Flexibility Enhancement with Vibration: Acute and Long-Term

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ABSTRACT

SANDS, W. A., J. R. MCNEAL, M. H. STONE, E. M. RUSSELL, and M. JEMNI. Flexibility Enhancement with Vibration: Acute and Long-Term. *Med. Sci. Sports Exerc.*, Vol. 38, No. 4, pp. 720–725, 2006. **Introduction:** The most popular method of stretching is static stretching. Vibration may provide a means of enhancing range of motion beyond that of static stretching alone. **Purpose:** This study sought to observe the effects of vibration on static stretching to determine whether vibration-aided static stretching could enhance range of motion acquisition more than static stretching alone in the forward split position. **Methods:** Ten highly trained male volunteer gymnasts were randomly assigned to experimental ($N = 5$) and control ($N = 5$) groups. The test was a forward split with the rear knee flexed to prevent pelvic misalignment. Height of the anterior iliac spine of the pelvis was measured at the lowest split position. Athletes stretched forward and rearward legs to the point of discomfort for 10 s followed by 5 s of rest, repeated four times on each leg and split position (4 min total). The experimental group stretched with the device turned on; the control group stretched with the device turned off. A pretest was followed by an acute phase posttest, then a second posttest measurement was performed following 4 wk of treatment. Difference scores were analyzed. **Results:** The acute phase showed dramatic increases in forward split flexibility for both legs ($P < 0.05$), whereas the long-term test showed a statistically significant increase in range of motion on the right rear leg split only ($P < 0.05$). Effect sizes indicated large effects in all cases. **Conclusion:** This study showed that vibration can be a promising means of increasing range of motion beyond that obtained with static stretching in highly trained male gymnasts. **Key Words:** STRETCHING, SPLITS, GYMNASTICS, CHILDREN

Although flexibility has been considered one of the pillars of fitness characteristics, the actual role of flexibility in determining or enhancing performance in sports has been difficult to characterize (11). Some sports that require the athlete to achieve relatively large ranges of motion, and often the athlete's opportunity to win, are based on this ability. Sports such as artistic gymnastics, rhythmic gymnastics, trampoline, diving, synchronized swimming, figure skating, martial arts, and others rely heavily on the athlete's ability to achieve limb positions that are beyond the norm. Achieving these positions can be problematic for some young athletes, and the time required to accomplish them has been shown to be extensive (20).

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Submitted for publication June 2005.
Accepted for publication November 2005.

0195-9131/06/3804-0720/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/01.mss.0000210204.10200.dc

Flexibility has been defined as the range of motion about a joint or a related series of joints (20). Simple static stretching is the most popular means of enhancing flexibility (4). Stretching is categorized based on whether the stretching motion is performed statically or dynamically. Stretching has also been categorized based on how the range of motion is achieved, "active" or "passive" referring to whether the motion is achieved by agonist muscle tension or by inertia, gravity, or both (11). Flexibility has received recent attention based on a more modern understanding of the role of stretching and flexibility in injury prevention (22). Stretching has also been associated with an acute loss of maximal strength and power (16,21). This effect, however, may be ameliorated by activities following stretching that involve more rapid movements (24). Methods of enhancing range of motion beyond static and ballistic stretching, and more recently proprioceptive neuromuscular facilitation, have scarcely been addressed. Settings such as sport and physical therapy may benefit from methods that can enhance range of motion relatively quickly and easily.

Whole body vibration and local vibration have been investigated for some time in the context of the tonic

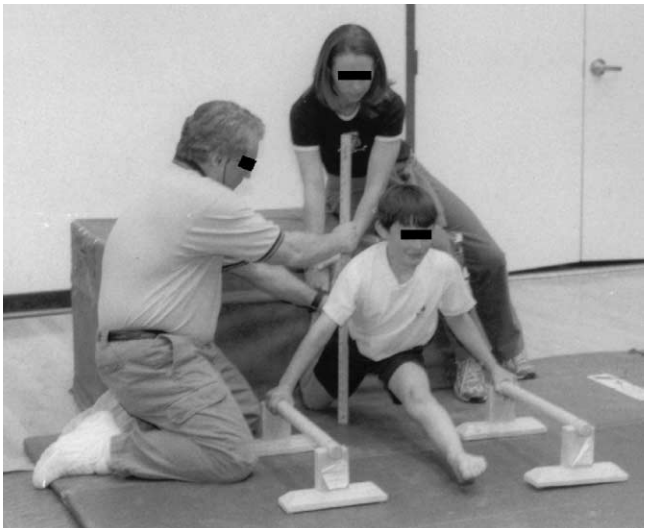

FIGURE 1—Test setup for split flexibility measurement.

