

Localised application of vibration improves passive knee extension in women with apparent reduced hamstring extensibility: a randomised trial

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Question: Does the localised application of vibration over the hamstrings improve hamstring extensibility? **Design:** Randomised controlled trial with concealed allocation, intention-to-treat analysis, and assessor blinding. **Participants:** 30 non-athletic females (aged 18–22 yrs) with limited hamstring extensibility bilaterally. **Intervention:** The experimental group received 3 sessions of localised application of vibration per week for 8 weeks. At each session, 3 sets of vibration were applied over the left and right hamstring muscles. The control group continued their usual daily activities. Both groups were asked to perform no specific exercises during the 8-week intervention period. **Outcome measures:** Hamstring muscle extensibility was measured bilaterally at baseline and at the end of the 8-week intervention period by measuring passive knee extension in supine with 90 deg of hip flexion. **Results:** At baseline, the mean lack of knee extension was 27 deg (SD 9) in the experimental group and 24 deg (SD 8) in the control group. At 8 weeks, this had changed to 13 deg (SD 5) in the experimental group and 23 deg (SD 9) in the control group. This was a significant treatment effect: mean between-group difference of 13 deg (95% CI 11 to 16). **Conclusion:** An 8-week regimen of localised application of vibration over the hamstring muscles significantly reduces knee extension lack in women with reduced range on the passive knee extension test. **Trial registration:** IRCT201011031254N6. [Bakhtiary AH, Fatemi E, Kahlili MA, Ghorbani R (2011) Localised application of vibration improves passive knee extension in women with apparent reduced hamstring extensibility: a randomised trial. *Journal of Physiotherapy* 57: 165–171]

Key words: Vibration, Flexibility, Hamstring extensibility

Introduction

Muscle extensibility has been defined as the ability of a muscle to extend to a predetermined endpoint and this endpoint is usually measured by the angle of a relevant joint (Weppler and Magnusson 2010). In clinical practice and some clinical research, the location of the endpoint is often determined by the sensation perceived by the patient or by the amount of resistance perceived by the therapist. Therefore many factors can affect the endpoint of joint range achieved in simple manual tests commonly used to assess muscle extensibility. For example, alterations in tolerance to stretch or changes in the extensibility of the surrounding non-muscular tissue could also cause improvements in the joint range achieved (Folpp et al 2006, Law et al 2009). Nevertheless, physiotherapists may be interested in the results of these simple manual tests, because poor results on the tests have been associated with injury risk or other clinical problems (Krivickas and Feinberg 1996, Kaufman et al 1999, Knapik et al 2001, Witvrouw et al 2003). Notably, gender differences were frequently apparent in these studies. Physiotherapists may also be interested in interventions that improve apparent muscle extensibility on simple manual tests, even if the precise mechanism of the improvement is unclear, because these interventions sometimes also improve more clinically relevant outcomes as well (Ross 2007, Khalili et al 2008, Christiansen 2008, Cristopoliski et al 2009, Aoki et al 2009, Rose et al 2010).

Several of these relationships between apparent muscle extensibility on simple manual tests and clinical outcomes have been identified for the hamstrings specifically.

When simple manual tests indicate reduced hamstring extensibility, this is often associated with hip and knee joint movement dysfunction (Frigo et al 1979, McNair et al 1992, Whyte et al 2010) and lumbosacral postural changes (Napiontek and Czubak 1988). A possible causative nature to these associations is suggested by research into simulation of hamstring shortening, which induces gait abnormalities in healthy people (Whitehead et al 2007). Imbalances in apparent muscle extensibility between the right and left hip extensors, including the hamstrings, may also predispose athletes to injury (Knapik et al 1991).

