

Ankle Strength and Force Sense After a Progressive, 6-Week Strength-Training Program in People With Functional Ankle Instability

Brent I. Smith, MS, ATC; Carrie L. Docherty, PhD, ATC; Janet Simon, MS, ATC; Joanne Klossner, PhD, LAT, ATC; John Schrader, HSD, LAT, ATC

Athletic Training Research Laboratory, Indiana University, Bloomington

Context: Although strength training is commonly used to rehabilitate ankle injuries, studies investigating the effects of strength training on proprioception have shown conflicting results.

Objective: To determine the effects of a 6-week strength-training protocol on force sense and strength development in participants with functional ankle instability.

Design: Randomized controlled clinical trial.

Setting: University athletic training research laboratory.

Patients or Other Participants: A total of 40 participants with functional ankle instability were recruited. They were randomly placed into a training group (10 men, 10 women: age = 20.9 ± 2.2 years, height = 76.4 ± 16.1 cm, mass = 173.0 ± 7.9 kg) or control group (10 men, 10 women: age = 20.2 ± 2.1 years, height = 78.8 ± 24.5 cm, mass = 173.7 ± 8.2 kg).

Intervention(s): Participants in the training group performed strength exercises with the injured ankle 3 times per week for 6 weeks. The protocol consisted of a combination of rubber exercise bands and the Multiaxial Ankle Exerciser, both clinically

progression of this protocol provided increasingly resistive exercise as participants changed either the number of sets or resistance of the Thera-Band or Multiaxial Ankle Exerciser.

Main Outcome Measure(s): A load cell was used to measure strength and force sense. Inversion and eversion strength was recorded to the nearest 0.01 N. Force-sense reproduction was measured at 2 loads: 20% and 30% of maximal voluntary isometric contraction.

Results: Increases in inversion ($F_{1,38} = 11.59$, $P < 0.01$, $\eta_p^2 = 0.23$, power = 0.91) and eversion ($F_{1,38} = 57.68$, $P < .01$, $\eta_p^2 = 0.60$, power = 0.99) strength were found in the training group at the posttest when compared with the control group. No significant improvements were noted in force-sense reproduction for either group.

Conclusions: Strength training at the ankle increased strength but did not improve force sense.

Key Words: functional ankle instability, Thera-Band, Multi-axial Ankle Exerciser, proprioception

Key Points

- A 6-week strength-training protocol increased strength in participants with functional ankle instability. Proprioception did not improve, but the statistical power was low.
- We recommend strength training to address strength deficits and appropriate rehabilitative exercises to address proprioceptive deficits.

The most common injury in athletics is the lateral ankle sprain, and recurrence rates have been found to be as high as 80%.¹ After trauma, structures including the lateral ankle ligaments, evertor musculature, capsular tissue, and lower leg nervous tissue may be compromised.² Damage to some or all of these structures may create instability in the joint and predispose the ankle to future injuries. *Functional ankle instability (FAI)* has been defined as recurrent instability or a sense of giving way.^{2,3} Nearly 40% of individuals who sustain an acute lateral ankle sprain experience FAI.² The source of this instability is still unclear, but a variety of explanations, including muscular and proprioceptive deficits, have been hypothesized.^{2,4} Previous research related to strength deficits in individuals with FAI has resulted in conflicting findings. Some authors^{5,6} have shown no strength differences between participants with FAI and those with stable ankles. However, in a recent meta-analysis, weakness was

associated with FAI, specifically concentric evertor strength.⁷ Based on this finding, strength training is important in rehabilitating people with FAI.

Various protocols have been developed for rehabilitation after both acute and recurrent ankle sprains, emphasizing management of pain, swelling, range of motion, strength training, and proprioceptive training.^{5,8–17} Strength-training exercises are used to increase muscular development and improve neuromuscular control.^{10,12–15,18} Previous researchers¹⁹ demonstrated increased group Ia sensory activity after muscle contraction. Strength gains during the first 3 to 5 weeks of strength training are thought to be primarily due to neural factors.¹⁸ Strength training has also been reported to influence motor-unit recruitment, selective activation of agonist muscles and their motor units, and antagonist coactivation.²⁰ However, whether the long-term effects of these influences extend to muscle proprioception is uncertain. Two studies^{21,22} have shown a link

Table 1. Group Differences in Function

Activity	Symptomatic/Total, No. (%)	Odds Ratio (95% Confidence Interval)	Relative Risk (95% Confidence Interval)
Walking on a flat surface			
Training group	7/20 (35)	0.54 (0.15, 1.92)	0.70 (0.33, 1.47)
Control group	10/20 (50)		
Walking on uneven ground			
Training group	20/20 (100)	0.00 (0.00, 0.00)	1.00 (1.00, 1.00)
Control group	20/20 (100)		
During recreational or sport activity			
Training group	18/20 (90)	0.00 (0.00, 0.00)	0.90 (0.78, 1.04)
Control group	20/20 (100)		
Walking up or down stairs			
Training group	4/20 (20)	0.25 (0.06, 1.01)	0.40 (0.15, 1.06)
Control group	10/20 (50)		

between strength and proprioception; however, others^{6,23} have not.

