

Two 4-Week Balance-Training Programs for Chronic Ankle Instability

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Context: Traditional single-limb balance (SLB) and progressive dynamic balance-training programs for those with chronic ankle instability (CAI) have been evaluated in the literature. However, which training program may be more beneficial is not known.

Objective: To investigate the effects of a progressive hop-to-stabilization balance (PHSB) program compared with an SLB program on self-reported function, dynamic postural control, and joint position sense (JPS) where angle and direction were self-reported by participants with CAI.

Design: Randomized controlled clinical trial.

Setting: A single testing location in a mid-Atlantic state.

Patients or Other Participants: A total of 18 participants (age = 18.38 ± 1.81 years; height = 175.26 ± 6.64 cm; mass = 75.79 ± 12.1 kg) with CAI.

Intervention(s): Participants were randomly assigned to the PHSB or SLB program. The PHSB and SLB groups pursued their 4-week programs 3 times a week. The PHSB group performed a battery of single-limb hop-to-stabilization exercises, while the SLB group performed a series of SLB exercises.

Exercises were advanced throughout the 4 weeks for both groups.

Main Outcomes Measure(s): Pretest and posttest measurements were the Foot and Ankle Ability Measure (FAAM)-Activities of Daily Living subscale; FAAM-Sports subscale; Star Excursion Balance Test in the anterior, posteromedial, and posterolateral directions; and weight-bearing JPS blocks (dorsiflexion, plantar flexion, inversion, eversion).

Results: A significant main effect of time was present for the FAAM-Activities of Daily Living, FAAM-Sports, Star Excursion Balance Test (anterior, posteromedial, and posterolateral directions), and JPS (dorsiflexion, plantar flexion, inversion), as posttest results improved for the PHSB and SLB groups. The main effect of group was significant only for the FAAM-Sports, with the SLB group improving more than the PHSB group.

Conclusions: Either a 4-week PHSB or SLB can be used in athletes with CAI, as both programs resulted in similar gains.

Key Words: dynamic balance training, joint position sense, postural stability

Key Points

- Both the progressive hop-to-stabilization balance (PHSB) and single-limb balance (SLB) programs improved self-reported function, dynamic postural control, and joint position sense in those with chronic ankle instability.
- Exercises in the 4-week PHSB and SLB programs were effective in improving dynamic postural control and joint position sense.
- Although the PHSB and SLB programs resulted in equal improvements, which type of balance training has the greatest effect on improving postural control and function is unknown.

Lateral ankle sprains (LASs) are among the most common injuries in athletes and physically active individuals.^{1–3} The reported injury rates for LASs are between 75% and 85% of all ankle injuries.⁴ It is estimated that every day in the United States, more than 25 000 ankle sprains occur, leading to time loss related to symptoms associated with LASs.⁵ Once an initial ankle sprain occurs, the individual may be predisposed to future ankle sprains.^{6,7} Sensorimotor impairment is frequent after LASs. Chronic ankle instability (CAI) may be a consequence of neuromotor impairment resulting from an LAS, and functional ankle instability may become evident. After the initial sprain, the patient may experience the subjective feeling of the ankle giving way and instances of instability.^{5,8–12}

Postural control is important and required for sports participation and performance¹³ and is degraded in CAI. Researchers^{10,12,14} have linked deficits in neuromuscular control, proprioception, strength, and postural control with

recurrent LASs. Postural-control deficits are a consequence of impaired proprioception and neuromotor control, which are commonly found in those with CAI.^{15–18} Injury to muscles and peripheral neural structures, central neural inhibition and sensory reorganization, and neuromotor impairment that may occur from LAS and CAI impair postural control and balance. Various balance-training programs improved postural control in those with CAI,^{10,19,20} but which type is superior in improving postural control and function is unknown.

