for both LE. One examiner took all the measurements at each visit for all the subjects.

Pre- and post-intervention flexibility measurements at each visit were obtained in the same order for all subjects. The measurements were taken in the following order: 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 (hamstring flexibility) with the contralateral limb resting in a straight position on the plinth (popliteal angle measurement) [27]; 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 straight; 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 [28]. The better of two repetitions was used for analysis in the sit-and-reach test.

The double inclinometer (DI) is a common method for measuring spinal range of motion (ROM) although the validity and reliability have been questioned, particularly in the lumbar region [29,30], in part due to the skill and practice that is necessary to be proficient [31]. No review articles were found that examined the reliability or validity of DI for the entire thoracolumbar (T1-S1) movement into flexion.

The Modified-Modified Schöber Test (MMST) uses a tape measure to compare the difference between a standard initial 15 cm measurement from a relaxed standing position and the final position in full forward trunk flexion in the standing position with the knees fully extended. The difference between these two measurements was recorded and represents the flexibility of the lumbar spine into flexion. It is reported to have moderate [32] to excellent [33] reliability in people with low back pain. A change in 1 cm is considered a meaningful detectable change in ROM [33].

Goniometric measurements generally have good to excellent reliability when performed by well-trained clinicians, although reliability varies from joint to joint. ROM measurements of Peripheral joints have generally shown greater reliability than spinal measurements and intra-rater reliability is greater than inter-rater reliability [34]. A standard full-circle plastic universal goniometer with 14-inch arms was used to obtain the LE measurements. The extensibility of the hamstrings and the two components of the triceps surae were recorded as goniometric measurement of passive knee extension and dorsiflexion respectively. Intra-rater goniometric passive range of motion (PROM) at the knee for both flexion and extension have shown high reliability [35]. This study quantified hamstring extensibility was the popliteal angle (PA), which is performed the same way as the knee extension angle for measuring hamstring flexibility (ICC = 0.94) except that instead of recording degrees lacking from zero degrees of extension (i.e. 20°), the amount of flexion is recorded (i.e. 160°) [27]. The intra-rater reliability for the PA has been reported as excellent (ICC >0.97) [36].

The sit-and-reach test is a common test used to assess overall trunk and hamstring flexibility [37]. Although it appears to have excellent reliability (ICC ≥0.94) [27,38-40] it cannot determine specific joint ROM limitations. The criterion-related validity for lumbar flexibility is low [39,41,42], its relationship to hamstring length is more controversial with results demonstrating moderate [37,39,41,42] to weak [43] criterion-related validity when correlated to the passive straight leg raise.

Data Analyses

We performed separate analyses of variance (ANOVA) on each of the outcome measures. To determine whether the effects of LV therapy differed for right and left limbs, we created 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 datasets that contained 6 measurements for each subject, taken before and after the intervention at each of three visits.

When interactions were detected between the main effects, a maximal model with all two- and three-way interactions was run. In these instances, Each outcome was 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). 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 9.2 was used for all analyses. The SAS PROC MIXED was used to fit linear models (left and right limbs) 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.

A Type III F Test was used to assess the significance of each main effect and interaction term (α=0.05). Using backward elimination, the interaction term with the highest non-significant p-value was removed one at a time until only significant interaction terms remained in the model or until the last non-significant interaction term was removed. If no interaction was found, final models were created only containing the main effects described previously.

Results

Table 3 summarizes the results for each of the 6 measurements below.

Table 3: Predicted mean differences (95% confidence intervals) in range of motion outcomes from mixed models assessing effects of localized vibration drum therapy on lower extremity flexibility.

Measurements	Parameter Estimate (95% CI)	Standard Error	Wald c^2 p-value
Double Inclinometer	10.1° (4.8-15.4)	2.62	0.0004
Modified-Modified Schöber Test	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

Effect of LV on Thoracolumbar Flexion (DI Method)

Interaction was found between the treatment and the PREPOST main effects (p=0.0004) indicating that changes in mean spinal flexion occurred within each visit for the experimental group. 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. Interaction among the main effects with the VISIT main effect was not found. The VISIT main effect did not differ from zero (p=0.2275) and no evidence was found to suggest that mean spinal flexion changed between visits. 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.