The proprioceptive system supports the awareness and control of human movement by gaining information from an assortment of peripheral afferents.²⁴ A range of conscious proprioception methods can be measured, from kinesthesia to joint reposition sense.²⁵ The existence of these deficits in people with ankle instability has been clearly documented.^{23,26–29} Previous force-sense investigations^{30,31} have identified a deficit in low-load force sense in participants with FAI. *Force sense* is an additional conscious proprioceptive sense that measures an individual's ability to detect muscle tension and may be particularly important in patients with ankle instability. By accurately controlling muscle tension at a joint, patients may be able to fire muscles when necessary and potentially decrease the chance of reinjury.

Strength-training protocols, including straight plane, diagonal, and rotary exercises, may assist in full return to activity after injury.¹¹ Increases in strength can vary depending on the amount of resistance and number of repetitions and sets. The Multiaxial Ankle Exerciser (Multiaxial, Inc, Lincoln, RI) is a method for improving strength in a functional rehabilitation protocol.¹¹ In addition, protocols using rubber exercise bands for strength development have been established and are adaptable for many muscle groups.^{5,9,10,17} A progressive 6-week strength-training protocol using rubber exercise tubing produced improvements in both strength and joint position sense in the ankle.¹⁰ These findings suggest that strength training without an emphasis on proprioception may be beneficial to improve both strength and proprioception deficits.

The objective of any rehabilitation protocol is the fast and safe return to the preinjury activity level. By investigating how strength training may improve both strength and proprioception at the same time, clinicians may allow patients to decrease treatment time and return to participation more rapidly.¹⁰ Previous investigators^{5,32–34} have focused on using a single strengthening program, such as rubber exercise tubing or an isokinetic dynamometer.³² By using a progressive 6-week strength-training protocol with both rubber exercise tubing and the Multiaxial Ankle Exerciser (MAE), individuals with FAI may be able to attain greater benefits in strength and proprioception. Therefore, the purpose of our study was to

determine the effects of a 6-week strength-training protocol using 2 strengthening procedures on strength development and force-sense reproduction in individuals with FAI.

METHODS

Participants

Forty physically active and healthy college students volunteered for this study. *Physically active* was defined as exercising at least 3 times per week. Participants were randomly assigned to either the training group (10 men, 10 women: age = 20.9 ± 2.2 years, height = 76.4 ± 16.1 cm, mass = 173.0 ± 7.9 kg) or the control group (10 men, 10 women: age = 20.2 ± 2.1 years, height = 78.8 ± 24.5 cm, mass = 173.7 ± 8.2 kg). All participants had a history of unilateral FAI determined using the modified Ankle Instability Instrument.³⁵ *Functional ankle instability* was defined by a history of lateral ankle sprains (<1 month ago [n = 4], 1–6 months ago [n = 13], 6–12 months ago [n = 11], 1–2 years ago [n = 6], and >2 years ago [n = 6]) and a feeling of instability during at least 2 of the following activities: (1) walking on a flat surface, (2) walking on uneven ground, (3) during recreational or sport activity, and (4) walking up or down stairs (Table 1). Although all participants who met our inclusion criteria were randomly assigned to a group, we recognize minor differences between groups for the various activities in which they reported symptoms. Volunteers were excluded from either group if they had current ankle pain or swelling, a history of ankle surgery or fracture, or any diagnosed neuromuscular dysfunction, such as multiple sclerosis or Parkinson disease. Before the study, all participants read and signed an informed consent document approved by the Indiana University Institutional Review Board for the Protection of Human Subjects.

Instrumentation

Strength and force sense were measured using a load cell (model # 41A; Sensotec, Inc, Columbus, OH). The load cell was positioned between 2 metal brackets built to rest approximately 6 in (15.24 cm) above the floor. The BioPac MP 150 system (BioPac Systems, Inc, Santa Barbara, CA) and AcqKnowledge Software (version 3.7; BioPac Systems, Inc) were used for data acquisition, storage, and retrieval.

