Effect of Coordination Training With and Without Stochastic Resonance Stimulation on Dynamic Postural Stability of Subjects With Functional Ankle Instability and Subjects With Stable Ankles

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Objective: To examine the effects of coordination training with and without stochastic resonance (SR) stimulation on dynamic postural stability.

Design: Experimental with repeated measures.

Setting: Research Laboratory.

Participants: Thirty subjects with functional ankle instability (FAI) and 30 healthy subjects.

Interventions: Subjects were assigned to a conventional coordination training group, SR stimulation coordination training group, or control group. Training groups performed coordination exercises for 6 weeks. Single leg jump-landing tests were performed before training began (pretest), and then once every 2 weeks. Jump-landing tests required subjects to land on a single leg on a force plate and stabilize quickly.

Main Outcome Measures: Anterior/posterior (A/P) and medial/lateral (M/L) time-to-stabilization (TTS).

Results: The FAI group improved their A/P TTS over their pretest by 16% (test 2), 22% (test 3), and 22% (posttest). They also improved their M/L TTS over their pretest by 16% (test 3) and 22% (posttest). Control groups did not improve their TTS ($P > 0.05$). SR stimulation did not statistically influence TTS ($P > 0.05$). Effect sizes (ES), however, for our 3-way interaction analyses for A/P TTS (ES = 0.40) and M/L TTS (ES = 0.30) suggested that SR stimulation improved the FAI group's M/L TTS after 2 weeks of training, and improved their A/P TTS and M/L TTS to a greater degree after 4 weeks than coordination training alone.

Conclusion: Coordination training can improve dynamic postural instabilities associated with FAI. SR stimulation might be an alternative therapy for FAI, as this stimulation might improve dynamic postural stability more quickly and to a greater extent than coordination training without SR stimulation.

Key Words: balance, jump-landing, time-to-stabilization

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Ankle sprains are common injuries that often lead to a pathology known as functional ankle instability (FAI).[1–3] This pathology is defined by reoccurring ankle sprains, and the causal factors of this instability might be a result of deficits at the ankle in mechanical stability, strength, proprioception, or muscle activation.[4–11] Functional ankle instability has also been associated with static and dynamic postural stability deficits, and researchers have suggested that these deficits could be causal factors of recurrent ankle sprains.[1,4–6,8–10,12–20] Coordination training has been recommended as therapy for FAI, and training that consists of single leg stance exercises have improved static postural stability associated with FAI.[1,4,6,8,13–16] However, the effects of coordination training on dynamic postural stability of subjects with FAI have not been thoroughly studied. Returning individuals to physical activity without adequate dynamic postural stability might be a reason ankle sprains continue to occur.

Sport medicine clinicians often return individuals to physical activity as quickly as possible, even though ankle stability might not be fully restored. Therapy that expedites the injury recovery process while simultaneously improving stability might allow individuals to return earlier to activity with adequate ankle stability. Recently, subsensory electrical noise and mechanical noise applied to the skin have been used to improve postural stability in healthy humans and elderly compared with postural stability tests without this noise therapy.[21–23] The stability benefit evident with the application of noise occurs through a phenomenon known as stochastic resonance (SR). Collins and his colleagues have suggested that this SR phenomenon enhances the detection of proprioceptive signals important for maintaining stability in healthy humans and patients with associated proprioceptive deficits.[21–24] SR stimulation might prove beneficial for improving postural stability in subjects with FAI, a patient population who might have a certain degree of proprioceptive deficits.

Rehabilitation protocols that adequately restore dynamic postural stability might help to decrease ankle sprain incidence. In addition, coordination training that uses SR stimulation might prove more beneficial for improving dynamic postural stability compared with coordination training without SR stimulation. The purpose of this study, therefore, was to examine the effects of 6 weeks of coordination training with and without SR stimulation on dynamic postural stability of subjects with FAI and subjects with stable ankles. Anterior/posterior (A/P) and medial/lateral (M/L) time-to-stabilization (TTS) measures were used to quantify dynamic postural stability.[17–20,25] A secondary purpose of this study was to determine if TTS measures improved the second, fourth, or sixth week of coordination training.