Effect of LV on Lumbar Flexion (MMST)

The results were similar to those for thoracolumbar flexion but the effects were much smaller. Interaction was observed between the treatment and PREPOST main effects but not with the VISIT main effect indicating that changes in mean lumbar flexibility after LV treatment occurred within each visit. The change within a single visit (PREPOST) was found to be statistically significant (p=0.0016). Mean lumbar flexibility was estimated to be 0.3 centimeters (95% CI, 0.1-0.5) larger in the experimental group than in the control group; indicating LV had a small effect on mean lumbar flexion. No other statistically significant changes were detected in the experimental or control groups.

Effect of LV on Hamstring Flexibility (PA measurement)

Interaction was found between the treatment and the PREPOST main effects (p=<0.0001) indicating that mean hamstring extensibility changes occurred within each visit for the experimental group The mean hamstring length of the left and right limbs for the experimental group was estimated to be 12.7 degrees (95% CI, 9.0-16.3) higher within each visit when compared to the control group. The parameter estimate for the VISIT main effect did not differ from zero and no evidence was found to suggest that mean PA of the left and right limbs changed between visits (p=0.9155) for the experimental group. Among the control group, mean hamstring length did not differ before and after (PREPOST) treatment (p=0.2019) or between visits (p=0.6206). 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.

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. Interaction was also found between the GROUP and PREPOST main effects. Among the controls, mean gastrocnemius length of the left and right limbs did not differ between (p=0.7138) or within visits (p=0.0649). However, among those who received LV, mean gastrocnemius length of the left and right limbs increased 3.7 degrees within visit (p=<0.001). As previously observed, changes in mean gastrocnemius length did not occur between visits (p=0.3304). Results indicate that LV consistently increased mean gastrocnemius length of the left and right limbs within visits (PREPOST) 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 PREPOST main 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 mean soleus length of the right and left limbs post LV treatment 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 main 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. Participants in the experimental group did consistently report that after the LV treatment they felt that their skin was itching at the application site, which resolved shortly after the termination of the LV treatment. An integumentary examination did note a hyperemic reaction at the site of the application drum for the LV for many in the experimental group. No hyperemic reactions were apparent on subsequent follow-up visits prior to the treatment. No data were collected to analyze this phenomenon. All subjects completed the study (Figure 2).

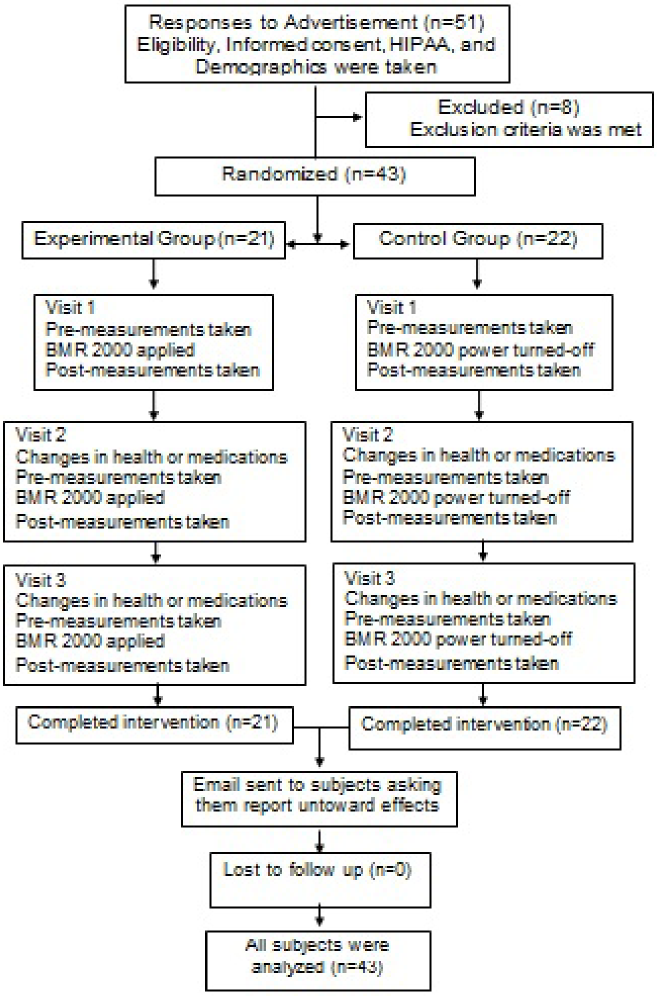

Figure 2: Study flow chart.