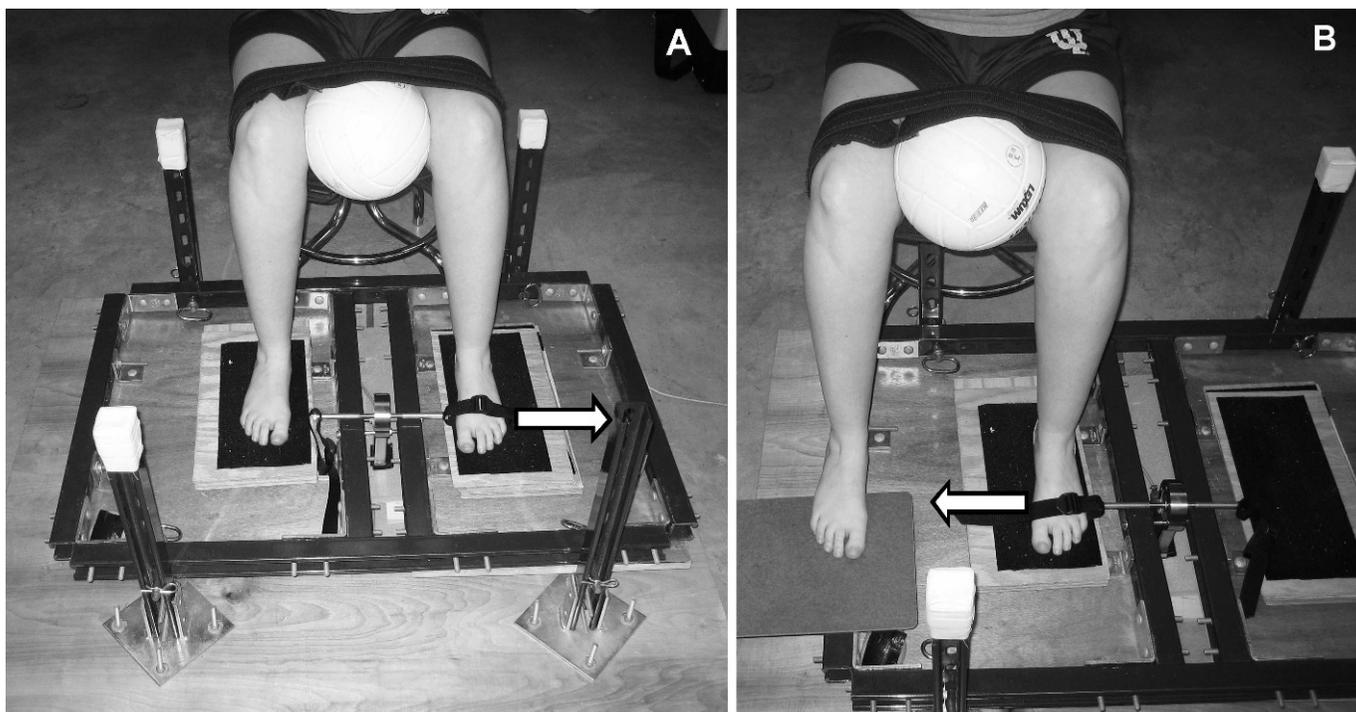


Figure 1. Participant positioning for maximal voluntary isometric contraction strength testing for the left ankle. A, Eversion strength. B, Inversion strength. Arrow illustrates direction of force application.

Procedures

All participants performed pretests for inversion and eversion strength and force sense at 2 loads. The training group performed a Thera-Band (The Hygenic Corporation, Akron, OH) and MAE strength training protocol 3 days per week for 6 weeks. The control group did not participate in any ankle rehabilitation during the same 6-week period. At the end of the 6 weeks, posttest measures for strength and force sense were repeated.

Strength Testing

Inversion and eversion strength was tested in all participants. They were barefoot, seated on a stool, with a volleyball between the thighs, and secured with a hook-and-loop strap. The foot was attached to the load cell with a looped nylon strap. For eversion strength testing, the load cell was situated medial to the test foot with the nylon strap placed directly over the distal end of the fifth metatarsal (Figure 1A). For inversion strength testing, the load cell was situated laterally to the test foot and nylon strap placed directly over the distal first metatarsal (Figure 1B). Three maximal isometric contractions were held for 5 seconds each with a 1-minute rest period between contractions. The maximum value in each direction was recorded as the maximum voluntary isometric contraction (MVIC).

Force-Sense Testing

Participant positioning for force-sense testing was identical to that for eversion strength testing. Force matching was conducted at 20% and 30% of the average eversion MVIC. We used low loads because the results of previous research³⁶ with larger forces (50% and 75%)

suggest that it was difficult for participants to sustain the contraction of the target force for the required 5 seconds. The participants used a digital readout to establish the target force with the involved limb and then held the contraction for 5 seconds before relaxing. They were then asked to reproduce the force with eyes closed. Once the participant thought the reference force had been reestablished, he or she hit a trigger button that electronically marked the data and maintained the contraction for 5 seconds. A practice trial, followed by 3 test trials, was performed at each force. A 30-second rest period was provided between trials, and the order of test forces was counterbalanced. Day-to-day reliability for this procedure with $n = 8$ participants was intraclass correlation coefficient $[2, k] = 0.84$; standard error of measurement = 0.79 N.