METHODS

Subjects

Seventy-six subjects who participated in physical activity for a minimum of 3 h/wk were recruited for this study. Thirty-eight subjects with stable ankles were matched to 38 subjects with clinically diagnosed FAI by height, mass, age, sex, and test leg. Eight subjects did not complete this study, and their matched subjects were consequently eliminated from data analysis. Therefore, 30 subjects with FAI (16 females, 14 males) and 30 subjects with stable ankles (16 females, 14 males) completed this study, and were used for data analysis. Subjects read and signed a consent form approved by The Committee for the Protection of the Rights of Human Subjects. Subjects received monetary compensation for their participation in this study.

Criteria for FAI used in this study has been previously described in our published reports.[17,18] In summary, subjects with FAI had a history of ankle sprain injury that required immobilization, and they then reported a minimum of 2 ankle sprains and 2 "giving way" sensations. These recurrent sprains and feelings of instability had to occur within the past year before their participation in this study. Table 1 provides the incidence of sprains and giving way in our subjects. Although subjects were not immobilized for any period of time with these subsequent sprains, they reported signs and symptoms of an acute ankle sprain injury with each sprain. Ankle sprain injury and acute signs/symptoms of this injury have also been described in our previous reports.[17,18]

As in our previous work, the ankle scoring lower on the Ankle Joint Functional Assessment Tool determined the test leg for subjects with bilateral instability of the ankle.[17,18] Table 1 provides our subjects' scores on this questionnaire. Positive anterior drawer and talar tilt tests were present in 67% and 76% of our subjects with FAI, respectively. Potential subjects with FAI were excluded if they had an ankle sprain injury within 6 weeks before their participation or participated in a rehabilitation program 6 weeks before this study. Subjects with stable ankles could not participate if they reported a history of ankle sprain injury or sensations of giving way at their ankle with weight-bearing activity. A history of lower extremity fractures, knee injuries, and hip injuries were exclusion criteria for all subjects. Finally, subjects reporting visual impairments that affected their balance, vestibular deficits, or neurologic dysfunctions were excluded.

Ten subjects with FAI (77 ± 20 kg, 170 ± 10 cm, 20 ± 2 y) and 10 subjects with stable ankles (78 ± 20 kg, 170 ± 10 cm, 22 ± 2 y) were members of the conventional coordination training (CCT) group , and they performed single leg coordination exercises for 6 weeks. An additional 10 subjects with FAI (72 ± 15 kg, 17 ± 10 cm, 22 ± 2 y) and 10 subjects with stable ankles (67 ± 15 kg, 170 ± 10 cm, 20 ± 1 yr) were members of the SR stimulation coordination training (SCT) group , and they performed single leg coordination exercises for 6 weeks with subsensory electrical noise (SR stimulation) applied to their ankle muscles and ligaments. Finally, 10 subjects with FAI (78 ± 12 kg, 180 ± 10 cm, 21 ± 3 y) and 10 subjects with stable ankles (77 ± 14 kg,

TABLE 1. Ankle Instability Characteristics

	Stable Ankle Group	FAI Group
	Mean (± SD)	Mean (± SD)
	No. give ways/y:	No. give ways/y:
CCT	N/H*	12.30 (6.30)
SCT	N/H*	4.30 (3.88)
Control	N/H*	3.04 (0.67)
	No. sprains/y:	No. sprains/y:
CCT	N/H*	5.30 (3.43)
SCT	N/H*	3.20 (1.13)
Control	N/H*	3.40 (1.51)
	Ankle Joint Functional Assessment Tool Score	Ankle Joint Functional Assessment Tool Score
CCT	25.20 (1.48)	15.70 (3.77)
SCT	24.20 (3.71)	17.20 (4.80)
Control	24.60 (1.26)	13.70 (5.33)

*N/H indicates no history.

180 ± 10 cm, 20 ± 1 y) were members of a control group, and they did not participate in coordination training.