Because of the potential role of hamstring extensibility in movement dysfunction and injury, a range of interventions intended to improve hamstring extensibility have been investigated (Kisner and Colby 2002). These include static stretches (de Weijer et al 2003, Folpp et al 2006, Bazett-Jones et al 2008, Law et al 2009, Ben and Harvey 2010), ballistic stretches (la Roche and Connolly 2006, Covert et al 2010), stretching with warm up (de Weijer et al 2003), stretching with local joint manipulation (Fox 2006), and local application of heat (Funk et al 2001). While some significant improvements in simple manual tests of apparent hamstring extensibility were noted in some of these trials, the effects were generally small from a clinical perspective. Where more direct measures of hamstring extensibility using standardisation of torque with recording of electromyography have been made, the interventions have not been effective. Therefore, alternative interventions with the potential to improve hamstring extensibility remain of interest.

As an alternative intervention, recent randomised studies have examined the application of vibration to the whole body in healthy or athletic participants. Whole body vibration significantly improved the results of simple clinical tests such as the sit-and-reach test (Fagnani et al 2006, Sands et al 2008, Jacobs and Burns 2009), although clinically the effects would be considered small to moderate. Issurin (2005) has suggested that whole body vibration may enhance excitatory inflow from muscle spindles to the alpha motorneuron pools and modulate the recruitment thresholds and firing rates of motor units and also depress the inhibitory impact of Golgi tendon organs providing more flexibility. An alternate hypothesis is that the improved flexibility performance may be due to the increased neural potentiation of the stretch reflex loop induced by vibration (Cochrane and Stannard 2005). Notably, these randomised studies used a whole-body intervention and range-of-motion tests that involve multiple muscles. Localising the application of the intervention and the measurement of the effect may help to clarify the effect. Also, local application of vibration is simpler, cheaper, and more widely available. However, studies that have examined more localised application of vibration have applied it to multiple local sites, have not used a range of motion test localised to a single muscle, and/or lacked an appropriate control group (Atha and Wheatley 1976, Issurin et al 1994, Kinser et al 2008, Cronin et al 2008). The results of these studies are inconsistent. Because of these issues, the effect of local vibration on hamstring extensibility is still unclear. In the absence of the equipment to test muscle extensibility directly using standardisation of torque with recording of electromyography, we elected to examine the effect of local vibration over the hamstrings on the range achieved on the passive knee extension test (Kendall et al 2005, Gnat et al 2010). Given the gender differences noted above, we restricted the participants to one gender. Therefore the study question was:

Does local vibration over the hamstrings improve the range of knee extension achieved on the passive knee extension test in healthy women?

Method

Design

A randomised trial with concealed allocation, intention-to-treat analysis, and assessor blinding was conducted. Participants were recruited from students at Semnan University of Medical Sciences, Iran. An individual interview was carried out to collect demographic and physical assessment data. After their eligibility was confirmed, participants were randomly allocated to one of two groups. Randomisation was achieved using a computer-generated random list drawn up by the statistician. The list had a block size of 30 but was provided to the recruiting investigators in sealed opaque envelopes. After each participant's eligibility and informed consent were confirmed, one of the sealed envelopes was opened at the reception of the Physiotherapy Department at Semnan University of Medical Sciences. Cards allocating the participant to the experimental group were then given to the physiotherapist to administer the vibration intervention. The experimental group underwent eight weeks of local vibration on the hamstrings muscles. Participants allocated to the control group did not receive this. Both groups were requested not to undertake any specific exercises during

the same period. Only the assessor was blinded to group allocation, while participants, physiotherapist and staff supervising the vibration protocol were not blinded.

Participants

Female university students were eligible to participate if their knee extension lack angle was more than 15 degrees on the passive knee extension test (Kendall et al 2005) bilaterally. The test is described in detail in 'Outcome measures'. A knee extension lack angle of 10 degrees or less is considered the normal range for the passive knee extension test and insufficient hamstring extensibility is one possible cause of a greater knee extension lack angle (Kendall et al 2005). Students were excluded if they reported any kind of musculoskeletal or neuromuscular disease or were assessed to have any type of hip, knee, or ankle joint deformity.

