Vibration and Stretching Effects on Flexibility and Explosive Strength in Young Gymnasts

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ABSTRACT

KINSEY, A. M., M. W. RAMSEY, H. S. O’BRYANT, C. A. AYRES, W. A. SANDS, and M. H. STONE. Vibration and Stretching Effects on Flexibility and Explosive Strength in Young Gymnasts. Med. Sci. Sports Exerc., Vol. 40, No. 1, pp. 133–140, 2008. Purpose: Effects of simultaneous vibration–stretching on flexibility and explosive strength in competitive female gymnasts were examined. Methods: Twenty-two female athletes (age = 11.3 ± 2.6 yr; body mass = 35.3 ± 11.6 kg; competitive levels = 3–9) composed the simultaneous vibration–stretching (VS) group, which performed both tests. Flexibility testing control groups were stretching-only (SF) (N = 7) and vibration-only (VF) (N = 8). Explosive strength-control groups were stretching-only (SES) (N = 8) and vibration-only (VES) (N = 7). Vibration (30 Hz, 2-mm displacement) was applied to four sites, four times for 10 s, with 5 s of rest in between. Right and left forward-split (RFS and LFS) flexibility was measured by the distance between the ground and the anterior suprailiac spine. A force plate (sampling rate, 1000 Hz) recorded countermovement and static jump characteristics. Explosive strength variables included flight time, jump height, peak force, instantaneous forces, and rates of force development. Data were analyzed using Bonferroni adjusted paired t-tests. Results: VS had statistically increased flexibility (P) and large effect sizes (d) in both the RFS (P = 1.28 × 10^-7, d = 0.67) and LFS (P = 2.35 × 10^-7, d = 0.72). VS had statistically different results of favored (FL) (P = 4.67 × 10^-8, d = 0.78) and nonfavored (NFL) (P = 7.97 × 10^-10, d = 0.65) legs. VF resulted in statistical increases in flexibility and medium d on RFS (P = 6.98 × 10^-3, d = 0.25) and statistically increased flexibility on VF NFL flexibility (P = 0.002, d = 0.31). SF had no statistical difference between measures and small d. For explosive strength, there were no statistical differences in variables in the VS, SES, and VES for the pre- versus posttreatment tests. Conclusions: Simultaneous vibration and stretching may greatly increase flexibility while not altering explosive strength. Key Words: VERTICAL JUMP, GYMNASTICS, RATE OF FORCE DEVELOPMENT, PEAK FORCE

There is little doubt that range of motion (ROM)/flexibility is an important component of fitness for development of many athletes, particularly gymnasts. Stretching is a common and useful method for increasing flexibility. Although stretching is an integral part of gymnastics and many other sports, there can be some drawbacks to its use (12,24).

Acute stretching as part of a warm-up, particularly slow and static stretching, can cause a loss of maximum strength, rate of force development, power, and explosive performance (24). This creates a dilemma for gymnasts in that stretching during warm-up is not only a tradition, but it may help the athlete achieve difficult positions during subsequent performance. However, the potential stretching-induced decrease in explosiveness could reduce performance capabilities. Thus, a warm-up method that would allow ROM enhancement while enhancing or at least not limiting explosiveness would be quite applicable.

Recent research dealing with the use of vibration as part of warm-up has indicated that forward-split flexibility among male gymnasts can be markedly enhanced (20). Vibration–stretching has also been shown to increase ROM in the shoulder joint of male gymnasts (15). There are some data indicating that vibration may enhance measures of explosiveness (18). Furthermore, muscles with increased muscle length or tension are most affected by vibration (17). Therefore, it may be advantageous to use a combination of vibration and stretching as part of the warm-up for gymnasts, thus enhancing ROM and preserving or enhancing explosive performance (24).