Procedure

Coordination Training

Table 2 describes the coordination training exercises and parameters. The CCT and SCT groups participated in 6 weeks of coordination training. Subjects trained approximately 10 min/session and trained 5 d/wk (Monday to Friday). Subjects did not wear their shoes while training. All subjects wore SR stimulator units (Afferent Corp, Providence, RI) with surface electrodes (2 × 2 cm) self-adhesive gel pads (Model Platinum 896230, Axelgaard Mfg. Co, Ltd, Fallbrook, CA) over the skin of the lateral soleus, peroneus longus, tibialis anterior, anterior talofibular ligament, and deltoid ligament. Subjects in the SCT received subsensory electrical noise stimulation (Gaussian white, zero mean, SD = 0.05 mA) from a SR stimulator while they trained. Stimulation was not administered to the CCT group even though they wore the SR stimulator units and surface electrodes during training. Subjects were blinded to their training group.

Single Leg Jump-landing

All subjects wore gym clothing and athletic shoes during test sessions. Subjects were tested on a single leg jump-landing test, which we have previously described.[17–19,25] This test required subjects to perform a double legged jump between 50% and 55% of their maximum jump height as they stood 70 cm from the center of a force plate. Subjects then "stuck" the landing on a single leg, stabilized as quickly as possible, and remained motionless in a single leg stance for 20 seconds. Subjects performed a pretest, and they then repeated test sessions after the 9th (test 2), 19th (test 3), and 29th (posttest) training sessions. Control group subjects were tested over 4 test sessions, with each session separated by 2 weeks. For each test session, subjects performed 3 practice trials and 7 testing trials, and 30 seconds of rest were given between trials. Trials were repeated if subjects failed to jump within the 50% and 55% mark, hopped on the test leg after landing, or touched down with the nonweight-bearing leg.

Data Collection

A Bertec strain gauge force plate, Bertec amplifier (Bertec Corp, Columbus, OH), and A/D converter (National Instruments Corp, Austin, TX) that was interfaced with a personal computer were used for data collection. Force plate analog signals were sampled at 180 Hz, amplified by a factor of 2, and converted to digital signals. MotionSoft MSFPLT computer program software package version 2.0 (Motionsoft Inc, Chapel Hill, NC) converted digital signals to ground reaction force vectors and moments. A/P TTS and M/L TTS were then calculated from the respective ground reaction force using a normalization method that we have previously described.[17] Time to stabilization for each component of the ground reaction force essentially determined the time point where the beginning ground reaction force resembled the ground reaction force of stabilized single leg stance.[17–20,25]

Statistical Analysis

Average A/P TTS and M/L TTS values for each subject were calculated using 7 test trials, and these values were used for data analyses. A 2 (training group) × 2 (ankle group) × 4 (test session) mixed design analysis of variance for each TTS measure determined the week dynamic postural stability improved. For the control groups, we were only interested in examining pretest versus posttest TTS means for each ankle group. Therefore, a 2 (test session) × 2 (ankle group) mixed model analysis of variance was used for each TTS measure. Tukey Honestly Significant Difference (HSD) hoc analyses were performed for all significant interactions. Effect sizes for our analyses were calculated using Cohen's[26] effect size (ES) index ($F = \sigma_m/\sigma$). Observed power (OP) values were calculated for our nonsignificant findings using Cohen's[26] power of F test tables. All statistical analyses were performed on SPSS 11.5 (Chicago, IL) for Windows (Microsoft). The α level was set a priori at 0.05.