Intervention

Participants in the experimental group undertook an 8-week protocol of vibration modelled on one of the whole body vibration trials that had identified an improvement in the sit-and-reach test (Fagnani et al 2006). They attended the Neuromuscular Rehabilitation Research Center for three sessions each week. At each session, three sets of vibration were applied over the left and right hamstring muscles. The vibration was applied using a 50 Hz vibrator apparatus^a, which was applied over the midline of the posterior aspect of left and right thighs (immediately over the hamstring muscles), while the participant was in the prone position with extended hip and knee joints. During each session in the first two weeks, vibration was applied three times for 20 seconds with a 1 minute rest between each application. During each session in the third and fourth weeks, vibration was applied three times for 30 seconds with a 1 minute rest between each application. During each session in the fifth and sixth weeks, vibration was applied three times for 45 seconds with a 1 minute rest between each application. During each session in the final two weeks, vibration was applied four times for 1 minute with a 1 minute rest between each application. No additional stretching was applied during these sessions.

Outcome measures

The passive knee extension test was performed on each side at baseline and at 8 weeks, one day after the final vibration session. To test the right side, for example, the participant lies supine. The assessor ensures that the left lower limb remains extended on the bed throughout the test to minimise pelvic movement. The assessor lifts the right lower leg so that the right hip and knee are flexed to 90 degrees. From this position, the amount of hip flexion is maintained at 90 degrees while the right knee is passively and carefully extended with one hand on the distal posterior surface of the leg. The amount of resistance is monitored manually and the knee is extended until firm resistance to further motion is felt.

During this procedure, a standard 360 degree plastic goniometer with two arms 45 cm long and 4.5 cm wide was used to determine the popliteal angle, using the greater trochanter, lateral femoral epicondyle, and lateral malleolus as anatomical reference points. Each knee's extension lack angle was then calculated as 180 degrees minus the popliteal angle. The passive knee extension test has excellent inter-rater reliability and good test-retest reliability (Gnat et al 2010).

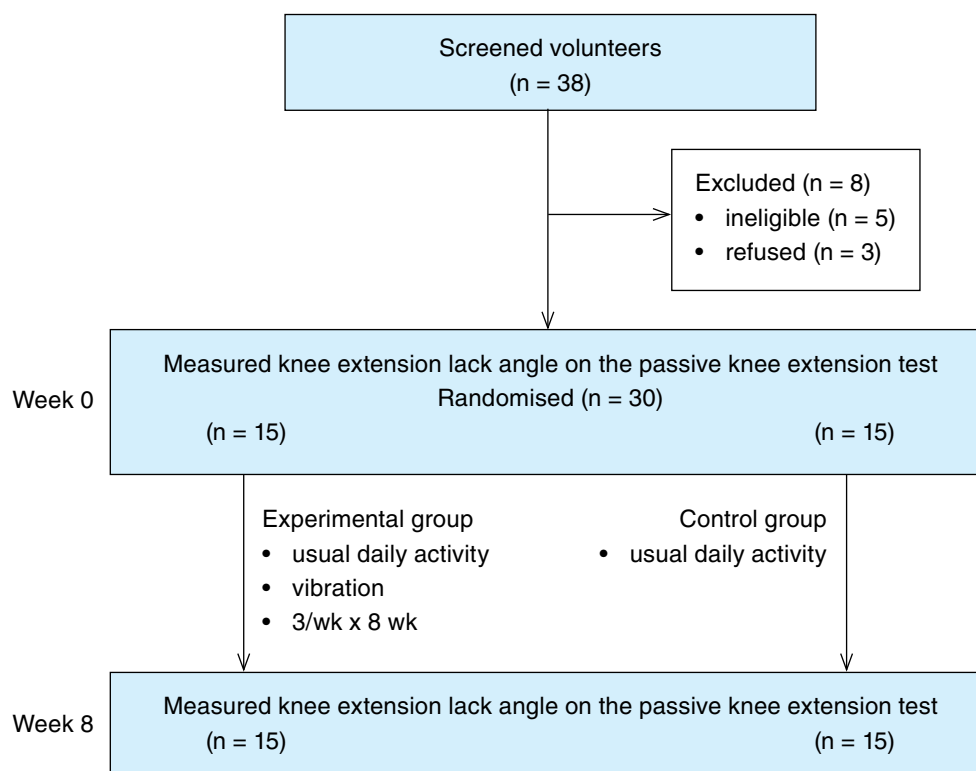


Figure 1. Design and flow of participants through the trial.

