

# Balance- and Strength-Training Protocols to Improve Chronic Ankle Instability Deficits, Part I: Assessing Clinical Outcome Measures

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**Context:** Functional rehabilitation may improve the deficits associated with chronic ankle instability (CAI).

**Objective:** To determine if balance- and strength-training protocols improve the balance, strength, and functional performance deficits associated with CAI.

**Design:** Randomized controlled clinical trial.

**Setting:** Athletic training research laboratory.

**Patients or Other Participants:** Participants were 39 volunteers with CAI, which was determined using the Identification of Functional Ankle Instability Questionnaire. They were randomly assigned to 1 of 3 groups: balance-training protocol (7 males, 6 females; age = 23.5 ± 6.5 years, height = 175.0 ± 8.5 cm, mass = 72.8 ± 10.9 kg), strength-training protocol (8 males, 5 females; age = 24.6 ± 7.7 years, height = 173.2 ± 9.0 cm, mass = 76.0 ± 16.2 kg), or control (6 males, 7 females; age = 24.8 ± 9.0 years, height = 175.5 ± 8.4 cm, mass = 79.1 ± 16.8 kg).

**Intervention(s):** Each group participated in a 20-minute session, 3 times per week, for 6 weeks. The control group completed a mild to moderately strenuous bicycle workout.

**Main Outcome Measure(s):** Participants completed baseline testing of eccentric and concentric isokinetic strength in each ankle direction (inversion, eversion, plantar flexion, and dorsiflexion) and the Balance Error Scoring System (BESS),

Star Excursion Balance Test (SEBT), and side-hop functional performance test. The same variables were tested again at 6 weeks after the intervention. Two multivariate repeated-measures analyses of variance with follow-up univariate analyses were conducted. The  $\alpha$  level was set a priori at .05.

**Results:** We observed time-by-group interactions in concentric ( $P = .02$ ) and eccentric ( $P = .01$ ) inversion, eccentric eversion ( $P = .01$ ), concentric ( $P = .001$ ) and eccentric ( $P = .03$ ) plantar flexion, BESS ( $P = .01$ ), SEBT ( $P = .02$ ), and side hop ( $P = .004$ ). With pairwise comparisons, we found improvements in the balance- and strength-training protocol groups in concentric and eccentric inversion and concentric and eccentric plantar flexion and the BESS, SEBT, and side hop (all  $P$  values = .001). Only the strength-training protocol group improved in eccentric eversion. The control group did not improve in any dependent variable.

**Conclusions:** Both training protocols improved strength, balance, and functional performance. More clinicians should incorporate hop-to-stabilization exercises into their rehabilitation protocols to improve the deficits associated with CAI.

**Key Words:** rehabilitation, Balance Error Scoring System, Star Excursion Balance Test, functional performance

## Key Points

- The balance- and strength-training groups improved their strength, balance, and functional performance.
- The control group did not improve, suggesting that bicycling alone or increasing passive motion did not improve strength, balance, and functional performance.
- Combining resistance-band and proprioceptive neuromuscular facilitation strength training was an effective intervention.
- More clinicians should incorporate hop-to-stabilization exercises into their rehabilitation protocols to improve the deficits associated with chronic ankle instability.

Lateral ankle sprains can pose a substantial health care burden.<sup>1</sup> They are the most prevalent musculoskeletal injuries in sports and in the physically active, but more than half (56%) of injured players do not seek professional treatment after ankle injury and therefore do not receive the proper rehabilitation.<sup>2</sup> McKay et al<sup>2</sup> found that at least 2 to 7 ankle sprains per 1000 person-years resulted in emergency department visits in the United States. This value is vastly underestimated, as other

researchers<sup>3</sup> have estimated that the true incidence rate in the general population was 5.5 times the aforementioned rate. After the initial lateral ankle sprain, individuals can develop many long-term problems, such as sensorimotor deficits,<sup>4</sup> decreased quality of life, reduced physical activity levels across the life span, chronic ankle instability (CAI), and an increased risk of ankle osteoarthritis (OA).<sup>5</sup>

As a precursor to OA, CAI is an encompassing term associated with several prolonged symptoms after an initial

**Table 1. Participant Demographics by Group<sup>a</sup>**

Group	n	Mean ± SD				Sex, No. (Male/Female)	NASA Physical Activity Status Scale, Average Score (Pretest, Posttest)
		Identification of Functional Ankle Instability Score	Age, y	Height, cm	Mass, kg		
Balance-training protocol	13	21.5 ± 3.8	23.5 ± 6.5	175.0 ± 8.5	72.8 ± 10.9	7/6	6.2, 6.1
Strength-training protocol	13	21.3 ± 3.1	24.6 ± 7.7	173.2 ± 9.0	76.0 ± 16.2	8/5	5.6, 6.1
Control	13	19.9 ± 4.5	24.8 ± 9.0	175.5 ± 8.4	79.1 ± 16.8	6/7	6.5, 6.7

Abbreviation: NASA, National Aeronautics and Space Administration.

<sup>a</sup> No differences were seen between groups or between the pretest and posttest in the average NASA Physical Activity Status Scale.

ankle sprain. Individuals with CAI experience both mechanical and functional instability of the ankle joint.<sup>6</sup> After spraining their ankles, they are more susceptible to reinjury, which can result in a cascade of long-term problems that can lead to OA.<sup>7</sup> A substantial contributor to CAI is recurrent ankle sprains, which can further damage the already impaired ankle function.<sup>1</sup> The prolonged symptoms of CAI include pain, weakness, or instability, which can lead to range-of-motion (ROM), strength, balance, and functional performance deficits.<sup>8</sup> Researchers<sup>9–11</sup> have reported that 68% to 78% of patients with CAI symptoms developed posttraumatic ankle OA and cartilage damage.

Numerous rehabilitation protocols to improve the deficits associated with CAI have been examined. These range from simple progressive strength<sup>12–15</sup> or balance<sup>16–19</sup> protocols to multicomponent (strength, balance, ROM) rehabilitation<sup>20,21</sup> approaches. These functional rehabilitation protocols effectively improve strength, balance, and self-reported function<sup>12–15,19,21–25</sup>; however, few researchers have assessed the improvements in functional performance that include power and agility. *Functional activity* is defined as dynamic, closed kinetic chain activity other than quiet standing.<sup>26</sup> Researchers who assessed functional performance after strength-training protocols did not identify clinically meaningful improvements.<sup>13,25</sup> Therefore, strength training alone may be insufficient to improve functional outcomes similar to the movements that occur more often during sport and physical activity. Balance-training protocols (BTPs)<sup>19,23</sup> and resistance-band protocols (RBPs) have been shown to improve strength<sup>12,13,15</sup> and postural-control<sup>18</sup> variables, respectively; however, they have not been examined in the same study.