RESULTS

A/P TTS

No significant training group × ankle group × test session interaction ($F_{(3,108)} = 0.54$, $P = 0.65$, ES = 0.30, OP = 0.30) was found (Fig. 1A). The test session × ankle group interaction ($F_{(3,108)} = 4.27$, $P = 0.01$, ES = 0.40) was significant (Fig. 2A). Tukey HSD post hoc testing revealed that the FAI group had longer A/P TTS compared with the stable ankle group at pretest. The FAI group improved their A/P TTS over their pretest by

TABLE 2. Coordination Training Exercises and Parameters

Single Leg Stance Exercise	Description	Parameters
Balance on foam	Subjects stood on their test leg, and remained as motionless as possible for 20 s. Subjects returned quickly to a single leg stance if they touched down with their nonweight bearing leg.	3 Sets × 20 s
Circular motion on a wobble board	Subjects stood on their test leg atop a wobble board. They performed clockwise circular motion with their foot for 30 s, and then performed counterclockwise motion with their foot for 30 s.	3 Sets × 60 s (30 clockwise, 30 counterclockwise)
Resistance band kicks	Subjects stood with resistance band tubing around their nontest leg. They kept their leg straight and performed kicks in 4 hip motions (hip extension, hip flexion, hip abduction, hip adduction).	3 Sets of 120 repetitions (30 repetitions for each hip motion)

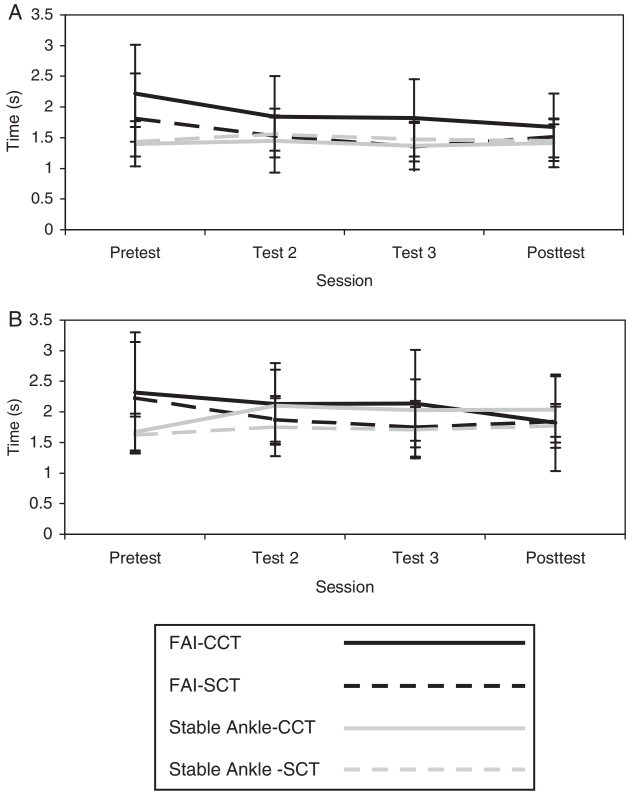

FIGURE 1. A, A/P TTS (3-way interaction). No significant training group × ankle group × test session interaction was found. B, M/L TTS (3-way interaction). No significant training group × ankle group × test session interaction was found.