Table 1. Baseline characteristics of the participants.

Characteristic	Participants randomised (n = 30)	
	Exp (n = 15)	Con (n = 15)
Age (yr), mean (SD)	20 (2)	20 (2)
Weight (kg), mean (SD)	66 (10)	60 (9)
Height (cm), mean (SD)	163 (12)	161 (14)

Exp = experimental group, Con = control group

Statistical analysis

Baseline characteristics were analysed using descriptive statistics and are presented as means with standard deviations. Change in the extension lack angle on the passive knee extension test was compared between groups with an independent t-test and is presented as a mean between-group difference in change with a 95% CI. This analysis assumes that the data from both knees of the same participant are not substantially correlated, which is consistent with existing literature (Baltaci et al 2003). However, to confirm this, we also present the same analysis of the data from the right knees independently of the data from the left knees to illustrate that these data provide very similar estimates of the magnitude of the effect.

Significance level was set a priori at $p < 0.05$. In the absence of an established minimum clinically worthwhile difference in the extension lack angle on the passive knee extension test, we nominated 10 degrees. We used the largest estimate of the standard deviation of the change in this variable from

O'Sullivan and colleagues (2009) to account for the duration of our intervention period. A total of 24 participants would provide 80% probability of detecting a difference of 10 degrees in extension lack angle at a two-sided significance level. To allow for some loss to follow-up, we increased the total sample size to 30.

Results

Flow of participants and therapists through the study

Thirty individuals (sixty knees) participated and underwent familiarisation and baseline testing. Randomisation assigned 15 subjects to the experimental group and 15 subjects to the control group (30 knees in each group). Baseline characteristics of the two groups are presented in Table 1 and the first two columns of Table 2. All participants completed the interventions as randomly allocated and all completed post intervention measurement at 8 weeks (Figure 1).

Vibration sessions were performed by an expert physiotherapist who had more than 10 years of experience in the field of musculoskeletal physiotherapy. The blinded outcome measurement was performed by a physiotherapist who had more than 15 years experience in working in the Neuromuscular Rehabilitation Research Center of the Semnan University of Medical Sciences.

The Neuromuscular Rehabilitation Research Center of Semnan, Iran, was the only centre involved in the study. This centre was established in 2009 to conduct research projects about rehabilitation methods for neuromuscular conditions.

Table 2. Mean (SD) knee extension lack angle for each group, mean (SD) difference within groups, and mean (95% CI) difference between groups.

Outcome	Groups				Difference within groups		Difference between groups
	Week 0		Week 8		Week 8 minus Week 0		Week 8 minus Week 0
	Exp (n = 30)	Con (n = 30)	Exp (n = 30)	Con (n = 30)	Exp	Con	Exp minus Con
Knee extension lack angle (deg)	27 (9)	24 (8)	13 (5)	23 (9)	-14 (7)	-1 (2)	-13 (-11 to -16)

Exp = experimental group, Con = control group, deg = degrees

Table 3. Mean (SD) knee extension lack angle of the left and right knees for each group, mean (SD) difference within groups, and mean (95% CI) difference between groups.

