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Effects of Strength Training on Strength Development and Joint Position Sense in Functionally Unstable Ankles

Carrie L. Docherty, MEd, ATC*; Josef H. Moore, PhD, PT†; Brent L. Arnold, PhD, ATC‡

* University of Michigan, Ann Arbor, MI; † US Army-Baylor Graduate Physical Therapy Program, Academy of Health Sciences, Fort Sam Houston, TX; ‡Curry School of Education, University of Virginia, Charlottesville, VA 22903

Objective: To examine the effects of ankle-strengthening exercises on joint position sense and strength development in subjects with functionally unstable ankles.

Design and Setting: Subjects were randomly assigned to a training or control group. The training group participated in a 6-week strength-training protocol using rubber tubing 3 times a week throughout the training period. The control group did not participate in the strength-training protocol.

Subjects: Twenty healthy college students (10 females, 10 males, age = 20.6 ± 2.23 years; ht = 176.40 ± 7.14 cm; wt = 74.18 ± 10.17 kg) with a history of functional ankle instability volunteered to participate in this study.

Measurements: We pretested and posttested dorsiflexor and evertor isometric strength with a handheld dynamometer and collected joint position sense (JPS) data at 20° for inversion and plantar flexion and at 10° for eversion and dorsiflexion.

Results: Statistical tests for strength and JPS revealed significant group-by-time interactions for dorsiflexion strength, eversion strength, inversion JPS, and plantar flexion JPS. Simple main-effects testing revealed improvements in training group strength and JPS at posttesting. There were no significant effects for eversion JPS, but the group main effect for dorsiflexion JPS was significant, with the experimental group having better scores than the control group.

Conclusions: Ankle-strengthening exercises improved strength, inversion JPS, dorsiflexion JPS, and plantar flexion JPS in subjects with functionally unstable ankles.

Key Words: proprioception, ankle sprains, rehabilitation

Inversion ankle sprains are the most common ankle injury, with more than 85% of all ankle sprains occurring to the lateral ligaments.[1] These injuries vary in their degree of severity and have been reported to produce a high incidence of chronic ankle instability that can affect both length of rehabilitation and level of participation in sport-related activities.[2,3] Ankle instability has been attributed most frequently to joint laxity, muscle weakness, and proprioception deficits.[4]

It has been suggested that ankle sprains produce trauma not only to joint ligaments and supporting musculature, but also to sensory nerve fibers within the joint capsule.[5] These nerve fibers provide feedback from the joint mechanoreceptors to assist in stabilization of the ankle during locomotion. Individuals with ankle sprains that result in ligamentous laxity may compensate by relying on muscle spindle, cutaneous, vestibular, or visual cues. One possible mechanism of compensation is provided by the muscle mechanoreceptors. It has been shown that muscle and tendon vibrations produce a sensation of joint movement.[6] Specifically, movement is sensed in the direction that a vibrating muscle would have been stretched. This indicates that muscle mechanoreceptors may aid in controlling joint motion and suggests that ankle rehabilitation might alter the sensitivity of these receptors.

One mechanism of acutely altering muscle mechanoreceptor sensitivity is via muscular contraction. Previous research has shown increased Group Ia sensory activity following muscle contraction.[7] Similarly, it is believed that strength gains during the first 3 to 5 weeks of strength training are primarily due to neural factors.[8] For example, strength training has been reported to influence motor unit recruitment, selective activation of agonist muscles and their motor units, and antagonist coactivation.[9] However, it is unclear whether these longer-term neurologic effects extend to muscle proprioceptors. At least 2 studies[10,11] have suggested a link between strength and proprioception, while others have not.[4,12] Thus, the purpose of our study was to determine whether an ankle-rehabilitation protocol consisting of strengthening exercises had an effect on joint position sense (JPS) and strength development in subjects with functionally unstable ankles.