Rehabilitation Procedures

Participants in the training group performed strength exercises with the injured ankle 3 times per week for 6 weeks. Previous investigators^{10,18} have demonstrated that 6 weeks of training is sufficient to appreciate strength gains. Our protocol was derived from rehabilitation programs used in earlier studies.^{5,10,11} The protocol consisted of Thera-Bands and the MAE, 2 clinically accepted strengthening methods for ankle rehabilitation. The progression of this protocol provided increasingly resistive exercise as participants changed either the number of sets or the resistance provided by the Thera-Band or MAE. All exercises were performed in stockings or with bare feet under the supervision of the primary investigator (B.I.S.).

When using the Thera-Band, the participant sat on the floor with one end of the tubing tied around a treatment table and the other end around the metatarsal heads of the involved foot. The knees were fully extended, and the

Table 2. Tubing Strength-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

Thera-Band was stretched to 170% of its resting length, regardless of the band color (resistance), as described by Kaminski et al.⁵ Exercises were performed in 4 directions: dorsiflexion, plantar flexion, inversion, and eversion. The exercise progression involved an increased number of sets or increased resistance each week (Table 2). Participants were instructed to use only the involved ankle joint during the exercises.

The second set of exercises included the MAE. The participants were seated with their lower legs hanging over the edge of the table. The involved foot was secured onto the foot plate in a closed kinetic chain position. The front, middle, and rear hook-and-loop straps were fastened with the foot centered on the foot plate. The thigh was parallel to the floor, promoting primary force generation by the lower leg. Proper thigh position was accomplished by adjusting the shaft length on the base of the MAE. The lower leg was perpendicular to the floor with the knee directly above the ankle. Participants were instructed to use only the ankle joint during the exercises (Figure 2). For each week in the program, exercise difficulty was increased in resistance, pattern complexity, sets, or repetitions (or a combination of these; Table 3). Exercise protocols followed established patterns documented in the MAE manual.³⁷

Members of the control group were asked to avoid any new strength or rehabilitative exercises for their ankles during the 6 weeks between pretest and posttest. However, they were allowed to continue their regular activities to maintain their preparticipation activity levels.

Data Processing

Trial error scores for the force-sense testing were calculated using the last second of the reference contraction and the first second of the reproduction contraction. Constant error, variable error, and absolute error were then calculated: *CE* is the average of the trial scores, *VE* is the standard deviation of the trial scores, and *AE* is the average of the absolute values of the trial scores.

Statistical Analysis

For the dependent variable of strength, 2 repeated-measures analyses of variance (RMANOVAs) were conducted: 1 for inversion and 1 for eversion. Each RMANOVA had 1 within-subjects factor (pretest, posttest) and 1 between-subjects factor (training group, control group). For the dependent variable of force sense, 3 RMANOVAs were conducted: 1 each for CE, VE, and AE. Each RMANOVA had 2 within-subjects factors (pretest, posttest and 20% MVIC, 30% MVIC) and 1 between-subjects factor (training group, control group). Tukey post

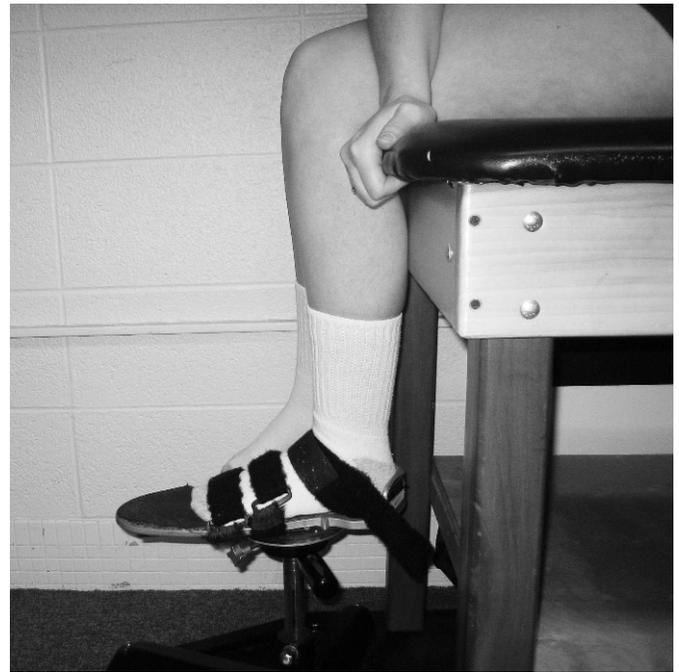


Figure 2. Participant positioning in Multiaxial Ankle Exerciser (Multiaxial, Inc, Lincoln, RI) for 6-week strength-training protocol.

hoc analysis was performed on all significant findings. The α level was set at $P < .05$ for all tests.