Outcome	Groups				Difference within groups		Difference between groups
	Week 0		Week 8		Week 8 minus Week 0		Week 8 minus Week 0
	Exp (n = 15)	Con (n = 15)	Exp (n = 15)	Con (n = 15)	Exp	Con	Exp minus Con
Right knee extension lack angle (deg)	27 (10)	24 (8)	12 (5)	22 (9)	-15 (7)	-2 (2)	-13 (-9 to -16)
Left knee extension lack angle (deg)	28 (9)	25 (9)	13 (6)	24 (9)	-14 (7)	-1 (3)	-14 (-10 to -17)

Exp = experimental group, Con = control group, deg = degrees

Compliance with trial method

To prepare the participants for the baseline measures, all subjects underwent familiarisation before baseline testing. All participants in the experimental group attended all of their 24 sessions of local vibration scheduled in the protocol. None of the subjects in the control group attended any of the vibration sessions. None of the participants in either group undertook any special exercise program, such as strengthening or stretching exercises, during the 8-week study period.

Effect of intervention

At baseline, the groups were similar with respect to age, weight, height (Table 1), and the knee extension lack angle on the passive knee extension test (Table 2). During the 8-week intervention period, the experimental group reduced their knee extension lack by 14 degrees (SD 7). This was significantly better than the control group, which only reduced their knee extension lack by 1 degree (SD 2). This significant mean between-group difference of 13 degrees and its 95% CI of 11 to 16 degrees both exceeded the proposed minimum clinically worthwhile effect that we had proposed, ie, 10 degrees.

The independent analyses of the data from the right and left knees confirmed that these analyses provide very similar estimates of the magnitude of the effect (Table 3). For the right knees, the mean between-group difference in change over the intervention period was 13 degrees (95% CI 9 to 16). For the left knees, the mean between-group difference

in change over the intervention period was 14 degrees (95% CI 10 to 17).

The individual data contributing to the group means presented in Tables 2 and 3 are presented in Table 4 (see eAddenda for Table 4).

Discussion

This trial showed that the 8-week protocol of local vibration over the hamstring muscles significantly reduced the amount of knee extension lack on the passive knee extension test in female university students who fell short of the normal range on this test bilaterally at baseline. While the passive knee extension test was originally developed to assess the 'length' of the hamstrings, we acknowledge that other factors may influence the amount of knee extension achieved on this test. Several aspects of our study design may have minimised the impact of these factors. For example, the amount of torque applied by the assessor may vary between applications. Although we could not control random variation in the peak torque applied by the assessor, systematic bias may have been avoided by blinding the assessor to group allocations and by instructing the assessor to base the decision about end of range only on the feeling of resistance. That is, although participants were unblinded, we sought to remove their influence on the test result by asking them not to express sensations such as stretch, discomfort, tightness, stiffness, and pain. Only the assessor's perception of resistance was used to determine the end-range of knee joint angle (de Weijer et al 2003).

Another factor that may have influenced the end point of the test is the degree to which the participants relaxed, thereby either voluntarily or subconsciously changing the contraction of the hamstrings during the test. This would be consistent with recent research in which stretching regimens produced no shift of the torque/angle curves or change in muscle stiffness (Law et al 2009, Ben and Harvey 2010), suggesting alterations in tolerance might explain the increases in end-range joint angle. Modification in sensation may occur by stimulating muscle spindle primary endings during vibration (Ribot-Ciscar et al 1998). This in turn may allow increases in end-range joint angles (Halbertsma et al 1996). Although the consistency of the applied torque is uncertain with our measurement, one explanation could be that the amount of background tension within the vibrated muscles reduced due to a decreased spontaneous firing rate in the muscle spindle primary endings after vibration (Ribot-Ciscar et al 1998), which may allow greater excursion of the knee. However, the occurrence of these changes needs to be proven by measuring the amount of applied torque, stiffness, and muscle cross-sectional area (Weppler and Magnusson 2010).

Another theoretical mechanism is that vibration applied over muscles may enhance blood circulation, which may produce a thermal effect. This thermal effect can be amplified by heat generation caused by the vibration of muscle fibres as well as the vasodilatation of cutaneous and deep blood vessels (Oliveri et al 1989). Although heat can facilitate muscular extensibility (Knight et al 2001), any heat would have dissipated between the last vibration session and testing.

