Journal of Sport Rehabilitation, 2011, 20, 157-173

Effects of 4 Weeks of Elastic-Resistance Training on Ankle-Evertor Strength and Latency

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Context: Several researchers have suggested that improving evertor strength and peroneus longus reaction time may help alleviate the symptoms of chronic ankle instability and reduce the rate of recurrent ankle sprains. ***Objectives:*** To determine the effectiveness of a 4-wk elastic-resistance exercise-training program on ankle-evertor strength and peroneus longus latency in subjects with and without a history of ankle sprains (HAS). ***Design:*** Randomized controlled clinical trial. ***Participants:*** 40 subjects (20 male, 20 female; 20 HAS, 20 healthy). Ten subjects (5 male and 5 female) from each of the HAS and healthy groups were randomly assigned to exercise or control groups. ***Interventions:*** 4-directional elastic-resistance exercise training 2 times/wk for 4 wk. ***Main Outcome Measures:*** Ankle-evertor strength and peroneal muscle latency after sudden inversion were measured before training, after 4 wk of training, and 4 wk posttraining. ***Results:*** Four weeks of elastic-resistance exercise training did not elicit significant changes in 1-repetition-maximum ankle-evertor strength between the exercise and control groups (P = .262), HAS and healthy groups (P = .329), or males and females (P = .927). Elastic-resistance exercise training did not elicit significant changes in peroneus longus muscle latency between the exercise and control groups (P = .102), HAS and healthy groups (P = .996), or males and females (P = .947). ***Conclusions:*** The 4-wk elastic-resistance exercise training had no effect on ankle-evertor strength and reflex latency of the peroneus longus after unexpected ankle inversion.

Keywords: chronic ankle instability, electromyography, rehabilitation, resistance training, muscle-reaction time

Lateral ankle sprains are one of the most common injuries to occur to those participating in sport activities.[1] After initially spraining an ankle, some individuals experience repetitive sprains and persistent symptoms. Several factors are thought to be related to recurrent ankle sprains, including strength of the ankle-evertor muscles,[2] muscle-reaction time,[3–7] and proprioceptive deficits.[7–10] Improvements in one or more of these factors may help alleviate the symptoms of functional instability and reduce the rate of recurrent ankle sprains.

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Elongated peroneal reaction time and proprioceptive deficits have been observed in individuals with functionally unstable ankles and are thought to contribute to their increased rate of recurrent ankle sprains. Konradsen and Ravn,[7] Konradsen et al,[9] and Löfvenberg et al[4] reported a prolonged peroneal-muscle reaction time in ankles with chronic lateral instability. Konradsen and Ravn[7] observed that functionally unstable subjects had a prolonged peroneal reaction time of 84 milliseconds, compared with stable subjects who had a peroneal reaction time of 69 milliseconds. They suggested that individuals with functionally unstable ankles may have partial deafferentation of the ankle joint that might lead to proprioceptive deficit. In a later study, Konradsen and Ravn[11] found .92 correlation between prolonged peroneal reaction time and increased postural sway in subjects with functionally unstable ankles. Eils and Rosenbaum[12] demonstrated that peroneal reaction time and postural sway can be improved in 6 weeks via a multistation proprioceptive-exercise program.

Peroneal weakness has been purported to be related to chronic ankle instability. However, direct evidence of peroneal weakness in individuals with functional ankle instability is inconclusive, with some reports of peroneal weakness[2] and others finding no differences between unstable and stable ankles.[13] Tropp[2] found weakness of the peroneal muscles by using isokinetic testing in patients with recurrent ankle sprains. In contrast to Tropp, Lentell et al[14] found no significant difference in the strength of ankle invertors and evertors, either isokinetically or isometrically, between the injured and noninjured ankles. In a review on the factors contributing to chronic ankle instability, Kaminski and Hartsell[15] suggested that despite inconclusive evidence of peroneal weakness in chronic ankle instability, strength training should be an integral part of any ankle-therapy program.

Proprioceptive training is often recommended for individuals with chronic ankle instability.[12,15,16] Elastic tubing has been recommended as a mode of progressive resistive exercise for strengthening and proprioceptive rehabilitation. Schulthies et al[17] used elastic tubing attached to the unaffected ankle to provide resistance through the pelvis to the weight-bearing ankle, knee, and hip joints. Han et al[18] recently demonstrated that 4 weeks of training with elastic-tubing rehabilitation exercises resulted in significant improvements in postural balance in subjects with and without a history of ankle sprains (HAS). Hale et al[19] also demonstrated that postural control can be improved in 4 weeks using Thera-Band resistance exercises in conjunction with neuromuscular-control exercises and functional tasks. Based on these reports[18,19] it appears that 4 weeks of proprioceptive training elicits improvements in postural control. It is unclear whether 4 weeks of training solely with elastic-resistance exercises imposes a sufficient overload to elicit changes in eversion strength and peroneal muscle latency.

The purpose of this study was to determine the effectiveness of an elastic-tubing exercise program on ankle-evertor strength and peroneus longus latency in individuals with and without HAS. We hypothesized that peroneus longus latency would improve for the subjects in the elastic-resistance-training group only for those with HAS. We also hypothesized that 1-repetition-maximum (1-RM) evertor strength would improve for all subjects in the elastic-resistance-training group.