RESULTS

For strength, we found a test-by-group interaction for both inversion ($F_{1,38} = 11.59, P < .01, \eta_p^2 = 0.23, \text{power} = 0.91$) and eversion ($F_{1,38} = 57.68, P < .01, \eta_p^2 = 0.60, \text{power} = 0.99$; Table 4). Inversion strength at the posttest was greater in the training group (100.2 ± 22.4 N) than in the control group (72.9 ± 24.0 N). Similarly, eversion strength at the posttest was greater in the training group (142.9 ± 38.9 N) than in the control group (100.4 ± 29.8 N).

For force-sense CE, no interactions were demonstrated for test by group ($F_{1,38} = 2.47, P = .12, \text{power} = 0.34$), force by group ($F_{1,38} = 0.29, P = .60, \text{power} = 0.08$), or test by force by group ($F_{1,38} = 1.18, P = .28, \text{power} = 0.19$).

For force-sense VE, we noted a test-by-group interaction ($F_{1,38} = 4.51, P < .05, \eta_p^2 = 0.11, \text{power} = 0.54$). However, follow-up pairwise comparisons revealed that the groups were not statistically different at either the pretest or posttest. We also found no force-by-group ($F_{1,38} = 0.06, P = .81, \text{power} = 0.06$) or test-by-force-by-group interaction ($F_{1,38} = 0.17, P = .69, \text{power} = 0.07$).

For force-sense AE, we showed no interactions for test by group ($F_{1,38} = .37, P = .55, \text{power} = 0.09$), force by group ($F_{1,38} = .01, P = .97, \text{power} = 0.05$), or test by force by group ($F_{1,38} = .54, P = .46, \text{power} = 0.11$).

DISCUSSION

The primary finding of this study was that a supervised 6-week strength-training protocol using Thera-Bands and the MAE increased inversion and eversion ankle strength in participants with FAI. Despite the development in strength, no statistically significant improvement in proprioception as measured by force sense was found.

Table 3. Multiaxial Ankle Exerciser Training Protocol

Week	Pattern	Resistance, °	Resistance, lb (kg)	Sets × Repetitions
1	Vertical and diagonal	30	11 (4.99)	2 × 10
2	V shapes	40	15.6 (7.08)	2 × 10
3	Vertical zig-zags	50	21 (9.53)	2 × 10
4	Horizontal V's	60	27 (12.25)	2 × 15
5	Circular shapes	70	32 (14.51)	1 × 15
6	Alphabet	70	32 (14.51)	2 × 1

Strength

The effect of a 6-week strength-training protocol on strength development in participants with FAI is clear. Those involved in a progressive resistive exercise protocol 3 times per week for 6 weeks produced higher inversion and eversion MVIC values than did the control group. Specifically, inversion strength values increased by approximately 25% and eversion values by almost 55%. These results agree with previous research demonstrating that strength training improved strength.^{10,12,18,38–40} Strength-training studies involving other joints provide further support for our results. At the shoulder, a 4-week Thera-Band-and-lightweight-dumbbell protocol increased internal and external shoulder rotation torque.³⁸ Moritani and de Vries¹⁸ used a 6-week training protocol with progressive-resistance–dumbbell exercises to improve strength of the elbow flexors. At the knee, an 8-week isotonic progressive-resistance exercise protocol increased isometric, isokinetic, and isotonic strength development.³⁹ Researchers¹⁸ concluded that increases in strength development were due to a combination of neural factors and hypertrophy.

Strength-training protocols specifically for the ankle commonly use Thera-Band resistance in clinical settings; however, studies providing objective evidence to support its use are limited.⁴⁰ To date, no investigators have evaluated the use of both Thera-Bands and the MAE to strengthen the ankle. Consistent with our results, strength improvements at the ankle have been reported with both a 6-week Thera-Band protocol¹⁰ and an 8-week isokinetic training protocol.¹² Bagheri et al³² showed that 6 weeks of progressive-resistance–Thera-Band exercises increased muscle strength of the dorsiflexors, plantar flexors, evertors, and invertors. However, greater improvement (approximately 18.2%) was seen with plantar flexion and eversion.³² In our study, eversion strength increased by almost 55%. This finding may indicate that combining a progressive-resistance–Thera-Band protocol and the MAE may be more effective in increasing eversion strength.

Researchers have used other strengthening protocols to increase strength of the ankle. Many of these methods include isometric and isokinetic strengthening with a dynamometer. Over 6 weeks of isokinetic strengthening of the invertors and evertors, strength gains were seen in individuals with FAI and stable ankles.³⁴ In older patients, 2 days of isokinetic strengthening for 2 weeks increased dorsiflexion peak torque and ankle mobility.³³ Connelly and Vandervoort³³ trained 28 individuals concentrically and eccentrically for dorsiflexion 3 days per week for 2 weeks. A 27% increase in concentric dorsiflexion and a 20% increase in eccentric dorsiflexion were seen after

Table 4. Strength and Force-Sense Errors (Mean ± SD)