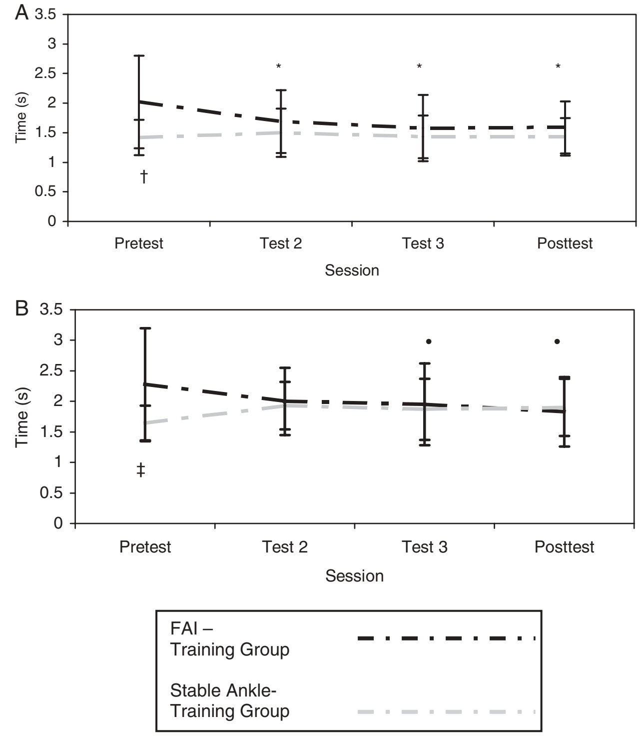

FIGURE 2. A, A/P TTS (test session × ankle group interaction). †The FAI group had significantly longer A/P TTS compared with the stable ankle group's A/P TTS at pretest. *The FAI group had significantly longer A/P TTS at pretest compared with their A/P TTS at test 2, test 3, and posttest. B, M/L TTS (test session × ankle group interaction). ‡The FAI group had significantly longer M/L TTS compared with the stable ankle's group M/L TTS at pretest. •The FAI group had significantly longer M/L TTS at pretest compared with their M/L TTS at test 3 and posttest.

16% at test 2, 22% at test 3, and 22% at posttest. The test session × training group ($F_{(3,108)} = 0.54$, $P = 0.41$, ES = 0.20, OP = 0.28) and ankle group × training group ($F_{(1,36)} = 2.68$, $P = 0.11$, ES = 0.35, OP = 0.50) interactions were nonsignificant. Main effects for test session ($F_{(3,108)} = 3.75$, $P = 0.01$, ES = 0.30) and ankle group ($F_{(1,36)} = 5.15$, $P = 0.02$, ES = 0.30) were significant. Main effect for training group ($F_{(1,36)} = 1.18$, $P = 0.28$, ES = 0.15, OP = 0.15) was nonsignificant.

The control groups did not improve their A/P TTS. No significant test session × ankle group ($F_{(1,18)} = 0.15$, $P = 0.70$, ES = 0.20, OP = 0.15) was found (Fig. 3A). Main effect for test session ($F_{(1,18)} < 0.01$, $P = 0.99$, ES = 0.05, OP = 0.06) and the main effect for ankle group ($F_{(1,18)} = 3.36$, $P = 0.08$, ES = 0.15, OP = 0.15) were nonsignificant.

M/L TTS

No significant training group × ankle group × test session interaction ($F_{(3,108)} = 0.58$, $P = 0.63$, ES = 0.40, OP = 0.50) was found (Fig. 1B). The test session × ankle group interaction ($F_{(3,108)} = 8.02$, $P < 0.01$, ES = 0.30) was significant (Fig. 2B). Tukey HSD post hoc testing revealed that the FAI group had longer M/L TTS compared with the stable ankle group at pretest. The FAI group improved their M/L TTS over their pretest by 16% at test 3, and 22% at posttest. The 12% improvement in M/L TTS at test 2 was not significantly greater than M/L TTS at pretest. Test session × training group ($F_{(3,108)} = 1.54$, $P = 0.21$, ES = 0.20, OP = 0.28) and ankle group × training group ($F_{(1,36)} = 0.05$, $P = 0.83$, ES = 0.25, OP = 0.21) interactions were nonsignificant. Main effects for test session ($F_{(3,108)} = 0.68$, $P = 0.57$, ES = 0.10, OP = 0.16), ankle group ($F_{(1,36)} = 1.21$, $P = 0.28$, ES = 0.15, OP = 0.15), and training group ($F_{(1,36)} = 1.80$, $P = 0.19$, ES = 0.20, OP = 0.23) were nonsignificant.

The control groups did not improve their M/L TTS. No significant test session × ankle group ($F_{(1,18)} = 0.04$, $P = 0.84$, ES = 0.12, OP = 0.07) was found for the control groups (Fig. 3B). Main effect for test session ($F_{(1,18)} = 1.28$, $P = 0.83$, ES = 0.10, OP = 0.09) and the main effect for ankle group ($F_{(1,18)} = 2.24$, $P = 0.15$, ES = 0.05, OP = 0.06) were nonsignificant.