METHODS

Subjects

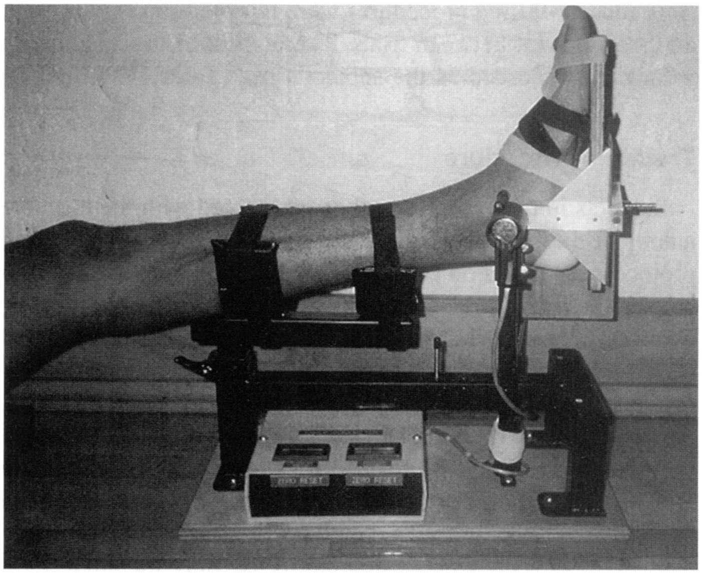
Twenty healthy college students (10 females, 10 males: age = 20.6 ± 2.23 years; ht = 176.40 ± 7.14 cm; wt = 74.18 ± 10.17 kg) volunteered to participate in this study. All subjects had a history of functional instability[5] of the ankle and no history of other lower extremity injuries or other neuromuscular deficits. Functional instability was defined as a history of 3 or more ankle sprains in the last 5 years. Specific minimum inclusion criteria included a previous diagnosis of a moderate inversion ankle sprain and 1 episode of the ankle "giving way" during the last 12 months. All subjects were asymptomatic and physically active at the time of the study. The subjects were randomly assigned to either the training or control group, with an even number of males and females in each group. The study was approved by the University of Virginia's Human Investigation Committee, and all subjects read and signed a written consent form approved by the university before beginning the study.

Test Procedures

Only the functionally unstable ankle was used in these testing procedures. All subjects were pretested for dorsiflexor and evertor muscle isometric strength, as well as for JPS for the inversion-eversion and plantar flexion-dorsiflexion motions. All subjects performed strength testing before the JPS test. Additionally, each subject warmed up on a stationary bicycle at a comfortable level for 5 minutes before testing. All positioning and testing was performed by the same researcher.

Joint Reposition Sense Testing

Joint reposition sense measurements were taken with a custom-designed electronic goniometer (Figure). The device was rebuilt according to the specifications of Myburgh et al,[13] with modifications to eliminate excessive movement during testing. First, a small, removable piece of wood was clamped to the transverse axis of rotation to eliminate sagittal plane movement during inversion-eversion testing. The piece of wood was then moved and clamped to the longitudinal axis to eliminate frontal plane movements during plantar flexion-dorsiflexion testing. Then, 2 pieces of hook-and-loop fastener fabric were attached to the footplate to assist in stabilization during the testing. Finally, a removable heel cup was fixed to the footplate to assist in accurate foot placement. Motion was detected by potentiometers placed on each axis of the goniometer. The potentiometers produced an analog signal that was digitally converted and numerically displayed on a liquid crystal display. All subjects were barefoot during testing to avoid positioning errors due to shoes. The subject's functionally unstable leg was supported in the leg rest in full extension, and the foot was placed against the footplate. The footplate was positioned to place the ankle in subtalar joint neutral (STJN), and the goniometer was set to zero. Both the leg and the foot were fastened with hook-and-loop fastener fabric strips. The subject was blindfolded throughout the testing to eliminate any visual cues.



Electronic goniometer.

Once positioned, subjects were free to go through a full range of motion to familiarize themselves with the device. All subjects were tested at 20 degrees from STJN for inversion and plantar flexion and at 10 degrees from STJN for eversion and dorsiflexion. For each test position, we placed a block at that specific point in the range of motion, and each subject actively moved the foot until the footplate hit the block. Once in each test position, subjects were instructed to concentrate on the position for 15 seconds. The block was then removed, and subjects were instructed to move the foot to the opposite extreme of motion. We then instructed the subjects to move the foot back to the test position. This was repeated for 3 trials, and the difference between the subject's reposition angle and the test angle was recorded as the JPS error. The mean of the 3 trials was used for analysis. Measurements were taken from the electronic readout to the nearest degree.

Strength Testing

A handheld dynamometer (MicroFET2, MicroFET, Draper, UT) was used for the isometric strength testing. All subjects were barefoot during the testing procedures, and peak force was measured by the dynamometer to the nearest 0.1 N. The functionally unstable ankle was tested for both dorsiflexor and evertor strength. To test strength, subjects were positioned with the foot off the end of the table in the supine or side-lying position for dorsiflexion or eversion, respectively. All testing was done consistent with the procedures outlined by Daniels and Worthingham.[14] All contractions were sustained for 3 seconds while the examiner applied an unmoving resistance.