Variable	Pretest, N	Posttest, N
Inversion strength		
Training group	80.1 ± 33.6	100.2 ± 22.4
Control group	75.9 ± 26.2	72.9 ± 24.0 ^a
Eversion strength		
Training group	92.4 ± 35.0	142.9 ± 38.9
Control group	97.5 ± 31.3	100.4 ± 29.8 ^a
Variable error		
Training group: 20% of MVIC	2.5 ± 1.5	4.7 ± 3.6
Control group: 20% of MVIC	3.2 ± 1.5	3.8 ± 3.3
Training group: 30% of MVIC	2.9 ± 1.6	6.0 ± 3.1
Control group: 30% of MVIC	4.2 ± 4.2	4.9 ± 3.5
Constant error		
Training group: 20% of MVIC	3.9 ± 3.3	8.2 ± 4.7
Control group: 20% of MVIC	3.0 ± 5.2	6.3 ± 6.0
Training group: 30% of MVIC	5.5 ± 4.4	11.0 ± 7.2
Control group: 30% of MVIC	5.3 ± 5.0	7.3 ± 5.7
Absolute error		
Training group: 20% of MVIC	4.8 ± 4.4	7.4 ± 5.3
Control group: 20% of MVIC	3.8 ± 2.3	7.9 ± 4.6
Training group: 30% of MVIC	6.7 ± 3.8	9.9 ± 6.1
Control group: 30% of MVIC	6.5 ± 3.4	9.8 ± 5.7

Abbreviation: MVIC, maximum voluntary isometric contraction.

^a Differences between training and control groups ($P < .01$).

training. Sekir et al⁴¹ found that inversion and eversion increased approximately 11% and 10%, respectively. Even though they noted differences in pretest and posttest strength, we found greater gains in inversion (25%) and eversion (55%). Again, this may be due to our protocol using a progressive-resistance–Thera-Band protocol and multiplane motions with the MAE, whereas Sekir et al⁴¹ used an isokinetic dynamometer for strengthening.

Kaminski et al⁵ reported no improvements in ankle eversion-inversion and plantar flexion-dorsiflexion strength ratios after a 6-week strength-training protocol with Thera-Bands that began with the medium red and ended with the extra-heavy blue. As did previous researchers,¹⁰ we initiated the protocol using the extra-heavy blue Thera-Band and progressed to the super-heavy silver. The lower resistance Thera-Band used by Kaminski et al⁵ might not have provided sufficient resistance to challenge the ankle musculature and improve strength. Our results indicated that our strength protocol was challenging enough to improve strength in the inversion and eversion directions. Additionally, with the MAE, strength training was completed in a variety of planes. This idea was supported by Fiore and Leard,¹¹ who outlined the importance of including straight-plane, diagonal, and circumduction activities in rehabilitation programs to prepare the injured ankle joint for full activity.

Force Sense

The combined results of the current study and previous literature^{10,17,34,40} suggest that the effect of strength training on proprioception remains unclear. We found no differences in force-sense errors between the training and control groups. However, because of the lack of statistical power, our findings for force sense should be interpreted with caution. Our results are consistent with those of

earlier investigators,^{17,34,40} but previous authors^{10,17} have shown a positive effect between strength training and other measures of proprioception, such as joint position sense.

Specifically, accuracy in joint position sense increased after a 6-week strength-training protocol.¹⁰ Joint position sense error for inversion at pretest was 6.8° and at posttest was 2.8° and for plantar flexion at pretest was 7.9° and at posttest, 1.4°. This improvement, or decrease in error scores, was attributed to muscle spindle sensitivity and γ -afferent activation.¹⁰ This would suggest that strength training alone was as effective in improving the proprioceptive measures of semidynamic and dynamic balance as was proprioception training alone or a combination of strength and proprioception training. Other groups have shown no differences in proprioception after a strengthening protocol. Hawke et al³⁴ conducted balance testing before and after 30 repetitions of inversion, eversion, dorsiflexion, and plantar flexion with a rubber resistive band stretched 50%, following the Kaminski et al⁵ protocol. Balance was assessed using the Biodex Stability System. No differences were found for the overall stability index, the medial-lateral stability index, or the anterior-posterior stability index. Strength did not improve, perhaps because of inadequate stimulation of motor unit components and, hence, proprioception similarly did not improve.⁵

Deficits in force sense in individuals with FAI have been reported.^{30,41} In 2008, Docherty and Arnold⁴² reported greater AE in FAI ankles (3.7 ± 2.2 N) than in uninjured ankles (2.8 ± 1.1 N). Variable error was also greater in the FAI ankles (3.2 ± 1.8 N) than in the uninjured ankles (2.4 ± 0.8 N).⁴² These values are consistent with our pretest AE (3.8 ± 2.3 N) and VE (3.2 ± 1.5 N) values. Therefore, we can conclude that FAI is associated with deficits in an individual's ability to accurately reproduce a given force. However, we are the first to specifically address how strength training affects force-sense measures in FAI individuals. Addressing proprioceptive deficits is an important part of any rehabilitation protocol, but especially so in people with FAI, who may be unable to accurately control muscle tension at a joint, predisposing them to future injury.