Proprioception is a somatosensory afferent that comprises kinesthesia and joint position sense (JPS). Joint position sense results from afferent input to the central nervous system and is determined by muscle spindles, cutaneous receptors, capsular and articular receptors, and ligamentous receptors in response to stimuli.^{8,12,16,21,22} *Joint position sense* is the ability to determine the active or passive position of a limb, including prediction and replication of a joint angle.^{8,12,16,21,22} Numerous authors have measured JPS

Table 1. Participant Baseline Demographics (N = 18; Mean ± SD)

| Variable | Single-Limb Balance | Progressive Hop-to-Stabilization Balance |
|---|---------------------|--|
| Age, y | 18.44 ± 1.87 | 18.33 ± 1.87 |
| Height, cm | 172.50 ± 7.43 | 178.02 ± 4.6 |
| Mass, kg ^a | 69.70 ± 10.18 | 81.89 ± 11.19 |
| No. of ankle sprains | 2.00 ± 0.0 | 2.00 ± 0.0 |
| No. of <i>yes</i> responses in Ankle Instability Instrument | 7.00 ± 0.0 | 7.00 ± 0.0 |
| Baseline Foot and Ankle Ability Measure scores | | |
| Activities of Daily Living (range, 0–84) | 70.88 ± 2.57 | 70.33 ± 4.44 |
| Sports (range, 0–37) ^b | 24.22 ± 1.85 | 21.00 ± 2.69 |

^a Indicates a difference between groups, $P = .028$.

^b Indicates a difference between groups, $P = .009$.

using a dynamometer,¹⁶ a custom-designed JPS device,²² or the standing weight-bearing, sloped-surface block method.^{23,24} Previous investigators^{16,18,19} hypothesized that CAI was associated with disruptions of the mechanoreceptors within the articular surfaces, cutaneous receptors, lateral ankle ligaments, and joint capsules of the talocrural and subtalar joints. Joint position sense is thought to decrease when these receptors are damaged by injury.^{13,22,23} The reduction in JPS is partially due to damaged mechanoreceptors sending corrupted signals.¹¹ Thus, upon loading, foot biomechanics may be altered, leading to the joint's inability to adapt to changes in surface, thereby predisposing the body to become more unstable and resulting in incorrect foot placement.^{24,25}

To address the movement and landing deficits associated with CAI, rehabilitation protocols are constantly evolving. According to McKeon and Hertel,⁹ mixed results in the literature did not definitively support the conclusion that balance and coordination training increased dynamic postural control in individuals with CAI. Specifically, it was unclear which component of the rehabilitation program contributed the most to the improvements in dynamic postural control and JPS.²⁰ However, despite being controversial at times, 4 weeks of traditional²⁰ or dynamic¹⁰ balance training was beneficial in improving self-reported function, dynamic postural control, and static postural control in physically active and recreational athletes. Currently, 2 clinically based 4-week programs evaluated in the literature have shown improvement in function and static and dynamic balance. One was a traditional program that included functional tasks and single-limb balance (SLB) activities,²⁰ and the other was a progressive dynamic balance-training program¹⁰ designed to challenge landing and movement deficits noted with CAI. Both programs have been used in research studies and in the clinical setting, but they have not been evaluated together.

To further CAI research, it is important to understand the differences in and benefits of dynamic-stabilization balance training compared with a traditional rehabilitation program. Although different types of balance training have been used to rehabilitate athletes with CAI, it is unclear if one type is superior in improving function, postural control, and JPS. Further, whether the components included in the 2 programs compared here will also benefit JPS in the same way as postural control is unknown.^{10,12,14,19} Therefore, the aim of our study was to compare the effects of a progressive

hop-to-stabilization balance (PHSB) program with an SLB program on self-reported function, dynamic postural control, and JPS when angle and direction were self-reported by participants who experienced CAI.