Methods

Design

A randomized controlled clinical trial was used in this investigation. The independent variables were treatment type (exercise or control), ankle history (HAS or healthy) and gender. The dependent variables were ankle-evertor strength and peroneus longus latency after sudden inversion.

Participants

Forty subjects (20 male, 20 female) participated in this study (age = 20.3 ± 3.8 y, height = 172.8 ± 10.2 cm, mass = 70.7 ± 12.8 kg). Twenty subjects (10 male, 10 female) with self-reported HAS were recruited for the study. Subjects were classified as having HAS if they reported having had one or more ankle sprains that resulted in pain during weight bearing for a duration of 1 or more days, within the past 12 months, and at least 2 or more ankle sprains that resulted in pain during weight bearing for a duration of 1 or more days within the past 36 months, but at the time of the study had no visual swelling or pain. Another 20 subjects (10 male, 10 female) who had not experienced an ankle sprain in the past 36 months were recruited as healthy subjects. All subjects had no history of fracture or major surgery in either lower extremity. Ten subjects (5 male, 5 female) from the HAS and 10 (5 male, 5 female) from the healthy group were randomly assigned to either exercise or control groups, resulting in 4 groups: exercise HAS, exercise healthy, control HAS, and control healthy. Before participation in this study, all subjects read and signed an informed-consent document approved by our institutional review board for human subjects.

Instruments

A Chatillon Model CSD 200C dynamometer (Itin Scale Co, Inc, Brooklyn, NY) was used to monitor the tension in the elastic tubing.

An inversion platform, with a foot-support base that rotated 37° after a trapdoor was released by an electronic magnetic switch, was used to induce an ankle-inversion perturbation. The angle of the inversion platform's base was measured with an electronic goniometer. A second electrical goniometer that was rigidly attached to the rear of the shoe and the subject's lower leg was used to measure the ankle-inversion angle.

A pair of 1-cm silver–silver chloride surface electrodes (Blue Sensor M-00-S, Medicotest, Rugmarken, Denmark) was used to record electromyographic (EMG) data for the peroneus longus. The EMG, ankle-inversion goniometer, and inversion-platform goniometer signals were sampled at 1000 Hz using a Gateway Solo 9100 interfaced to a Keithley-Metrabyte KPCMCIA, 12-channel, 16-bit analog-to-digital converter (Keithley Instruments Inc, Cleveland, OH). The EMG signals were differentially amplified with a gain of 1000 and a bandwidth of 16 to 500 Hz at -3 dB using the Noraxon Telemyo System (Noraxon USA Inc, Scottsdale, AZ). The Noraxon EMG amplifier has an input noise below 1 μV RMS and an effective common-mode rejection ration of 135 dB.

We developed an ankle-strength-training machine that was specially designed to rotate around the subtalar-joint axis to measure ankle-evertor strength (see Figure 1). The machine was designed so that the axis of rotation for ankle inversion/eversion was inclined 42° above the dorsum of the foot with an anteromedial deviation of 23°, as reported by Inman.[20] The axis of rotation for the ankle-strength-training machine was aligned at the height of the subtalar joint to allow the subject to freely rotate into inversion and eversion. The subject stood on the tested leg with the foot strapped on a moveable platform. Weight was attached (via pulleys) to the moveable platform, which turned the ankle toward inversion or eversion (Figure 1).

Procedures

Exercise Intensity and Duration. Proprioceptive training is thought to improve muscle strength via neural rather than muscular enhancements. Neural adaptations to muscle strength occur in the initial stages of training, usually within 4 weeks.[21,22] Four weeks of proprioceptive training has been shown to improve postural control.[18,19,23] Based on these reports of improved postural control we hypothesized that 4 weeks of elastic-resistance training would elicit changes in strength and reflex latency.

Exercise resistance was provided by 185-cm-long elastic tubing (Figure 2A) with an internal diameter of 7 mm, external diameter of 16 mm, and a padded foot strap on each end (Functional PT Products, Heber City, UT). Previous work in our laboratory has shown that untrained subjects are initially unable to safely perform elastic-resistance exercises with proper technique using a tension greater than

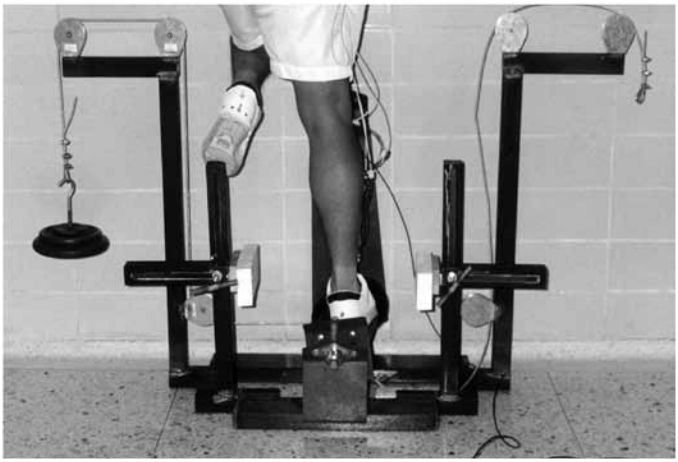

Figure 1 — Ankle-inversion/eversion strength-training machine with the axis of rotation for ankle inversion/eversion inclined 42° above the dorsum of the foot with an anteromedial deviation of 23° about the subtalar joint. The axis of rotation for the ankle-strength-training machine was aligned at the height of the subtalar joint to allow the subject to freely rotate into inversion and eversion.