vibration reflex, motor control, muscle tension, and strength development (13). The use of local vibration as a modality for increasing range of motion has been presented by only a few investigators (1,12). Only the Issurin et al. (12) study involved stretching during vibration. These studies, however, showed a promising means of enhancing flexibility. Issurin et al. (12) showed that physical education students who stretched during vibration could improve their range of motion in a simple split flexibility test. Atha and Wheatley (1) used vibration, but not during the actual stretching, to show that vibration alone was as good as, but not better than, static stretching in increasing range of motion.

This study was conducted to examine the acute and long-term influence of vibratory stimulation on forward split flexibility in young highly trained male gymnasts. Highly trained athletes who had accumulated months to years of experience with static stretching were important to this study in order to investigate whether the use of vibration would be applicable to this class of athletes. Acute and long-term effects were of interest because of pilot work that had shown startling acute effects and thus raised the question of whether the effects persisted beyond acute exposure.

METHODS

Subjects. Young male gymnasts (N = 10, age = 10.1 ± 1.5 yr, height = 136.2 ± 10.6 cm, mass = 31.8 ± 6.7 kg) participating in intensive gymnastics training (5 $\text{d}\cdot\text{wk}^{-1}$, 3–4 $\text{h}\cdot\text{d}^{-1}$) at the U.S. Olympic Training Center in Colorado Springs, CO, volunteered to serve as subjects. This study was approved by the human subjects research committee of Eastern Washington University, and all subjects and parents or guardians provided written informed consent or assent before participation.

Equipment. The vibration devices were custom built through the U.S. Olympic Committee, Sport Biomechanics and Engineering. Each device was 36 cm long by 24 cm wide by 22.4 cm tall and had a mass of 17.0 kg. The devices were designed to be floor units and consisted of a heavy base to which was attached an upper section that was vibrated by an electric motor with a shaft that included a weight that was attached in an off-center position. The resulting "wobble" of the motor and weight was transferred to the upper section and resulted in a sinusoidal vibration frequency of approximately 30 Hz and an approximate displacement of 2 mm. A 30-Hz vibration frequency is part of a range of frequencies that cause inhibitory effects on monosynaptic stretch reflexes (23). The frequency and displacement were confirmed by placing a magnetic motion sensor on the top surface of the upper section of the vibration device. (Liberty, Polhemus, Inc., Colchester, VT). The sensor provided vertical displacement information that was sampled at 240 Hz and stored via AMM 3D software (Advanced Motion Measurement, LLC, Phoenix, AZ). The devices' vibrational movements were also recorded via a NAC high-speed video unit (Instrumentation Marketing, Burbank, CA) at 200 Hz. A meter stick was placed near the top edge with close-up video images showing the vertical excursions of the top surface of the vibrating upper section. The frequency and displacement values above represent unloaded values and some variation owing to damping that resulted from the gymnasts' limbs on the device is likely to have occurred during actual use.

Procedures—acute study. The athletes were randomly assigned to experimental (N = 5) and control (N = 5) groups. The entire group (N = 10) represented the entire accessible team of these athletes. The athletes participated in their standard team warm-up consisting of calisthenic exercises, walking, jogging, light stretching, and some basic tumbling. Following this preparation, the athletes had their height, mass, and birth date recorded.