METHODS

This study was a single-blinded randomized clinical trial to compare 4 weeks of 2 supervised balance-training programs on measures of self-reported function, dynamic balance, and JPS. Individuals with CAI were randomly assigned to 1 of 2 groups: the PHSB or the SLB program. The independent variables were group and time (pretest, posttest). Assessment of both groups before and after the 4-week intervention period consisted of the Foot and Ankle Ability Measure (FAAM) Activities of Daily Living (ADL) subscale, FAAM-Sports subscale, Star Excursion Balance Test (SEBT; anterior [A], posteromedial [PM], and posterolateral [PL] directions), and ankle JPS (dorsiflexion [DF], plantar flexion [PF], inversion [INV], and eversion [EV]).

Participants

Eighteen participants (2 females, 16 males; age = 18.38 ± 1.81 years; height = 175.26 ± 6.64 cm; mass = 75.79 ± 12.1 kg) started and completed the study over a 6-month period. Fourteen of the participants were in high school, while 4 were in college. All participants were scholastic or recreational athletes. We used a random-number generator by an outside assessor to randomly place participants into the PHSB ($n = 9$) or the SLB ($n = 9$) group. A flow diagram based on the CONSORT statement shows the inclusion and exclusion of participants throughout the study (Figure 1). The inclusion criteria were a history of at least 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 as noted by the Ankle Instability Instrument²⁶ (answer of *yes* to at least 5 *yes-or-no* questions) and a feeling of “giving way” (at least 2 episodes in the 6 months before the study).²⁷ Participants were excluded if they had sustained a lower extremity injury, including an ankle sprain, within the 6 weeks before the study or had a history of lower extremity surgery involving the ankle or disorders known to affect balance.²⁷ Participant demographics are presented in Table 1; the groups did not differ except in weight and FAAM-Sports score. The Office of Research Compliance at the university approved the study, and participants volunteered and provided consent under this approval.

Procedures

Eligible participants completed the pretest FAAM-ADL and FAAM-Sports questionnaires, the SEBT, and the weight-bearing JPS blocks. After the last exercise session, posttest measurements were completed within the week (average = 3 days). The posttest was performed to the same specifications as the pretest. Participants received an intervention according to their group allocation. Only the primary researcher was blinded to treatment allocation. Participants met with the researcher 3 times a week over a 4-week period for approximately 30 minutes per session to perform the PHSB or SLB program. The injured ankle was