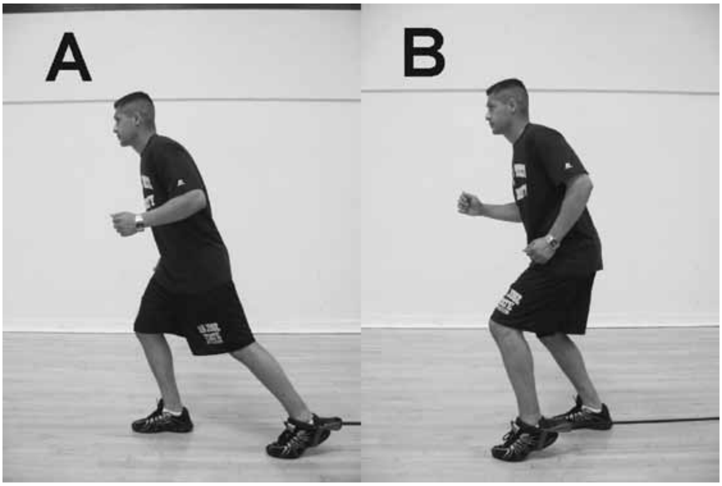

Figure 2 — Front-pull exercise. The subject stood on the affected foot, flexing the unaffected lower extremity at the hip and knee, while pulling the tubing forward (A to B), then slowly returned to the starting position (B to A).

20% of body weight.[17] The perturbation induced by attaching the elastic tubing to the ankle of the support leg with a resistance of 16% of body weight is extremely challenging to untrained subjects. Therefore, the tension in the elastic tubing was initially set at 16% of body weight for the first week and increased as follows: to 18% in the second week, 20% in the third week, and 22% in the fourth week.

Subjects assigned to the exercise group made 3 visits per week, every other day, for 4 weeks to perform the elastic-resistance exercise training. Each exercise consisted of 3 sets of 15 repetitions, with the injured foot (exercise HAS group) or randomly assigned foot (exercise healthy group) on the ground and the other foot connected to one end of the elastic tubing. Subjects had 30-second rest periods between exercises and 2-minute rest periods between sets.

Description of the Exercises. The regimen for the exercise group consisted of 4 different exercises: front pull, back pull, crossover, and reverse crossover. The following procedures were used for each of the 4 elastic-tubing exercises. Subjects in the exercise HAS group used their unaffected foot to pull on the elastic tubing, and they used the lower extremity with the symptomatic foot to support their body weight. For the exercise healthy group, 1 foot was randomly assigned to correspond to the side of the affected ankle of the symptomatic subjects. Resistance-exercise training was performed by attaching one end of the elastic tubing to the unaffected foot at the level of the malleoli and the other end to a stable attachment. The subject stepped away from the tubing attachment site, stretching the tubing to obtain the desired resistance. The length–tension relationship of the cord was measured, and different cord lengths corresponding to the different tensions were marked on the floor. The subjects were instructed to stand at the marked position to ensure that the exercise was performed at the proper tension. The length–tension relationship of the cord was verified each day. When executing each of the 4 elastic-resistance exercises, the subjects were instructed to balance on the affected-ankle side and support their body weight on the affected-ankle side; they were not allowed to transfer weight to the cord leg during movement in any exercise.

For the front pull, subjects faced away from the fixed attachment of the elastic tubing so that the tubing pulled them backward. Each subject stood on the affected foot with the unaffected foot positioned behind the affected foot and the hip and knee extended (Figure 2A). While balancing on the affected foot, the subject flexed the unaffected hip and knee, pulling the tubing forward (Figure 2B). The subject then slowly returned to the starting position (Figure 2A).

For the back pull, subjects faced the fixed attachment of the elastic tubing so that the tubing pulled them forward. Each subject stood on the affected foot with the unaffected foot positioned ahead of the affected foot and the hip and knee flexed (Figure 3A). While balancing on the affected foot, the subject extended the uninjured lower extremity at the hip and knee, pulling the tubing backward (Figure 3B). The subject then slowly returned to the starting position (Figure 3A).

For the crossover, the subject stood perpendicular to the fixed attachment of the elastic tubing so that the unaffected foot was closer to it with the feet slightly wider than shoulder width apart (Figure 4A). The subject stood on both lower extremities with hips and knees flexed. While balancing on the affected foot, the subject adducted the hips by crossing the unaffected foot in front of the affected foot (Figure 4B). The subject then slowly returned to the starting position (Figure 4A).