If conservative management of CAI is unsuccessful and a patient develops ankle OA, invasive surgical interventions are recommended to improve joint stability. Yet surgical interventions can increase health care costs and place greater stress on the body, so it is important to determine if functional rehabilitation interventions can improve the deficits associated with CAI, specifically functional performance. Therefore, the purpose of our study was to determine if balance- and strength-training protocols would improve the strength, balance, and functional performance deficits associated with CAI.

## METHODS

### Participants

Thirty-nine individuals with CAI volunteered for this study. The demographics for each group are presented in

Table 1. Inclusion criteria were a history of at least 1 substantial ankle sprain with associated inflammatory symptoms and at least 1 interrupted day of desired physical activity, multiple episodes of the ankle “giving way,” recurrent sprain, and “feelings of instability” in the 6 months before the study.<sup>27</sup> Volunteers were determined to have CAI if they scored 11 or more on the Identification of Functional Ankle Instability Questionnaire (IdFAI), which is an accurate tool for identifying individuals with CAI.<sup>28</sup> If both ankles were determined to have CAI, the ankle with the highest score (ie, the most severely affected ankle) was considered the involved limb. Volunteers were excluded if they had sustained an acute lower extremity injury in the 3 months before the study; had participated in formal rehabilitation in the 3 months before the study; had a history of lower extremity surgery or fracture that required alignment in the involved limb; or had any diagnosed neurologic dysfunction, such as multiple sclerosis, Parkinson disease, or head injury. All participants completed the National Aeronautics and Space Administration Physical Activity Status Scale<sup>29</sup> to establish their physical activity level.

Group allocation and the participant flow chart are presented in Figure 1. After beginning the study, participants were excluded if they developed an unrelated lower extremity injury or were noncompliant (attended <80% of the 18 sessions). One participant was excluded from the analysis due to the inability to progress in the balance training. All participants provided written informed consent, and the study was approved by Indiana University’s Institutional Review Board for the Protection of Human Subjects.

### Procedures

Each participant performed baseline isokinetic strength, balance, and functional performance testing of the CAI limb. Testing order of the variables was determined using a counterbalanced matrix. Immediately after baseline testing, each participant was sequentially allocated to a group: BTP, strength-training protocol (STP), or control (CON). Individuals in all groups participated in their assigned treatment protocol 3 days each week for 6 weeks under the supervision of a researcher (E.A.H.). They were instructed not to increase or decrease their physical activity levels during the 6-week period. After 6 weeks, posttest isokinetic strength, balance, and functional performance measures were tested in all participants. All testing and rehabilitation sessions took place in the athletic training research laboratory.

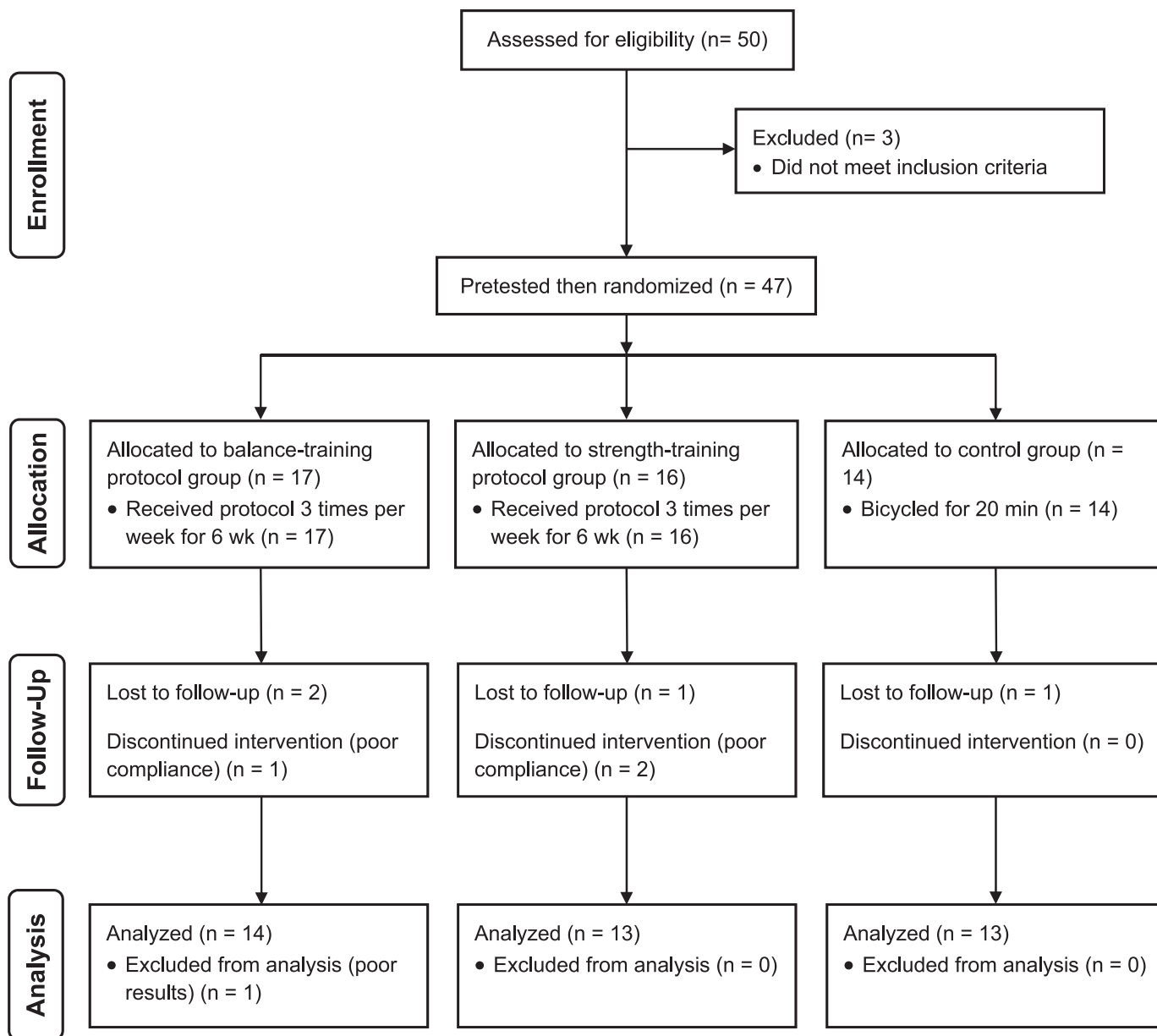


Figure 1. Participant flow diagram.