The forward-split (one leg is flexed forward at the hip while the other leg is hyperextended rearward at the hip) is a movement/position commonly assumed by gymnasts during various portions of their routines. Enhancing ROM for this position would be advantageous to gymnastic performance. Additionally, various types of jumping movements are regularly performed during gymnastic routines. These jumps largely depend on the ability of the athlete to express...
explosive strength (23). Explosive strength is defined as the ability of the neuromuscular system to produce dynamic force rapidly in an open kinetic-chain movement, such as jumping, in which rate of force development is at or near maximum (22). The key element of explosive strength is rate of force development—the ratio of force development to time, which is related to acceleration and expressed in newtons per second. Static jumps (SJ) are a purely concentric movement related to the capability of the contractile elements. SJ may be a good monitoring measure for athletes who generally perform a movement without an eccentric phase like cyclists. Countermovement jumps (CMJ) contain an eccentric and concentric phase that constitute a stretch-shortening cycle (SSC), and they are associated with many dynamic movements, including running, bounding, and tumbling. CMJ depend both on contractile elements and elastic properties of the muscle and connective tissue.

The enhancement or preservation of explosiveness after a warm-up containing a stretching element would be an advantage for the gymnast during a subsequent performance. Several studies and reviews have indicated that performance enhancement, including force production, may be achieved by acute local vibration effects (10,13,14). Chronic enhancement is also possible. One study (N = 28) reported that in a male athletic population, localized vibration (44 Hz, 3-mm amplitude) repetitively applied through cables during exercise for several weeks resulted in maximal dynamic force enhancement (9). Although exact mechanisms for these observations are unclear, possible mechanisms of increased performance with vibration have been speculated to include the neuromotor tonic vibration reflex (8,9), increased fiber conduction speed (14), and increased efficiency of motor unit recruitment (11).

The purpose of this study was to examine the effects of simultaneous stretching and vibration on forward-split flexibility and explosive force as measured by vertical jump in competitive female gymnasts. This study was designed to be cross-sectional and hypothesis generating. Previous observations with limited subject numbers indicated that stretching with direct muscle vibration would enhance flexibility while preserving explosive force. This study was designed to verify that observation.

**METHODS**

Methods of research were approved by the institutional review board of East Tennessee State University. Participants were all volunteers. Before testing, parental written consent and child assent documents pertaining to test procedures were signed and collected from participants and guardians. There was one experimental vibration–stretching (VS) group (N = 22) that performed two tests: 1) flexibility and 2) jumping. Leg favoritism/dominance was specified by the rear leg in the forward-split position (20).

There were four control groups whose constituents were subpopulations of the VS group. These four control groups consisted of SF: stretching without vibration–flexibility testing (N = 7); VF: vibration without stretching–flexibility testing (N = 8); SES: stretching without vibration–explosive strength (jump) testing (N = 8); and VES: vibration without stretching–explosive strength (jump) testing (N = 7).

The research design used a counterbalanced procedure for the VS group. Data were collected on two consecutive days: body composition factors were measured the first day, and then athletes were randomly assigned so that half performed the stretching test on day 1 and half performed the jumping test. These groups were then switched for day 2 so that the athletes were not involved in the same testing twice. Jumping test procedures alternately assigned athletes to perform SJ or CMJ first, keeping the jumping sequence constant before and after treatment.

The research design for controls was counterbalanced, and data were collected on four separate days. Test days 1 and 3 involved the stretching–without-vibration protocol, whereas test days 2 and 4 involved vibration without stretching. There was a 7-d period between same-treatment administrations. Athletes were randomly assigned to the flexibility or jump test on day 1, and then they performed the opposite test on day 2, with the opposite treatment. This was switched on days 3 and 4 so that no one would repeat the same protocol and test. Values hereafter are expressed as group mean ± standard deviation (SD).

**Participant athletes.** All athletes were competitive female gymnasts from two different gymnastics clubs. The VS group contained 22 athletes (age 11.3 (± 2.6) yr) who had trained for 5.5 (± 2.7) yr and competed for 2.4 (± 1.6) yr in gymnastics at competitive levels 3–9, mode level 4, at the time of the study. The control groups were composed of eight athletes (age 10.6 (± 2.2) yr) who had trained for 5.0 (± 3.1) yr and competed for 2.1 (± 1.3) yr at the time of the study in gymnastics at competitive levels 4–9, mode level 4 (25). However, on two test days, only seven of the eight athletes in the control groups were present to participate in the testing; thus, the SF and VES groups only contained seven participants.