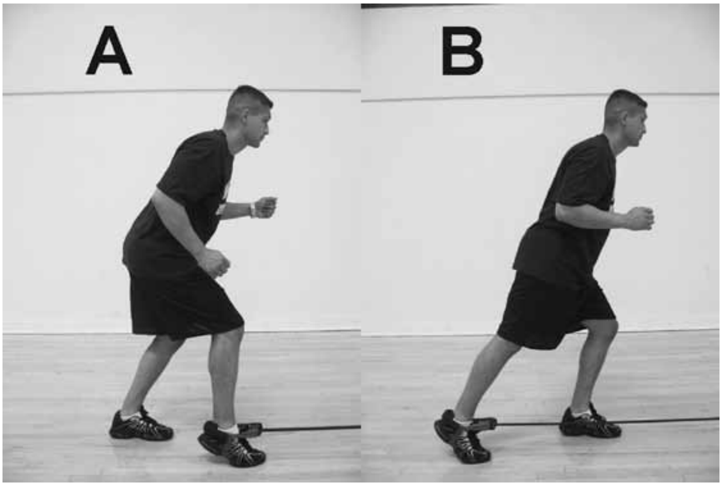

Figure 3 — Back-pull exercise. The subject stood on the affected foot, flexing the unaffected lower extremity at the hip and knee, while pulling the tubing backward (A to B), then slowly returned to the starting position (B to A).

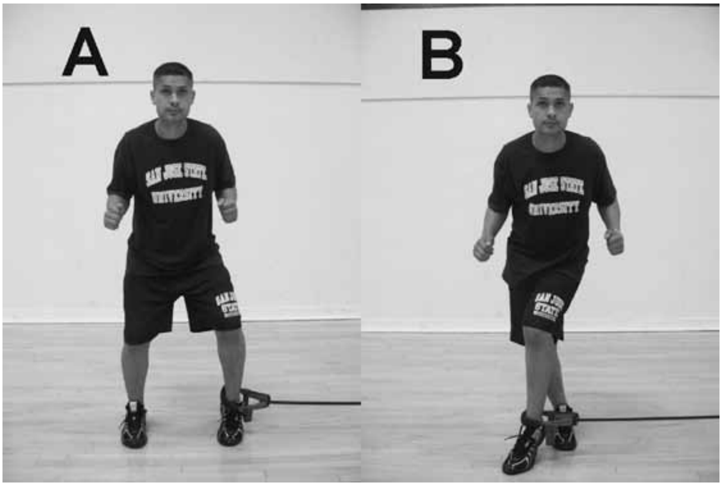

Figure 4 — Crossover exercise. The subject stood on both lower extremities, with the hips and knees flexed. While balancing on the affected foot, the subject adducted the hip by crossing the unaffected foot in front of the affected foot (A to B), then slowly returned to the starting position (B to A).

For the reverse crossover, the subject stood perpendicular to the fixed attachment of the elastic tubing. The subject's unaffected foot was closer to the fixed attachment, with the hips adducted and lower extremities crossed so that the unaffected foot was in front of the affected foot (Figure 5A). The subject stood on both lower extremities with hips and knees flexed. While balancing on the affected foot, the subject abducted the hips until the feet were slightly wider apart than shoulder width (Figure 5B). The subject then slowly returned to the starting position (Figure 5A).

Evaluations. The subjects' height, body mass, age, gender, dominant foot, and HAS were recorded. The dominant foot was defined as the leg they used when kicking a ball. Each subject was required to wear the same low-top tennis shoes (Lozan, K•Swiss, Westlake Village, CA) for all evaluations. All subjects were measured for ankle-evertor strength and peroneus longus latency after sudden inversion. They were asked to make 3 visits for testing: initial evaluation, 4-week evaluation (after 4 wk of treatment), and 4-week follow-up (4 wk after treatment cessation). The evaluations were conducted within 4 days before the first, fourth, and eighth weeks.

Ankle-evertor strength was measured by having the subject stand on 1 leg (injured or randomly assigned) with the foot strapped on the movable platform of the ankle-strength-training machine. Weights were attached to the platform to produce an inversion moment about the subtalar joint. The subject performed isotonic exercise by maximally everting the ankle to lift the weight as high as possible. One-RM evertor strength was determined by using an initial guess of the subject's

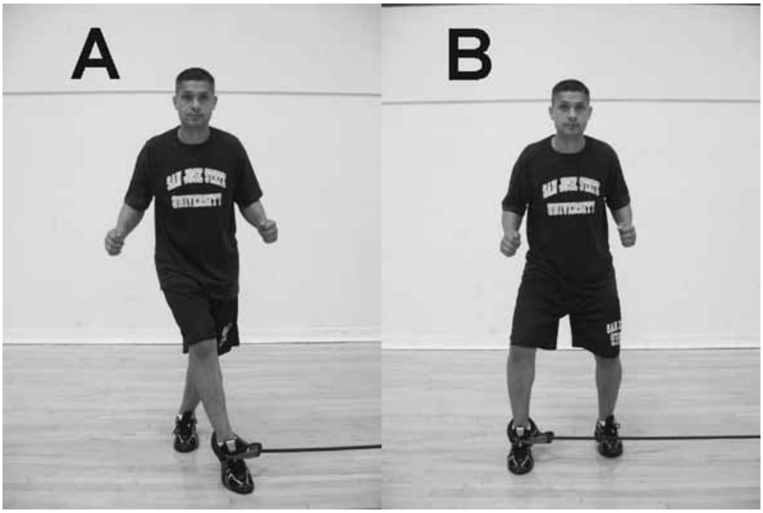

Figure 5 — Reverse crossover exercise. The subject stood on both lower extremities, with the hips and knees flexed and the unaffected lower extremity adducted in front of the affected foot. While balancing on the affected foot, the subject abducted the hips until the feet were slightly wider apart than shoulder width (A to B), then slowly returned to the starting position (B to A).