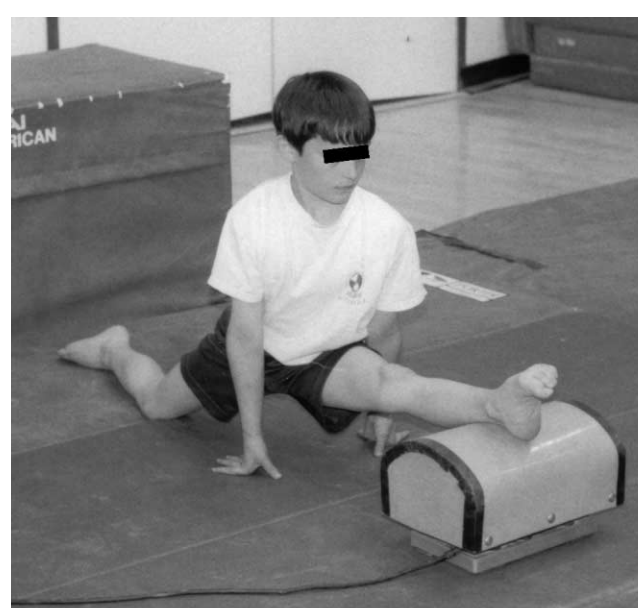

FIGURE 2—Forward split stretching position on the vibration device. The targeted leg in this position is the forward leg.

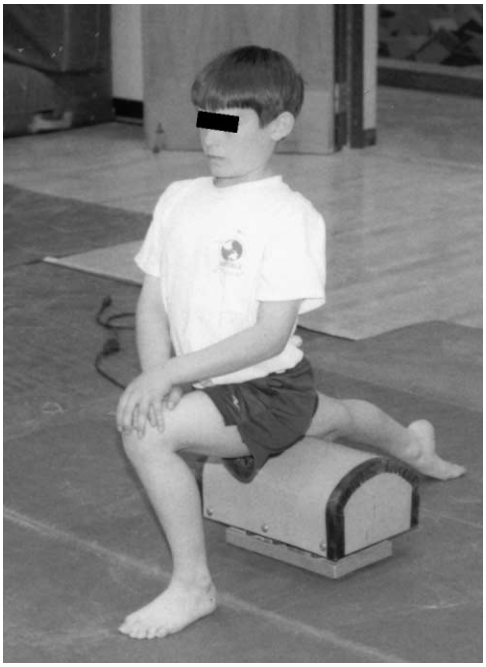

FIGURE 3—Forward split stretching position on the vibration device. The targeted leg in this position is the rear leg. Note that the gymnast was encouraged to "lean back" in this position to emphasize stretching of the anterior thigh.

The Beighton et al. (2) joint laxity test was administered to assess initial joint laxity and to determine initial similarity of the two groups. Then, all athletes were initially tested in a forward split as shown in (Fig. 1). The test consisted of adopting a forward split position with the rear leg flexed at the knee and the shank held vertically against a matted block. This test is modified from the original forward split test used in the Talent Opportunity Program of USA Gymnastics (19) in women's gymnastics in order to reduce "cheating" in the split position. The ideal position for a forward split has the pelvis aligned perpendicularly to each leg so that flexion of the forward thigh and hyperextension of the rear thigh occurs in the sagittal plane relative to the frontal plane of the pelvis (18). By placing the rear knee in flexion against the matted block, the gymnast is less likely to cheat in the forward split position by allowing his pelvis to turn toward the rear leg.

After the athlete adopted the test position and descended to the limit of his self-selected level of discomfort, a measurement was taken of the height of the anterior superior iliac spine via palpation and comparison with a vertical meter stick. The lower the anterior superior iliac spine, the lower the split and the better the performance. Each split was performed in random order and two trials of each position were recorded with a brief rest between each trial. All athletes were able to achieve the test position and remain there while a measurement was obtained.

Following the initial forward split measurements, the athletes were then instructed to perform forward split stretching on the vibration devices in two positions. The first position has the athlete place his forward leg on the vibrating device such that the posterior calf area is supported by the device (Fig. 2). The second position has the gymnast assume a lunge position with the rear thigh directly on top of the vibrating device (Fig. 3). The protocol consisted of each athlete stretching to the point of discomfort for 10 s followed by 5 s of rest. The rest position involved simply rising a few inches from the lowest split position to relieve most of the discomfort of the split. However, the gymnast was still in a stretched position. This was repeated four times to result in 1 min of total stretching in each position (i.e., left and right, forward leg and rearward leg), totaling 4 min for one complete stretching session. Athletes counted out loud with assistance from the investigator and coach to measure time. Simple counting was chosen because of the youth of the subjects and the fact that their training situation would generally not permit strict stopwatch-like timing in the following long-term study. Experimental group athletes stretched with the vibration device turned on, whereas the control group performed the same stretching with the vibration device turned off.

The athletes performed a single stretching bout in their assigned group conditions. Following the initial stretching bouts, the athletes were retested for acute effects in both left and right forward splits in the positions described above.