**Isokinetic Strength Testing.** Force was assessed using a Cybex dynamometer (model HUMAC Norm; CSMi Solutions, Stoughton, MA) in the concentric and eccentric modes at 90°/s. Participants were positioned based on the procedures described in the manual. All testing was performed with the participants in a recumbent position, the distal thigh on the thigh stabilizer, and the hip and knee at 90°. The involved limb was strapped down at the pelvis and distal thigh. Participants performed up to 3 practice trials at submaximal effort and then 3 test trials in each direction (dorsiflexion, plantar flexion, inversion, and eversion). They rested for 30 seconds between trials. The average of the peak torque (Newton-meters) of the 3 trials was used for statistical analysis.

**Balance Testing: Star Excursion Balance Test.** The Star Excursion Balance Test (SEBT) is a measure of dynamic balance. The 3 SEBT directions that we measured were anterior, posterolateral, and posteromedial, as sup-

ported by previous research in which authors identified those with lower extremity injury<sup>30</sup> and CAI.<sup>31</sup> Before the SEBT, participants were instructed on proper reaching technique and were allowed 4 practice trials in each direction, as recommended by Robinson and Gribble.<sup>32</sup> They performed 3 consecutive test trials in each direction. The order of directions was randomized.

Participants stood barefoot with the great toe at the center of the SEBT grid. While standing on the involved limb, they reached as far as possible with the nonstance limb along the reach direction.<sup>33</sup> Keeping their hands on their hips, participants lightly touched the line with the most distal portion of the reaching foot and returned to a bilateral stance. The distance was measured from the center of the grid to the farthest reach point. An *unsuccessful trial* was defined as a trial in which participants lifted their hands off their hips, moved or lifted the stance foot, lifted the heel, transferred weight to the reach foot when touching the

measuring tape, did not touch the tape, did not return the reach foot to the starting position, lost their balance, or were unable to maintain a unilateral stance during the trial.<sup>33</sup> Unsuccessful trials were discarded and reattempted.

The maximum distance (centimeters) for each reach direction was recorded. Reach distances were normalized to limb length, which was measured from the anterior-superior iliac spine to the distal tip of the medial malleolus. To calculate the composite score, we added all maximum reach distances, divided the sum by 3 times the limb length, and multiplied the quotient by 100. This composite score was used for statistical analysis.

**Balance Testing: Balance Error Scoring System.** The Balance Error Scoring System (BESS) is a measure of static balance and consists of 3 stances: double-legged stance, single-legged stance, and tandem stance in a heel-to-toe fashion.<sup>34</sup> Participants performed all stances on firm and foam surfaces (model BeBalanced; Airex AG, Sins, Switzerland) with their hands on their hips and eyes closed.<sup>34</sup> They performed 1 practice trial for each condition to ensure proper technique, followed by 1 test trial. Errors were counted for each 20-second trial. An *error* was defined as lifting the hands off the iliac crests; opening the eyes; stepping, stumbling, or falling; moving the hip into more than 30° of abduction; lifting the forefoot or heel; or remaining out of test position for more than 5 seconds.<sup>34</sup> The maximal possible score for each stance was 10.<sup>34</sup> The total score was used for statistical analysis.

**Functional Performance Testing.** The side-hop test was performed by hopping laterally on 1 limb over a 30-cm distance.<sup>35</sup> One repetition was the ability to hop laterally and return to the starting position. We instructed participants to complete 10 repetitions as fast as they could. A trial was deemed *unacceptable* if the contralateral foot was put down or did not clear the 30-cm distance. An electric stopwatch (model Speedtrap 2; Brower Timing Systems, Draper, UT) was used to determine the fastest time. One to 3 practice trials were performed, followed by 3 test trials. The average of 3 test trials was used for statistical analysis.

## Rehabilitation Procedures

**Balance-Training Protocol.** The BTP was designed by McKeon et al<sup>19</sup> to challenge an individual's ability to maintain single-limb stance while performing various balance exercises. Participants performed these dynamic activities to challenge efficient recovery of single-limb balance after a perturbation and to effectively develop spontaneous strategies to execute movement goals.<sup>19</sup> The exercises were (1) hop to stabilization, (2) hop to stabilization and reach, (3) hop-to-stabilization box drill, (4) progressive single-limb-stance activities with eyes open, and (5) progressive single-limb-stance activities with eyes closed. Participants advanced to the next level of the test after they completed the previous level with no errors. Errors consisted of touching down with the opposite limb, excessive trunk motion (>30° lateral flexion), removing the hands from the hips during hands-on-hips activities, bracing the nonstance limb against the stance limb, or missing the target. Progression levels related to each exercise were described by McKeon et al.<sup>19</sup>

**Strength-Training Protocol.** The procedures for the STP were based on the 6-week RBP and proprioceptive

neuromuscular facilitation (PNF) strength protocol of Hall et al<sup>13</sup> in addition to heel raises. For the RBP exercises, participants sat on the floor with 1 end of the band wrapped around a treatment table and the other end wrapped around the metatarsal heads of the involved foot. Exercises were performed in 3 directions: dorsiflexion, inversion, and eversion. We instructed participants to maintain a consistent pace of approximately 3 to 5 seconds per repetition throughout the full ROM. Each week, they progressed by increasing the number of sets or band resistance or both (Table 2).<sup>12</sup> Participants completed all 3 directions before progressing to the next set.

To strengthen the plantar flexors, participants performed single-legged heel raises on a step to allow full ROM. They were allowed to use a rail for balance, but they were not to use it to support their weight. In addition to the RBP and heel raises, a slow-reversal PNF technique was performed during the same session. It involved a concentric contraction of the antagonist muscle followed by a concentric contraction of the agonist muscle<sup>36</sup> against maximal manual resistance in a diagonal pattern. The procedures were the same as those used in a previous study.<sup>13</sup> Manual resistance was applied by an investigator (E.A.H.) to the distal aspect of the foot at the metatarsal heads. We instructed participants to provide maximal effort for each repetition. Maximal counteracting resistance was applied at a moderate speed throughout the entire ROM of the isotonic contraction, with each phase of the diagonal pattern taking approximately 3 to 5 seconds to complete. At the end of the range, the investigator changed hand positions to complete the other phase of the diagonal pattern. Participants rested for 60 seconds between sets but did not rest between repetitions. Progressions of the heel raises and PNF strength protocol are provided in Table 2.

**Control Group.** Members of the CON group participated in a 20-minute bicycle workout with consistent mild to moderate resistance. They were instructed to avoid any new strength or rehabilitative exercises for their ankles during the 6 weeks between pretest and posttest procedures. They were allowed to participate in regular activities.

