

Effect of Vibration on Forward Split Flexibility and Pain Perception in Young Male Gymnasts

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Serious stretching in many sports involves discomfort and is often an early ceiling on improvements. **Purpose:** To continue investigation of the use of vibration to enhance acute range of motion while assessing the influence of vibration and stretching on pressure-to-pain threshold perception. **Methods:** Ten young male gymnasts were assessed for split range of motion. One side split was randomly assigned as the experimental condition, and the other side split was assigned as the control. Both side splits were performed on a vibration device; the experimental condition had the device turned on and the control condition was performed with the device turned off. In addition, the athletes were assessed for pressure-to-pain transition using an algometer on the biceps femoris (stretched muscle) and vastus lateralis (nonstretched muscle) bilaterally. **Results:** Pre-post difference scores between the vibrated split (most improved) and the nonvibrated split were statistically different ($P = .001$, 95% confidence interval of the difference 2.3 to 5.8 cm). Following the stretching protocol, the force values for the pressure-to-pain threshold comparing the vibrated and nonvibrated biceps femoris muscle were not statistically different. The nonstretched vastus lateralis muscle also showed no statistical difference in pressure-to-pain threshold between the vibration and nonvibration conditions. **Conclusion:** This study showed that vibration improved split range of motion over stretching alone, but did not show a difference in pressure-to-pain perception in either the stretched or nonstretched muscles.

Keywords: algometer, flexibility, stretching, pain

Flexibility has been defined as the range of motion in a joint or a related series of joints. Many sports require large range of motion movements to properly and safely execute skills. Gymnastics, figure skating, diving, and others rely on the display of unusual or unique body shapes just for their artistic nature. Other sports such as martial arts, hurdling, and wrestling use large range of motion movements

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simply as essential aspects of technique.¹ Several investigators have recently sought to expand our understanding of the role of vibration combined with stretching²⁻⁴ while relying on earlier work.⁵⁻⁷ However, there is a paucity of information on potential mechanisms that may account for the sometimes staggering improvements in range of motion resulting from vibration applied to stretching that have been noted in elite athletes in figure skating,⁴ synchronized swimming,² and gymnastics.^{3,8}

It has been speculated that increased temperature, increased relaxation, decreased myotatic reflex activity,⁵ reduction of phasic and static stretch reflexes via intrafusal muscle fatigue,⁹ and reduced pain¹⁰ might be related to the increased range of motion often observed with vibration and stretching.^{3,5} Unfortunately, to our knowledge, none of these mechanisms have been tested in regard to vibration and flexibility. Serendipitously, the authors have noted that many athletes in our previous studies provided unsolicited comments about pain reduction during and following the vibration stimuli. In an environment that deals with elite athletes and aspirants (the U.S. Olympic Committee defines an elite athlete as being among the top eight in the world), we are often limited to investigations that are noninvasive and that provide a minimum or no intrusion on training time and capability. Pressure-to-pain threshold was chosen as a potential means of ascertaining pain reduction in stretched muscles based on previous work with an algometer in studies of delayed onset muscle soreness,¹¹ identification of trigger points and hypersensitive areas,¹¹ and in assessing the influence of massage on muscle soreness.¹² Algometry, in assessing the pressure-to-pain threshold, has been considered reliable and valid in determining muscle soreness.^{13,14}

The purpose of this study was to reinforce previous findings on range of motion enhancements via the application of stretching and vibration, and to further explore whether these changes in flexibility are associated with changes in pressure-to-pain threshold of the treated limb versus the untreated limb.

Methods

Subjects

Ten young male gymnasts (age 10.7 [0.99] yr; height 137.5 [5.4] cm; mass 31.0 [5.9] kg) volunteered to participate in this study in compliance with U.S. Olympic Committee policies on the use of human subjects and with approval from the Eastern Washington University Institutional Review Board. The athletes were part of a USA Gymnastics national training camp being held at the Olympic Training Center in Colorado Springs, Colorado. The athletes had a training age (5.0 [1.5] yr) and competitive level (all were USA Gymnastics Level 9 competitors). All athletes had a preferred right side split, and all athletes were right leg dominant as determined by querying which leg they would use to kick a ball.