80% 1-RM and increasing the resistance weight by increments of 4.45 N (1 lb) and then using the smallest possible increment of 2.22 N (0.5 lb). The operational definition of a successful lift required the subject to evert the ankle by at least 5°. Maximum eversion angle during exercise ranged from 8.2° to 12.1° ± 6.9°. The subjects were given 2 minutes' rest between trials.

To measure peroneus longus latency, surface electrodes were placed over the muscle belly of the peroneus longus. To ensure the same posttest recording site, the position of each electrode on the leg was marked with small dots that, with other reference marks (ie, scars) on the subject's skin, were transferred to transparent plastic sheets. These plastic sheets were used in the posttest to identify the previous locations of the electrodes. Subjects were instructed to stand with the foot being measured on the inversion platform and the toe of the other foot barely touching the plate to maintain all body weight on the ankle to be tested (Figure 6A). Ten trials of sudden inversion were recorded (Figure 6B). Trials in which the subjects preactivated the lower leg muscles were excluded from data collection. The EMG signals were full-wave rectified before muscle latency was determined. A typical trial of peroneus longus EMG before and after dropping the trapdoor on the inversion platform is shown in Figure 7. The mean and standard deviation of the peroneus longus baseline activation were computed for the 100-millisecond period before the inversion platform was dropped. Peroneus longus latency was defined as the time from the start of the inversion-platform drop to the time that the peroneus longus EMG was 10 SDs above the baseline activation[5] (see Figure 7).

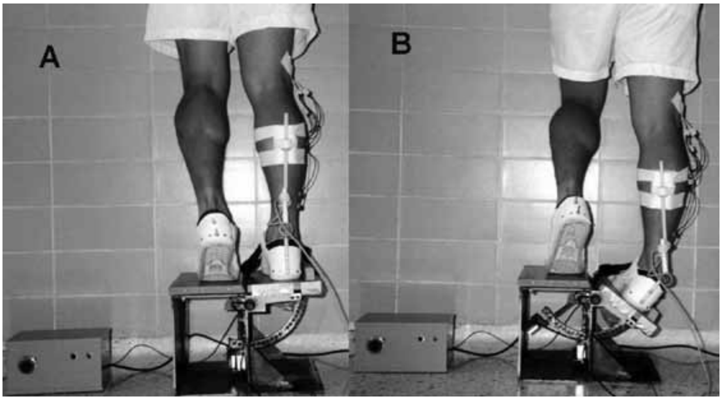

Figure 6 — Subject standing on the inversion platform (A) before trapdoor release and (B) after the trapdoor was released by an electronic magnetic switch, causing the foot-support base to rotate 37°. An electrical goniometer was rigidly attached to the rear of the shoe and tightly taped to the rear of the subject's lower leg to determine inversion/eversion of the ankle joint.

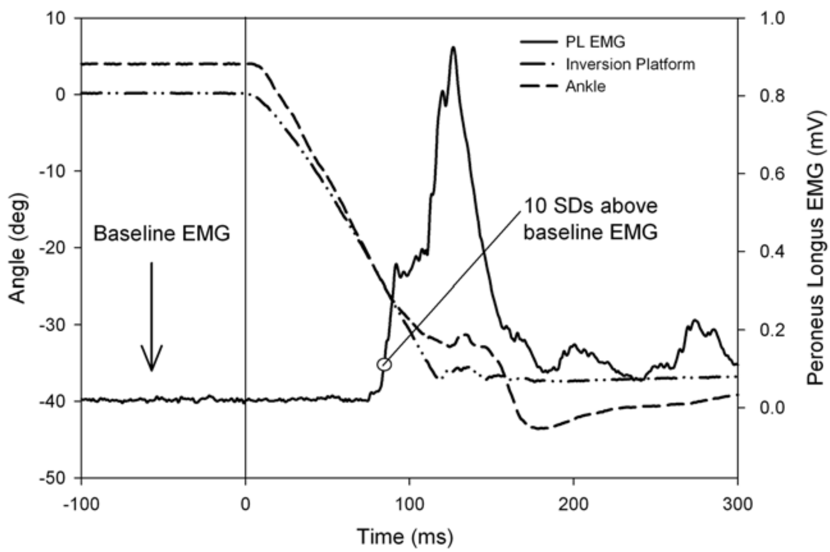

Figure 7 — A typical trial of full-wave-rectified EMG from the peroneus longus (PL) muscle 100 milliseconds before and 300 milliseconds after sudden ankle inversion. Baseline activation of the PL was computed by averaging the EMG activation 100 milliseconds before release of the inversion platform. PL latency was defined as the time between release of the inversion platform door and the first point where PL activation was 10 SDs above the baseline activation.

Reliability Analysis and Minimal Detectable Change

Nine subjects (not in the experiment) participated in a test–retest assessment of measurement reliability. Peroneus longus latency and isotonic strength were measured on 2 separate days (48 h apart), and between-days reliability was determined using SPSS (16.0 for Windows) to compute the intraclass correlation coefficient (ICC) using a 2-factor mixed-effects model and type consistency.[24] The between-days averaged-measures ICC for peroneus longus latency was .955, with a 95% confidence interval from .919 to .980. The standard error of measurement (SEM), or typical error of measurement,[25] was calculated by dividing the standard deviation of the between-days differences by the square root of 2. The SEM was used to calculate the minimum detectable change (MDC) within 95% confidence limits ($MDC_{95\%}$ = 1.96 × square root of 2 × SEM).[25] The SEM for peroneus longus latency was 5.6 milliseconds, and the $MDC_{95\%}$ was 15.5 milliseconds.