## Statistical Analysis

Two multivariate repeated-measures analyses of variance were conducted: 1 with the balance- and functional performance-dependent variables (BESS, SEBT, and side hop) and the other with the strength-dependent variables (concentric and eccentric inversion, concentric and eccentric eversion, concentric and eccentric plantar flexion, and concentric and eccentric dorsiflexion). If we observed a difference, we conducted follow-up univariate analyses on each dependent variable. The univariate analyses addressed 1 within-subject factor (time at 2 levels: pretest and 6 weeks posttest) and 1 between-subjects factor (group at 3 levels: BTP, STP, CON). Finally, we used a post hoc Bonferroni comparison to identify any specific differences within groups. We set the  $\alpha$  level a priori at .05. Effect sizes were calculated using a bias-corrected Hedges *g* with corresponding 95% confidence intervals.<sup>37</sup> Effect sizes were interpreted as *weak* ( $\leq 0.39$ ), *moderate* (0.40–0.69), or *strong* ( $\geq 0.70$ ).<sup>38</sup> We used SPSS (version 23; IBM Corp, Armonk, NY) to analyze the statistics.



**Table 2. Progression of the Strength-Training Protocol Group in Proprioceptive Neuromuscular Facilitation and Heel Raises**

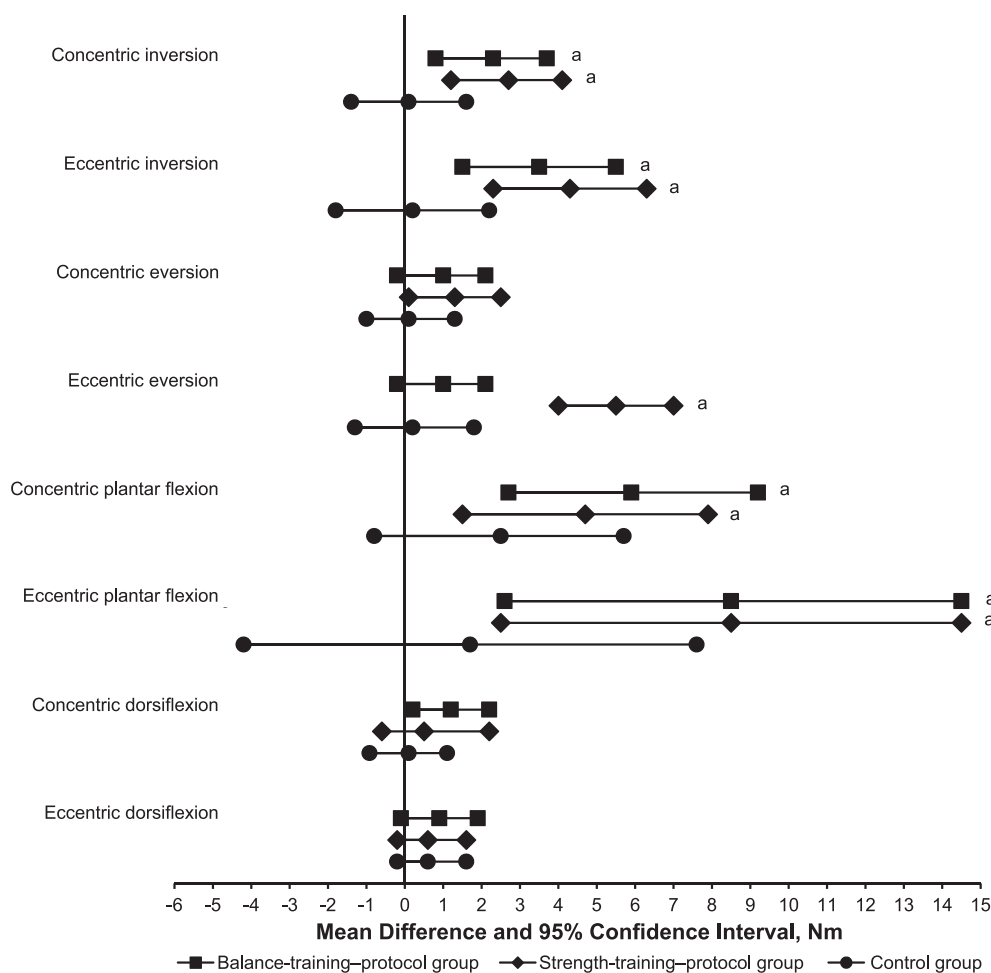
Week	Resistance Band	Sets × Repetitions	Activity	Sets × Repetitions
1	Light blue (heavy)	3 × 10	Proprioceptive neuromuscular facilitation and heel raises	2 × 10
2	Light blue (heavy)	4 × 10	Proprioceptive neuromuscular facilitation and heel raises	2 × 15
3	Dark blue (super-heavy)	3 × 10	Proprioceptive neuromuscular facilitation and heel raises	3 × 10
4	Dark blue (super-heavy)	4 × 10	Proprioceptive neuromuscular facilitation and heel raises	3 × 15
5	Purple (ultra-heavy)	3 × 10	Proprioceptive neuromuscular facilitation and heel raises	4 × 10
6	Purple (ultra-heavy)	4 × 10	Proprioceptive neuromuscular facilitation and heel raises	4 × 15