**Anthropometric measures.** Physical characteristics including height, mass, body fat percentage, and skinfold measures were recorded on test day 1. Body mass and body fat percentage data were measured using a standing Tanita Bioelectric Impedance Analyzer: BF-350 (Arlington Heights, IL). Conductance electrodes were cleaned and dried before each use. Skinfold measures were taken at two sites, the triceps and thigh, using Lange skinfold calipers (Beta Technology Inc., Cambridge, MD). Height was measured with a portable, custom-made stadiometer fitted with Luufkin (Cooper Industries Inc., Raleigh, NC) steel tape (model Y125).

**Vibration equipment and protocol.** The vibration equipment consisted of two vibrating units, each with a mass of 15.00 (± 0.13) kg, and dimensions of 33.6-cm length, 22.8-cm height, and 22.8-cm width. These devices had a fixed base with superimposed, vibrating, upper casing-structure.
Vibration frequency was 30 Hz, with a mean displacement of upper casing-structure of approximately 2 mm (20).

The vibration–stretching protocol was based on a protocol from a previous study (20); it consisted of 10 s of vibration–stretching with 5 s of rest in between, at four sites, for four repetitions, in a vertically loaded/cyclic manner. Each athlete went through all four sites and then repeated the same order three more times, with proper exposure and rest between each site. Stretching was performed to the point of discomfort. VS group athletes were in the forward-split position and stretching while vibrating. The sites included posterior forward lower leg on the vibration device while in position and the rearward anterior thigh on the vibrating device while in position. Athletes had been familiarized with the tests and positioning on the device 1 wk before testing (20).

The control groups’ timing/rest protocol did not differ from the stretch–vibration protocol. Control group athletes were familiar with the proper positioning and device. The SF protocol assumed the same positions as shown in Figures 1 and 2, but the vibration device was not oscillating. Athletes in the VF group targeted the vibration to the Achilles sites by sitting, relaxed, on a pad, with the legs draped over the vibration device, with proper contact points of the anterior lower leg on the device. Athletes were instructed to place ample body weight on the vibration device. Anterior thigh sites were targeted by athletes kneeling/lying over the vibration device and resting the upper body on a pad, relaxed and comfortable. These positions targeted both legs at the same time as shown in Figures 3 and 4. The same exposure and rest intervals were used, but both legs were exposed to vibration simultaneously, shortening the overall treatment time.

Flexibility measures. Gymnasts’ flexibility variables were measured before and after the vibration–stretching protocol. In a forward-split position, with the rear lower leg
and foot perpendicular to the ground (assisting hip alignment), the distance between the ground and ASIS was measured (Fig. 5). The reliability for the flexibility tests (trial 1 vs trial 2) was excellent. ICCα for flexibility was VS R = 0.97, SF R = 0.93, and VF R = 0.93. Pre- versus post flexibility tests had small to medium effect sizes (Table 1).

**Vertical jump measures.** Using a portable force-plate with a sampling rate of 1000 Hz and LabView 8.0 (National Instruments, Austin, TX) software, CMJ and SJ were recorded. Vertical jump height was calculated from flight times; the relationship of take-off to landing center-of-mass heights by this method has been shown to differ by only 2% (3). All jumps were performed using a hands-on-hips technique. SJ involved the gymnasts assuming a 90° knee-bend position, (as measured by a handheld goniometer) holding for three counts, and jumping. The CMJ began in an upright position, had no pause, and was one, fluid, jumping movement. Depth for the eccentric portion of the CMJ was self-selected. Two trials of each jump were recorded consecutively after one practice jump was performed, and the averages of the two trials were used in data analysis. The reliability for jump characteristics (trial 1 vs trial 2) was good to excellent. Mean ICCα for jump height was VS R = 0.87, SES R = 0.82, and VES R = 0.79. Mean ICCα for flight time was VS R = 0.86, SES R = 0.81, and VES R = 0.79. Mean ICCα for peak force was VS R = 0.89, SES R = 0.95, and VES R = 0.93.

For analyses of the CMJ, time zero for both the instantaneous force calculations and the rate of force development calculations was set at the end of the unloading phase as designated by the trough of the counter-movement of the force–time curve. Time zero for the same measures of the SJ was set immediately before the initial rise in force on the force–time curve. Peak force, instantaneous forces, and rates of force development over intervals of the jumps were analyzed from the force–time curve.