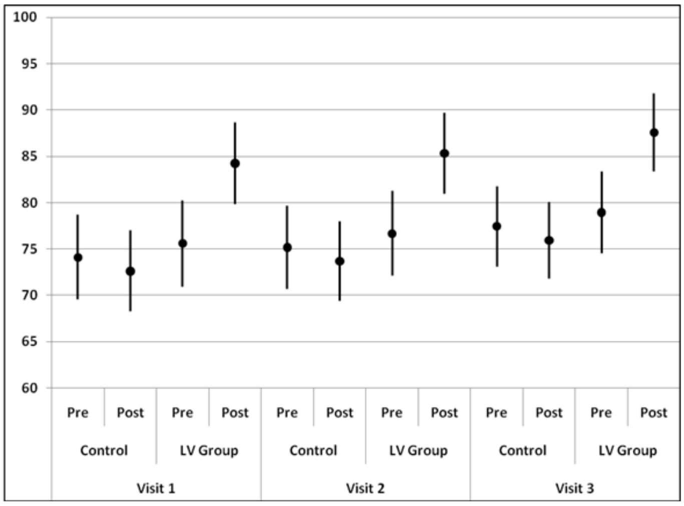

Figure 3: Mean differences and 95% confidence intervals for pre and post double inclinometer thoracolumbar flexion measurements among participants in a RCT of vibration drum therapy across three study visits.

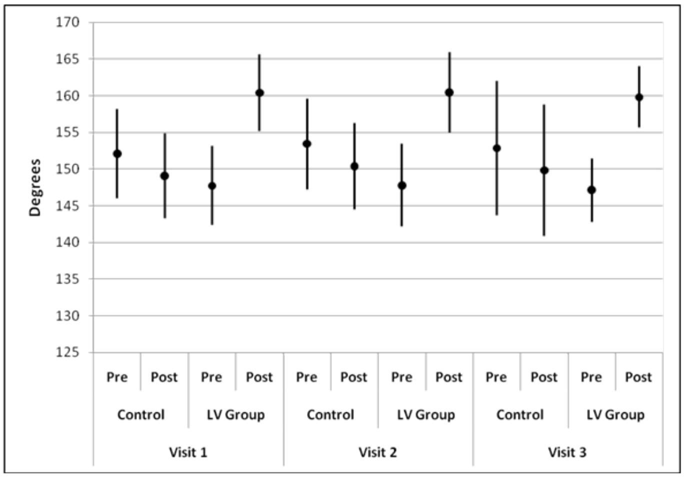

Figure 4: Mean differences and 95% confidence intervals for pre and post hamstring goniometric popliteal angle measurements among participants in a RCT of vibration drum therapy across three study visits.

Discussion

Most coaches recommend some type of stretching to enhance flexibility [44]. Poor flexibility is believed to be an important contributor to injury in adults and children [43]. 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 [19,20,45-48], it has been investigated with primarily positive results to enhance strength [47-51], performance [46,47,52] and treat injuries [53]. 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 [18,20,21,23,45,47,48] with the exception of the sit-and-reach test [26,46] 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 stretch position. A stretch position for the muscle was avoided during the application of the treatment to avoid influences that might occur with stretching. 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 [16]. Although he did not state how the physiological changes might directly influence flexibility, the review provided evidence and insight for physiological changes that occur with vibration [16]. Physiological variables that have the potential to influence flexibility include: local temperature and perfusion changes, viscoelastic changes to the muscle itself, proprioception changes, alterations in muscle spindle and Golgi organ activity, muscle relaxation and an increased tolerance to stretch and pain [16]. Any or all of these physiological variables have the potential to influence flexibility immediately after the application of LV. 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 [18].

Even though data were not formally collected, many of the subjects that underwent LV experienced a hyperemic reaction and pruritus at some of the application sites of the LV. These experiences were unique to the experimental group. This reaction is potentially related to increased perfusion and/or increased temperature [54]. Evidence in WBV literature suggests that WBV may be more effective at increasing muscle temperature than a traditional 10-minute warm-up on a stationary bike or water bath immersion at 41°C [55]. Increased perfusion and metabolic demand are supported in the literature [16,18] although the exact mechanism is unknown. The repeated physical deformation of the tissues, potential release of histamines, and the concentric-eccentric contractions required to adapt to the vibration stimulus may help explain this phenomenon [16]. It is unclear if the LV in this study was applied for a sufficient time to cause changes in muscle temperature. It is likely time dependent [54]. Although this phenomenon has not been investigated with LV, it could explain the hyperemic reaction and temporary changes to the viscoelastic properties of the targeted muscles allowing for increased flexibility.