**RESULTS**

**Strength**

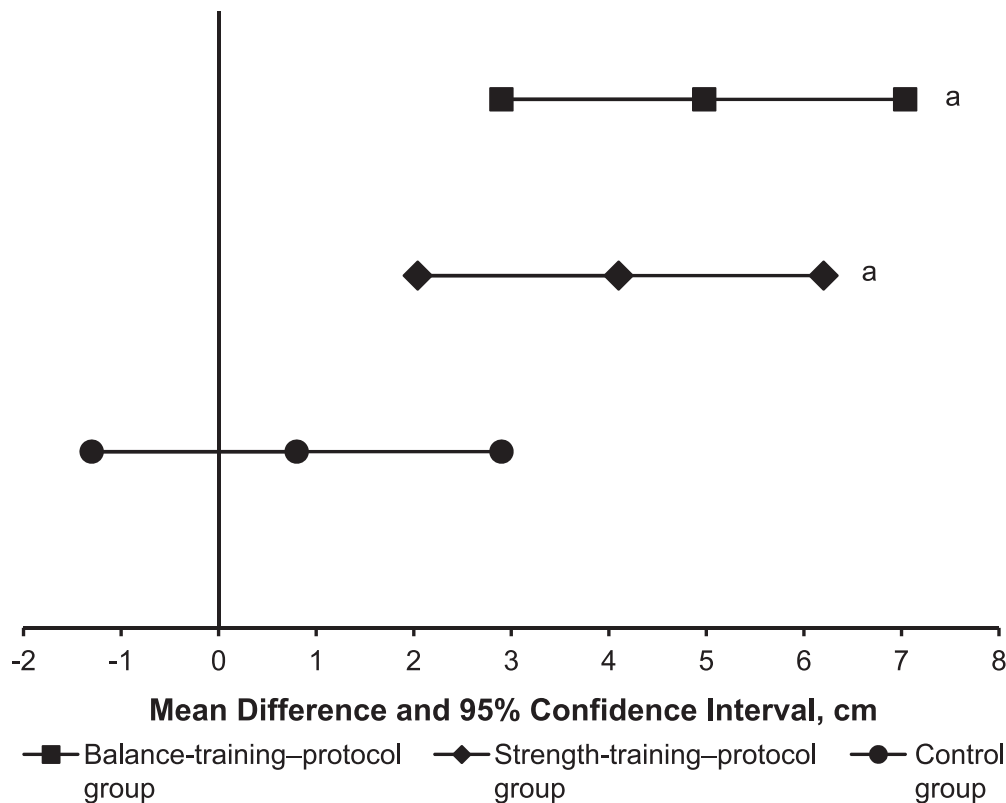
Using the multivariate analysis, we observed a time-by-group interaction ( $P = .001$ ,  $\eta^2 = 0.50$ ). All mean differences and 95% confidence intervals for each isokinetic strength measure are presented in Figure 2. The univariate test yielded a time-by-group interaction for the concentric ( $P = .02$ ,  $\eta^2 = 0.19$ ) and eccentric ( $P = .01$ ,  $\eta^2 = 0.22$ ) inversion strength measures. Both the BTP and STP groups improved from pretest to posttest ( $P = .001$ ); however, the CON group did not improve ( $P = .87$ ). We did not observe a time-by-group interaction for concentric eversion ( $P = .20$ ,  $\eta^2 = 0.08$ ) but did note a time-by-group interaction for eccentric eversion ( $P = .01$ ,  $\eta^2 = 0.43$ ). The

STP group improved in eccentric eversion ( $P = .001$ ), whereas the BTP ( $P = .08$ ) and CON ( $P = .24$ ) groups did not improve. We found a time-by-group interaction for both concentric ( $P = .001$ ,  $\eta^2 = 0.31$ ) and eccentric ( $P = .03$ ,  $\eta^2 = 0.18$ ) plantar flexion. The BTP and STP groups improved after the intervention in both concentric and eccentric plantar flexion ( $P = .01$ ), whereas the CON group did not improve in either factor ( $P = .13$  and  $P = .56$ , respectively). Finally, no time-by-group interaction was identified for the concentric ( $P = .07$ ,  $\eta^2 = 0.14$ ) or eccentric ( $P = .05$ ,  $\eta^2 = 0.15$ ) dorsiflexion contractions, and the effect sizes were weak (Hedges  $g < 0.3$ ). Whereas the time-by-group interaction for eccentric dorsiflexion was close to the a priori  $\alpha$  level, follow-up pairwise comparisons did not show improvement in the BTP ( $P = .07$ ), STP ( $P = .25$ ), or CON ( $P = .21$ ) groups. We did not see differences among groups



**Figure 2. Forest plot of the isokinetic strength measures including the mean differences and 95% confidence intervals for each group. <sup>a</sup> Improvement from pretest to posttest.**

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**Figure 3.** Forest plot of the Star Excursion Balance Test including the mean differences and 95% confidence intervals for each group. <sup>a</sup> Improvement from pretest to posttest.

at pretest or posttest on the strength measures ( $P$  values  $> .05$ ).

### Balance and Function

The multivariate analysis yielded a time-by-group interaction ( $P = .001$ ,  $\eta^2 = 0.26$ ). Using the univariate analysis, we observed a time-by-group interaction for the SEBT ( $P = .02$ ,  $\eta^2 = 0.21$ ). Specifically, the BTP and STP groups improved from pretest to posttest (both  $P$  values =  $.001$ ). The CON group did not improve from pretest to posttest ( $P = .56$ ; Figure 3). The effect sizes were strong for the BTP (Hedges  $g = 0.7$ ) and moderate for the STP (Hedges  $g = 0.6$ ) groups. We did not note differences among groups at pretest or posttest ( $P > .05$ ).

The univariate analysis for the BESS also yielded a time-by-group interaction ( $P = .01$ ,  $\eta^2 = 0.23$ ). We showed improvements between the pretest and posttest in the BTP and STP groups (both  $P$  values =  $.001$ ). No improvement occurred in the CON group ( $P = .56$ ; Figure 4). The effect sizes were strong for the BTP group (Hedges  $g = 0.9$ ) and moderate for the STP group (Hedges  $g = 0.6$ ). We did not demonstrate differences among the groups at pretest ( $P > .05$ ) but did find a difference between the BTP and CON groups at posttest ( $P = .01$ ). No differences were present between the STP and CON groups or BTP and STP groups ( $P > .05$ ).

We documented a time-by-group interaction for the side-hop dependent variable ( $P = .004$ ,  $\eta^2 = 0.26$ ). Specifically, the BTP and STP groups improved from pretest to posttest (both  $P$  values =  $.001$ ). We did not detect improvement in the CON group ( $P = .70$ ; Figure 5). The effect sizes were

strong for the BTP and STP groups (both Hedges  $g = 0.8$ ) but weak for the CON group (Hedges  $g = 0.1$ ). We did not identify differences among groups at the pretest or posttest ( $P > .05$ ).