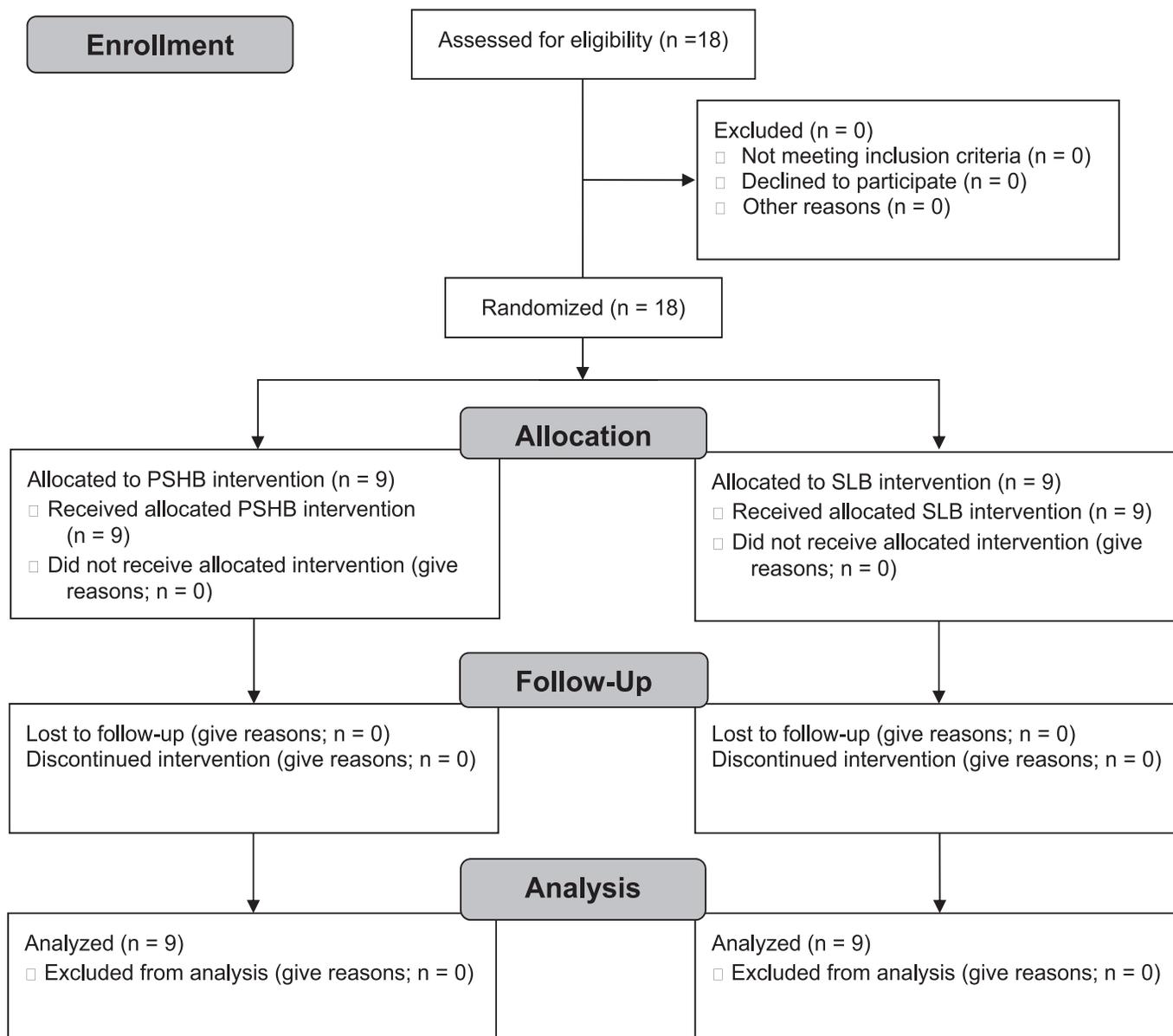


Figure 1. CONSORT flow diagram.

used for the training sessions. If a participant reported bilateral ankle instability, the self-reported worse limb was used for training and analysis. All exercises were performed at a single testing location for environmental control. One researcher administered and supervised all testing and exercising sessions for the primary outcomes of FAAM-ADL, FAAM-Sports, JPS blocks, and SEBT. This researcher was not blinded to the treatment allocation.

Disability Questionnaires: FAAM-ADL and FAAM-Sports

The participants completed the FAAM-ADL and FAAM-Sports as previously described.^{28–30} The FAAM scores were based on grading criteria established for the instrument.^{28,29} The FAAM-ADL and FAAM-Sports are reliable and valid responsive measures of self-reported physical function in healthy participants and are able to detect deficits associated with CAI.^{28,29} The minimally clinically impor-

tant differences that patients perceived for the FAAM-ADL and FAAM-Sports subscales were 8% and 9%, respectively.²⁸

Dynamic Balance

The SEBT was used to evaluate dynamic balance in 3 directions: A, PM, and PL. Extensive descriptions of test administration have been provided by previous authors.^{10,31–33} Individuals performed 3 trials in each direction. The directional order was determined by participants randomly drawing 3 index cards. Each person began with the involved leg in the center of the grid. Each reach distance was measured from a mark on the tape as the distance from the center of the grid to the point of maximum excursion of the reach leg. The trial was discarded and repeated if the researcher felt the participant was using the reach leg for a substantial amount of support at any time, the stance foot did not remain completely on



Figure 2. Slope surface board and angle wedges.

the ground, or the participant was unable to maintain balance on the support leg throughout the trial. The participant's true leg length was measured in accordance with previously established methods so that we could calculate normalized reach distances.^{10,31–33} The normalized mean of 3 trials for each direction was used for analysis. The SEBT has been reported to have high reliability and validity in detecting reach deficits between athletes with CAI and healthy athletes.^{33–35}

