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original research

Rehabilitation for Chronic Ankle Instability With or Without Destabilization Devices: A Randomized Controlled Trial

Luke Donovan, PhD, ATC*; Joseph M. Hart, PhD, ATC, FNATA†‡; Susan A. Saliba, PhD, PT, ATC, FNATA†; Joseph Park, MD‡; Mark Anthony Feger, PhD, ATC†; Christopher C. Herb, PhD, ATC§; Jay Hertel, PhD, ATC, FNATA, FACSM†

*Department of Kinesiology, University of Toledo, OH; Departments of †Kinesiology and ‡Orthopaedic Surgery, The University of Virginia, Charlottesville; §Department of Athletic Training & Nutrition, Weber State University, Ogden, UT

Context: Individuals with chronic ankle instability (CAI) have deficits in neuromuscular control and altered movement patterns. Ankle-destabilization devices have been shown to increase lower extremity muscle activity during functional tasks and may be useful tools for improving common deficits and self-reported function.

Objective: To determine whether a 4-week rehabilitation program that includes destabilization devices has greater effects on self-reported function, range of motion (ROM), strength, and balance than rehabilitation without devices in patients with CAI.

Design: Randomized controlled clinical trial.

Setting: Laboratory.

Patients or Other Participants: A total of 26 patients with CAI (7 men, 19 women; age = 21.34 ± 3.06 years, height = 168.96 ± 8.77 cm, mass = 70.73 ± 13.86 kg).

Intervention(s): Patients completed baseline measures and were randomized into no-device and device groups. Both groups completed 4 weeks of supervised, impairment-based progressive rehabilitation with or without devices and then repeated baseline measures.

Main Outcome Measure(s): We assessed self-reported function using the Foot and Ankle Ability Measure. Ankle ROM was measured with an inclinometer. Ankle strength was assessed using a handheld dynamometer during maximal voluntary isometric contractions. Balance was measured using a composite score of 3 reach directions from the Star Excursion Balance Test and a force plate to calculate center of pressure during eyes-open and eyes-closed single-limb balance. We compared each dependent variable using a 2 × 2 (group × time) analysis of variance and post hoc tests as appropriate and set an a priori α level at .05. The Hedges *g* effect sizes and associated 95% confidence intervals were calculated.

Results: We observed no differences between the no-device and device groups for any measure. However, both groups had large improvements in self-reported function and ankle strength.

Conclusions: Incorporating destabilization devices into rehabilitation did not improve ankle function more effectively than traditional rehabilitation tools because both interventions resulted in similar improvements. Impairment-based progressive rehabilitation improved clinical outcomes associated with CAI.

Key Words: ankle sprain, impairment-based progressive rehabilitation, postural control, strength

Key Points

- Incorporating destabilization devices into an impairment-based progressive rehabilitation program for patients with chronic ankle instability did not improve self-reported function, range of motion, strength, or balance more than traditional unstable surfaces did.
- A 4-week impairment-based progressive rehabilitation program improved patient-oriented outcomes as measured by self-reported function questionnaires.
- The patient-oriented improvements appeared to be related to improvements in ankle strength and motor-unit recruitment of the lower limb musculature during strength testing.
- Clinicians should use an impairment-based progressive rehabilitation model when treating patients with chronic ankle instability.
- Researchers should continue to use the patient, clinician, and laboratory model to help identify mechanisms that improve patient-oriented and clinically oriented outcomes.

Lateral ankle sprains are among the most common musculoskeletal injuries in competitive athletes[1,2] and recreationally active individuals.[3] Researchers[4] have estimated that approximately 47% to 74% of people who sustain lateral ankle sprains will have recurrent sprains 6 to 18 months after the first ankle sprain. Approximately 30% of patients develop *chronic ankle instability* (CAI),[5] which is defined as residual symptoms of instability and repetitive ankle sprains that last more than 1 year.[6]

The cause of CAI remains unclear; however, different characteristics have been identified in patients with CAI and healthy individuals. They include but are not limited to

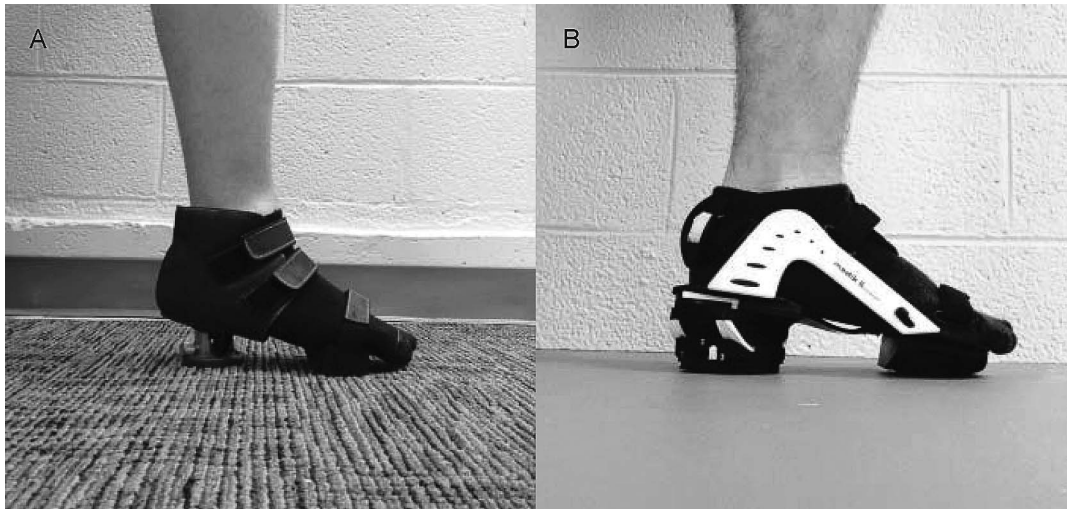

Figure 1. A, Myolux Athletik (Cevres Santé, Le Bourget-du-Lac, France) and B, Myolux II (Cevres Santé) destabilization devices.

impaired proprioception,[7,8] decreased neuromuscular control,[9,10] decreased range of motion (ROM),[11,12] decreased strength,[7,9,13] and altered gait.[14–17] Treatment of CAI often consists of conservative rehabilitation programs that are designed to improve ROM, strength, proprioception, and neuromuscular control.[18] Traditionally, rehabilitation programs have incorporated tools, such as foam pads, with balance exercises to improve neuromuscular control. However, given that patients cannot wear these tools, they are mostly used for relatively nonfunctional exercises, such as static balance. This limitation may decrease the ability of clinicians to maximize patients' improvement in functional activities.

Ankle-destabilization devices consist of either a boot or sandal with an articulator below the heel designed to mimic the motion that occurs at both the subtalar and talocrural joints during walking and other functional movements. The goal of destabilization devices is to force the patient into controlled plantar flexion, inversion, and internal rotation while completing functional tasks to facilitate feed-forward motor control of the musculature surrounding the ankle joint.[19]

Investigators have completed laboratory studies of 2 specific destabilization devices, the Myolux Athletik (boot) and Myolux II (sandal; Cevres Santé, Le Bourget-du-Lac, France), to assess alteration in muscle activity during functional tasks in both healthy individuals[20] and patients with CAI (Figure 1).[21] Donovan et al[21] evaluated the surface electromyography (sEMG) measures of 6 lower extremity muscles during balance, the Star Excursion Balance Test (SEBT), lateral hopping, and walking when comparing the 2 destabilization devices with a shod control condition in 15 patients with CAI. The results included a pronounced increase in the peroneus longus sEMG amplitude during all tasks,[21] which shows the potential for these devices to increase lateral stability of the ankle joint. Given the immediate increase in peroneus longus activity during each functional task, we hypothesized that these devices may be able to improve neuromuscular control and increase strength during closed kinetic chain exercises if incorporated into a progressive rehabilitation program. Other instability tools have been shown to cause a more global increase in lower extremity muscle activation during balance tasks and not specifically target the peroneus longus[22]; therefore, we wanted to determine whether the targeted emphasis on the peroneus longus would be more beneficial in improving ankle function because the peroneus longus is the main lateral dynamic stabilizer of the ankle.[23]

In addition to the limited ability of clinicians to incorporate unstable surfaces in functional rehabilitation, little evidence is available for a rehabilitation model designed to treat CAI. Recently, Donovan and Hertel[18] presented a new paradigm for the conservative treatment of patients with CAI. They asserted that rehabilitation should encompass exercises for all impairments detected in patients with CAI within 4 broad domains of functional activities, ROM, strength, and balance by an "assess, treat, re-assess" approach.[18] Furthermore, they emphasized the importance of implementing gait retraining in the rehabilitation of patients with CAI.[18] Finally, they recommended including self-report function instruments, such as the Foot and Ankle Ability Measure (FAAM), to assess how patients rate their function as they progress through the program; however, this was not included in their rehabilitation model.[18] Therefore, we have modified their rehabilitation paradigm to incorporate assessing self-reported function throughout the rehabilitation process (Figure 2).

Researchers[10,24–26] have completed multiple intervention studies to determine whether specific rehabilitation techniques (eg, balance training, strength training, joint mobilizations) improve impairments associated with CAI. Whereas these investigators found improvements in patients with CAI, each group incorporated only 1 intervention to address 1 area of impairment. We acknowledge that the purposes of these studies were to determine whether specific interventions improved associated impairments and that these were not advocated as the only treatments that should be used for patients with CAI. However, we believe that combining multiple treatment techniques, as is typical in clinical practice, may cause a larger improvement in symptoms and function in patients with CAI.