DISCUSSION

Our results indicate that coordination training improved A/P dynamic postural stability after 2 weeks

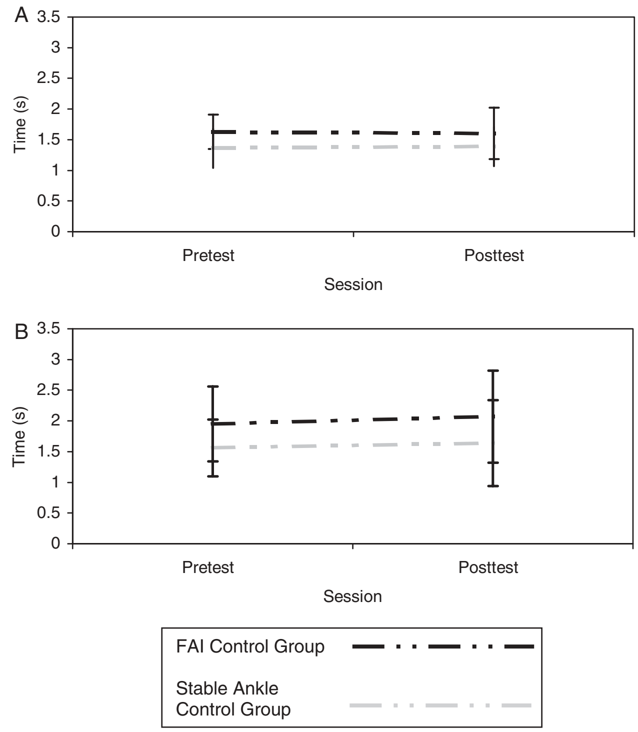

FIGURE 3. A, A/P TTS (control group: test session × ankle group interaction). The stable ankle control group and the FAI control group did not improve their posttest A/P TTS compared with their pretest A/P TTS. B, M/L TTS (control group: test session × ankle group interaction). The stable ankle control group and the FAI control group did not improve their posttest M/L TTS compared with their pretest M/L TTS.

of training and M/L dynamic postural stability after 4 weeks of training in subjects with FAI. These findings suggest that M/L stability takes longer to rehabilitate than A/P stability. The M/L TTS is an indication of frontal plane stability, which is typically thought of as the primary plane of instability for subjects with FAI.[6,27] Furthermore, adequate ankle stability probably does not return until both A/P and M/L dynamic postural stability improves. Clinicians might consider returning individuals to activity after 4 weeks of coordination training, which is when both A/P TTS and M/L TTS are improved over pretest scores. Four weeks, however, might be too long for individuals to remain inactive, and clinicians might consider incorporating exercises that emphasize frontal plane stability or implementing an alternative therapy.

SR stimulation might serve as an alternative therapy to improve M/L stability more quickly than coordination training alone. Our results suggest that M/L stability might be improved 2 weeks earlier when SR stimulation is used as an adjunct therapy to coordination training. As demonstrated in Figure 1B, the percent improvement in M/L TTS at test 2 over pretest scores was greater in the FAI group training with SR (16%) than the FAI group training without SR (8%). SR stimulation, however, did not affect the A/P TTS after 2 weeks of coordination training, as both FAI training groups improved their test 2 scores over pretest scores by 16%. Interestingly, SR stimulation might have implications for improving A/P and M/L stability to a greater extent after 4 weeks of coordination training. The FAI group training with SR had a greater percent improvement at test 3 over pretest scores (A/P TTS = 25%, M/L TTS = 22%) than the percent improvement at test 3 over pretest scores of the FAI group training without SR (A/P TTS = 18%, M/L TTS = 8%). We suggest, therefore, that SR stimulation might facilitate rehabilitation more than coordination training alone by enhancing M/L stability after 2 weeks of training, and by improving A/P and M/L stability to a greater degree after 4 weeks of training.