Procedures—long-term study. The pretest for the acute study served as the pretest for the long-term study. The long-term study consisted of the athletes performing the same stretching protocol as described in the acute study in their respective groups for 4 wk. The athletes trained 5 $d \cdot wk^{-1}$, with attendance and compliance during each stretching session recorded by the head coach. Table 1 shows the descriptive statistics of attendance. Following the 4 wk of training, the athletes were retested in the forward split, repeating the protocol of the pretest. No vibration or other stretching treatment other than their standard warm-up was undertaken before posttest measurements.

Analysis. The direction of the split (left or right) for the present study was defined by the rear leg in the split

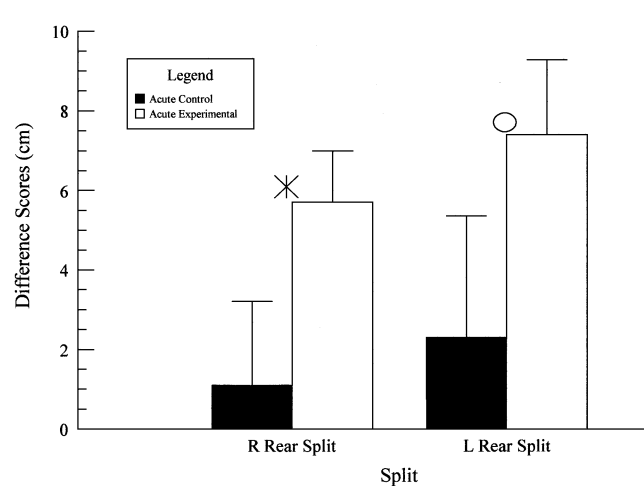

FIGURE 4—Acute phase difference scores. The calculated difference scores for both the right rear split and the left rear split showed statistical significance. * $P < 0.01$; O, $P < 0.05$.

TABLE 1. Descriptive statistics of experimental and control groups.

Test	Variable	Group	Mean (± SD)
Pretest	Age (yr)	Control	10.2 (2.2)
		Experimental	10.0 (0.7)
	Height (cm)	Control	137.5 (12.8)
		Experimental	134.9 (9.1)
	Mass (kg)	Control	33.3 (9.2)
		Experimental	30.3 (3.5)
	Beighton (Score)	Control	4.2 (1.6)
		Experimental	4.8 (2.3)
	Attendance (d)	Control	14.4 (1.9)
		Experimental	14.0 (1.2)
Posttest	Height (cm)	Control	137.6 (13.2)
		Experimental	135.8 (8.7)
	Mass (kg)	Control	33.2 (8.5)
		Experimental	30.5 (3.3)

position. This study was considered exploratory because of the small number of subjects available with the desired characteristics and the paucity of similar investigations. This was a combination of an acute and long-term pretest, posttest, control group design. Descriptive statistics, reliability analysis, Pearson product–moment correlation coefficients, and matched-pairs *t*-tests based on difference scores between pretest and posttest were calculated. Means of the two test trials were used for further data reduction and analysis. Statistical significance was set at $P < 0.05$. Statistical effect size (d) and statistical power at alpha = 0.05 (p_s) were also determined (9).

RESULTS

(Table 1) shows descriptive information relative to the experimental and control groups from the pretest and the long-term posttest. Note that no statistically significant differences existed between groups on any of the variables listed (all $P > 0.50$). Initial split scores were also not statistically different between groups ($P > 0.05$).

Acute study. Trials reliability of the acute study showed intraclass correlation coefficients of 0.98 or above for both splits in pretest and posttest conditions. The relative technical errors of measurement ranged from 2.7 to 4.3% (www.sportsci.org/resource/stats/precision.html).

Figure 4 shows the results of the pre–post difference scores for the acute phase of the study. The effect size for the acute phase right rear split was d = 2.19, and statistical power was $p_s > 0.84$. The effect size for the acute phase left rear split was d = 1.67, and statistical power was $p_s > 0.84$. The effect size was considered large in both split tests (9). Using all 10 subjects, Pearson product–moment correlation coefficients between left and right splits were r = 0.92 ($P < 0.01$) in the pretest and r = 0.90 ($P < 0.01$) in the posttest . The correlation between the pretest right split and the posttest right split was r = 0.73 ($P < 0.05$), and the left split correlation between pre- and posttest was r = 0.69 ($P < 0.05$). All effect sizes for the correlation values are considered large (9).