Specifically, Hoch et al[26] and McKeon et al[10] found similar magnitudes of change in patients' self-reported function after completing a 2-week mobilization interven-

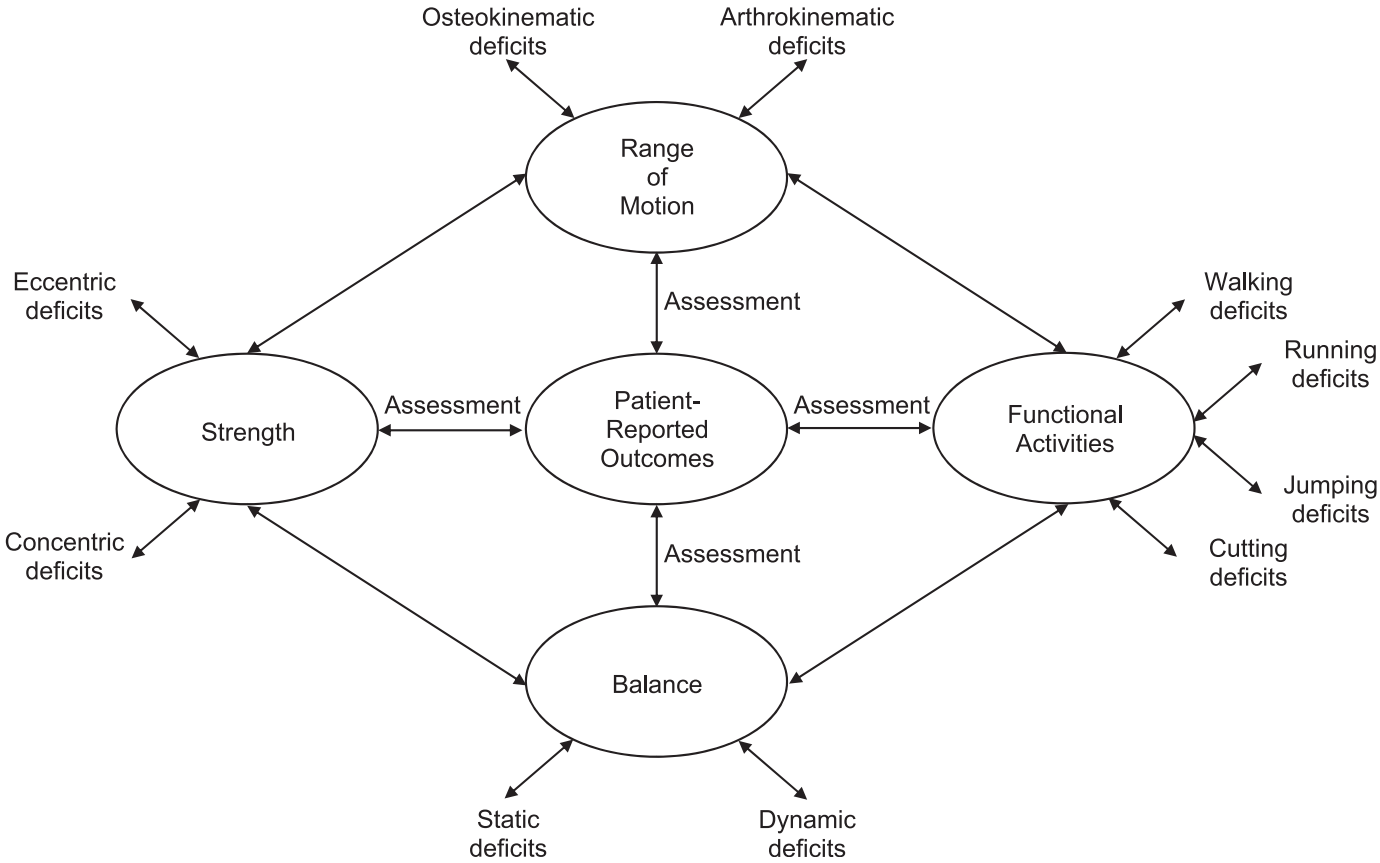

Figure 2. Modification to the rehabilitation paradigm to include self-reported function. Donovan L, Hertel J. A new paradigm for rehabilitation of patients with chronic ankle instability. *Phys Sportsmed*. 2012;40(4):41–51. Reprinted by permission of the publisher Taylor & Francis Ltd, www.tandfonline.com.

tion and a 4-week balance intervention, respectively. Whereas both interventions resulted in improvement when compared with preintervention scores, the postintervention self-reported function scores were still lower than those of a healthy group. These authors stated that their studies were limited because the duration of the intervention may have been too short to fully restore self-reported function.[10,26] We agree with this limitation, but we also believe the self-reported function scores were lower than those of a healthy group after the interventions because the patients in these studies[10,26] completed exercises to improve only 1 of the 4 domains composing the rehabilitation paradigm of Donovan and Hertel.[18] Therefore, the primary purpose of our study was to examine the effects of a 4-week supervised rehabilitation intervention that encompassed functional exercises, ROM, strength, and balance with or without destabilization devices in patients with CAI. The dependent variables (self-reported function, ankle ROM, strength, static and dynamic balance, sEMG during strength testing, and sEMG during balance testing) were organized using the patient, clinician, and laboratory (PCL) model as described by McKeon et al.[27] We believe the PCL model is an appropriate method for organizing our variables because the combined PCL evidence could identify specific mechanisms responsible for any changes associated with the clinical tests and the self-reported function of patients after the 4-week intervention.[27] In addition to determining the effectiveness of using destabilization devices in rehabilitation, our secondary purpose was to determine the effects of an impairment-based progressive rehabilitation program in patients with CAI.

METHODS

Study Design

We performed a single-blinded randomized clinical trial to compare 4 weeks of supervised rehabilitation with or without destabilization devices on measures of self-reported function, ankle ROM, ankle strength, and balance. Our independent variables were group (no device, device) and time (prerehabilitation, postrehabilitation). We did not include a true control group (group that received no intervention) because researchers have shown that our measures of interest do not change over time in patients with CAI who do not receive interventions or alter their current level of physical activity.[10,25,26] On the basis of these studies,[10,25,26] time alone did not appear to improve measures of self-reported function, ROM, strength, or balance in patients with CAI. Our patient-oriented variables were self-reported function measured by the FAAM Activities of Daily Living (ADL) and Sports scales, Single Assessment Numeric Evaluation (SANE) for ADLs and Sport, and global rating of change (GROC) scores. The clinically oriented variables were ROM (standing straight-knee dorsiflexion, standing bent-knee dorsiflexion, seated inversion, seated eversion, seated plantar flexion, and posterior glide test), strength (dorsiflexion, inversion,

eversion in neutral, eversion in plantar flexion, and plantar flexion), and dynamic balance (SEBT). Our laboratory-oriented variables were static balance (eyes-open center-of-pressure [COP] area, eyes-open COP velocity, eyes-closed COP area, eyes-closed COP velocity) and sEMG amplitudes of the anterior tibialis, peroneus brevis, peroneus longus, and medial gastrocnemius during the strength and balance tests. A comprehensive list of dependent variables is presented in Table 1.

Participants

Twenty-six (7 men, 19 women; age = 21.34 ± 3.06 years, height = 168.96 ± 8.77 cm, mass = 70.73 ± 13.86 kg) of 37 young adults with CAI recruited from a university setting and surrounding community completed the study. Of the 37 original recruits, 7 did not meet the inclusion criteria (FAAM Sports score > 85), 2 dropped out due to time constraints, 1 had an unrelated injury, and 1 had a recurrent ankle sprain during the rehabilitation program (Figure 3). The inclusion criteria were a history of more than 1 ankle sprain, with the initial sprain occurring more than 1 year before the study, and self-reported functional deficits at the time of the study due to ankle symptoms that qualified by a score of less than 85% on the FAAM Sports scale and equal to or greater than 10 on the Identification of Functional Instability scale.[28] All participants were *physically active*, which was defined as being involved in at least 20 minutes of exercise per day for 3 days or more per week; had no history of lower extremity injury, including ankle sprains within the 6 weeks before the study; and had no history of ankle surgery or disorders known to affect balance.[28] Patient demographics are presented in Table 2. We observed no differences in demographics between groups. All participants provided written informed consent, and the study was approved by the Institutional Review Board for Health Sciences Research of the University of Virginia (No. 16922).

Instruments

Ankle-Destabilization Devices. The device group used both the Myolux Athletik and Myolux II destabilization devices during rehabilitation (Figure 1). Both devices have been demonstrated to increase neuromuscular activation of the muscles around the ankle during walking gait.[20,21] The Myolux II was designed for the earlier stages of functional rehabilitation, whereas the Myolux Athletik was intended for the later phases of rehabilitation and sport performance. The major difference between the devices is that the Myolux II is a full-length sandal and the Myolux Athletik is not a full-length device and uses a metatarsal puck (Figure 1). In addition, the articulator of the Myolux II can produce about 30° of inversion and plantar flexion, whereas that of the Myolux Athletik can produce approximately 45° of inversion and plantar flexion. Given the differences in ROM production between the 2 devices, the Myolux Athletik is more challenging to use during rehabilitation exercises than the Myolux II. Therefore, patients in the device group would progress from the Myolux II to the Myolux Athletik.