Future Research

The use of Thera-Bands and MAEs are common practices in the clinical setting, and investigations of both should continue. Future researchers should evaluate the effects of proprioception training alone on strength. Improved strength after a proprioception-training protocol may suggest that such training alone can save time and resources when rehabilitating an ankle injury. Additionally, the effects of other types of strength-training protocols, such as dynamometers for isotonic and isokinetic training, on ankle force sense should be investigated. Comparing different lengths of strengthening programs may also be beneficial. Many authors have studied 6-week programs; however, strength gains have been seen in as few as 2 weeks. Proprioceptive measures, including joint position sense, force sense, dynamic balance, semidynamic balance, and static balance, should be researched. In addition to investigating strength protocols, assessing outcomes is an important part of the rehabilitation process. By evaluating the Ankle Instability Instrument and other subjective questionnaires before and after rehabilitation, changes in

patient self-reported function and disability can also be determined.

CONCLUSIONS

A 6-week strength-training protocol increased strength in participants with FAI. Yet the effects of this training protocol on proprioception are still unclear. Our findings suggest that strength training has no effect on proprioception, but because statistical power for the force-sense measure was low, our results for proprioception are inconclusive. This finding supports continuing the current clinical practice of strength training to address strength deficits and adding other rehabilitation exercises to address proprioceptive deficits in force sense.

REFERENCES

1. Yeung MS, Chang KM, So CH, Yuan WY. An epidemiological survey on ankle sprain. *Br J Sports Med.* 1994;28(2):112–116.
2. Freeman MA, Dean MR, Hanham IW. The etiology and prevention of functional instability of the foot. *J Bone Joint Surg Br.* 1965;47(4):678–685.
3. Hertel J. Functional instability following lateral ankle sprain. *Sports Med.* 2000;29(5):361–371.
4. Verhagen RA, de Keizer G, van Dijk CN. Long-term follow-up of inversion trauma of the ankle. *Arch Orthop Trauma Surg.* 1995;114(2):92–96.
5. Kaminski TW, Buckley BD, Powers ME, Hubbard TJ, Ortiz C. Effect of strength and proprioception training on eversion to inversion strength ratios in subjects with unilateral functional ankle instability. *Br J Sports Med.* 2003;37(5):410–415.
6. Lentell G, Katzmann LL, Walters MR. The relationship between muscle function and ankle stability. *J Orthop Sports Phys Ther.* 1990;11(12):605–611.
7. Arnold BL, Linens SW, de la Motte SJ, Ross SE. Concentric evorter strength differences and functional ankle instability: a meta-analysis. *J Athl Train.* 2009;44(6):653–662.
8. Bernier JN, Perrin DH. Effect of coordination training on proprioception of the functionally unstable ankle. *J Orthop Sports Phys Ther.* 1998;27(4):264–275.
9. Bernier J, Sieracki J, Levy LS. Functional rehabilitation of the ankle. *Athl Ther Today.* 2000;5(2):38–44.
10. Docherty CL, Moore JH, Arnold BL. Effects of strength training on strength development and joint position sense in functionally unstable ankles. *J Athl Train.* 1998;33(4):310–314.
11. Flore R, Leard JS. A functional approach in the rehabilitation of the ankle and foot. *Athl Train J Natl Athl Train Assoc.* 1980;15(4):231–235.
12. Uh BS, Beynonn BD, Helie BV, Alosa DM, Renstrom PA. The benefit of a single-leg strength training program for the muscles around the untrained ankle. *Am J Sports Med.* 2000;28(4):568–573.
13. Hutton MA. *Sports Injuries: Recognition and Management.* New York, NY: Oxford University Press; 1990.
14. Chromiak JA, Mulvaney DR. A review: the effects of combined strength and endurance training on strength development. *J Appl Sport Sci Research.* 1990;4(2):55–60.
15. Case WS. Ankle injuries. In: Sanders B, ed. *Sports Physical Therapy.* Norwalk, CT: Appleton & Lange; 1990:456–464.
16. Irrgang JJ, Whitney SL, Cox ED. Balance and proprioception training for rehabilitation of the lower extremity. *J Sport Rehabil.* 1994;3(1):68–83.
17. Blackburn JT, Prentice WE, Guskiewicz KM, Busby MA. Balance and stability: the relative contributions of proprioception and muscular strength. *J Sport Rehabil.* 2000;9(4):315–328.
18. Moritani T, de Vries HA. Neural factors versus hypertrophy in the time course of muscle strength gain. *Am J Phys Med.* 1979;58(3):115–130.
19. Hutton RS, Smith JL, Eldred E. Postcontraction sensory discharge from muscle and its source. *J Neurophysiol.* 1973;36(6):1090–1103.