**Statistical analysis.** Data were analyzed using the Statistical Package for the Social Sciences version 13.0. Reliability for flexibility measures and jump trials was determined using Cronbach’s alpha (ICCα). Analyses of group differences were determined using effect size and t-tests. Analyses included differences in preferred and split-leg positions when stretching. The forward-split position as well as the preferred leg was designated by the rearward leg in the position. Effect sizes are statistics that measure the magnitude of an effect independent of sample size. Cohen’s effect sizes (d) were measured by the formula:

\[
\text{Cohen's } d = \frac{M_1 - M_2}{\sigma_{\text{pooled}}} = \sqrt{\frac{(\sigma_1^2 + \sigma_2^2)/2}{n}}
\]

Small effect sizes are considered \( d \leq 0.2 \), moderate effect sizes are \( 0.2 < d < 0.8 \), and large effect sizes are \( d \geq 0.8 \) (5). Statistical differences between means were determined by Bonferroni adjusted paired t-tests \( (P \leq 0.05) \). t-test values

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**TABLE 1. Flexibility results.**

<table>
<thead>
<tr>
<th>Group</th>
<th>Test</th>
<th>Trial</th>
<th>Mean Height (cm)</th>
<th>Effect Size (d)</th>
<th>t-Test (P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VS (N = 22)</td>
<td>Right forward-split</td>
<td>Pre vibration-stretching</td>
<td>26.2 ± 7.1</td>
<td>0.67</td>
<td>1.28 × 10−7*</td>
</tr>
<tr>
<td>VS (N = 22)</td>
<td>Left forward-split</td>
<td>Pre vibration-stretching</td>
<td>27.5 ± 7.1</td>
<td>0.72</td>
<td>2.35 × 10−7*</td>
</tr>
<tr>
<td>SF (N = 7)</td>
<td>Right forward-split</td>
<td>Pre stretch-no vibration</td>
<td>19.4 ± 5.0</td>
<td>0.08</td>
<td>2.49 × 10−3</td>
</tr>
<tr>
<td>SF (N = 7)</td>
<td>Left forward-split</td>
<td>Pre stretch-no vibration</td>
<td>20.3 ± 5.4</td>
<td>0.05</td>
<td>6.37 × 10−1</td>
</tr>
<tr>
<td>VF (N = 8)</td>
<td>Right forward-split</td>
<td>Pre vibration-no stretch</td>
<td>20.2 ± 6.8</td>
<td>0.25</td>
<td>6.98 × 10−2*</td>
</tr>
<tr>
<td>VF (N = 8)</td>
<td>Left forward-split</td>
<td>Pre vibration-no stretch</td>
<td>18.5 ± 6.7</td>
<td>0.30</td>
<td>2.6 × 10−1</td>
</tr>
</tbody>
</table>

* Statistically different before vs after treatment (Bonferroni adjusted P value). Table 1 (mean ± SD) represents results of the flexibility tests from all groups: vibration-stretching (VS), stretching-only (SF), and vibration-only (VF).
RESULTS

Anthropometric Measures

**VS group.** The VS group body mass was 35.3 (± 11.6) kg, height was 138.5 (± 15.0) cm, and BMI was 17.6 (± 3.4). Skinfold data revealed a triceps mean of 7.9 (± 2.8) mm and a thigh mean of 11.3 (± 4.1) mm. Bioelectric impedance of the athletes showed a mean body fat percentage of 16.1 (± 8.9). Nine members of the VS group were left-leg dominant, and 13 were right-leg dominant.

**Control groups.** Body composition measures of the control group were body mass 34.6 (± 11.1) kg, height 135.9 (± 15.2) cm, and BMI 18.2 (± 2.5). Skinfold data revealed triceps measures of 9.1 (± 2.9) mm and thigh measure of 12.8 (± 3.9) mm. Bioelectric impedance of the athletes showed a mean body fat percentage of 16.0 (± 7.4). The athletes (N = 8) were 10.6 (± 2.2) yr old, had trained for 5.0 (± 3.1) yr, and had competed for 2.1 (± 1.3) yr at gymnastics competitive levels 4–9, mode level 4. SF had four right-leg-dominant and three left-leg-dominant members. VF had four right-leg-dominant and four right-leg-dominant members.