Equipment

The vibration apparatus was a Power-Plate Pro 5 Airdaptive (Power-Plate North America, Northbrook, IL). The vibration device platform is approximately 54 cm × 77 cm × 32 cm with a total mass of 158 kg. The vibrations were set at the

lowest displacement setting (2 mm) with a 30-Hz vibration frequency. The instrument characteristics were similar to those presented previously.³ The 30-Hz frequency was chosen as a part of the range of frequencies that cause inhibitory effects on the monosynaptic stretch reflex.¹⁵ These characteristics resulted in a peak acceleration of 3.62 g with a root mean square (RMS) of 2.56 g. A 3.2-cm gymnastics mat was placed on the floor under the gymnast while he was performing his forward split positions on the vibration device. A 2.5-cm stiff rubber mat was placed on top of the vibration device's upper surface where the gymnast placed his forward heel or his rearward thigh of the split. The stiff rubber mat prevented skin injury of the gymnast due to the sandpaper-like material that was painted on the top surface of the vibration apparatus.

Outcome Measure

Flexibility. Measurement of the split position took place on a gymnastics mat with two wooden blocks placed at the side of the gymnast for hand placement and balance. The rear shin of the gymnast was placed vertically against a padded gymnastics block. These procedures have been described previously.³ A meter stick was used to measure the height from the floor of the anterior-superior iliac spine (ASIS) of the pelvis of the gymnast's rear leg while he performed a forward split. The same investigator palpated and measured the height of the ASIS for all trials. If the gymnast was flexible enough to get his ischial tuberosity on the mat, then his forward foot was raised on a 30-cm metal stool to ensure that the gymnast could not get completely down in the split position. When the stool was used, it was used for all test trials for the gymnast such that consistent test conditions were maintained across all trials.

Subsequent to the initial pain/force determination and recording for all four muscles, the athlete was measured for forward split flexibility. The athlete assumed a forward split position with his rear leg held vertically by a gymnastics padded block. The vertical rear leg places the rectus femoris muscle on stretch and helps restrict the athlete's ability to turn the pelvis toward the rear leg. This procedure is commonly used in gymnastics to help the gymnast maintain a "square" pelvis, which means that a line from left to right ASIS is as perpendicular as possible to the anterior/posterior lines of the legs of the forward split. Failure to use this technique provides an opportunity for the athlete to turn the pelvis dramatically and thus get lower by virtue of changing the split position from a forward/rearward emphasis to a more sideward emphasis. Once the gymnast was in the split position with the rear leg vertical, the same investigator palpated the ASIS and measured the height of the ASIS from the floor using a meter stick. The athlete then relaxed for a few moments and resumed the same position when the investigator repeated the measurement. Then the athlete switched to his other side split and the procedures were repeated for two more trials on the other side (Figure 1). Test order was randomized.

After the initial split test, the gymnast had one split randomly assigned to be the vibrated split and the other side split served as the control. The gymnast first adopted a forward split with one foot on top of the vibrating plate. The rear leg was placed behind the gymnast on the mat in a split posture (Figure 2). Following this, the athlete placed his rear thigh on top of the vibration platform in a lunge



Figure 1 — Test position; measuring the height of the anterior superior iliac spine.



Figure 2 — Split treatment; forward leg of the split on the vibration device.

position with the forward leg bent and foot flat on the floor while the rear leg rested on the vibration platform. The athlete was instructed to lean back during the stretching of the rear leg to emphasize hip hyperextension (Figure 3). The starting leg and condition were randomized. The vibration condition had the vibration platform turned on during the time when the forward and rearward leg of a particular side split was used. The control condition was performed in the same way except that the vibration platform was not turned on. All split positions were held for 45 seconds, with time being controlled by the vibration device. Following the vibration and nonvibration split stretching treatments, the athletes were again assessed for pressure-to-pain transition of the four muscles, and height of the ASIS in both forward splits was determined. All measurements were taken twice.