Atha and Wheetley [26] 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 that the change in flexibility was likely due to central mediated muscle relaxation and/or a change in tolerance to stretching and/or pain [26].

Multiple neurophysiologic changes have occurred with vibration [16]. The stimulation of the muscle spindle through the tonic vibration reflex (TVR) is frequently cited in the WBV literature [56] 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 [16,56,57]. The TVR increases recruitment of motor units and is thought to account for changes in strength after the application of vibration [7]. Additionally, the responses from both the muscle spindle and Golgi organ may be dependent on the amount of stretch and/or contraction of the targeted muscle group [16]. If the TVR was stimulated to the extent that it influenced the results of this study then no changes or decreased range of motion would be evident. The direct application of vibration to the muscle could have resulted in a decreased sensitivity of the muscle spindles resulting in muscle relaxation and decreased resistance to stretching except that even if this occurred these changes are likely short-lived (<40 seconds) [57]. The measurements in this study were taken immediately after the application of vibration, and only the double-inclinometer of total spinal range of motion had the potential to be completed within the first minute post-vibration. Additionally, the voluntary muscular contraction of the LE and spinal muscles when arising from the hook-lying position (last position for the application of LV in this study prior to re-measurement) would likely return the muscle spindles sensitivity to their pre-vibratory level [58].

Cutaneous, muscle, and joint afferents all appear to play a role in joint movement and position senses [59]. The LV device was in direct contact with the skin and may have activated cutaneous receptors like the Pacinian corpuscles (PC) or Meissner corpuscles (MC). Although the PC preferentially favor higher frequencies (>200 Hz) [59-61] than used in our study, the amplitude should have been sufficient to activate this group and other cutaneous receptors [61] since they are also response to pressure. If the PC were activated, this could alter proprioception and account for changes in joint motion [59,60]. MC are activated by lower frequencies but they are less likely to be involved with altered proprioception [60,61]. Vibration at 30Hz with approximately 50-250 μm (0.05-0.25 mm) amplitude activated the MC but did not alter proprioception in the hand while increasing the frequency to 300 Hz (0.05 mm amplitude) activated the PC and significantly altered proprioception [60]. Unless the PC are activated, it is unlikely that a vibration inhibition of the proprioception received significant contributions from the cutaneous afferents. Although PC are preferentially activated by higher frequencies [59,60], it is unknown if or to what extent they are activated with lower frequencies that use higher amplitudes. This study used amplitudes of 4 mm; in the studies that demonstrated that PC were sensitive to high frequencies, they used amplitudes < 0.05 mm [59-61], A vibration induced analgesic effect or altered tolerance to stretch or pain could allow for increased range of motion. These effects are temporary and specific to the targeted areas [57,59-61]. Vibration does decrease the sensitivity of some cutaneous afferents and their recovery to pre-vibration levels will vary and may take up to 20 minutes if exposed to longer periods of vibration (10 minutes) [62].

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 [63]. There are multiple methods of stretching that may improve flexibility [64].

Perhaps even greater differences between the experimental and control group might have been demonstrated for both the short-term and long-term effects if the muscles had been placed in a stretched position with VE [22,65] and 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. Could more significant gains have been seen in a patient population with limitations in ROM?

Limitations

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 [19]. 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 [34] this was not done. Additionally, it is unknown if activities between the three visit influenced the results, since that data was not collected.

Conclusion

This study examined LV and its effects on flexibility without placing the muscle in a stretched position. 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. These short-term changes did not occur in the control group. No long-term or between visit changes in mean ROM measurements for the experimental or control groups were observed. Further research is needed to verify the physiological reasons for these changes and if they are similar to those noted with WBV. Some of the gains in flexibility were small and may not have reached clinical significance, but even small gains may be important when high levels of flexibility are required for performance (e.g., ballet or gymnastics) [22]. Although LV increases pre-exercise flexibility and may be helpful as an adjunct to pre-performance preparation, optimal flexibility has not been determined, and in certain circumstances less flexibility may actually improve the economy of the performance [66].

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