We contend that the percent improvements in TTS associated with SR stimulation might indicate that this adjunct therapy enhanced A/P and M/L instabilities in subjects with FAI. In addition, the effect sizes associated with the 3-way interaction analyses of A/P TTS and M/L TTS presented in Figure 1A and B suggest that our SR stimulation had an effect on our ankle groups over our 4 test sessions. Effect sizes associated with these analyses were moderate (0.30) and high (0.40), as defined by Cohen.[26] Consequently, we should have expected significant F statistics with moderate or high effect sizes, but our sample size might have limited our ability to detect a statistically significant results. Future research should examine the effects of SR stimulation on dynamic postural stability with a larger sample size to confirm our findings.

The mechanism by which SR stimulation improves postural stability is currently unknown. SR stimulation is thought to enhance the detection of weak sensory feedback signals important for maintaining postural stability.[21–24] We speculate that the SR stimulation applied to the leg and ankle of subjects with FAI might have enhanced the detection of weak sensory feedback signals related to dynamic postural stability. These weak sensory signals that might have become detectable with SR stimulation could have lead to improved stability. Future research should examine the mechanism by which SR stimulation improves signal detection in subjects with FAI.

The effects of standard coordination training protocols on single leg stance have been widely examined, and static postural stability associated with FAI has been improved in subjects with FAI after they performed several weeks of rehabilitation using a standard coordination training protocol.[4,6,8,13–16] Interestingly, our current results suggest that a standard coordination training protocol also might have implications for improving dynamic postural instabilities associated with FAI. This finding might be particularly important for clinicians who are rehabilitating dynamic postural instabilities in patients with FAI, as protocols have not been specifically designed to improve dynamic postural stability. Clinicians might be assured that dynamic postural instabilities associated with FAI might be improved with a standard coordination training protocol that is typically used to enhance static postural stability.

Standard coordination training protocols have also been reported to decrease recurrent ankle sprain incidence associated with FAI.[3,13,28,29] We did not, however, examine the incidence of ankle sprain injury after our coordination training. Subjects with FAI did not sustain ankle sprains during their participation in this study, and they reported a 25% increase in ankle stability as measured by the Ankle Joint Functional Assessment Tool after completing the study. We speculate, therefore, that our coordination training protocol might have implications for decreasing incidence of ankle sprains. Future research should examine relationships between dynamic postural stability improvements and incidence of ankle sprains after coordination training.

Clinical Significance

Coordination training improved dynamic postural instabilities associated with FAI in the A/P plane after 2 weeks of training, and M/L plane improved after 4 weeks. These findings might provide guidelines for return-to-play decision, as clinicians might return individuals with FAI to physical activity once A/P and M/L instabilities improve after 4 weeks of coordination training. A potential new method of coordination training with SR stimulation was also examined in this study. Interestingly, our new method of coordination training that used SR stimulation as an adjunct therapy might have implications for returning individuals with FAI to activity after 2 weeks of training. Application of SR stimulation to functionally unstable ankles, additionally, might improve A/P and M/L stability to a greater degree after 4 weeks of training than coordination training alone. Sport medicine clinicians might, therefore, consider using SR stimulation to return individuals with FAI to activity earlier in the rehabilitation process with greater stability. Improving A/P and M/L stability before returning individuals with FAI to physical activity might have implications for reducing ankle sprain incidence.