The between-days averaged-measures ICC for ankle-evertor 1-RM strength was .979, with a 95% confidence interval from .944 to .992. The SEM for ankle-evertor 1-RM strength was 0.93 lb, and the $MDC_{95\%}$ was 2.6 lb.

Sample-Size Determination

G*Power[26] version 3.0 was used to determine sample size using a meaningful significant difference in peroneus longus latency of 11.2 milliseconds (2 × $MDC_{95\%}$), a 7.9-millisecond SD, a 2-tailed *t* test, and an alpha level of .05. To obtain an estimated power of 80%, 7 subjects per group were required. The required sample size for 1-RM ankle-evertor strength using a meaningful significant difference of 5.2 lb (2 × $MDC_{95\%}$), 4.4-lb SD, a 2-tailed *t* test, and an alpha level of .05 was 8 subjects per group with an estimated power of 80%. Based on the a priori analysis of power, 10 subjects per group were used to allow for possible subject dropout.

Statistical Analysis

The data were analyzed in SAS using a linear mixed model[27] with an autoregressive lag 1 covariance structure and linear slopes as implemented in SAS Proc Mixed (SAS Institute Inc, Cary, NC) to determine intercepts and slopes for each dependent variable, during the exercise phase and the rest phase of this study. The linear mixed model had 3 fixed factors, treatment (exercise, control), ankle history (HAS, healthy), and gender (male, female), and one random factor, subjects. Mixed-model intercepts and slopes of different groups were compared for differences using *t* tests with an alpha <.01 as the critical level of significance.

Results

A post hoc reliability analysis was performed using the preintervention, postintervention, and follow-up peroneus longus latency and 1-RM evertor-strength measures for the healthy subjects in the control group to determine the test–retest reliability for each variable over the 4- and 8-week testing intervals. The preintervention-to-postintervention (4-wk) averaged-measures ICC for peroneus longus latency was .974 (95% CI .870–.995), and for 1-RM evertor strength, was .978 (95% CI

.889–.996). The preintervention-to-follow-up (8-wk) averaged-measures ICC for peroneus longus latency was .943 (95% CI .717–.989), and for 1-RM evertor strength, was .980 (95% CI .899–.996).

The means, standard deviations, and results of the linear mixed-model analysis for 1-RM ankle-evertor strength and peroneus longus latency after sudden ankle inversion by time (preintervention, postintervention, and 4-wk follow-up) are shown in Tables 1 and 2. Unlike ANOVA, linear mixed models compare the pretest means using the intercepts, and then the change between means from preintervention to postintervention or postintervention to follow-up test are compared by analyzing the slopes for each group (change in the means).

Table 1 Intercepts and Slopes for Ankle-Evertor 1-Repetition-Maximum Strength (lb) Before Training, After Training, and 4 Weeks Posttraining

		Estimate	SD	*t*	*P*
Starting point					
treatment	exercise	14.45	3.58		
	control	14.90	4.29		
	difference	–0.45	5.59	–0.36	.721
ankle history	HAS	15.35	3.71		
	healthy	14.00	4.07		
	difference	1.35	5.50	1.09	.281
gender	male	16.95	3.58		
	female	12.62	3.00		
	difference	4.33	4.65	4.16	.000
Change over first 4 weeks					
treatment	exercise	–0.31	1.21		
	control	–0.78	1.39		
	difference	0.47	1.83	1.14	.262
ankle history	HAS	–0.74	1.12		
	healthy	–0.33	1.43		
	difference	–0.41	1.83	–9.91	.329
gender	male	–0.56	1.16		
	female	–0.52	1.39		
	difference	–0.04	1.88	–0.09	.927
Change over the next 4 weeks					
treatment	exercise	–0.47	1.07		
	control	–0.33	0.80		
	difference	–0.14	1.34	–0.45	.652
ankle history	HAS	–0.50	0.85		
	healthy	–0.29	1.07		
	difference	–0.21	1.34	–0.69	.500
gender	male	–0.67	0.85		
	female	–0.20	0.94		
	difference	–0.47	1.30	–1.59	.123

HAS, history of ankle sprains. Linear mixed models were used to compare the initial values for each group on the pretest (intercept), and the changes from pretest to posttest and the changes from posttest to follow-up test were compared by analyzing the slopes.