Flexibility Tests

**Right forward-split test.** Vibration–stretching flexibility test measures resulted in greater right forward-split flexibility, ranging from 0.0 to 35.1%, with a group average increased flexibility of 18.6% (± 10.4%). SF flexibility test measures resulted in athlete’s right forward-split flexibility ranging from −6.1 to 8.6, with a group mean increased flexibility of 2.0% (± 4.8%). VF flexibility test measures resulted in individual’s right forward-split flexibility ranging from −1.3 to 19.4%, with a group average increase in flexibility of 9.1% (± 6.9%).

**Left forward-split test.** VS left forward-split flexibility increased from 7.1 to 43.4% of initial flexibility readings, with an average gain of 18.5% (± 7.8%). SF left forward-split flexibility increased from −10.5 to 7.4% of initial flexibility readings, with an average decreased flexibility of 1.9% (± 8.2%). VF left forward-split flexibility increases ranged from 0.0 to 34.3% of initial flexibility readings, with an average gain of 10.0% (± 11.4%).

**Favored-leg results.** Statistical analysis comparing favored legs with nonfavored legs in the VS group demonstrated increased flexibility in the favored leg, ranging from 2.5 to 43.4%, with an average increase in flexibility of 19.5% (± 9.5%) (Fig. 6). SF resulted in increased flexibility in the favored leg, ranging from a...
10.5% decrease in flexibility to an 8.6% increase, with an average increased flexibility of 0.2% (± 7.8%). VF demonstrated flexibility alterations in the favored leg, ranging from −1.3 to 34.3%, with an average increased flexibility of 9.8% (± 11.7%). Effect sizes were moderate in groups, with vibration as a component of treatment; effect size was small in the SF group: VS d = 0.78, SF d = 0.01, and VF d = 0.26.

**Non-favored-leg results.** VS non-favored-leg flexibility was altered from 0.0 to 34.1%, with an average increase in flexibility of 17.6% (± 8.8%). SF non-favored-leg flexibility was altered from −4.1 to 6.6%, with an average increase in flexibility of 0.3% (± 6.2%). VF non-favored-leg flexibility was altered from 1.03 to 18.18%, with an average increase in flexibility of 9.4% (± 6.4%). Effect sizes were moderate in groups, with vibration as a component of treatment, and were small in the SF group: VS d = 0.65, SF d = 0.01, and VF d = 0.31.

**Pre- versus posttest differences.** VS t-tests of mean measures resulted in statistically different increases in flexibility for both the favored and nonfavored legs (favored P = 4.67 × 10−8, nonfavored P = 7.97 × 10−10). SF t-tests of mean measures were not statistically different before versus after in flexibility for both the favored and nonfavored legs (favored P = 0.882, nonfavored P = 0.946). VF t-tests of mean measures resulted in statistically different flexibility for the favored leg (P = 0.050) because of the Bonferroni adjustment and statistically different flexibility of the nonfavored legs (P = 0.002).

**Explosive strength (jump) tests.** There were no statistical differences when comparing pre- and posttests of instantaneous forces (30, 50, 150, 200, and 250 ms), when comparing the rates of force development for intervals of 50 ms, and when comparing rates of force development pre- and posttests for six 50-ms intervals in all groups. Jump height, flight time, and peak force gave small effect sizes for VS and VES, and medium effect sizes for SES (Tables 2 and 3).

**Jump height: SJ.** Gymnasts’ performance in the before and after SJ showed a range of decreased (−) height to increased (+) height. The individuals’ performance after treatment had the following ranges: VS = −19.2 to +17.9%, SES = −16.1 to +2.6%, and VES = −11.9 to +12.1%. The mean percent changes in SJ height before versus after treatment were VS = −0.9% (± 9.1%), SES = −6.6% (± 6.8%), and VES = −0.9% (± 9.3%).

**Jump height: CMJ.** Gymnasts’ performance in the before and after CMJ had a range of decreased (−) height to increased (+) height. The individuals’ performance after treatment had the following ranges: VS = −10.0 to +10.4%, SES = −11.7 to +3.8%, and VES = −4.7 to +4.7%. The mean percentage changes in CMJ height before versus after treatment were VS = −0.6 (± 7.3%), SES = −5.3 (± 6.9%), and VES = +0.4 (± 4.0%).