Pressure-to-Pain Threshold. The pressure-to-pain threshold was measured via an algometer (Force One, FDIX 50, Wagner Instruments, Greenwich, CT). The algometer is a handheld device with an integral load cell that transduces the pressure applied to the subject through a 0.11-cm-diameter round solid contact surface attached to the load cell. The algometer had a capacity of 222.4 N (50 lb), mass 0.4 kg, and dimensions of 70 mm × 100 mm × 30 mm. Sampling was set at 100



Figure 3 — Split treatment; rear leg on the vibration device with the gymnast leaning backward.

Hz. The accuracy and linearity of the algometer were tested by comparison with a small one-dimensional force platform (PASCO, CI-6461, Roseville, CA). The algometer was placed vertically and manually pressed against the center of the force platform. The force platform was set to sample at 100 Hz. Sampling was begun when the algometer was held in a still position. The correlation for the paired forces from the algometer and the force platform over 100 trials was $r = .99$, standard error of estimate = 0.32 N. The algometer was thereby considered to be both reliable and valid in that its linearity and comparability with another force-measuring device demonstrated both excellent linearity and low error.

The athletes were first measured for pressure-to-pain threshold on both thighs at a position approximately 10 cm proximal to the superior border of the patella over the vastus lateralis (VLO). The VLO was palpated before marking. The VLO is a single-joint muscle and was used as a control muscle to determine if there were pressure-to-pain perception changes from pre- to posttest using a muscle that was not likely to be stretched during the vibration-stretch treatments. A pen was used to mark the application point for consistent algometer placement. Then the athletes were turned and the posterior thigh was marked approximately 10 cm proximal to the posterior joint line of the knee on the biceps femoris (BF) muscle. The BF muscle was palpated before marking. The BF is a biarticular muscle that is stretched as a consequence of the split position of the forward leg.

Following marking, the athletes were instructed that the investigator was going to press on the marked areas with a small device that senses the amount of force being applied. The investigator would apply force slowly and smoothly while the athlete should concentrate on when the force applied by the investigator transitioned from a feeling of pressure to a feeling of pain. The athlete was therefore in complete control of how much force the investigator used and could terminate the application of force at any time. The investigator performed two trials in succession on each marked spot. There was a pause of approximately 30 s between algometer applications (Figure 4). None of the athletes reported undue discomfort and appeared to have no trouble in determining and announcing the transition from pressure to pain.

Pressure-to-pain threshold was not measured during the split itself due to the time constraints of gradually increasing the pressure placed on the skin by the algometer (initial work showed that this often took 5 to 10 s). Multiplying this time by four sites was too long for the stretch duration used in this protocol. Measuring the sites that faced the floor, or in the case of the rear thigh, which was placed on the vibration platform, precluded getting the algometer into any reasonable position for measurement during the split positions. Finally, the actual treatment of vibration and stretching results in pain when the athlete achieves his end point position. The application of the algometer with efforts to seek a pressure-to-pain threshold may have confused the athlete as to which pain he was supposed to perceive: an onset of pressure to pain versus the pain that was a normal part of stretching.

Procedures

Time Line. Athletes proceeded through data collection in the following way:

1. Reported to the laboratory for measurement.



Figure 4 — Algometer placement for vastus lateralis measurement.

2. Height, mass, age, training age, preferred split, and dominant leg determination.
3. VLO and BF were palpated bilaterally and marked.
4. Pretest, algometer measurements were taken of pressure-to-pain threshold.
5. Pretest, forward split measurements.
6. Random assignment of one side split to vibration and stretching treatment with the other side split assigned to stretching alone.
7. Application of vibration and or control treatments.
8. Posttest, algometer measurements were taken of pressure-to-pain threshold.
9. Posttest, forward split measurements.
10. End of session.

Analysis. Reliability was tested as trends across trials using Cronbach's alpha statistic. The means of the two trials were used for further data analyses. Difference scores between pre- and posttest forward split positions (vibrated vs nonvibrated) and the pain values were tested via matched pairs *t* tests. Effect size estimates¹⁶ and Pearson product-moment correlation coefficients were also calculated.