20. Komi PV, Sale DG. Neural adaptation to strength training. In: *Strength and Power in Sport*. Oxford, UK: Blackwell Scientific Publication; 1992:249–265.
21. Tropp H. Pronator weakness in functional instability of the ankle joint. *Int J Sport Med*. 1986;7(5):291–294.
22. Wiksten DL, Perrin DH, Hartman M, Gieck J, Weltman A. The relationship between muscle and balance performance as a function of age. *Isokinet Exerc Sci*. 1996;6(2):125–132.
23. Lentell G, Baas B, Lopez D, McGuire L, Sarrels M, Snyder P. The contributions of proprioceptive deficits, muscle function, and anatomic laxity to functional instability of the ankle. *J Orthop Sports Phys Ther*. 1995;21(4):206–215.
24. Park S, Toole T, Lee S. Functional roles of the proprioceptive system in the control of goal-directed movement. *Percept Mot Skills*. 1999;88(2):631–647.
25. Riemann BL, Lephart SM. The sensorimotor system, part I: the physiologic basis of functional joint stability. *J Athl Train*. 2002;37(1):71–79.
26. Forkin DM, Koczur C, Battle R, Newton RA. Evaluation of kinesthetic deficits indicative of balance control in gymnasts with unilateral chronic ankle sprains. *J Orthop Sports Phys Ther*. 1996;23(4):245–250.
27. Garn SN, Newton RA. Kinesthetic awareness in subjects with multiple ankle sprains. *Phys Ther*. 1988;68(11):1667–1671.
28. Konradsen L, Magnusson P. Increased inversion angle replication error in functional ankle instability. *Knee Surg Sports Traumatol Arthrosc*. 2000;8(4):246–251.
29. Jerosch J, Bischof M. Proprioceptive capabilities of the ankle in stable and unstable joints. *Sports Exerc Inj*. 1996;2(4):167–171.
30. Docherty CL, Arnold BL, Hurwitz S. Contralateral force sense deficits are related to the presence of functional ankle instability. *J Orthop Res*. 2006;24(7):1412–1419.
31. Arnold BL, Docherty CL. Ankle low-load force replication error is related to self-reported ankle giving-way and perceived ankle instability. *J Athl Train*. 2006;41(3):233–238.
32. Bagheri. Effects of strength training of the ankle muscles on balance. *Tehran Uni Med J*. 2006;63(6):902–912.
33. Connelly DM, Vandervoort AA. Effects of isokinetic strength training on concentric and eccentric torque development in the ankle dorsiflexors of older adults. *J Gerontol A Biol Sci Med Sci*. 2000;55(10):B465–472.
34. Hawke RL, Van Lunen BL, Arnold BL, Gansneder BM. Acute proprioception measurements following resistive ankle exercise [abstract]. *J Athl Train*. 1998;33(suppl 2):S26.
35. Docherty CL, Gansneder BM, Arnold BL, Hurwitz SR. Development and reliability of the ankle instability instrument. *J Athl Train*. 2006;41(2):154–158.
36. Arnold B. Ankle evertor force sense and reproduction are not related to injury severity or episodes of rolling over or giving way [abstract]. *J Athl Train*. 2002;37(suppl 2):S23.
37. Multiaxial, Inc. *Instructions for Use and Operation of the Multiaxial Ankle Exerciser*. Lincoln, RI: Multiaxial, Inc; 1992.
38. Treiber FA, Lott J, Duncan J, Slavens G, Davis H. Effects of Thera-Band and lightweight dumbbell training on shoulder rotation torque and serve performance in college tennis players. *Am J Sports Med*. 1998;26(4):510–515.
39. Tsaklis P, Abatzides G. ACL rehabilitation program using a combined isokinetic and isotonic strengthening protocol. *Isokinet Exerc Sci*. 2002;10(4):211–219.
40. Powers ME, Buckley BD, Kaminski TW, Hubbard TJ, Ortiz C. Six weeks of strength and proprioception training does not affect muscle fatigue and static balance in functional ankle instability. *J Sport Rehabil*. 2004;13(3):201–227.
41. Sekir U, Yildiz Y, Hazneci B, Ors F, Aydin T. Effect of isokinetic training on strength, functionality and proprioception in athletes with functional ankle instability. *Knee Surg Sports Traumatol Arthrosc*. 2007;15(5):654–664.
42. Docherty CL, Arnold BL. Force sense deficits in functionally unstable ankles. *J Orthop Res*. 2008;26(11):1489–1493.

Address correspondence to Carrie L. Docherty, PhD, ATC, Athletic Training Research Laboratory, Indiana University, 2805 East Tenth Street, Bloomington, IN 47408. Address e-mail to cdocher@indiana.edu.