Surface Electromyography. Surface EMG was measured using DE 2.1 differential EMG sensors (Delsys, Boston, MA). These rectangular sensors consisted of 2 parallel bars that were 1 cm long, 1 mm wide, and separated by 1 cm. As recommended by the manufacturer, the sensors were placed over the midbelly of each muscle parallel to fiber orientation, so the bars were perpendicular to the muscle belly. Before placement, the skin was shaved, abraded, and cleaned with isopropyl alcohol. Input impedance was greater than 10^{15} Ω//0.2 pF, with a signal-to-noise ratio of 1.2 μV. The signal was amplified with a gain of 1000 and digitized with a 4-channel acquisition system (Bagnoli EMG system; Delsys) at 1000 Hz. Data were collected using The MotionMonitor software (Innovative Sports Training Inc, Chicago, IL) and processed using EMGworks software (version 4.1.1; Delsys). The data-processing methods have been reported by Donovan et al,[21] who examined the effects of ankle-destabilization devices on the sEMG amplitudes of lower extremity muscles during functional exercises. We filtered the data with a band-pass filter from 10 to 500 Hz and smoothed it with a 50-sample moving-window root mean square (RMS) algorithm, as recommended by Konrad.[29] Before data collection, we inspected sEMG signals visually for each muscle to assess for cross-talk by manually testing each muscle independently and ensuring that the sEMG signals of other muscles were not activating.[29]

Static Balance. Static balance was assessed with the Accusway Plus force plate (AMTI, Watertown, MA). The COP 95% confidence eclipse area (cm^2) and average velocity (cm/s) were calculated from the 3-dimensional forces and moments that resulted from the foot–force-plate interface. We sampled the data at a rate of 50 Hz and used a fourth-order, zero-lag, low-pass filter with a cutoff frequency of 5 Hz to filter the COP data using Balance Clinic software (AMTI).[30]

Procedures

Participants completed the FAAM-ADL scale, FAAM-Sports scale, Identification of Functional Instability scale, and Godin Leisure-Time Activity questionnaires. Next, we assessed their general foot and ankle descriptive measures, ROM, strength, and balance. After data collection, they were assigned randomly to treatment groups. The randomization sequence was determined by a random-number generator, which was prepared by a separate investigator (J.H.) who assigned the sequence within sealed envelopes to ensure that group allocation was concealed. Each participant completed 12 supervised rehabilitation sessions over a 4-week period. Participants returned to the laboratory between 2 and 7 days after rehabilitation was completed and repeated the baseline testing. The investigators (L.D., M.A.F.) who collected the data were blinded to group assignment until all data were processed. Similarly, the clinician (C.C.H.) supervising the rehabilitation programs was not involved in the baseline or follow-up measurement sessions. Procedures are outlined in Figure 3.

Foot and Ankle Descriptive Measures. We included descriptive measures of the foot and ankle to estimate foot type and ankle laxity. Standing rear-foot alignment and the navicular-drop test were completed using the methods described by Gupta et al[31] and Picciano et al,[32] respectively. We measured ankle laxity (anterior displacement and inversion) with an ankle arthrometer (Blue Bay Research Inc, Navarre, FL) using previously described methods.[33]

Table 1. Dependent Variables Organized by Patient-Oriented, Clinically Oriented, and Laboratory-Oriented Outcomes

Outcomes										
					Laboratory Oriented					
		Clinically Oriented			Strength Surface Electromyography Amplitude		Balance Surface Electromyography Amplitude		Force Plate	
Patient Oriented[a]	Subscale	Range of Motion	Strength	Balance	Task	Muscle(s)	Task	Muscles	Task	Measure
Foot and Ankle Ability Measure	Activities of Daily Living	Dorsiflexion with straight knee and bent knee	Dorsiflexion	Star Excursion Balance Test	Dorsiflexion	Anterior tibialis	Eyes-open balance	Anterior tibialis, peroneus brevis, peroneus longus, and medial gastrocnemius	Eyes-open balance	COP area and velocity
	Sport	Inversion	Inversion		Inversion	Anterior tibialis	Eyes-closed balance	Anterior tibialis, peroneus brevis, peroneus longus, and medial gastrocnemius	Eyes-closed balance	COP area and velocity
Single Assessment Numeric Evaluation	Activities of Daily Living	Eversion	Eversion		Eversion	Peroneus brevis and peroneus longus	Star Excursion Balance Test	Anterior tibialis, peroneus brevis, peroneus longus, and medial gastrocnemius		
	Sport	Plantar flexion	Eversion in plantar flexion		Eversion in plantar flexion	Peroneus brevis and peroneus longus				
Global rating of change			Plantar flexion		Plantar flexion	Medial gastrocnemius				

Abbreviation: COP, center of pressure.

[a] Self-reported function.

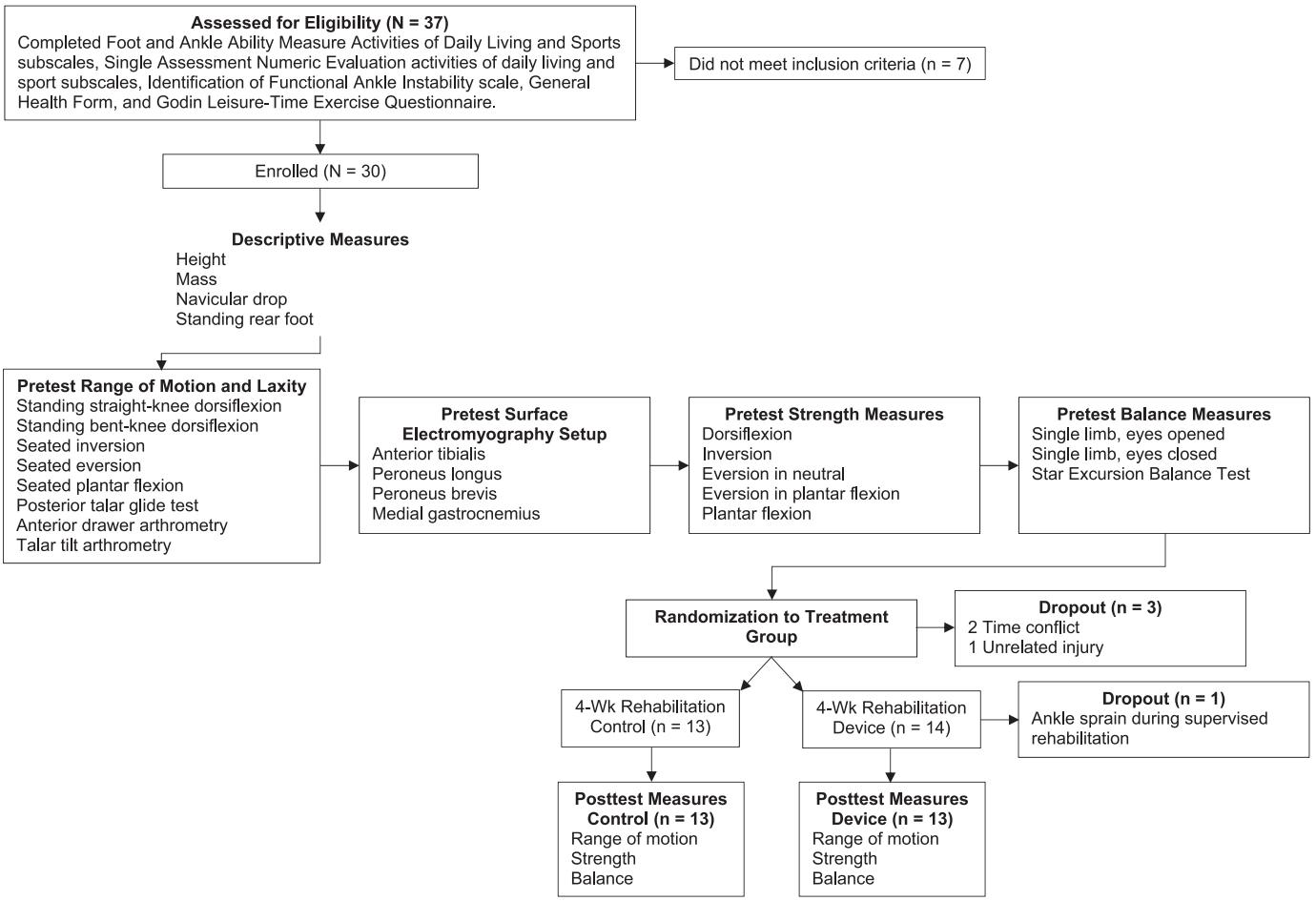

Figure 3. CONSORT flowchart that outlines the methods used for this study.

Range-of-Motion Measures. Range of motion was measured using a bubble inclinometer (Fabrication Enterprises Inc, Irvington, NY) and goniometer (Fabrication Enterprises Inc). Dorsiflexion was assessed in both the standing straight-knee and standing bent-knee positions with the bubble inclinometer.[34] We used the goniometer to evaluate inversion and eversion with patients positioned supine. Plantar flexion was measured using the bubble inclinometer with patients positioned supine. The posterior talar-glide test result was used to estimate the arthrokinematic motion of the talocrural joint.[35] Participants sat on the edge of a table with their knees at 90° of flexion. The bubble inclinometer was placed on the lateral lower limb. During the test, the investigator glided the foot posteriorly while maintaining it perpendicular to the floor. When the foot could no longer be glided due to

Table 2. Participant Baseline Demographics (N = 26; Mean ± SD)[a]

Variable	Group	
	No Device (n = 13)	Device (n = 13)
Age, y	21.46 ± 2.88	21.31 ± 3.35
Height, cm	169.11 ± 10.61	168.81 ± 6.89
Mass, kg	75.33 ± 13.70	66.12 ± 12.90
No. of sprains	3.08 ± 1.50	6.15 ± 5.37
Last sprain, mo	24.46 ± 22.51	10.27 ± 9.82
First sprain, y	5.58 ± 3.57	7.92 ± 5.22
Baseline Foot and Ankle Ability Measure Activities of Daily Living scale (range, 0–84)	87.65 ± 7.96	85.76 ± 7.26
Baseline Foot and Ankle Ability Measure Sports scale (range, 0–32)	65.87 ± 18.24	67.07 ± 13.42
Identification of Functional Ankle Instability (range, 0–37)	22.92 ± 1.71	23.23 ± 5.15
Godin Leisure-Time Physical Activity Score (range for this data set, 13–30)	58.77 ± 16.45	79.69 ± 31.66
Standing rear-foot angle, °	5.67 ± 2.93	4.15 ± 0.99
Navicular drop, mm	6.85 ± 3.03	6.85 ± 2.30
Anterior drawer arthrometry, mm	9.37 ± 4.34	11.72 ± 5.15
Inversion arthrometry, °	45.67 ± 9.82	45.07 ± 7.45
Average time per rehabilitation session, min	65.18 ± 4.69	66.25 ± 7.98

[a] Indicates no differences between groups at baseline.

restriction of the ankle joint, the knee-flexion angle was recorded. The knee-flexion angle also represents the angle between the foot and lower limb. These same methods have been reported by Cosby and Hertel.[35]

Strength. Ankle strength (dorsiflexion, inversion, eversion in neutral, eversion in a relaxed plantar-flexion position, plantar flexion) was measured using a handheld dynamometer (Accelerated Care Plus Corp, Reno, NV). Before testing, participants walked at a self-selected pace for 5 minutes to warm up. We used the testing positions recommended by Kelln et al.[36] For each position, we instructed individuals to complete the task at 50% effort and 75% effort before completing the maximal-effort trials. Three 5-second maximal voluntary isometric contraction (MVIC) trials were completed for each motion. Participants rested for 15 seconds between trials. The mean force (N) during the 3 trials was calculated, normalized to body mass (kg), and used in the statistical analysis. We collected sEMG during all MVIC trials.