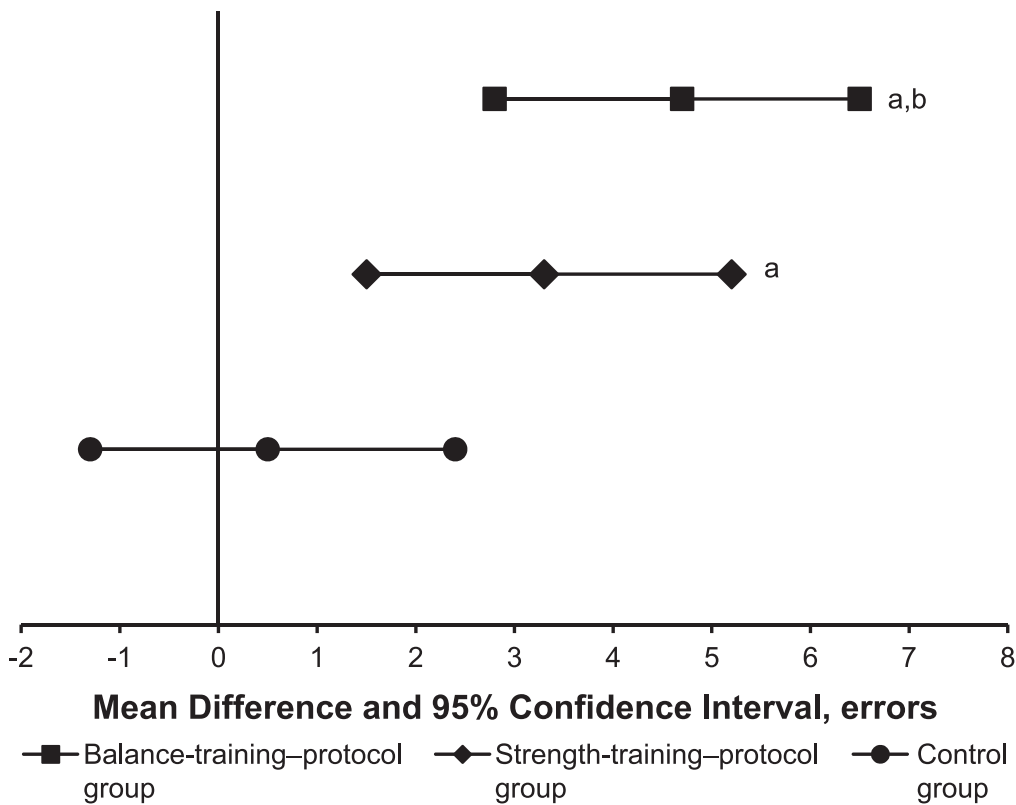
### DISCUSSION

The purpose of our study was to determine if the clinical deficits associated with CAI would improve after a BTP or STP. With the exception of the BESS, we observed no differences in absolute scores between groups at the pretest or posttest. However, improvements occurred over time, which might be clinically meaningful in both rehabilitation groups for strength, balance, and functional performance.

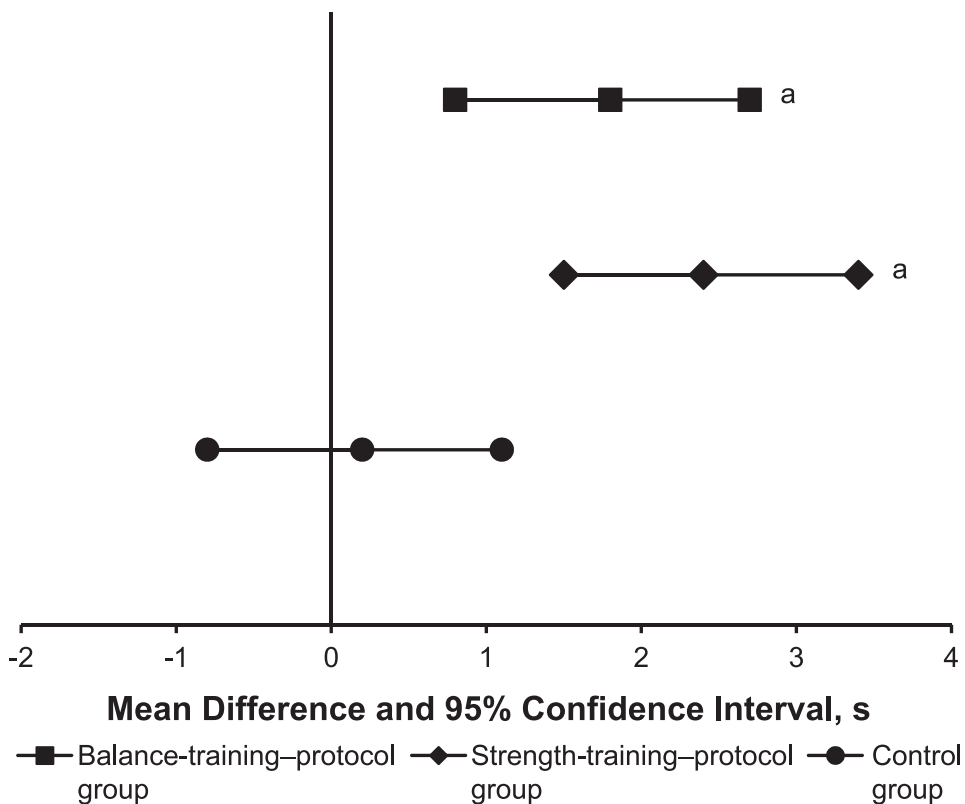
### Strength

The BTP group improved in concentric and eccentric inversion and concentric and eccentric plantar flexion. The STP group improved in concentric and eccentric inversion, eccentric eversion, and concentric and eccentric plantar flexion. Overall, both rehabilitation groups gained strength.

The improvements in inversion and eversion strength in the STP group agree with the results of previous research,<sup>12,13,15</sup> but we are the first, to our knowledge, to further examine both concentric and eccentric strength gains. In their rehabilitation study, Kaminski et al<sup>14</sup> examined isokinetic strength but were unable to document improvements. They attributed the lack of improvements to inadequate resistance in the RBP. Given that both contractions are essential for neuromuscular control to improve the dynamic stability of the joint, our design



**Figure 4.** Forest plot of the Balance Error Scoring System including the mean differences and 95% confidence intervals for each group. <sup>a</sup> Improvement from pretest to posttest. <sup>b</sup> Difference between balance-training protocol and control groups at posttest.



**Figure 5.** Forest plot of the side-hop functional performance test including the mean differences and 95% confidence intervals for each group. <sup>a</sup> Improvement from pretest to posttest.

allowed us to determine if a particular protocol more effectively improved a certain type of contraction. An *eccentric contraction* lengthens the muscle under tension to decelerate the joint, whereas a *concentric contraction* produces the propulsive force for movement by shortening the muscle.<sup>39</sup> We identified improvements in concentric and eccentric inversion in both rehabilitation groups but only in eccentric eversion in the STP group, which may have a better chance of eccentrically controlling the eversion stress from a lateral ankle sprain.

Dorsiflexion strength did not improve in any group. This finding conflicts with the results of previous investigators<sup>12,13,15</sup> who found increases in isometric dorsiflexion strength after an RBP and a PNF protocol. The dorsiflexion strength results approached a difference ( $P$  values = .051–.07); however, the effect sizes were weak (Hedges  $g < 0.3$ ). Based on this information, we suggest that resistance-band and PNF strengthening could continue to be used to enhance lower limb strength, but health care providers might want to incorporate additional exercises that specifically target the anterior lower extremity muscles.

Improvements in plantar-flexion strength were present in both the BTP and STP groups. Using resistance bands, previous rehabilitation protocols have not elicited similar improvements.<sup>13</sup> Hall et al<sup>13</sup> reported that they were unable to provide sufficient resistance for a larger muscle group. We adapted the protocol for this study by having participants perform heel raises instead of resistance-band exercises, and it effectively increased plantar-flexion strength. Improving eccentric control for plantar flexion will assist in a softer landing during a jumping motion, which may translate to improved functional performance by absorbing energy throughout the entire kinetic chain and not just the ankle.<sup>40</sup> The single-legged hop and heel raises also likely contributed to the strength gains in the BTP and STP groups, respectively. Despite not having a true “strength-training” component in the BTP, participants in this group still gained strength. The hop-to-stabilization action probably contributed to the eccentric strength gains because it improved eccentric plantar flexion, which improved the ability to land softly from a hop. This makes balance training an effective protocol for increasing not only balance but also strength.