The possibility that the vibration increased the 'length' of the hamstrings should also be considered. Using vibration on the human body has been studied for several decades (Hagbarth 1973, Delecluse et al 2003, Kinser et al 2008). Some of the studies focus on the effect of vibration on the muscle strength or flexibility (Fagnani et al 2006, Jacobs and Burns 2009, Kinser et al 2008). Most of these studies used whole body vibration to improve flexibility in athletic or normal subjects (Fagnani et al 2006, Sands et al 2008). Although most of these studies identified the beneficial effect of vibration on simple clinical tests intended to assess muscle length (Issurin 2005, Issurin et al 1994, Sands et al 2008), in a recent study Cronin and colleagues (2008) showed no benefit from hamstring vibration on the dynamic knee range of motion. However, their method for application of vibration was different from other studies, as they used vibration on the hamstrings muscles and recorded knee flexion, which would be limited by quadriceps extensibility.

The effect of vibration in this study is consistent with what has been observed after whole body vibration. Nazarov and Zilinsky (1984) reported that stretch exercises with vibration gave a greater increase in simple clinical measures of flexibility than stretch exercises alone. In a more recent study, Fagnani and colleagues (2006) demonstrated that whole body vibration also may increase flexibility alone without any further stretching exercises. These studies were focused on athletic subjects and showed enhancement of athletes' flexibility as a result of vibration in both short-term and long-term protocols. However, further investigations examining the passive mechanical properties of muscles are required to determine whether the changes are due to true alterations in muscle 'length'.

The underlying mechanisms of the effect of vibration on flexibility might involve a shift of the pain threshold and the stimulation of muscle spindle and Golgi tendon organs, causing the inhibition of the contraction (Issurin et al 1994), which involves neural circulatory and thermoregulatory factors (Mester et al 1999). Vibratory stimulation of the muscle spindle may produce Ia input, which modulates the recruitment thresholds and firing rates of motor units. Issurin (2005) has proposed that vibration enhances excitatory inflow from muscle spindles to the motor neuron pools and depresses the inhibitory impact of Golgi tendon organs due to accommodation to vibration stimuli. Ribot-Ciscar and colleagues (1998) demonstrated that after tendon vibration, a stretched muscle was perceived as being less stretched than it actually was, which indicates that vibration produces centrally localised neural changes. They demonstrated that the static stretch sensitivity of the muscles was decreased during the 3 sec following vibration exposure, due to a decreased spontaneous firing rate in the muscle spindle primary endings after vibration. This may contribute to the increased flexibility after vibration. The level of Golgi tendon organ excitation is therefore a possible mechanism for the muscle flexibility after vibration (Bosco et al 1999, Issurin et al 1994). Lundeberg and colleagues (1984) showed that the application of vibration to muscles produces analgesic effects during and after the procedure. This may delay the start of pain, which serves as a natural barrier to muscle elongation techniques, although it was shown that vibration has no effect on the pain perception in the vibrated muscles (Sands et al 2008).

The use of vibration in pathological conditions such as muscle shortening remains an exciting area for further research. However, research in these fields is in its early stage. Much research is still needed on the optimal frequencies, amplitudes, and vibration durations to improve each of these factors. More studies are also needed to provide further knowledge about the optimal frequency and progression of the vibration.

An 8-week protocol of vibration over the hamstrings in young women can reduce knee extension lack by 10 degrees on the passive knee extension test. These findings indicate a possible beneficial effect of local vibration to improve muscle extensibility. Further research is required to understand the mechanisms underlying this effect. ■

Footnotes: ^aModel VR-7N, ITO, Tokyo, Japan.

eAddenda: Table 4, available at jop.physiotherapy.asn.au.

Ethics: The Semnan University of Medical Sciences Ethics Committee approved this study. All participants gave written informed consent before data collection began.

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