Static Balance. Participants completed 3 eyes-open and 3 eyes-closed single-limb balance trials on the force plate for 10 seconds each. They stood with 1 foot in the center of the force plate, crossed their upper limbs in front of their chests, lifted the uninvolved limb to about 30° of hip flexion and 45° of knee flexion, and stood as still as possible for the 10-second trials.[10] Trials were considered unsuccessful if the uninvolved limb touched the ground or the standing limb or if the individual was unable to maintain the testing position for the entire 10-second trial. The mean area and velocity were calculated from the 3 successful trials.

Dynamic Balance. We used the SEBT to assess dynamic balance. Participants completed 3 trials in the anterior, posteromedial, and posterolateral directions using the testing procedures recommended by Gribble et al.[37] The average of the 3 trials in each direction was calculated and normalized to limb length to form a composite reach-distance percentage of the limb length of participants.[38] Surface EMG was collected during all static-balance and dynamic-balance trials.

Data Reduction of the sEMG Amplitudes

We calculated the sEMG amplitudes during strength testing, static balance, and dynamic balance to find an estimate of the motor-unit recruitment needed from each muscle to complete the task and to identify whether the amount of recruitment would change after rehabilitation. Surface EMG amplitude as measured by the area under the curve has been shown to effectively identify differences in motor-unit recruitment in patients with CAI.[39]

Amplitude During MVIC. The area under the RMS curve was calculated for the middle 3-second period of each strength trial for the corresponding muscle (dorsiflexion = anterior tibialis, inversion = anterior tibialis, eversion in neutral = peroneus brevis and longus, eversion in plantar flexion = peroneus brevis and longus, plantar flexion = medial gastrocnemius) and averaged. The area under the RMS curve was normalized to a 3-second period collected during a quiet resting period.

Single-Limb Eyes-Open and Eyes-Closed Balance Amplitudes. During both the eyes-open and eyes-closed trials, the area under the RMS curve was calculated for the middle 3-second period of each trial and normalized to the area under the RMS curve of a 3-second quiet resting period. The mean amplitudes of the 3 trials for each trial were calculated.

Star Excursion Balance Test Amplitudes. We calculated a composite mean area under the RMS curve of the stance limb during the SEBT for a 500-millisecond period before maximal reach distance. The composite mean amplitude was normalized to a time-matched 500-millisecond period during quiet resting. These sEMG data-reduction techniques were reported by Feger et al.[39]

Rehabilitation Programs

Rehabilitation began a minimum of 48 hours after prerehabilitation measurements. Patients completed 3 supervised rehabilitation sessions per week for 4 weeks; all patients completed a total of 12 sessions. Each rehabilitation session lasted approximately 1 hour and was supervised by an athletic trainer (C.C.H.) with 4 years of clinical experience. Rehabilitation groups were prescribed exercises that addressed deficits in functional activity, ROM, strength, and balance and reflected the previously described rehabilitation paradigm.[18] Each group (device, no device) completed the same type of base functional activity, ROM, strength, and balance exercises. Furthermore, the amount of time or repetitions for each exercise was the same for both groups. The 2 groups differed in the way the functional activity and balance exercises were progressed by using different instability tools to make the exercises more challenging. Specifically, the device group used both destabilization devices during weight-bearing activities throughout rehabilitation, and the no-device group used foam and balance discs during the same activities. For a given exercise, the device group typically progressed from using a firm surface to using the Myolux II and then to the Myolux Athletik. The no-device group typically progressed from using a firm surface to using a foam pad and then to a DynaDisc (Exertools Inc, Petaluma, CA). For example, a patient in the no-device group would progress from eyes-closed single-limb balance on a firm surface to eyes-closed single-limb balance on a foam surface. Alternatively, a patient in the device group would progress from eyes-closed single-limb balance on a firm surface to eyes-closed single-limb balance using the Myolux II. We recognize that the instability tools we used were drastically different, which could have resulted in our groups progressing differently over the 4-week period; however, we considered this a strength in determining whether implementing destabilization devices during rehabilitation was more effective than using other instability tools. The initial intensity and duration of each exercise were based on the clinical judgment of the athletic trainer who evaluated the ROM, strength, and balance of the patients and started them at a level that he perceived would be challenging. If the starting point was too challenging or not challenging enough, the clinician altered the starting point accordingly. When the initial starting point was established, the clinician used set criteria to progress the patient through the rehabilitation program. Detailed rehabilitation protocols and progression criteria are provided in the Appendix. On average, both the no-device and device groups had the same length of rehabilitation sessions and training volume throughout the intervention (Table 2).

Table 3. Self-Reported Function Scores for the No-Device and Device Groups (Mean ± SD) and Hedges *g* Effect Sizes With 95% Confidence Interval

Variable	No-Device Group		Device Group		Time Main Effect *P* Value	Group Main Effect *P* Value	Group × Time Interaction *P* Value	Pooled Prerehabilitation-Postrehabilitation Hedges *g* Effect Size (95% Confidence Interval)[a]
	Prerehabilitation	Postrehabilitation	Prerehabilitation	Postrehabilitation				
Foot and Ankle Ability Measure Activities of Daily Living scale, %	87.65 ± 7.96	95.60 ± 3.31	85.76 ± 7.26	95.97 ± 4.55	<.001	.69	.46	1.49 (0.88, 2.11)
Foot and Ankle Ability Measure Sports scale, %	65.87 ± 18.24	86.85 ± 11.39	67.07 ± 13.42	85.82 ± 8.33	<.001	.98	.71	1.50 (0.88, 2.11)
Single Assessment Numeric Evaluation Activities of Daily Living score	87.85 ± 11.15	95.08 ± 4.35	83.00 ± 20.49	94.54 ± 8.41	.006	.49	.49	0.74 (0.18, 1.30)
Single Assessment Numeric Evaluation Sport score	72.62 ± 20.89	90.23 ± 8.35	73.77 ± 16.14	89.00 ± 10.54	<.001	.99	.71	1.11 (0.53, 1.70)
Global rating of change score	NA	4.77 ± 1.42	NA	4.46 ± 1.94	NA	.65	NA	NA

Abbreviation: NA, not applicable.

[a] Effect sizes were calculated comparing the pooled prerehabilitation means of both groups with the pooled postrehabilitation means of both groups, with a positive effect size denoting an increase in self-reported function after rehabilitation.

Follow-Up Testing

After 4 weeks of rehabilitation, participants again completed the FAAM-ADL and FAAM-Sports questionnaires, provided a GROC,[40] and had their ankle ROM strength and balance retested between 48 and 96 hours after their last rehabilitation visits. The GROC was a Likert-based questionnaire; participants selected a number ranging from –7 (*A very great deal worse*) to 7 (*A very great deal better*) after we instructed them to rate the overall condition of their ankles from the time treatment began until the current time.

Statistical Analysis

For each dependent variable (self-reported function, ROM, strength, balance, sEMG strength amplitudes, sEMG balance amplitudes), a 2×2 mixed-model analysis of variance was conducted. The between-subjects factor was group (no-device rehabilitation, rehabilitation with ankle-destabilization devices), and the within-subject factor with repeated measures was time (prerehabilitation, postrehabilitation). We used Tukey post hoc tests to identify specific differences when interactions were present. The α level was set a priori at .05 for all analyses. As recommended by Hopkins et al[41] in their review article that provided statistical-analysis considerations for sports medicine studies, we did not control for multiple comparisons. We calculated the Hedges *g* effect sizes and associated 95% confidence intervals (CIs), comparing the pooled postrehabilitation means of both groups with the pooled prerehabilitation means of both groups to provide an interpretation of the magnitude of change in the dependent variables. Effect sizes were interpreted as *large* (≥0.80), *moderate* (0.50–0.79), *small* (0.49–0.20), and *trivial* (<0.20).[42] We analyzed the data using SPSS statistical software (version 20.0; IBM Corporation, Armonk, NY).

RESULTS

Patient-Oriented Outcomes

We did not observe interactions or group main effects in FAAM-ADL percentage, FAAM-Sports percentage, SANE-ADL scores, or SANE-Sport scores. A time main effect was revealed. After completing rehabilitation, combined groups had higher self-reported function scores for FAAM-ADL percentage (prerehabilitation = 86.71 ± 7.53, postrehabilitation = 95.79 ± 4.55; $P < .001$), FAAM-Sports percentage (prerehabilitation = 66.47 ± 13.42, postrehabilitation = 86.33 ± 9.79; $P < .001$), SANE-ADL (prerehabilitation = 85.42 ± 16.53, postrehabilitation = 94.81 ± 8.41; $P = .006$), and SANE-Sport (prerehabilitation = 73.19 ± 18.30, postrehabilitation = 89.62 ± 9.33; $P < .001$). The average GROC score of the pooled groups was 4.62, indicating that patients believed they were between *Moderately better* and *Quite a bit better* postrehabilitation. We observed large effects sizes with CIs that did not cross zero for the FAAM-ADL, FAAM-Sports, and SANE-Sport scores. In addition, the SANE-ADL score had a moderate effect size with CIs that did not cross zero (Table 3).