Reliability values ranged from 0.93 to 0.99 for all pairs of test trials including pressure-to-pain measurements and split measurements. These values indicate excellent reliability across trials. Absolute technical errors of measurement for pre- and posttest, vibrated and nonvibrated split measurements ranged from 1.5 to 0.6 cm, and the relative technical errors of measurement ranged from 2.2 to 6.2%. Absolute technical errors of measurement for the pressure-to-pain threshold

values of left and right, vibrated and nonvibrated BF and VLO ranged from 4.5 to 9.0 N, and the relative technical errors of measurement ranged from 9.3 to 16.4%.

Results

Split Range of Motion

Raw score values showed that the vibrated pre- (28.7 [7.0] cm) and posttests (20.8 [4.9] cm) and the nonvibrated pre- (28.4 [5.6] cm) and posttests (24.5 [5.0] cm) improved (vibrated difference = 7.9 [3.0] cm, $t = 8.4$, $P < .001$, 95% confidence interval 5.8 to 10.0 cm; nonvibrated difference = 3.9 [1.9] cm, $t = 6.4$, $P < .001$, 95% confidence interval 2.5 to 5.2 cm). The correlation between pretest and posttest vibrated splits was $r = .93$ and for nonvibrated splits was $r = .94$. Pre-post difference scores were determined between the vibrated split and the nonvibrated split and showed a statistically significant difference ($t = 5.24$, $P = .001$, 95% confidence interval of the difference 2.3 to 5.8 cm, Figure 5) indicating that vibration and stretching increased range of motion more than stretching alone. Effect size (d) was 0.47 indicating a moderate effect.¹⁶

Pressure-to-Pain Perception

Algometer force values showed that there was no difference between vibrated VLO (43.9 [14.78] N) or BF (55.1 [22.1] N) pressure-to-pain threshold and nonvibrated VLO (40.4 [13.3] N) or BF (55.2 [26.8] N) pressure-to-pain threshold (VLO = 3.43 [9.5] N, $t = 1.14$, $P = .28$, 95% confidence interval -3.34 to 10.20

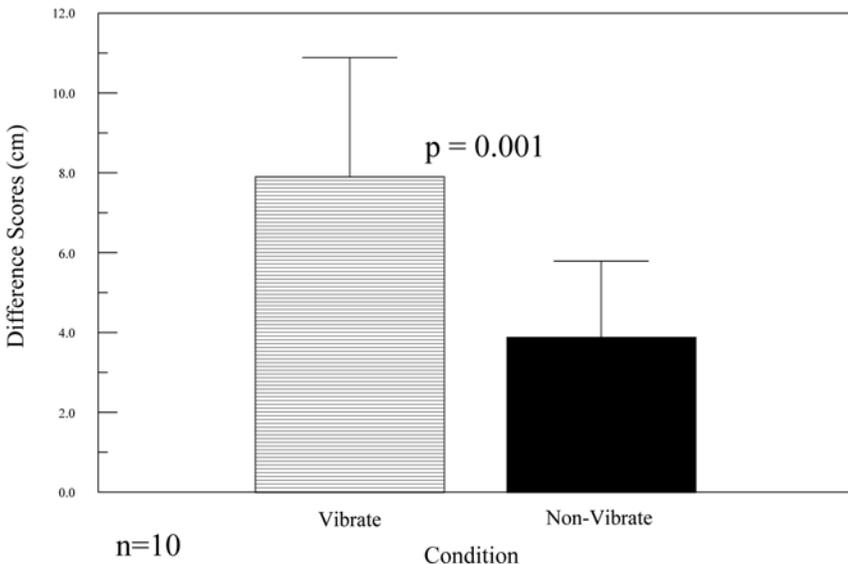


Figure 5 — Results of the change in split position from pretest to posttest.

cm, effect size (d) = 0.17; BF = -0.11 [8.5] N, t = -0.41, P = .97, 95% confidence interval -6.2 to 6.0 N, effect size (d) = 0.04). The correlation between pretest and posttest vibrated and nonvibrated VLO was r = .78, for the vibrated and nonvibrated BF the correlation was r = .96.¹⁶