Both muscle-testing procedures were repeated for 3 trials, with a 10-second rest between trials. The highest of the 3 isometric values was recorded as the subject's peak force.[15]

Training Procedure

Subjects in the experimental group trained with the unstable ankle 3 times a week for 10 minutes each day. The training protocol was based on clinical experience and was designed to provide progressive resistive exercise and a sufficient training overload. The progressive training protocol (Table 1) consisted of 6 weeks of strength training using elastic tubing (Thera-Band Tubing Resistive Exerciser, The Hygenic Corporation, Akron, OH). For training, each subject sat on the floor with one end of the elastic band attached to a table and the other end attached to the leg. For all exercises, subjects remained on the floor in the seated or semireclined position, with the knee fully extended. Subjects were instructed to use only the ankle joint and not to allow leg movement during the exercises. Once seated, subjects stretched the elastic band to a designated mark on the floor, which was calculated to be 70% of the band's maximal stretch. During each exercise session, subjects performed inversion, eversion, plantar flexion, and dorsiflexion.

Control subjects were asked to refrain from strength training or applying other treatments to their ankles during the study period. However, they were permitted to continue normal daily activities and to maintain current physical activity levels.

Statistical Analysis

A repeated-measures multivariate analysis of variance (MANOVA), with pretest to posttest measures as a within-subjects factor and group membership and gender as between-subjects factors, was performed on the 6 dependent measures. Significant multivariate tests were followed by univariate analyses of variance. Significant univariate F tests were tested post hoc to locate specific group differences. The α level for all statistical tests was .05.

RESULTS

The MANOVA produced a significant Wilks λ ($\lambda = 0.13$, $P < .0005$) for the group-by-time interaction when all the dependent variables were considered simultaneously. Based on this result, gender was eliminated as a factor in subsequent ANOVAs. The mean values for strength and JPS are presented in Tables 2 and 3, respectively. Univariate tests for strength and JPS revealed significant group-by-time interactions for dorsiflexion strength ($F_{1,18} = 66.07$, $P < .0005$), eversion strength ($F_{1,18} = 9.99$, $P = .005$), inversion JPS ($F_{1,18} = 8.52$, $P = .009$), and plantar flexion JPS ($F_{1,18} = 5.79$, $P = .027$). Simple main-effects testing revealed improvements in training group strength (Table 2) and JPS (Table 3) at posttesting. Additionally, JPS univariate tests revealed no significant effects for eversion JPS, but a significant group main effect for dorsiflexion JPS ($F_{1,18} = 4.55$, $P = .047$), with the experimental group having better scores than the control.

Table 1. Resistive Tubing Training Protocol

Week	Tubing	Sets × Repetitions
1	blue—extra heavy	3 × 10
2	blue—extra heavy	4 × 10
3	black—special heavy	3 × 10
4	black—special heavy	4 × 10
5	silver—super heavy	3 × 10
6	silver—super heavy	4 × 10

DISCUSSION

Proprioception is the general term attached to the use of proprioceptor inputs to control human movement and posture. If these inputs are perceived by the individual, the more specific term "kinesthesia" is used.[16] The relationship between ankle joint function and proprioception has been previously established.[4,10,12,17] However, the relationship between joint strength and proprioception is not as clear. For example, a significant relationship between lower extremity muscle strength and postural sway has been demonstrated in the elderly,[11] and increases in postural sway and ankle weakness have also been reported in soccer athletes.[10] In contrast, others[4,12] have not found simultaneous decreases in strength and proprioceptive measures. One reason for this may be the different methods used to assess proprioception. For example, those studies demonstrating proprioceptive deficits[10,11] used protocols employing active muscle contractions, whereas Lentell et al[4,12] used either a passive protocol or a rather crude measure of proprioception.

Our results indicate that ankle-strengthening exercises improve inversion JPS and plantar flexion JPS in subjects with functionally unstable ankles. Theoretically, there are two possible sensory mechanisms that may have produced the change. It is possible that joint mechanoreceptors were stimulated by the motion of the exercise, resulting in an increased sensitivity. However, we feel this is not likely. Joint mechanoreceptors respond specifically to extremes in the range of motion and local compression.[18] While our training protocol was performed throughout the entire range of motion, the JPS testing was done only in the midrange of the total range of motion. Thus, we feel that the joint mechanoreceptors were not

Table 2. Control and Experimental Group Mean Strength (N) Scores and Standard Deviations

Movement	Pretest	Posttest
Dorsiflexion		
Control	33.8 ± 7.2	33.9 ± 5.0
Experimental	33.3 ± 4.8	50.6 ± 6.3*
Eversion		
Control	30.8 ± 6.0	27.7 ± 11.6
Experimental	30.9 ± 6.5	45.0 ± 4.9*

* Significantly different from control.