Long-term study. Trials reliability of the posttest following the 4 wk of training showed intraclass correlation coefficients of 0.98 for both right and left rear leg splits. The long-term posttest relative technical errors of measurement were 4.3 and 4.2% for the right rear and left rear leg splits, respectively.

The long-term study difference score results are shown in (Fig. 5). The right rear split showed a statistical difference ($P < 0.05$), whereas the left rear leg split did not ($P > 0.05$). The effect size for the right rear split was d = 1.37, and statistical power was $p_s \approx 1.4$. The effect size of the left rear split was d = 0.84, and statistical power was $p_s \approx 0.40$. Again, both effect size values were considered large (9). Using all 10 subjects, Pearson product–moment correlation coefficients were calculated between the pretest and the long-term posttest. The correlation between the pretest and posttest right rear split was r = 0.87 ($P < 0.01$), and the correlation for the left rear split was r = 0.52 ($P > 0.05$). The effect sizes that correspond to these correlation values are considered large (9).

DISCUSSION

This study investigated the potential acute and long-term effects of low frequency vibration stimuli on the forward split range of motion of highly trained young male gymnasts. The selection of highly trained gymnasts was based on the desire to determine whether vibration training could enhance range of motion in athletes who were accustomed to intense flexibility training and had participated in static stretching for periods ranging from months to years before the investigation. This approach presented a challenge to the experiment because many of the athletes had achieved a state where, according to their coach, their improvements in range of motion were trivial or non-existent.

The acute effects of the vibration treatment resulted in immediate and startling increases in range of motion (Fig. 4). The long-term effects showed that one split side reached statistical significance, whereas the other did not (Fig. 5). The lack of statistical significance on one side during the long-term posttest may result from the increased

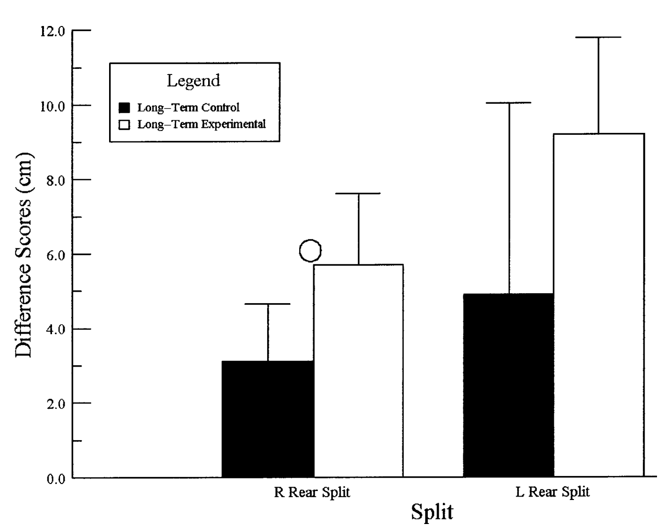

FIGURE 5—Chronic phase difference scores. The right rear split showed a statistically significant difference, whereas the left rear split did not. *Open circle*, $P < 0.05$.

variability of the splits observed in the control group. The trends and the effect sizes for the long-term study, however, speak to a promising means of increasing range of motion and deserve further study. Moreover, the ability to increase range of motion in the already highly trained elite athlete has resulted in rapid adoption of the technology into training at the Olympic Training Center among all gymnasts and other athletic groups such as synchronized swimmers. Finally, no deleterious effects were noted throughout the study or since.

Although an abundance of literature is found regarding vibration effects on humans and animals, most studies have incorporated whole body vibration such as experienced while standing or squatting on a vibrating plate, or studies of local vibration with the intent to study tension development, the tonic vibration reflex, motor control, and strength and power development. Little research effort has been directed at the influence of vibration on stretching and flexibility enhancement.

Atha and Wheatley (1) performed an acute effects study with similar objectives as the acute study here, showing that 15 min of locally applied vibration at 44 Hz with an approximate displacement of 0.1 mm resulted in similar short-term improvements in flexion range of motion of the hip and low back (sit and reach test) as static stretching. Both the stretching condition and the vibration condition improved hip flexion range of motion over the control condition involving no exercise. Vibration was applied by placing vibrating cushions on the hamstring area and low back, but the subjects were not vibrated while stretching. The magnitudes of the changes in sit and reach scores were approximately 0.9 cm in both experimental conditions. The authors concluded that vibration and static stretching were similar in their ability to improve hip flexion range of motion.