Table 2 Intercepts and Slopes for Peroneus Longus Latency After Sudden Ankle Inversion Before Training, After Training, and 4 Weeks Posttraining

		Estimate	SD	*t*	*P*
Starting point					
treatment	exercise	65.90	17.17		
	control	73.38	16.99		
	difference	–7.48	24.15	–1.38	<.177
ankle history	HAS	72.64	16.99		
	healthy	66.65	17.17		
	difference	5.99	24.15	1.11	<.276
gender	male	73.91	17.87		
	female	65.37	16.64		
	difference	8.54	24.15	1.58	<.124
Change over first 4 weeks					
treatment	exercise	0.55			
	control	–11.18	22.18		
	difference	11.73	31.04	1.69	<.102
ankle history	HAS	–5.33	21.51		
	healthy	–5.29	22.36		
	difference	–0.04	31.04	–0.01	<.996
gender	male	–5.08	23.17		
	female	–5.55	20.66		
	difference	0.47	31.04	0.07	<.947
Change over the next 4 weeks					
treatment	exercise	–0.94	19.14		
	control	5.68			
	difference	–6.62	26.83	–1.10	<.228
ankle history	HAS	3.01	18.34		
	healthy	1.72	19.59		
	difference	1.29	26.83	0.22	<.831
gender	male	3.72	20.39		
	female	1.02	17.49		
	difference	2.70	26.83	0.45	<.657

HAS, history of ankle sprains. Linear mixed models were used to compare the initial values for each group on the pretest (intercept), and the changes from pretest to posttest and the changes from posttest to follow-up test were compared by analyzing the slopes.

Ankle-Evertor Strength

There were no 2- or 3-way interactions between treatment, HAS, and gender for 1-RM ankle-evertor strength (see Table 1). There was no difference in the preintervention values between the exercise and control groups ($P = .721$, Cohen's $d = .08$) or the HAS and healthy groups ($P = .281$, Cohen's $d = .25$), suggesting that the groups were equal at the start. As expected there was a difference in 1-RM ankle-evertor strength on the preintervention test between males (16.95 ± 3.58 lb, 95% CI 15.38–18.52 lb) and females (12.62 ± 3.00 lb, 95% CI 11.31–13.93 lb) with a Cohen's *d* of .93.

Four weeks of elastic-resistance exercise training did not elicit significant changes in 1-RM ankle-evertor strength. There were no differences in the change in 1-RM ankle-evertor strength on the postintervention test between the exercise and control groups (P = .262, d =.26), HAS and healthy groups (P = .329, d = .22), or males and females (P = .927, d = .02).

There were no significant changes in 1-RM ankle-evertor strength 4 weeks after concluding training (follow-up test) between the exercise and control groups (P = .652, d = .10), HAS and healthy groups (P = .500, d = .16), or males and females (P = .123, d = .36).

Peroneus Longus Latency

There were no 2- or 3-way interactions between treatment, HAS, and gender for peroneus longus muscle latency (see Table 2). There was no difference in the pre-intervention values for peroneus longus latency between the exercise and control groups (P = .177, d = .31), HAS and healthy groups (P = .276, d = .25), or males and females (P = .124, d = .35), suggesting that the groups were equal at the start. Although not significant, the initial value for peroneus longus latency was 5.99 ± 24.15 milliseconds (95% CI -4.59 to 16.57 ms) slower for the HAS group than the healthy group.

Four weeks of elastic-resistance exercise training did not elicit significant changes in peroneus longus muscle latency. There was no difference in the change in peroneus longus latency on the postintervention test between the exercise and control groups (P = .102, d = .38), HAS and healthy groups (P = .996, d = .00), or males and females (P = .947, d = .01).

There were no significant changes in peroneus longus latency 4 weeks after concluding training (follow-up test) between the exercise and control groups (P = .228, d = .25), HAS and healthy groups (P = .831, d = .04), or males and females (P = .657, d = .10).

Discussion

The goal of this study was to determine the effects of a 4-week elastic-resistance exercise program on ankle-evertor strength and neuromuscular reflex responses to sudden inversion in subjects with and without HAS. Chronic ankle instability has been attributed to ligament laxity, muscle weakness, and neural factors that include both proprioception and muscle-reaction time.[28] Elastic-resistance exercises are commonly used in rehabilitation because they enable the clinician to use a safe and effective closed kinetic chain (CKC) progressive overload to rehabilitate the injured patient.[16,18] When using elastic resistance to rehabilitate an injured joint, the clinician can easily adjust the resistance in small increments to match the patient's progress by increasing or decreasing the stretch of the elastic tubing.[18] Most ankle-rehabilitation programs use a combination of strengthening exercises and coordination exercises with an ankle disk or wobble board.[4,16] In this study we sought to quantify the rehabilitative training effect of 4 weeks of training with elastic-resistance exercise on ankle-evertor strength and reflex response time.

There are very few ankle-rehabilitation-training studies that have used exclusively elastic-resistance exercises.[16] Han et al[18] used elastic-tubing exercise to train subjects with and without HAS for 4 weeks. Subjects in their elastic-resistance-training group showed a significant improvement in postural control. Docherty et al[29] also used elastic-resistance exercises, and their subjects showed significantly improved dorsiflexion and inversion strength and inversion and plantar-flexion joint-position sense.[29]

In the current study, 4 weeks of elastic-tubing exercise did not elicit any change in 1-RM ankle-evertor strength. Recent evidence suggests that sensorimotor training causes specific neural adaptations to the muscle that relate more to force control than maximal-voluntary-contraction force.[18,30,31] Gruber et al[31] observed that 4 weeks of sensorimotor training resulted in increased rate of force development without considerable adaptations in maximal-voluntary-contraction force. They suggested that these specific adaptations are probably mediated by training-induced alterations in neural control of the muscle rather than muscle-fiber alterations. In addition, Gruber et al[31] observed that sensorimotor-training-induced alterations affected both synergistic and antagonistic muscles, which would clearly enhance postural control as observed by Han et al.[18]