Table 3. Control and Experimental Group Mean Joint Position Sense Scores (Degrees of Error) and Standard Deviations

Movement	Pretest	Posttest
Inversion		
Control	6.3 ± 3.17	6.4 ± 2.63
Experimental	6.8 ± 5.0	2.8 ± 2.8*
Eversion		
Control	4.1 ± 2.9	3.8 ± 3.1
Experimental	4.6 ± 4.3	2.1 ± 1.5
Dorsiflexion		
Control	4.6 ± 1.8	4.78 ± 2.1
Experimental	4.2 ± 3.6	1.9 ± 1.2
Plantar flexion		
Control	6.5 ± 4.7	5.5 ± 3.6
Experimental	7.9 ± 6.0	1.4 ± 0.9*

* Significantly different from control.

stimulated due to the lack of extreme range of motion or compression in the testing procedures. However, even if our protocol did stimulate the mechanoreceptors, it has been demonstrated that anesthetizing the joint ligaments and capsule does not affect postural sway or JPS measures.[19] These findings add further support to our belief that the joint mechanoreceptor mechanism is not responsible for the changes we noted.

We believe the more likely mechanism for our results was the muscle spindle. The muscle spindle has two basic physiologic responses. The static response signals sustained spindle length (ie, sustained muscle stretch) and instantaneous spindle length,[20–22] while the dynamic response signals the rate of length changes.[22] In addition to the sensory endings, the spindles also receive connections from static and dynamic gamma-efferent nerves, which enhance the afferent responses.[23,24] We believe it is possible that the strength training may have increased gamma-efferent activity. Specifically, the spindle may have been more sensitive to instantaneous stretch, resulting in greater acuity in sensing joint position. For example, the training of the evertors and dorsiflexors may have increased the amount of static gamma-efferent activity to the spindles of these muscles. Thus, at posttraining, the evertor and dorsiflexor spindles may have been more sensitive to stretches resulting from inversion and plantar flexion, respectively. It is also possible that dynamic gamma efference increased the sensitivity to the rate of length changes. However, because we used a relatively slow, active motion to assess JPS, it is unlikely that the dynamic spindle receptors were stimulated by our testing protocol. It is important to note that there were no statistically significant improvements for eversion JPS. The reason for this is unclear. Unfortunately, strength data for the invertors were not collected. Thus, it is not possible to establish a relationship between strength and JPS for this muscle group.

Another possible effect of strength training on JPS may have been an improvement in the alpha-gamma coactivation. During volitional concentric contraction, simultaneous activity in the alpha and gamma motor neurons has been reported.[25,26] Additionally, spindle firing in the contracting muscle has been observed.[27] Since muscle shortening is known to decrease primary-ending firing frequency (even during static and dynamic gamma stimulation),[28] the likely function of this coactivation is to maintain an appropriate spindle length during contraction, thereby maintaining spindle firing during shortening. However, our data do not support this mechanism for improving JPS. Specifically, there was an increase in evertor strength without a corresponding increase in eversion JPS. If this mechanism had been responsible for improving JPS, eversion JPS should have improved with strength.

It is also possible that practice of these joint motions without any resistance may have improved JPS. However, this does not seem likely due to the lack of JPS improvement for eversion. Had practice alone been a sufficient stimulus for improvement, improvements in all directions would have been expected.

Other studies using normal[29] or functionally unstable ankles[30,31] have also demonstrated positive balance effects with training protocols involving joint motion. Combined strength and balance training has been shown to improve balance-board performance.[31] Unfortunately, because the training included both balance and strength components, it was not possible to determine the individual effects of either component. Similarly, ankle-disk training with functionally unstable ankles has been shown to decrease postural sway in both stable and unstable ankles.[30] These researchers argued that the bilateral effects of unilateral training suggest a central mechanism of balance improvement rather than the peripheral mechanisms (ie, spindle receptors) we propose. In contrast, Cox et al[32] demonstrated no difference in postural sway after balance training without joint motion. Thus, it appears that strength training, proprioceptive training, and combinations of both improve proprioception, balance, or both, provided the training involves joint motion. Questions remain as to what combination of these treatments is optimal and what mechanisms are involved.

Finally, our results revealed a significant main effect in dorsiflexor JPS scores between the control group and training group, which were not different initially. The training group improved sufficiently after training to produce the significant main effect, but not sufficiently to produce a significant interaction.

CONCLUSIONS

We found that our training protocol increased strength, inversion JPS, dorsiflexion JPS, and plantar flexion JPS in subjects with functionally unstable ankles. These findings suggest that strength training can play the dual role of increasing both strength and joint position sense. Our results are most likely due to changes in muscle spindle sensitivity or in central mechanisms related to the spindles, rather than joint mechanoreceptor sensitivity. We believe the training protocol may have increased the gamma motor activity,[23,24] improved central mechanisms of motor control,[30] or produced a combination of central or spindle mechanisms. Future research should be designed to more specifically detect differences due to gamma activity, alpha-gamma coactivation, or central mechanisms.

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