Table 4. Range of Motion for the No-Device and Device Groups (Mean ± SD) and Hedges *g* Effect Sizes With 95% Confidence Intervals

Variable	No-Device Group		Device Group		Time Main Effect *P* Value	Group Main Effect *P* Value	Group × Time Interaction *P* Value	Pooled Prerehabilitation-Postrehabilitation Hedges *g* Effect Size (95% Confidence Interval)[a]
	Prerehabilitation	Postrehabilitation	Prerehabilitation	Postrehabilitation				
Standing straight-knee dorsiflexion	34.15 ± 10.38	38.31 ± 7.99	42.08 ± 6.98	47.31 ± 6.96	.02	.003	.78	0.51 (−0.05, 1.06)
Standing bent-knee dorsiflexion	38.08 ± 11.12	43.46 ± 10.68	46.38 ± 7.12	51.08 ± 7.38	.001	.03	.81	0.50 (−0.05, 1.05)
Posterior talar glide	9.10 ± 8.71	14.49 ± 9.77	15.41 ± 8.56	17.05 ± 5.08	.02	.14	.21	0.41 (−0.14, 0.96)
Seated plantar flexion	64.00 ± 9.70	67.38 ± 10.65	64.62 ± 7.18	67.85 ± 5.67	.003	.87	.94	0.39 (−0.16, 0.94)
Seated inversion	32.67 ± 10.42	34.69 ± 8.51	36.92 ± 7.43	35.85 ± 8.16	.72	.40	.25	0.05 (−0.49, 0.60)
Seated eversion	14.31 ± 7.45	18.69 ± 6.10	15.92 ± 6.30	16.85 ± 5.89	.11	.95	.29	0.41 (−0.14, 0.96)

[a] Effect sizes were calculated comparing the pooled prerehabilitation means of both groups with the pooled postrehabilitation means of both groups, with a positive effect size denoting an increase in range of motion after rehabilitation.

Clinically Oriented Outcomes

Range of Motion. We observed no interactions for any ROM measure. A group main effect was revealed for standing straight-knee dorsiflexion and standing bent-knee dorsiflexion between groups (Table 4). However, the device group had more standing straight- and bent-knee dorsiflexion at baseline and did not have a greater change from prerehabilitation to postrehabilitation than the no-device group. When groups were combined, standing straight-knee dorsiflexion (prerehabilitation = 38.12° ± 9.56°, postrehabilitation = 42.81° ± 8.66°; $P = .02$), standing bent-knee dorsiflexion (prerehabilitation = 42.23° ± 10.08°, postrehabilitation = 47.27° ± 9.80°; $P = .001$), and posterior talar glide (prerehabilitation = 12.26° ± 9.05°, postrehabilitation = 15.77° ± 7.74°; $P = .02$) increased after rehabilitation. For plantar flexion, the combined groups had an increase in ROM (prerehabilitation = 64.31° ± 8.37°, postrehabilitation = 67.62° ± 8.36°; $P = .003$). We observed no changes in inversion or eversion ROM. All ROM measures had effect sizes that ranged from trivial to moderate with CIs that crossed zero (Table 4).

Strength. When groups were combined, strength increased postrehabilitation in all motions, including dorsiflexion (prerehabilitation = 1.80 ± 0.60 N/kg, postrehabilitation = 2.13 ± 0.61 N/kg; $P < .001$), inversion (prerehabilitation = 1.41 ± 0.31 N/kg, postrehabilitation = 1.82 ± 0.44 N/kg; $P < .001$), eversion in neutral (prerehabilitation = 1.64 ± 0.39 N/kg, postrehabilitation = 2.08 ± 0.49 N/kg; $P < .001$), eversion in plantar flexion (prerehabilitation = 1.41 ± 0.33 N/kg, postrehabilitation = 1.74 ± 0.43 N/kg; $P < .001$), and plantar flexion (prerehabilitation = 3.34 ± 0.87 N/kg, postrehabilitation = 3.93 ± 1.15 N/kg; $P = .002$). We did not observe interactions or group differences for any measure except dorsiflexion (Table 5). The device group had greater prerehabilitation dorsiflexion strength than the no-device group; however, the dorsiflexion-strength scores from prerehabilitation-to-postrehabilitation were not different between groups. Furthermore, inversion, eversion in neutral, and eversion in plantar flexion had large effect sizes with CIs that did not cross zero. In addition, dorsiflexion and plantar flexion had moderate effect sizes with CIs that did not cross zero (Table 5).

Dynamic Balance. We observed an increase in composite reach distances during the SEBT (prerehabilitation = 75.11 ± 7.82%, postrehabilitation = 79.11 ± 6.66%; $P = .003$) when comparing the prerehabilitation with postrehabilitation scores of the combined groups. In addition, we noted a group difference, which we believe was due to the nearly 7% difference in baseline scores between the 2 groups. The no-device group had a baseline reach distance of 71.65% and a postrehabilitation reach distance of 76.61%. The device group had a baseline reach distance of 78.57% and a postrehabilitation reach distance of 81.60%. No group-by-time interaction was revealed. The effect size was moderate but had a CI that crossed zero (Table 6).

Laboratory-Oriented Outcomes

Static Balance. When groups were combined, we did not find an interaction or group differences but did demonstrate

Table 5. Strength Normalized to Mass (N/kg) for the No-Device and Device Groups (Mean ± SD) and Hedges *g* Effect Sizes With 95% Confidence Intervals

Motion	No-Device Group		Device Group		Time Main Effect *P* Value	Group Main Effect *P* Value	Group × Time Interaction *P* Value	Pooled Prerehabilitation-Postrehabiliation Hedges *g* Effect Size (95% Confidence Interval)[a]
	Prerehabilitation	Postrehabilitation	Prerehabilitation	Postrehabilitation				
Dorsiflexion	1.62 ± 0.32	1.83 ± 0.37	1.98 ± 0.60	2.42 ± 0.68	<.001	.02	.12	0.57 (0.01, 1.12)
Inversion	1.32 ± 0.28	1.72 ± 0.41	1.49 ± 0.34	1.93 ± 0.46	<.001	.17	.77	1.07 (0.49, 1.65)
Eversion in neutral	1.61 ± 0.44	1.96 ± 0.49	1.68 ± 0.34	2.19 ± 0.48	<.001	.36	.23	0.97 (0.40, 1.55)
Eversion in plantar flexion	1.34 ± 0.32	1.66 ± 0.43	1.48 ± 0.33	1.83 ± 0.44	<.001	.24	.89	0.85 (0.28, 1.42)
Plantar flexion	3.10 ± 0.86	3.48 ± 0.98	3.58 ± 0.85	4.38 ± 1.17	.002	.055	.24	0.57 (0.02, 1.13)

[a] Effect sizes were calculated comparing the pooled prerehabilitation means of both groups with the pooled postrehabilitation means of both groups, with a positive effect size denoting an increase in strength after rehabilitation.

Table 6. Static and Dynamic Balance for the No-Device and Device Groups (Mean ± SD) and Hedges *g* Effect Sizes With 95% Confidence Intervals

Task	No-Device Group		Device Group		Time Main Effect *P* Value	Group Main Effect *P* Value	Group × Time Interaction *P* Value	Pooled Prerehabilitation-Postrehabiliation Hedges *g* Effect Size (95% Confidence Interval)[a]
	Prerehabilitation	Postrehabilitation	Prerehabilitation	Postrehabilitation				
Eyes open								
Single-limb balance area, cm^2	7.23 ± 2.70	5.75 ± 1.78	7.44 ± 2.37	6.85 ± 2.48	.04	.42	.36	−0.44 (−0.99, 0.11)
Single-limb balance velocity, cm/s	4.26 ± 1.26	3.85 ± 0.89	4.51 ± 1.70	4.51 ± 1.44	.38	.35	.39	−0.15 (−0.69, 0.40)
Eyes closed								
Single-limb balance area, cm^2	29.71 ± 10.18	24.36 ± 8.55	26.44 ± 9.63	21.79 ± 5.57	.047	.26	.88	−0.57 (−1.14, −0.01)
Single-limb balance velocity, cm/s	9.96 ± 2.99	8.91 ± 2.41	9.71 ± 2.77	9.08 ± 2.33	.03	.97	.58	−0.32 (−0.88, 0.24)
Star Excursion Balance Test composite score, %	71.65 ± 8.07	76.61 ± 7.42	78.57 ± 6.03	81.60 ± 4.88	.003	.02	.43	0.54 (−0.01, 1.10)

[a] Effect sizes were calculated comparing the pooled prerehabilitation means of both groups with the pooled postrehabilitation means of both groups, with a negative effect size denoting an increase in static balance postrehabilitation and a positive effect size denoting an increase in reach distance for the Star Excursion Balance Test.

Table 7. Surface Electromyography Amplitudes Normalized to Quiet Resting During Maximal Voluntary Isometric Contractions for the No-Device and Device Groups (Mean ± SD) and Hedges *g* Effect Sizes With 95% Confidence Intervals

Motion	Muscle	No-Device Group		Device Group		Time Main Effect *P* Value	Group Main Effect *P* Value	Group × Time Interaction *P* Value	Pooled Prerehabilitation-Postrehabilitation Hedges *g* Effect Size (95% Confidence Interval)[a]
		Prerehabilitation	Postrehabilitation	Prerehabilitation	Postrehabilitation				
Dorsiflexion	Anterior tibialis	40.71 ± 24.50	55.28 ± 20.50	52.82 ± 22.27	53.19 ± 13.37	.10	.47	.11	0.36 (−0.19, 0.90)
Inversion	Anterior tibialis	13.17 ± 9.17	27.82 ± 11.69	17.56 ± 14.21	22.87 ± 12.72	.004	.94	.15	0.81 (0.25, 1.38)
Eversion in neutral	Peroneus brevis	36.15 ± 29.70	48.05 ± 30.52	41.04 ± 26.99	58.01 ± 39.50	.03	.51	.68	0.45 (−0.10, 1.00)
	Peroneus longus	28.79 ± 17.77	39.11 ± 19.38	24.62 ± 11.17	47.14 ± 37.27	.006	.80	.28	0.70 (0.14, 1.26)
Eversion in plantar flexion	Peroneus brevis	33.25 ± 30.20	49.11 ± 26.97	42.20 ± 21.69	62.02 ± 40.14	.01	.29	.76	0.58 (0.02, 1.13)
	Peroneus longus	33.03 ± 20.93	42.79 ± 22.95	30.85 ± 14.91	48.92 ± 33.41	.01	.80	.43	0.58 (0.03, 1.13)
Plantar flexion	Medial gastrocnemius	18.48 ± 13.35	19.95 ± 11.74	25.70 ± 10.44	27.41 ± 10.97	.53	.07	.96	0.13 (−0.41, 0.67)

[a] Effect sizes were calculated comparing the pooled prerehabilitation means of both groups with the pooled postrehabilitation means of both groups, with a positive effect size denoting an increase in surface electromyography amplitudes during maximal voluntary isometric contractions.

decreases in eyes-open area (prerehabilitation = 7.34 ± 2.49 cm^2, postrehabilitation = 6.30 ± 2.19 cm^2; $P = .04$), eyes-closed area (prerehabilitation = 28.09 ± 9.83 cm^2, postrehabilitation = 23.02 ± 7.12 cm^2; $P = .047$), and eyes-closed average velocity (prerehabilitation = 9.83 ± 2.82 cm/s, postrehabilitation = 9.00 ± 2.32 cm/s; $P = .03$) after rehabilitation. In addition, the effect size for COP area during eyes-closed single-limb balance was moderate with CIs that did not cross zero. All other effects sizes were trivial to small with CIs that crossed zero (Table 6).