Discussion

The change in range of motion as demonstrated by the split pre-post difference scores coincide with a growing body of literature.^{2-7,17} The ability to increase range of motion rapidly and relatively painlessly has not gone unnoticed by a variety of high-performance areas of sports: gymnastics,^{3,8} figure skating,⁴ and synchronized swimming.² The importance of vibration-induced enhancement of flexibility cannot be overstated. Several of the studies listed above were performed on elite athletes who have been stretching for years intending to increase their range of motion but rarely making progress beyond the first few years.^{1,18}

There is a paucity of literature on vibration and flexibility, vibration with flexibility applied to highly trained athletes, and vibration and flexibility applied to children. Moreover, it is doubtful that comparisons between whole-body vibration (WBV) and local, limb, muscle, or tendon vibration are universally valid. Atha and Wheatley¹⁹ used 15 minutes of 44 Hz and 0.1-mm displacement on the low back and hamstrings while subjects sat (ie, did not stretch) and concluded the vibration alone and static stretching alone were comparable in improving passive hip flexion range of motion. Issurin and colleagues performed one of the earliest studies of vibration with flexibility and strength.⁵ They used 44 Hz and 3-mm displacement vibrations applied for 6 to 7 s, with 3 to 4 s of rest two to four times via a vibrating ring suspended from a motor near the ceiling. Subjects placed their foot into the vibrating ring and performed stretching of the leg. The training period lasted 3 wk. The influence of this training on split flexibility was profound. Issurin and colleagues simply measured the distance between the feet in a forward split and found a 14.5-cm increase in the vibration condition, whereas the static stretching condition reached only 4.1 cm. In a study using WBV, changes in sit and reach flexibility were observed in female hockey players of 8.3% compared with a control condition of 5.3%.⁶

Investigators have posited several mechanisms for the improvement of flexibility via vibration. Issurin and colleagues⁵ and later Van den Tillaar²⁰ proposed three mechanisms that may explain the benefits of vibration for stretching: 1) increase in pain threshold, 2) increase in blood flow with commensurate increase in temperature, and 3) induced relaxation of the stretched muscle. To these should be added the simple idea that vibration may alter proprioception to such an extent that movement capabilities are changed. There is some evidence that vibration stimuli lead to an adaptive increased threshold in position sensors such as in the fingers and elsewhere.²¹ This may simply reset thresholds of motion and position mechanoreceptors, thus allowing the range of motion to increase.

Two additional potential mechanisms may be the reduction of phasic and static stretch reflexes resulting from the vibration.²² Bongiovanni and Hagbarth⁹ have proposed a different potential mechanism in intrafusal fiber fatigue, which could be caused by the vibration stimulation of the spindle within the extrafusal fibers. Following the application of vibration, a persisting after-discharge of

motoneurons that is indicative of reverberation of the interneuron pool may also account for some of the residual vibration sensation that the athletes often reported and a reduction in static stretch reflexes in the stretched muscle.²² In a study of vibration (90 Hz) of soleus and anterior tibialis muscles and stretch reflex short and medium latency reflex responses, Bove and colleagues²³ showed that short latency responses were affected more than medium latency responses, and after vibration the medium latency responses were even more reduced than the short latency responses. When the vibration frequency was reduced to 30 Hz, there was little effect on the short latency response, but the medium latency response was again significantly reduced. The authors concluded that the mechanisms were based on presynaptic inhibition of the group Ia afferent fibers or a “busy line” phenomenon that is created when both vibration stimulation and stretching influence the same Ia pathways.²⁴ Finally, the combination of a strong stretch stimulus and vibration may result in Golgi tendon organ activation via Ib pathways, resulting in autogenic inhibition of the vibrated muscle.