Issurin et al. (5,12) provided two reports that had similar objectives as the long-term study described here. They used vibration (44 Hz and 3-mm displacement) as a means of enhancing both strength and range of motion in male physical education students. The subjects stretched during the application of vibration by placing their foot on to a ring suspended from an overhead vibrating device. The vibrating ring provided the stimulation for the leg in the ring while the subject stretched the leg. The training period was 3 wk, and the protocol for stretching was similar to that used in the present study. The subjects placed their foot on to the ring and stretched for 6–7 s, which was followed by 3–4 s of rest, and this was repeated two to four times. The subjects also performed static stretching exercises with the same parameters as the vibration stretching. The increase in split range of motion (distance between the feet) was 14.5 cm (pretest 166.75 ± 12.05 cm, posttest 181.25 ± 8.66 cm) in the vibration condition, whereas the traditional stretching condition resulted in a 4.1-cm improvement (pretest 171.63 ± 7.67 cm, posttest 175.81 ± 7.71 cm).

Issurin et al. (12) proposed three potential mechanisms that may explain the benefits of vibration for stretching: (a) increase in pain threshold, (b) increase in blood flow with a commensurate increase in temperature, and (c) induced relaxation of the stretched muscle. It has been argued that static stretching should take place with exercises performed in a position that is at, or just below, the subject's pain threshold (4). Painful stimuli from stretching are common, however, in those sports that involve serious stretching and extreme ranges of motion. Therefore, a reduction in pain might allow the subject to proceed to greater ranges of motion before pain stops progress. Although vibration has been shown to reduce pain sensations (15,17), the frequency required may be higher than that used in this study. Pantaleo et al. (17) showed that vibration at 110 Hz resulted in a reduction in pain sensation, whereas vibration at 30 Hz failed to reduce pain sensations. A series of studies by Lundeberg et al. (15), however, showed that relatively low-frequency vibration also reduced pain.

Vibration-induced blood flow changes have been documented. Vibration has been thought to decrease blood flow based on ergonomic situations usually involving prolonged standing (14). However, increases in heart rate, fluid volume, blood flow velocity, and blood pressure have been noted from vibration stimuli (14). Collectively, these may account for an increase in overall blood flow and local muscle temperature. Increased temperature of muscle has been linked to increased muscle extensibility (10).

Anecdotally, the investigators observed that the gymnasts commonly performed their splits after the vibration treatment by descending to where they would normally stop because of reaching their accustomed range of motion limits, but then to their surprise they were able to descend farther without the accustomed discomfort. The athletes ultimately reached a point in their descent where pain became noticeable and the range of motion reached its limits. This may be because of the reduction of phasic and static stretch reflexes from the vibration (3). Bongiovanni and Hagbarth (5) 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 (3). In a study of vibration (90 Hz) of soleus and anterior tibialis muscles and stretch reflex short- and medium-latency reflex responses, Bove et al. (6) 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, little effect was seen 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 (8). 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.

The relaxation effect brought on by vibration has been described by several investigators (23). At least one investigator, however, found no effect from 4 min of vibration massage on recovery from short-term fatigue (7). The relaxation effect from vibration results in a paradox that is based on the feelings of relaxation in conjunction with tension caused by the TVR. As presented previously, the tension level created by the TVR is small and may not be a significant factor in permitting most of the muscle to relax nor overwhelm the effects of reduced short- and medium-latency stretch reflexes.

The present study has shown that there may be a promising use of vibration in the enhancement of flexibility in acute and long-term training. Future research should address the role of vibration in the mechanisms of range of motion enhancement. Considerable research has been performed on the use of whole body vibration on strength and power with mixed results (13). Flexibility enhancement investigations have lagged behind those involving strength and power. Thus, an area of application of vibration appears to exist that may offer training, rehabilitation, and recovery benefits that have been left largely untouched. Vibration effects on range of motion enhancement are incompletely understood and may provide a window into further understanding of the role of muscles spindles, Golgi tendon organs, the importance of higher central nervous system influence on polysynaptic reflexes, and other aspects of motor control.

This study was supported by funding from the U.S. Elite Coaches Association for Women's Gymnastics.

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