Strength sEMG Amplitudes. We observed an increase in sEMG amplitudes when comparing prerehabilitation with postrehabilitation values for the combined groups: anterior tibialis during inversion (prerehabilitation = 15.37 ± 11.93, postrehabilitation = 25.34 ± 12.23; $P = .004$), peroneus brevis during eversion in neutral (prerehabilitation = 38.59 ± 27.92, postrehabilitation = 53.03 ± 34.95; $P = .03$), peroneus longus during eversion in neutral (prerehabilitation = 26.71 ± 14.70, postrehabilitation = 43.13 ± 29.39; $P = .006$), peroneus brevis during eversion in plantar flexion (prerehabilitation = 37.72 ± 26.16, postrehabilitation = 55.57 ± 34.14; $P = .01$), and peroneus longus during eversion in plantar flexion (prerehabilitation = 31.94 ± 17.84, postrehabilitation = 45.86 ± 28.25; $P = .01$). For the anterior tibialis during ankle inversion, a large effect size was revealed with CIs that did not cross zero. During eversion in neutral, the peroneus longus had a moderate effect size with CIs that did not cross zero. Both the peroneus brevis and peroneus longus had moderate effect sizes with CIs that did not cross zero during ankle eversion in a plantar-flexed position. All other effect sizes were trivial to small with CIs that crossed zero (Table 7).

Balance sEMG Amplitudes. We did not observe differences in sEMG amplitudes of any muscle during eyes-open or eyes-closed single-limb balance or the SEBT composite score. All effect sizes were trivial to small and had CIs that crossed zero (Table 8).

DISCUSSION

Our primary findings were that incorporating destabilization devices into a 4-week impairment-based progressive rehabilitation program for patients with CAI did not cause greater changes in self-reported function, ROM, strength, balance, or sEMG amplitude during strength and balance measures than performing rehabilitation without the devices.

When we combined the groups and used the PCL model,[27] we found that an impairment-based progressive rehabilitation program effectively improved patient-oriented outcomes, some clinically oriented outcomes, and some laboratory-oriented outcomes. Specifically, by interpreting effect sizes that were moderate to large and had associated CIs that did not cross zero as clinically meaningful, we are able to isolate the clinically oriented and laboratory-oriented outcomes that had the greatest improvements.

Patient-oriented evidence has been recognized as the most important component of evidence-based practice.[43] Our data indicated that completing 4 weeks of impairment-based rehabilitation effectively improved patient-oriented outcomes in patients with CAI. Specifically, we found large

Table 8. Surface Electromyography Amplitudes Normalized to Quiet Resting During Static and Dynamic Balance for the No-Device and Device Groups (Mean ± SD) and Hedges *g* Effect Sizes With 95% Confidence Intervals

Task	Eyes	Muscle	No-Device Group		Device Group		Time Main Effect	Group Main Effect	Group × Time Interaction	Pooled Prerehabilitation-Postrehabiliation Hedges *g* Effect Size	
				Prerehabilitation	Postrehabilitation	Prerehabilitation	Postrehabilitation	*P* Value	*P* Value	(95% Confidence Interval)[a]	*P* Value
Single limb	Open	Anterior tibialis	9.83 ± 7.18	8.83 ± 6.51	11.79 ± 8.36	8.86 ± 5.81	.16	.69	.49	−0.28 (−0.84, 0.27)	
Single limb	Closed	Anterior tibialis	15.16 ± 8.65	19.93 ± 9.96	22.57 ± 11.60	19.41 ± 8.05	.72	.29	.09	0.06 (−0.49, 0.62)	
Single limb	Open	Peroneus brevis	8.22 ± 6.45	13.55 ± 13.64	7.99 ± 5.16	9.74 ± 4.63	.16	.36	.48	0.42 (−0.14, 0.98)	
Single limb	Closed	Peroneus brevis	19.62 ± 13.06	27.69 ± 18.84	20.37 ± 10.32	17.86 ± 9.60	.42	.28	.13	0.19 (−0.37, 0.74)	
Single limb	Open	Peroneus longus	11.84 ± 4.20	12.06 ± 7.42	10.84 ± 4.27	14.46 ± 12.53	.30	.79	.36	0.25 (−0.31, 0.81)	
Single limb	Closed	Peroneus longus	24.35 ± 11.98	25.04 ± 13.37	17.53 ± 7.40	19.44 ± 11.62	.61	.11	.81	0.11 (−0.44, 0.67)	
Single limb	Open	Medial gastrocnemius	10.08 ± 7.33	7.47 ± 3.36	17.45 ± 8.68	16.32 ± 12.36	.36	.009	.72	−0.19 (−0.75, 0.36)	
Single limb	Closed	Medial gastrocnemius	14.49 ± 9.33	9.18 ± 3.90	23.35 ± 12.07	20.14 ± 16.61	.14	.01	.71	−0.33 (−0.89, 0.22)	
Star Excursion Balance Test composite	Not applicable	Anterior tibialis	5.35 ± 3.14	6.63 ± 4.05	7.84 ± 3.71	7.62 ± 4.28	.35	.22	.19	0.14 (−0.41, 0.68)	
		Peroneus brevis	2.95 ± 2.49	6.15 ± 6.17	5.53 ± 11.46	4.23 ± 6.13	.43	.90	.07	0.13 (−0.42, 0.67)	
		Peroneus longus	3.85 ± 3.18	6.72 ± 10.40	4.88 ± 7.14	3.78 ± 5.21	.55	.69	.19	0.13 (−0.42, 0.67)	
		Medial gastrocnemius	1.28 ± 1.00	1.78 ± 2.13	5.36 ± 10.04	2.56 ± 3.75	.45	.13	.29	−0.20 (−0.75, 0.34)	

[a] Effect sizes were calculated comparing the pooled prerehabilitation means of both groups with the pooled postrehabilitation means of both groups, with a positive effect size denoting an increase in surface electromyography amplitudes during single-limb balance and the Star Excursion Balance Test.

improvements in the FAAM-ADL, FAAM-Sports, and SANE-Sport scores after the intervention. In addition, we observed moderate improvements in the SANE-ADL score after rehabilitation.

When comparing the magnitude of change in self-reported function between our study and other studies,[10,26,44] it appears that using the CAI rehabilitation paradigm that Donovan and Hertel[18] proposed results in greater improvement in self-reported function. In patients with CAI who performed a 4-week comprehensive rehabilitation program, Hale et al[44] found improved Foot and Ankle Disability Index Sport scale (later renamed the FAAM-Sports) scores. Their results were similar to ours, except the magnitude of change of the FAAM-Sports score was much higher in our study (20% versus 11%). We believe this result is due to the supervision in our program and incorporation of unstable surfaces or destabilization devices into the functional exercises. In addition, we used an impairment-based model in our progression of exercises versus starting each participant at the same level of difficulty for each exercise as Hale et al[44] did. We also observed that our progressive rehabilitation protocol had a greater magnitude of change in the FAAM-Sports score than McKeon et al[10] reported when testing the effects of balance training and Hoch et al[26] reported when examining joint mobilizations (20%, 15%, and 15%, respectively). Our observations are of particular interest because we incorporated a balance-training program that was similar to that of McKeon et al.[10] Although McKeon et al[10] did use an impairment-based rehabilitation model by starting patients at various levels of difficulty based on their initial balancing capabilities, they incorporated only balance-related exercises. We believe that by including ROM, strength, and other functional exercises, we could produce a greater improvement in self-reported function.

On the basis of our definition of *CAI*, our patients would, on average, no longer qualify as having CAI because the mean postrehabilitation FAAM-Sports scores exceeded the 85% inclusion threshold. Furthermore, patients reached approximately 96% of their perceived ankle function during ADLs. After completing 4 weeks of impairment-based rehabilitation, patients perceived only a 14% deficit in ankle function during sport-related activities and a 4% deficit in ADLs.

In addition to improvements in patient-oriented outcomes, our patients had improved clinically oriented outcomes, specifically strength. They had large improvements in isometric strength during inversion, eversion in neutral, and eversion in plantar flexion with CIs that did not cross zero. Moreover, moderate improvements occurred in dorsiflexion and plantar flexion with CIs that did not cross zero. The identified improvements in ankle strength after rehabilitation were consistent with past findings,[25,45] given that these investigators reported large improvements in ankle inversion and eversion strength. Whereas we and the authors of these strength studies[25,45] used similar methods to measure ankle strength, we cannot compare the magnitude of change among strength measures because the patients with CAI in the other studies[25,45] completed 6 weeks of strengthening exercises. Four weeks of rehabilitation is enough time to cause large improvements in ankle inversion and eversion strength in patients with CAI; however, it remains unclear whether the type of strengthening exercises or the incorporation of functional activity, ROM, and balance exercises affects ankle-strength measures.