**Flight time.** Individual SJ flight times were altered after treatment, with the following ranges: VS = −10.1 to +8.8%, SES = −8.4 to +5.5%, and VES = −6.2 to +5.8%. Mean decreased flight times of SJ relating post- to pretesting were VS = −0.7 (± 4.6%), SES = −2.8 (± 4.4%), and VES = −0.6 (± 4.7%). Individual CMJ flight times were altered after treatment, with the following ranges: VS = −5.2 to +11.3%, SES = −6.5 to +2.0%, and VES = −2.4 to +2.3%. Mean changed flight times of CMJ relating post- to pretesting were VS = −0.4 (± 3.8%), SES = −2.7 (± 3.6%), and VES = +0.2 (± 2.0%).

**Pre- versus postperformance testing.** According to t-tests of mean jump measures, jump height, flight time, and peak force showed no statistical differences in both SJ and CMJ for groups; VS, SES, and VES and effect sizes were small (Tables 2 and 3). However, group SES show moderate effect sizes for both SJ and CMJ.

**DISCUSSION**

A unique finding in this study is that the addition of vibration to a stretching routine can increase flexibility while maintaining explosive strength (e.g., jumping ability). This observation is especially important considering that the athletes were already warmed up, as evidenced by the lack of change in ROM among the groups not receiving the vibration treatments.

Indeed, the acute vibration–stretching and vibration-only treatments resulted in statistically different increases in flexibility, whereas stretching-only had no significant change. The increases in flexibility after vibration–stretching and vibration-only treatments coincide with previous results of studies involving a vibration treatment (1,20,21). Statistically greater flexibility was also noted in the VS group, both for the favored and nonfavored legs, and in the VF group for the nonfavored leg. In this context, stretching plus vibration seems to improve flexibility in both legs and to a greater extent than vibration alone. However, there were no

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**Table 3. Countermovement jumps.**

<table>
<thead>
<tr>
<th>Group</th>
<th>Trial</th>
<th>Mean Jump Height (cm) ± SD</th>
<th>Effect Size (d)</th>
<th>t-Test (P)</th>
<th>Mean Flight Time (ms) ± SD</th>
<th>Effect Size (d)</th>
<th>t-Test (P)</th>
<th>Mean Peak Force (N) ± SD</th>
<th>Effect Size (d)</th>
<th>t-Test (P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VS (N = 22)</td>
<td>Pre</td>
<td>23.6 ± 4.2</td>
<td>0.06</td>
<td>0.50</td>
<td>437.2 ± 37.6</td>
<td>0.06</td>
<td>0.55</td>
<td>890.3 ± 252.3</td>
<td>−0.11</td>
<td>0.41</td>
</tr>
<tr>
<td>VS (N = 22)</td>
<td>Post</td>
<td>23.4 ± 3.9</td>
<td>0.32</td>
<td>0.008</td>
<td>435.0 ± 35.4</td>
<td>0.32</td>
<td>0.07</td>
<td>866.5 ± 287.9</td>
<td>0.03</td>
<td>0.81</td>
</tr>
<tr>
<td>SES (N = 6)</td>
<td>Pre</td>
<td>22.0 ± 3.7</td>
<td>0.26</td>
<td>0.55</td>
<td>422.1 ± 35.2</td>
<td>0.26</td>
<td>0.55</td>
<td>873.4 ± 237.3</td>
<td>0.03</td>
<td>0.81</td>
</tr>
<tr>
<td>SES (N = 6)</td>
<td>Post</td>
<td>20.8 ± 3.6</td>
<td>0.02</td>
<td>0.92</td>
<td>410.6 ± 36.3</td>
<td>0.02</td>
<td>0.92</td>
<td>897.4 ± 341.4</td>
<td>0.26</td>
<td>0.55</td>
</tr>
<tr>
<td>VES (N = 7)</td>
<td>Pre</td>
<td>21.9 ± 3.9</td>
<td>0.01</td>
<td>0.7</td>
<td>421.5 ± 36.7</td>
<td>0.01</td>
<td>0.7</td>
<td>897.4 ± 341.4</td>
<td>0.26</td>
<td>0.55</td>
</tr>
<tr>
<td>VES (N = 7)</td>
<td>Post</td>
<td>22.0 ± 3.6</td>
<td>−0.02</td>
<td>0.92</td>
<td>422.0 ± 34.6</td>
<td>−0.02</td>
<td>0.92</td>
<td>897.4 ± 341.4</td>
<td>0.26</td>
<td>0.55</td>
</tr>
</tbody>
</table>

Table 3 represents countermovement jumps’ explosive strength data from all groups: vibration–stretching (VS), stretching-only (SF), and vibration-only (VF).
statistical differences in flexibility for either leg of the SF group. Increased flexibility, particularly for the nonfavored legs, was observed only when vibration was part of treatment, and it may be a driving factor for encouraging the use of vibration with a warm-up routine, to increase flexibility that may otherwise be unattainable through stretching-only.