However, from a pragmatic standpoint, most athletes will indicate that the primary restriction to increased range of motion is the pain they encounter. Stretching is uncomfortable when the athlete places him- or herself in the extreme range of motion, and anything that can alleviate the pain associated with stretching may be beneficial for increasing range of motion. One of the mechanisms postulated for the increase in range of motion is a transient anesthesia brought on by vibration.^{10,25} Vibration has been shown to alleviate pain sensations, have no effect on pain, be frequency dependent with pain sensations, and vary by individual.²⁵ Vibration has been studied in the prevention of delayed onset muscle soreness (DOMS).²⁶ Together, these studies showed that muscle pain from exertion and pressure could be reduced by the application of vibration both before and after eccentric exercise leading to DOMS. This study sought to explore the relationship of pain with vibration and stretching by operationalizing pain as the pressure-to-pain threshold that could be measured using an algometer.

The lack of statistically significant results of the pre-post pressure-to-pain threshold differences may indicate a number of things: a) pressure-to-pain reduction did not occur; b) pressure-to-pain reduction may not be the mechanism involved in enhanced range of motion; c) although the effects of vibration are felt for several minutes following its application, the time window of pain reduction may have been exhausted before posttest measurement; d) the pain mechanism for stretching may be different than that measured by the algometer as the transition from pressure to pain. Pain reduction may not have happened or there may have been confusion between sensations of more superficial tissue (eg, skin and fascia) versus deeper muscle pain. The pain receptors for skin and for muscle arise from different afferent nerve fibers. Skin pain arises from group I and II afferent nerve fibers, whereas deep tissue pain comes from group III and Group IV afferents.²⁷ A study by Kosek, Ekholm, and Hansson²⁸ showed that skin sensitivity to pain may matter when using an algometer to determine the pressure-to-pain threshold. Future studies using the algometer to investigate pain may need to anesthetize the skin to prevent a confusion of sensations based on the pain source relative to the muscle tissue that is the target of stretching.²⁷

Although the effects of vibration are felt for several minutes following vibration application,²⁹ if there is a pressure-to-pain threshold reduction, it may not be

evident once the vibration stimulation ceases. The relatively short application of vibration used in this study (45 s) may not be long enough to induce pain reduction. For example, Lundeborg showed a reduction in pain sensations in subjects after a 30- to 45-min exposure to vibration.³⁰ The vibration frequency that best alleviates pain may be different from the 30 Hz used in this study. Again, Lundeborg showed that 50- to 150-Hz stimulation resulted in pain reduction.³⁰

Pain has been a particularly slippery concept to classify and measure.³¹ Pain has been described relative to its location (eg, shoulder pain), intensity (eg, sharp), duration (eg, chronic), and so forth. The pain of stretching may be different than the pressure-to-pain threshold.^{32,33} Individual variation in pain tolerance and perception tends to be high.³⁴ In this study, it is unlikely that a vibration-induced pressure-to-pain threshold reduction occurred based on the fact that neither the BF nor the VLO showed any difference in pressure-to-pain threshold. Or the pain reduction may have only occurred during the application of vibration while performing the split and disappeared upon standing and subsequent testing. These are largely speculations, however, because there is evidence that pain reduction continues after the application of vibration and at least some investigators have found that the 30-Hz stimulation used in this study did result in pain reduction.²⁹

Practical Applications

The information gained from this study adds further support to the idea that vibration applied to stretching activities can enhance stretching efforts. Vibration is a relatively simple idea and can be applied by a variety of devices. Reduction of pain, as investigated in this study (ie, pressure-to-pain threshold), may not be the primary mechanism on which range of motion gains depend, or future studies may demonstrate that pain or pressure-to-pain threshold inhibition is present only during the actual application of vibration and not following it.

Conclusion

The results of this study agreed with a growing body of literature that shows the effectiveness of vibration and stretching to improve range of motion. The secondary purpose of this study resulted in ambiguous results with no change in the pressure-to-pain threshold perception before and after vibration and stretching. The study of pain (including the pressure-to-pain threshold) is wrought with a number of methodological problems that make classification and measurement particularly difficult. Future research in this area will be needed to investigate more aspects of the influence of pain and pressure-to-pain threshold on stretching with and without vibration.

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