### Balance and Functional Performance

Performance on the SEBT and BESS improved after the BTP and STP. For the SEBT dependent variable, the BTP and STP groups had strong (Hedges  $g = 0.7$ ) and moderate (Hedges  $g = 0.6$ ) effect sizes, respectively. For the BESS, the BTP and STP groups had strong (Hedges  $g = 0.9$ ) and moderate (Hedges  $g = 0.6$ ) effect sizes, respectively.

The hop-to-stabilization and reach components of the BTP mimicked the SEBT. During this protocol, participants were instructed to reach in all 8 directions of the original SEBT after landing from a hop. This exercise gave participants more confidence in their ability to reach farther on the SEBT. The single-legged balance components of the BTP also mimicked the static-balance component of the BESS, which explains the greater effect size for the BTP than for the STP group. Researchers<sup>19</sup> studying the BTP have reported improvements in the laboratory measures of static postural sway and the clinical measure of dynamic

stability; however, few authors have examined other deficits, such as strength and functional performance. Other rehabilitation protocols that improved SEBT performance were wobble-board training,<sup>17,18</sup> multicomponent rehabilitation,<sup>20,21</sup> and an exercise therapy program.<sup>41</sup>

Whereas the STP did not have a “balance-training” component, static and dynamic balance improved. Investigators<sup>13</sup> who used a resistance-band STP were not able to elicit improvements on the Y-Balance test, a dynamic component of the SEBT. This could be attributed to either the addition of the PNF exercises or the replacement of the plantar-flexion resistance-band exercises with heel raises. The PNF strength patterns are thought to improve the neuromuscular control<sup>42</sup> associated with dynamic balance. However, PNF strength training alone did not result in the same response<sup>13</sup>; the combination of PNF with a resistance band improved dynamic balance. Another explanation could be the improvements in eccentric plantar-flexion strength after the heel raises. We changed the strength protocol by having participants perform heel raises because neither the resistance-band nor manual-resistance exercises performed alone during the PNF strength protocol increased plantar-flexion strength.<sup>13</sup> The increase in eccentric plantar-flexion strength provided better control during the single-legged squat in the SEBT. One consideration must be noted: the SEBT and Y-Balance test require dramatically different types of muscular control, as one is a pushing task and the other is a reaching task.<sup>43,44</sup>

The side-hop test assesses functional performance. Both the BTP and the STP groups showed large effect sizes (both Hedges  $g$  values = 0.8), whereas the CON group had a weak effect size (Hedges  $g = 0.1$ ). Improvement in the side-hop test is explained by the improvements in strength and balance. Hall et al<sup>13</sup> reported that functional performance did not improve when resistance-band and PNF strength training were performed separately but that a clinically important improvement occurred when they were combined.

The BTP follows the dynamical systems theory because it suggests that the sensorimotor system is free to develop and change strategies as it interacts with the environment.<sup>45–47</sup> It was an effective intervention because it emphasized dynamic stabilization after perturbations, such as planned and unplanned movements in direction, landing, and dynamic reaching tasks.<sup>19</sup> We not only confirmed the static and dynamic balance improvements from the initial study by McKeon et al<sup>19</sup> but added the improvements in strength and functional performance.

### LIMITATIONS

Our study had some limitations. The researchers were not blinded to group allocation; however, the researcher and participants were blinded to the pretest scores. Another limitation was the difficulty in controlling effort. We instructed participants to provide their maximal effort for each task, but it is difficult to confirm that they did so.

### CONCLUSIONS

To our knowledge, this is the first study in which the effects of different ankle rehabilitation protocols were compared with those of a sham control group. Both the BTP and STP improved strength, balance, and functional



performance. The lack of improvement using the CON protocol implies that bicycling alone or increasing continuous passive motion did not improve strength, balance, or functional performance. More clinicians should incorporate hop-to-stabilization exercises into their rehabilitation protocols to improve the deficits associated with CAI. The combination of resistance-band and PNF strength training is another effective intervention. Given that both appear to be effective, the health care practitioner should select the most appropriate rehabilitation protocol based on the setting, time, and athlete's limitations. The findings of our study are clearly transferable because they provide the clinician with clinically applicable dependent variables and data that can be used in any clinical practice.