Increased flexibility through acute vibration (1), as well as increased flexibility through stretching (24), has been shown to occur in previous studies. Possible mechanisms by which vibration and stretching affect flexibility may include decreased musculotendinous stiffness, muscular antagonist inhibition, and increased pain threshold (1,16,19,24).

Explosive strength performance variables, including jump height, flight time, peak force, rate of force development over several intervals, and instantaneous forces over the jump, were not statistically different when comparing pre- versus postjump testing in either the CMJ or SJ. However, the SES group showed effect sizes much larger than any other group for jump height, flight time, and peak force. Although in the present study, the underlying mechanisms (e.g., peak force and rate of force development) did not show statistically different alterations, jump height seems to be reduced by stretching. Previous studies of stretching effects on performance have generally concluded that stretching results in decreased explosive strength parameters, such as force production and rate of force development and, thus, decreased performance, including jump height, which agrees with the observations of the present study (2,7,24,26).

In previous studies of acute vibration treatment, increased power and increased jump height have been observed. Vibration has been shown to excite primary spindle endings, whereas stretching has been shown to blunt α-motoneuron signaling (8). However, there were no stretching components in the majority of previous vibration studies. It is important to note that in the present study, stretching alone did result in a loss of jump performance; however, the addition of acute vibration seems to have preserved the ability to express explosive strength. This observation is supported by the observations of Cardinale and Lim (4), who used indirect WBV methods of vibration application. It may be possible that some of the underlying mechanisms that increase ROM simultaneously inhibit explosive strength (8). A combination of these effects may explain why there was no gain or loss in explosive strength parameters of the gymnasts tested as a result of the addition of vibration (6,9).

In future research, it may be advantageous to change the stretch–vibration protocol to longer than 10 s. This alteration could result in reduced sensations of pain, or it could cause activation of other underlying mechanisms and, therefore, produce greater gains in flexibility and/or result in an enhancement of explosiveness. Also, future research could involve the use of two force plates for jumping tests, allowing single-leg force outputs to be examined. In turn, this could give an indication of the ability of each leg to produce power and explosiveness as an aftereffect of vibration, or the combination of vibration and stretching. These alterations in explosiveness could then be associated with flexibility changes (or vice versa). This technique could show a leg-by-leg analysis of the effects of stretching, vibration, or, for gymnasts, vibration–stretching, which would be very important, considering that many events such as beam rely on single-leg take-offs. When dealing with athletes, it is important to note individual responses. For example, in this study, vibration–stretching consistently produced positive ROM alterations. All but one subject showed an increase in ROM, and that subject showed no change. With vibration alone, only one athlete showed a negative flexibility response. With jumping, the treatments produced less consistent individual effects. In future research, it is imperative that individual responses be accounted for, to potentially identify responders and nonresponders to the various treatments.

**SUMMARY**

The increase in flexibility noted in the present study (resulting from vibration–stretching) is in accordance with previous research that also found increased flexibility with a similar protocol involving vibration and stretching (20). It is notable that whereas vibration combined with stretching did not enhance jumping performance, it caused no loss of explosive strength. Therefore, in this study, vibration in combination with stretching greatly increased flexibility while not impairing explosive strength. Explosive strength is commonly impaired by stretching alone; thus, the results of this study support the addition of vibration to stretching as a beneficial warm-up/training tool for gymnasts.

We would like to acknowledge USECA for their generous grant, which was the major funding source for this study. We would also like to thank Daniel Duckworth, Jon Calloway, Tanya Wolf, and Jennifer Whittington for their assistance in collecting data. Special thanks are extended to Appalachian Gymnastics Club (Johnson City, TN; Debbie Neilson) and New River Gymnastics Academy (Boone, NC; Anna George) for use of their facilities and volunteering athletes.

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