Whereas the magnitude of change was considered moderate with associated CIs that crossed zero by 0.05, we found that standing straight-knee and standing bent-knee dorsiflexion ROM improved by approximately 4° and 5°, respectively. For mean differences between prerehabilitation and postrehabilitation ROM measures, our ROM improvements were consistent with the finding by Hoch et al,[26] who examined the effects of a 2-week joint-mobilization intervention on dorsiflexion ROM using the weight-bearing lunge test.

Similar to the dorsiflexion ROM measures, we found a moderate increase in dynamic balance as measured by the SEBT composite percentage, with associated CIs that crossed zero by 0.01. After 4 weeks of rehabilitation, our patients improved by about 4% in the SEBT. Our SEBT improvements were consistent with previous studies.[44,46]

As with the clinically oriented outcomes, most improvements in the laboratory-oriented outcomes revolved around strength. We found a large increase in sEMG amplitude measures of the anterior tibialis during inversion strength testing postrehabilitation. Furthermore, we found moderate increases in sEMG amplitude measures of the peroneus brevis and peroneus longus during eversion in plantarflexion strength testing and of the peroneus longus during eversion in neutral strength testing. One mechanism causing the improvement in the clinically oriented strength measure could be related to the improvement of sEMG amplitudes of the associated muscle during the strength test. In addition to increased force production, the increases in sEMG amplitudes during strength testing indicated that the strength portion of rehabilitation could improve motor recruitment. Although this finding has not been reported in the ankle literature, an increase in neural drive represented by an increase in sEMG amplitudes of the quadriceps has been established after a knee-extension strength program.[47]

Whereas we observed more consistent improvements in sEMG amplitudes during strength testing, we did find moderate improvements in the COP area during the eyes-closed single-limb balance test; however, we observed no alterations in the other 3 static balance variables. Our balance-training protocol and data-collection procedures were similar to those of McKeon et al,[10] who found improvements in single-limb balance as measured by a force plate using a time-to-boundary analysis. Time to boundary is a reliable method to detect changes in postural control during balance tasks and a more sensitive measure than traditional postural-control assessments during balance.[10] Similar to our study, McKeon et al[10] did not find consistent differences in traditional COP measures during a eyes-open or eyes-closed single limb task but did demonstrate improvements in COP velocity during the eyes-closed single-limb condition. Because we found improvements only in COP average area, we believe a limitation of our static-balance measure was in not calculating time to boundary; we might have overlooked potential differences by not using this more reliable method of detecting changes in postural control during single-limb balance.

We found no differences in sEMG amplitude for the 4 muscles we tested during the eyes-open and eyes-closed

single-limb tasks or during the SEBT. This may be from our not finding large improvements in static balance or dynamic balance after the 4 weeks of rehabilitation.

Overall, we observed that destabilization devices effectively improved self-reported function and strength in patients with CAI; however, using these devices was no more effective than using traditional unstable surfaces. We hypothesized that the destabilization devices may improve clinical outcomes more effectively than traditional unstable surfaces by isolating and increasing the sEMG amplitude of the peroneus longus during functional tasks.[20,21] However, we found that after 4 weeks of rehabilitation, neither group increased sEMG amplitudes during the balance measures, which shows that the devices were incapable of causing lasting changes in muscle activation after the device was removed. The positive change may have occurred because both the destabilization devices and the unstable surfaces (foam and DynaDisc) used in the no-device group were incorporated into functional tasks, such as lunging, step-ups, and hopping, which made it possible to challenge individual patients in both groups throughout the entire protocol. At this time, we cannot conclude that ankle-destabilization devices should not be included in rehabilitation for patients with CAI because we did not measure long-term outcomes and do not know whether the groups acted similarly over time. However, traditional unstable surfaces cost less than $100, and a pair of ankle-destabilization boots costs approximately $475.

When both groups were combined, we observed substantial improvements in patient-oriented outcomes as measured by valid self-reported ankle-function questionnaires. Using the PCL model, the exact mechanism that caused the large improvements in self-reported ankle function remains unclear because we did not include groups of patients who completed only 1 domain from the rehabilitation paradigm of Donovan and Hertel.[18] However, it does appear to be related to improvements in ankle strength and motor-unit recruitment of the anterior tibialis, peroneus brevis, and peroneus longus during isometric strength testing because we found the greatest clinically oriented and laboratory-oriented improvements in these measures.

In addition to presenting how ankle function changed after the intervention, we discuss how the patients progressed through the program and some of the limitations associated with the design of the programs. Given that the program was considered an impairment-based progressive rehabilitation program, each patient who completed it may have progressed differently through each exercise. In theory, patients from either group may not have progressed enough during the balance or functional exercises to use any instability tool. However, we found that each patient advanced enough to use an instability tool, but no patients reached the final progression of all exercises, showing that they were challenged throughout the entire program. In addition, we observed that the starting point of each exercise was different, but most patients did not start using an instability tool until their second week of rehabilitation. As mentioned, we relied on the clinical expertise of the certified athletic trainer who conducted the rehabilitation sessions to determine the best starting point for each exercise for each patient on the basis of the initial evaluation. Whereas this allowed each patient, regardless of group assignment, to have a unique rehabilitation experience, we believe that it best replicated the rehabilitation progression seen in a clinic environment and greatly improved the external validity of this study. Finally, we designed the program so that each group had the same number of phases for each exercise. Overall, we were able to match the number of phases for each functional and balance exercise between groups. However, for the figure-of-8 dot-jumping and walking exercises, we were not able to match each phase of the exercises between groups and provided the device group with an additional opportunity to increase the difficulty of these exercises. Although we knew that the foam pad or DynaDisc could not be incorporated, we included these exercises because the ability to wear the destabilization devices during the exercises was unique.

A limitation of this study was the lack of long-term follow-up of patients. Therefore, we do not know how long the changes in ankle function remained above 85% on the FAAM-Sports scale. In addition, we do not know the effects an impairment-based progressive rehabilitation program had on the prevention of recurrent ankle sprains. We hypothesize that these individuals will have a decrease in bouts of instability because balance training has been shown to decrease the prevalence of ankle sprains.[48] Furthermore, each rehabilitation session lasted approximately 1 hour and was completed 3 times each week, which is consistent with clinic-based rehabilitation but may not be appropriate for the traditional athletic training environment. Therefore, researchers should continue to determine the most important components or exercises of this rehabilitation program so clinicians can maximize the use of time and improvements in function for patients. The 4 domains of Donovan and Hertel's[18] rehabilitation paradigm should be compared with one another and in combinations to determine the most important aspects of rehabilitation for patients with CAI. Finally, 1 patient had a recurrent sprain while using the devices during a hopping task, showing that an inherent risk of reinjury remains for patients with CAI when completing functional exercises. This person was not included in any of the baseline measures or the analysis.

CONCLUSIONS

Incorporating destabilization devices in an impairment-based progressive rehabilitation program did not improve clinical measures of self-reported function, ROM, strength, or balance more than incorporating traditional unstable surfaces. In addition, a 4-week impairment-based progressive rehabilitation program substantially improved patient-oriented outcomes as measured by self-reported function questionnaires. The exact mechanism for the patient-oriented improvements is still relatively unclear but appears to be related to improvements in ankle strength and motor-unit recruitment of lower limb musculature during strength testing. Therefore, we recommend that clinicians use an impairment-based progressive rehabilitation model when treating patients with CAI and that researchers continue to use the PCL model to assist in identifying mechanisms that improve patient-oriented and clinically oriented outcomes.

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Appendix. Rehabilitation Protocol for the No-Device and Device Groups

All domains of exercises had target times for completion. The clinician (C.C.H.) used a stopwatch to ensure that all the time spent on each exercise was within the provided time frame and his best clinical judgment to ensure that all participants used the same amount of time for each domain. We documented exercise data for all participants (Appendix Table). No differences in rehabilitation sessions were observed between groups.

Range-of-Motion Exercises

If participants had arthrokinematic joint restriction at the talocrural, distal tibiofibular, proximal tibiofibular, or calcaneocuboid joints and had no contraindications to joint mobilizations, they received 2 sets of 2-minute grade III joint mobilizations as described by Hoch et al,[26] which has been shown to increase range of motion (ROM). Their arthrokinematics were assessed before each session and were treated according to clinical indication. In addition to joint mobilizations, participants completed seated towel stretches and standing stretches with the knee straight and bent. Range-of-motion exercises were performed for a total of 5 to 10 minutes per session. Eight participants from the no-device group and 6 participants from the device group received joint mobilizations.

Strength Exercises

Strength exercises consisted of double-legged heel raises, double-legged forefoot raises, 4-way manual ankle resistance, D1 and D2 proprioceptive neuromuscular facilitation patterns, 4-way walks, and short foot exercises (SFEs). When participants completed 3 sets of 10 double-legged heel and forefoot raises, they progressed to single-legged stance heel and forefoot raises. Participants completed 3 sets of 10 repetitions of the 4-way manual ankle resistance and the D1 and D2 proprioceptive neuromuscular facilitation patterns. The clinician increased resistance if the participant or the clinician did not believe the exercise was challenging. The clinician increased resistance on the basis of best clinical judgment to ensure that all repetitions were challenging to the patients. For the 4-way walks, participants walked on their heels, toes, medial aspect of the foot, and lateral aspect of the foot for 10 m. When they completed 10 m with ease in a position, they increased the distance by 10 m in that position. The SFEs were designed to target the intrinsic muscles of the foot. During the SFEs, patients were seated with the foot flat on the floor and were instructed in lay terms to pull the head of the first metatarsal to the calcaneus. Strength exercises were performed for 10 to 15 minutes per session.