## REFERENCES

- Gribble PA, Bleakley CM, Caulfield BM, et al. Evidence review for the 2016 International Ankle Consortium consensus statement on the prevalence, impact and long-term consequences of lateral ankle sprains. *Br J Sports Med.* 2016;50(24):1496–1505.
- McKay GD, Goldie PA, Payne WR, Oakes BW. Ankle injuries in basketball: injury rate and risk factors. *Br J Sports Med.* 2001;35(2):103–108.
- Kemler E, van de Port I, Valkenberg H, Hoes AW, Backx FJ. Ankle injuries in the Netherlands: trends over 10–25 years. *Scand J Med Sci Sports.* 2015;25(3):331–337.
- Hertel J. Sensorimotor deficits with ankle sprains and chronic ankle instability. *Clin Sports Med.* 2008;27(3):353–370.
- Gribble PA, Bleakley CM, Caulfield BM, et al. 2016 consensus statement of the International Ankle Consortium: prevalence, impact and long-term consequences of lateral ankle sprains. *Br J Sports Med.* 2016;50(24):1493–1495.
- Delahunt E, Coughlan GF, Caulfield B, Nightingale EJ, Lin CWC, Hiller CE. Inclusion criteria when investigating insufficiencies in chronic ankle instability. *Med Sci Sports Exerc.* 2010;42(11):2106–2121.
- McKeon PO, Hubbard-Turner T, Wikstrom EA. Consequences of ankle inversion trauma: a novel recognition and treatment paradigm. In: Zaslav KR, ed. *An International Perspective on Topics in Sports Medicine and Sports Injury.* Rijeka, Croatia: InTech; 2012:457–480.
- Hertel J. Functional instability following lateral ankle sprain. *Sports Med.* 2000;29(5):361–371.
- Harrington KD. Degenerative arthritis of the ankle secondary to long-standing lateral ligament instability. *J Bone Joint Surg Am.* 1979;61(3):354–361.
- Hintermann B, Boss A, Schäfer D. Arthroscopic findings in patients with chronic ankle instability. *Am J Sports Med.* 2002;30(3):402–409.
- Hirose K, Murakami G, Minowa T, Kura H, Yamashita T. Lateral ligament injury of the ankle and associated articular cartilage degeneration in the talocrural joint: anatomic study using elderly cadavers. *J Orthop Sci.* 2004;9(1):37–43.
- 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.
- Hall EA, Docherty CL, Simon J, Kingma JJ, Klossner JC. Strength-training protocols to improve deficits in participants with chronic ankle instability: a randomized controlled trial. *J Athl Train.* 2015;50(1):36–44.
- 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.
- Smith BI, Docherty CL, Simon J, Klossner J, Schrader J. Ankle strength and force sense after a progressive, 6-week strength-training program in people with functional ankle instability. *J Athl Train.* 2012;47(3):282–288.
- Kidgell DJ, Horvath DM, Jackson BM, Seymour PJ. Effect of six weeks of dura disc and mini-trampoline balance training on postural sway in athletes with functional ankle instability. *J Strength Cond Res.* 2007;21(2):466–469.
- Linens SW, Ross SE, Arnold BL. Wobble board rehabilitation for improving balance in ankles with chronic instability. *Clin J Sport Med.* 2016;26(1):76–82.
- Wright CJ, Linens SW, Cain MS. A randomized controlled trial comparing rehabilitation efficacy in chronic ankle instability. *J Sport Rehabil.* 2017;26(4):238–249.
- McKeon PO, Ingersoll CD, Kerrigan DC, Saliba E, Bennett BC, Hertel J. Balance training improves function and postural control in those with chronic ankle instability. *Med Sci Sports Exerc.* 2008;40(10):1810–1819.
- Eils E, Rosenbaum D. A multi-station proprioceptive exercise program in patients with ankle instability. *Med Sci Sports Exerc.* 2001;33(12):1991–1998.
- Hale SA, Hertel J, Olmsted-Kramer LC. The effect of a 4-week comprehensive rehabilitation program on postural control and lower extremity function in individuals with chronic ankle instability. *J Orthop Sports Phys Ther.* 2007;37(6):303–311.
- Mattacola C, Lloyd J. Effects of a 6-week strength and proprioception training program on measures of dynamic balance: a single-case design. *J Athl Train.* 1997;32(2):127–135.
- Mettler A, Chinn L, Saliba SA, McKeon PO, Hertel J. Balance training and center-of-pressure location in participants with chronic ankle instability. *J Athl Train.* 2015;50(4):343–349.
- 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.
- 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):654–663.
- Webster KA, Gribble PA. Functional rehabilitation interventions for chronic ankle instability: a systematic review. *J Sport Rehabil.* 2010;19(1):98–114.
- Gribble PA, Delahunt E, Bleakley C, et al. Selection criteria for patients with chronic ankle instability in controlled research: a position statement of the International Ankle Consortium. *J Orthop Sports Phys Ther.* 2013;43(8):585–591.
- Simon J, Donahue M, Docherty C. Development of the Identification of Functional Ankle Instability (IdFAI). *Foot Ankle Int.* 2012;33(9):755–763.
- Houston MN, Hoch JM, Gabriner ML, Kirby JL, Hoch MC. Clinical and laboratory measures associated with health-related quality of life in individuals with chronic ankle instability. *Phys Ther Sport.* 2015;16(2):169–175.
- Plisky PJ, Rauh MJ, Kaminski TW, Underwood FB. Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. *J Orthop Sports Phys Ther.* 2006;36(12):911–919.
- Hubbard TJ, Kramer LC, Denegar CR, Hertel J. Contributing factors to chronic ankle instability. *Foot Ankle Int.* 2007;28(3):343–354.
- Robinson RH, Gribble PA. Support for a reduction in the number of trials needed for the Star Excursion Balance Test. *Arch Phys Med Rehabil.* 2008;89(2):364–370.
- Gribble PA, Hertel J. Considerations for normalizing measures of the Star Excursion Balance Test. *Meas Phys Educ Exerc Sci.* 2003;7(2):89–100.
- Bell DR, Guskiewicz KM, Clark MA, Padua DA. Systematic review of the Balance Error Scoring System. *Sports Health.* 2011;3(3):287–295.

35. Caffrey E, Docherty CL, Schrader J, Klossner J. The ability of 4 single-limb hopping tests to detect functional performance deficits in individuals with functional ankle instability. *J Orthop Sports Phys Ther.* 2009;39(11):799–806.
36. Knott M, Voss DE. *Proprioceptive Neuromuscular Facilitation: Patterns and Techniques.* 2nd ed. New York, NY: Hoeber Medical Division; 1968.
37. Borenstein M, Hedges LV, Higgins JPT, Rothstein HR. *Introduction to Meta-Analysis.* West Sussex, United Kingdom: John Wiley & Sons, Ltd; 2009:21–32.
38. Cohen J. *Statistical Power Analysis for the Behavioral Sciences.* 2nd ed. Hillsdale, NJ: Lawrence Erlbaum Associates; 1988.
39. Zatsiorsky VM, Kraemer WJ. *Science and Practice of Strength Training.* 2nd ed. Champaign, IL: Human Kinetics; 2006:44.
40. Devita P, Skelly WA. Effect of landing stiffness on joint kinetics and energetics in the lower extremity. *Med Sci Sports Exerc.* 1992;24(1): 108–115.
41. Cruz-Diaz D, Lomas-Vega R, Osuna-Pérez M, Contreras FH, Martínez-Amat A. Effects of 6 weeks of balance training on chronic ankle instability in athletes: a randomized controlled trial. *Int J Sports Med.* 2015;36(09):754–760.
42. Adler SA, Beckers D, Buck M. *PNF in Practice: An Illustrated Guide.* 2nd ed. New York, NY: Springer; 2000.
43. Coughlan GF, Fullam K, Delahunt E, Gissane C, Caulfield BM. A comparison between performance on selected directions of the Star Excursion Balance Test and the Y Balance Test. *J Athl Train.* 2012; 47(4):366–371.
44. Fullam K, Caulfield B, Coughlan GF, Delahunt E. Kinematic analysis of selected reach directions of the Star Excursion Balance Test compared with the Y-Balance test. *J Sport Rehabil.* 2014;23(1): 27–35.
45. Davids K, Glazier P, Araujo D, Bartlett R. Movement systems as dynamical systems: the functional role of variability and its implications for sports medicine. *Sports Med.* 2003;33(4):245–260.
46. Wikstrom EA, Hubbard-Turner T, McKeon PO. Understanding and treating lateral ankle sprains and their consequences: a constraints-based approach. *Sports Med.* 2013;43(6):385–393.
47. McKeon PO. Cultivating functional variability: the dynamical-systems approach to rehabilitation. *Athl Ther Today.* 2009;14(4):1–3.

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