CKC elastic-resistance training as applied in the current study may induce changes in either neural control[18,30,31] or reflex responses to proprioceptive input that lead to improved postural control while having little or no effect on strength development. To elicit changes in muscle strength it may be necessary to include open kinetic chain (OKC) elastic-resistance exercises.[29] Clearly further research is necessary to compare the effects of OKC versus CKC elastic-resistance exercise and the putative alterations in neural control versus strength development. It is plausible that CKC elastic-resistance exercises may elicit improved postural control, whereas OKC elastic-resistance exercises may elicit strength gains by allowing the patient to overcome resistance through a larger range of motion. In addition to the differences between OKC and CKC elastic resistance outlined here, it is equally likely that using CKC elastic resistance with an intensity of 16% body weight increasing to 22% of body weight, 3 times per week for 4 weeks, is not a sufficient overload stimulus to elicit strength gains. Further study of both the intensity and the duration of CKC elastic resistance is needed to determine whether the lack of strength gains observed in this study can be attributed to insufficient intensity and duration of strength training or the training stimulus induced by CKC elastic resistance is only neural, as evidenced by improved postural control.

An additional explanation for the discrepancy between our results and those of Docherty et al[29] may be the method of strength testing for ankle eversion. Docherty et al[29] used a handheld dynamometer, whereas we used isotonic resistance, to determine 1-RM evertor strength. Further research is necessary to identify the most accurate and reliable method (handheld dynamometer, isokinetic, isotonic, isometric) to measure ankle-inversion and -eversion strength. When using an isokinetic device to measure ankle-inversion and -eversion strength the leg to be tested is rigidly strapped in place so that only movement of the ankle joint is allowed. This clearly should improve the reliability of isokinetic measures. However, close inspection of the movement plane relative to the axis of motion for inversion/eversion in the ankle reveals that the isokinetic device does not adequately measure true inversion/eversion of the ankle; some or most of the motion being measured is abduction and adduction of the foot in the transverse plane. When a handheld dynamometer is used to measure ankle-inversion and -eversion strength it is difficult to isolate the movement so that only ankle inversion/eversion is measured.

Individuals with chronic ankle instability have been shown to have prolonged reflex response times after a sudden ankle inversion.[4,7,32,33] We anticipated that the inversion and eversion overloads[34] imposed by our elastic-resistance exercises might improve the reflex response time of the peroneus longus muscle after an unexpected ankle perturbation. The literature pertaining to the effects of ankle-rehabilitation exercises on reflex latency is inconclusive, with some exercise programs improving latency[12] and others showing no change.[3] In the current study we demonstrated that a 4-week elastic-resistance exercise program had no effect on the reflex latency of the peroneus longus muscle after an unexpected ankle inversion. The training effects of ankle-rehabilitation programs that have elicited changes in reflex response appear to cause minimal improvement in latency.[33] Linford et al[35] observed that 6 weeks of neuromuscular training in healthy subjects reduced muscle latency in the peroneus longus by 4.8 milliseconds in healthy subjects. An additional example of minimal changes in latency after training was a report that muscle-reaction times actually increased by approximately 3 milliseconds, suggesting that the training slowed the neuromuscular response time.[12] Although this change was statistically significant, it unknown whether a 3- to 4-millisecond improvement in reflex response time would reduce the likelihood of an ankle-inversion injury. Depending on the loading rate, the position of the foot relative to the center of mass, the momentum of the body, and the muscle preactivation before ground contact, there may be instances in which a 3- to 4-millisecond improvement in reflex response may reduce the severity of injury.

The extent to which improved reflex latency of the peroneal muscles can protect an individual from incurring an inversion injury depends on several factors such as the rate of loading, the position of the body on landing, momentum of the center of mass at landing, preactivation of the lower limb muscles, reflex latency of the muscles, and maximal strength of the muscles. [6,36–38] The peroneals are minimally active before ground contact and during support in normal gait.[6] Because of this the initial resistance to an unexpected inversion force is primarily provided by passive ankle-joint stiffness to forced inversion, which is 0.9 Nm/° during full weight bearing.[38] The muscle response to an unanticipated inversion force occurs 65 to 75 milliseconds after contact, with the maximal eversion torque occurring 115 to 135 milliseconds after initial contact.[6,36] This appears to be a good estimate of the limitations of the neuromuscular system to respond to an ankle-inversion stimulus. Because the neuromuscular system is relatively slow to respond to an unexpected event it is imperative that clinicians and coaches focus on training exercises designed to rehabilitate the injured joint to a preinjured level and train patients to avoid injury-inducing situations.

Our method of subject selection in the HAS group is a limitation of this study because we relied on a self-reported history of ankle sprain. The use of an ankle-instability instrument such as the Ankle Joint Functional Assessment Tool or the Foot and Ankle Disability Index along with a clinical evaluation of the subject's ankle would give additional evidence of the nature and extent of the subject's ankle instability.

Conclusion

The 4-week elastic-resistance exercise training had no effect on ankle-evertor strength and reflex latency of the peroneus longus after unexpected ankle inversion. CKC elastic-resistance exercises may induce neural alterations that lead to improved muscle control rather than muscle strength. Elastic-resistance exercises alone do not elicit ankle-eversion-strength gains, so clinicians are encouraged to include additional strengthening exercises in ankle-rehabilitation programs.

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