Balance Exercises

Our balance exercises followed a similar protocol to that of McKeon et al[10] because they reported improved self-reported function and postural control in patients with chronic ankle instability. Furthermore, balance exercises were divided into static and dynamic. During a given rehabilitation session, patients completed 1 phase of each category of exercise. They were progressed to the next phase at the next rehabilitation session if they successfully completed the progression criteria. The categories of exercises for balance were eyes-open static, eyes-closed static, reaching tasks, hop to stabilization without instability tools, and hop to stabilization with instability tools. The starting phase of each exercise was determined by clinician judgment stemming from the initial evaluation.

Appendix Table. Form Used to Document Exercise Data for Participants[a]

Range of Motion

Arthrokinematic restriction present? If yes, list joints:

Joint Mobilization Type/Grade	Sets	Duration (minutes)

Stretching exercises

Stretch Position	Sets	Duration (seconds)
Seated Straight Knee		
Seated Bent Knee		
Standing Straight Knee		
Standing Bent Knee		

Strength

Exercise (circle appropriate)	Sets	Repetitions
Double legged/Single legged heel raises		
Double legged/Single legged forefoot raises		
4-way manual resistance		
D1/D2 PNF		
4-way walks		
Short Foot Exercise		

Appendix Table. Continued From Previous Page

Balance

Category: Eyes Open Static Balance (circle appropriate phase) Goal 3×30 seconds	Sets	Duration (seconds)
Phase 1. Eyes Open Single leg balance		
Phase 2. Eyes Open Single leg balance on a (foam or ankle destabilization sandal)		
Phase 3. Eyes Open Single leg balance on (DynaDisc or ankle destabilization boot)[b]		

Category: Eyes Closed Static Balance		
Phase 1. Eyes Closed Single leg balance		
Phase 2. Eyes Closed Single leg balance on a (foam or ankle destabilization sandal)		
Phase 3. Eyes Closed Single leg balance on (DynaDisc or ankle destabilization boot)		

Category: Reach Tasks (circle appropriate phase) Goal 2×10 each direction	Sets	Repetitions
Phase 1. Completing the exercise standing on a firm surface		
Phase 2. Completing the exercise on (foam or ankle destabilization sandal)		
Phase 3. Completing the exercise standing on (DynaDisc or ankle destabilization boot)		

Category: Hop to stabilization no instability tool. Goal is 10 consecutive trials	Direction of Hops	Repetitions Completed
Phase 1. 18 inch hop with arm assistance		
Phase 2. 18 inch hop with hands on hips		
Phase 3. 27 inch hop with arm assistance		
Phase 4. 27 inch hop with hands on hips		
Phase 5. 36 inch hop with arm assistance		
Phase 6. 36 inch hop with hands on hips		

Category: Hop to stabilization with instability tool (foam or ankle destabilization boot)
Phase 1. 18 inch hop with arm assistance while jumping on to a (foam or ankle destabilization boot)
Phase 2. 18 inch hop with hands on hips while jumping onto a (foam or ankle destabilization boot)
Phase 3. 27 inch hop with arm assistance while jumping onto a (foam or ankle destabilization boot)
Phase 4. 27 inch hop with hands on hips while jumping onto a (foam or ankle destabilization boot)
Phase 5. 36 inch hop with arm assistance while jumping onto a (foam or ankle destabilization boot)
Phase 6. 36 inch hop with hands on hips while jumping onto (foam or ankle destabilization boot)

Functional Exercises

Category: Lunges (circle appropriate phase) Goal is 2×10 each leg	Sets	Repetitions
Phase 1. Complete lunges on a firm surface		
Phase 2. Complete lunges with (foam or wearing ankle destabilization sandal) beneath stance leg and lunge on top another (foam or wearing ankle destabilization sandal)		
Phase 3. Complete lunges with (DynaDisc or wearing ankle destabilization boot) beneath the stance leg and lunge on top another (DynaDisc or wearing ankle destabilization boot)		

Category: Forward Step-ups and Step-downs (circle appropriate phase) Goals is 3×10	Sets	Repetitions
Phase 1. Step on and off a box		
Phase 2. Step on and off a box (foam or ankle destabilization sandal) on top and beneath it		
Phase 3. Step on and off a box (DynaDisc or ankle destabilization boot) on top and beneath		

Category: Lateral Step-ups and Step-downs (circle appropriate phase) Goal is 3×10	Sets	Repetitions
Phase 1. Step on and off a box		
Phase 2. Step on and off a box (foam or ankle destabilization sandal) on top and beneath it		
Phase 3. Step on and off a box (DynaDisc or ankle destabilization boot) on top and beneath it		

Category: Dot Jumping Drill (circle appropriate phase) Goal is 3×30 seconds	Sets	Duration (seconds)
Phase 1. Double legged lateral to medial hops, double legged anterior to posterior jumps, double legged figure 8 jumps (shod or ankle destabilization boot)		
Phase 2. Single legged lateral to medial jumps, single legged anterior to posterior jumps, and single legged figure 8 jumps (shod or ankle destabilization boot)		

Appendix Table. Continued From Previous Page

Walking (Condition)	Time	Speed

Abbreviation: PNF, proprioceptive neuromuscular facilitation.

[a] Form is reproduced in its original format.

[b] Exertools Inc, Petaluma, CA.

Static. The static-balance exercises for the no-device and device groups consisted of 6 phases of single-legged balance exercises. Participants progressed to the next phase after they successfully completed 3 sets of 30 seconds each.

Reaching Tasks. Participants stood on 1 limb and reached with the contralateral limb as far as they could in a total of 8 directions that were in all planes of motion. The reaching task for both groups had 3 phases. Participants completed 2 sets of 10 reaches in random directions in each condition. When they completed 2 sets of 10 reaches, they progressed to the next phase.

Hop to Stabilization. The hop-to-stabilization exercises used the same protocol that McKeon et al[10] used. Participants performed 10 hops in each of 4 directions: medial to lateral, anterior to posterior, anteromedial to posterolateral, and anterolateral to posteromedial. Each repetition consisted of a hop from the starting position to the target position and back to the starting position. Given that some people may have been unable to hop the full 36 in (91.44 cm) on a firm surface, we divided the hop-to-stabilization exercises into 2 categories: hop to stabilization with no instability tools and hop to stabilization with instability tools. This exercise had 6 phases for each category. Some directions were more challenging than others, so we progressed each direction independently but used the same 6 phases. The Myolux II (Cevres Santé, Le Bourget-du-Lac, France) device was not included in this progression because it is not designed to withstand the forces of such exercises. Participants progressed to the next level after they completed 10 error-free hops. Balance exercises were completed in 15 minutes.

Functional Exercises

Participants progressed through lunges, step-ups and step-downs, forward running, dot-drill jumps and cutting, and gait-training exercises. Similar to the balance exercise, participants completed 1 phase per session from each category. Each exercise was progressed independently.

Lunges. Participants in both groups performed lunges with their hands on their hips, lunging forward to a 90°/90° position, touching the knee to the ground, and returning to the starting position. Lunges were completed on both limbs. Participants in both groups completed 3 phases of lunges. They progressed to the next phase after they completed 2 sets of 10 error-free lunges. Participants committed errors if they took their hands off their hips, lost balance during descent and ascent, were unable to reach the 90°/90° position, or excessively altered the trunk lean during any phase of the lunge.

Step-Ups and Step-Downs. For both groups, this exercise required the participants to step onto a 30-cm–high box with the injured limb and then step off the box onto the injured limb. They stepped forward onto and off the box and stepped laterally onto and off the box. Both groups completed 3 phases in each direction, with each phase progressed independently of the other phases.

Dot-Drill Jumps and Cutting. The dots were separated by 24 in (60.96 cm). Participants were instructed to jump from dot to dot as fast as they could while remaining comfortable.

The no-device group completed 2 phases. Phase 1 consisted of double-legged lateral-to-medial hops, double-legged anterior-to-posterior jumps, and double-legged figure-of-8 randomized jumps. Phase 2 comprised single-legged lateral-to-medial jumps, single-legged anterior-to-posterior jumps, and single-legged figure-of-8 randomized jumps. For the figure-of-8 randomized jumps, the athletic trainer told participants which dot to jump to before each trial so that each task was unique. Participants in this group progressed from phase 1 to phase 2 after completing three 30-second sets of phase 1 in each direction. When they reached the single-legged jump phase, they progressed the duration by 15 seconds after completing 3 successful trials at the previous duration.

The device group completed 4 phases. Phase 1 comprised double-legged lateral-to-medial hops, double-legged anterior-to-posterior jumps, and double-legged figure-of-8 randomized jumps. Phase 2 included double-legged lateral-to-medial hops, double-legged anterior-to-posterior jumps, and double-legged figure-of-8 randomized jumps while wearing the Myolux Athletik (Cevres Santé) devices. Phase 3 comprised single-legged lateral-to-medial jumps, single-legged anterior-to-posterior jumps, and single-legged figure-of-8 randomized jumps. Phase 4 consisted of single-legged lateral-to-medial jumps, single-legged anterior-to-posterior jumps, and single-legged figure-of-8 randomized jumps while wearing the Myolux Athletik devices. Participants in this group progressed from phases 1 to 2, phases 2 to 3, and phases 3 to 4 after they completed three 30-second sets in each phase. When they reached the single-legged jump with the Myolux Athletik device, they progressed the duration by 15 seconds after completing 3 successful trials at the previous duration.

Treadmill Walking. Each group walked on a treadmill (Gait Trainer 3; Biodex Medical Systems, Inc, Shirley, NY) starting at 5 minutes and progressing to 15 minutes over the first 6 sessions. Both groups continued to complete 15 minutes of treadmill walking for the remaining 6 sessions. The no-device group was instructed to walk at their preferred walking speeds. The device group completed the treadmill walking while wearing the devices. Functional exercises were completed in 15 to 30 minutes.

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Address correspondence to Luke Donovan, PhD, ATC, Department of Kinesiology, University of Toledo, 2801 West Bancroft Street, HHS-2505A Mail Stop 119, Toledo, OH 43606. Address e-mail to luke.donovan@utoledo.edu.