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REFERENCES

1. Freeman M, Dean M, Hanham I. The etiology and prevention of functional instability of the foot. *J Bone Joint Surg*. 1965; 47B:678–685.
2. Bahr R, Karlsen R, Lian O, et al. Incidence and mechanisms of acute ankle inversion injuries in volleyball. A retrospective cohort study. *Am J Sports Med*. 1994;22:595–600.
3. Tropp H, Askling C, Gillquist J. Prevention of ankle sprains. *Am J Sports Med*. 1985;13:259–262.
4. Tropp H, Ekstrand J, Gillquist J. Factors affecting stabilometry recording recordings of single limb stance. *Am J Sports Med*. 1984;12:185–188.
5. Tropp H. Pronator muscle weakness in functional instability of the ankle joint. *Int J Sports Med*. 1986;7:291–294.
6. Goldie P, Evans O, Bach T. Postural control following inversion injuries of the ankle. *Arch Phys Med Rehabil*. 1994;75:969–975.
7. Bernier J, Perrin D, Rijke A. Effect of unilateral functional instability of the ankle on postural sway and inversion and eversion strength. *J Athl Train*. 1997;32:226–232.
8. Bernier J, Perrin D. Effect of coordination training on proprioception of the functionally unstable ankle. *J Orthop Sports Phys Ther*. 1998;27:264–275.
9. Ryan L. Mechanical stability, muscle strength and proprioception in the functionally unstable ankle. *Aust Physiother*. 1994;40:41–47.
10. Konradsen L, Ravn J. Prolonged peroneal reaction time in ankle instability. *Int J Sports Med*. 1991;12:290–292.
11. Osborne M, Chou L, Laskowski E, et al. The effect of ankle disk training on muscle reaction time in subjects with a history of ankle sprain. *Am J Sports Med*. 2001;29:627–632.
12. Cornwall M, Murrell P. Postural sway following inversion sprain of the ankle. *J Am Podiatr Med Assoc*. 1991;81:243–247.
13. Eils E, Rosenbaum D. A multi-station proprioception exercise program in patients with ankle instability. *Med Sci Sports Exerc*. 2001;33:1991–1998.
14. Gauffin H, Tropp H, Odenrick P. Effect of ankle disk training on postural control in patients with functional instability of the ankle joint. *Int J Sports Med*. 1988;9:141–144.
15. Matsusaka N, Yokoyama S, Tsurusaki T, et al. Effect of ankle disk training combined with tactile stimulation to the leg and foot on functional instability of the ankle. *Am J Sports Med*. 2001;29:25–30.
16. Rozzi S, Lephart S, Sterner R, et al. Balance training for persons with functionally unstable ankles. *J Orthop Sports Phys Ther*. 1999;29:478–486.
17. Ross S, Guskiewicz K. Single-leg jump-landing stabilization times in subjects with functionally unstable ankles. *J Athl Train*. 2005; 40:298–304.
18. Ross S, Guskiewicz K. Examination of static and dynamic postural stability in individuals with functionally stable and unstable ankles. *Clin J Sport Med*. 2004;14:332–338.
19. Brown C, Ross S, Mynark R, et al. Assessing functional ankle instability with joint position sense, time to stabilization, and electromyography. *J Sport Rehabil*. 2004;13:122–134.
20. Wikstrom E, Tillman M, Borsa P. Detection of dynamic stability deficits in subjects with functional ankle instability. *Med Sci Sports Exerc*. 2005;37:169–175.
21. Priplata A, Niemi J, Salen M, et al. Noise-enhanced human balance control. *Phy Rev Lett*. 2002;89:238101-1–238101-4.
22. Gravelle D, Laughton C, Dhruv NT, et al. Noise-enhanced balance control in older adults. *Neuroreport*. 2002;13:1–4.
23. Priplata A, Niemi J, Harry J, et al. Vibrating insoles and balance control in elderly people. *Lancet*. 2003;362:1123–1124.
24. Collins J, Priplata A, Gravelle D, et al. Noise-enhanced human sensorimotor function. *IEEE Eng Med Biol Mag*. 2003;22:76.
25. Ross S, Guskiewicz K. Time to stabilization: a method for analyzing dynamic postural stability. *Athl Ther Today*. 2003;8:37–39.
26. Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. 2nd ed. Hillsdale, NJ: Lawrence Erlbaum Associates Publishers; 1988: 274–275.
27. Friden T, Zatterstrom R, Lindstrand A, et al. A stabilometric technique for evaluation of lower limb instabilities. *Am J Sports Med*. 1989;17:118–122.
28. Holme E, Magnusson S, Becher K, et al. The effect of supervised rehabilitation on strength, postural sway, position sense and re-injury risk after acute ankle ligament sprain. *Scand J Med Sports*. 1999;9:104–109.
29. Wester J, Jespersen St, Nielsen K, et al. Wobble board training after partial sprains of the lateral ligaments of the ankle: a prospective randomized study. *J Orthop Sports Phys Ther*. 1996;23:332–336.