Joint Position Sense Blocks

Joint position sense in the involved leg was determined using the weight-bearing, sloped-surface block method (Figure 2).²⁴ A custom-built device consisted of 2 sloped-surface boards 30 cm (length) × 30 cm (width) × 1.5 cm (height) connected by a hinge to allow block placement and a set of blocks with sloped surfaces at angles between 0° and 25° in increments of 2.5°. A total of 11 angles were used for PF, DF, and INV, and 5 angles were used for EV.²⁴ Of 36 total trials, 21 were in the sagittal plane and 15 in the frontal plane; 10 were for PF, 10 for DF, 10 for INV, 5 for EV, and 1 for neutral (0°), with 1 measure in each plane.

Following the testing protocol described by Sekizawa et al,²⁴ participants were provided reference angles of 0°, 12.5°, and 25° for PF, DF, and INV as well as 5° and 10° for EV. These reference angles were given again at the halfway point of each trial. Trials were performed for PF and DF first, followed by INV and EV, using a randomized order of angles. Each trial used a combination of angle and direction. Direction was determined by positioning the angled surface board to represent the 4 directions. Participants self-reported the angle and direction. Data for JPS were calculated by taking the estimated angle minus the actual slope angle to equal the estimated angle error.²³ All angles in each of the 4 directions were combined to

form a continuum of movement and use the same representation with positive and negative values for the 4 directions as described by Sekizawa et al.²⁴

Interventions

The PHSB Program. We used the 4-week progressive dynamic balance-training program developed by McKeon et al¹⁰ for those with CAI (Table 2). The exercises consisted of single-limb hops to stabilization at 18, 27, and 36 in (46, 69, and 91 cm) in combinations of 4 different directions, hop to stabilization and reach, unanticipated hop to stabilization using a 9-marker grid, and single-limb-stance activities with eyes open and closed and on compromising surfaces. These tasks were designed to challenge the participants' ability to maintain a single-limb stance while landing from a hop under various balance and compromising conditions.¹⁰ Before progression to the next level of difficulty within each of the 4 components, error-free completion of the task had to be demonstrated. The required number of error-free repetitions varied within each of the 4 components. For this intervention, participants did not complete the programs in their entirety. Participants in this group completed single-limb hops to stabilization, hop to stabilization and reach, single-limb activities, and up to level 5 for unanticipated hop to stabilization.

The SLB Program. We used a rehabilitation protocol developed by Hale et al²⁰ for patients with CAI that involved stretching, strengthening, functional tasks, a home exercise program, and the neuromuscular control exercises. For the purpose of this study, only the neuromuscular control component of the rehabilitation program from Hale et al was used; thus, a modified program was followed (Table 3). The exercise components consisted of single-limb stance for 60 seconds with 2 repetitions; single-limb stance with a ball toss; single-leg stance kicking against

Table 2. Progressive Hop-to-Stabilization Balance Program¹⁰

| Exercise | Description | Start | Progression |
|------------------------------------|---|--|---|
| Single-limb hop to stabilization | Start to target at 18 → 27 → 36 in (46 → 69 → 91 cm) Anterior/posterior Medial/lateral Anterolateral/posteromedial Anteromedial/posterolateral | 10 hops/direction at 7 levels of difficulty with 2/distance | When able to perform 10 error-free reps at each level of difficulty |
| Hop to stabilization and reach | Similar to above except: hop → stabilize → reach back to start → hop back to start → reach to target | 5 reps/direction at 7 levels of difficulty with 2/distance | When able to perform 5 error-free reps at each level of difficulty |
| Unanticipated hop to stabilization | Stand in middle of 9-marker grid Sequence of numbers displayed As sequence changes, hop to new target position | Use any combination of hops to target position 7 levels of difficulty based on time (1–3) and compromised surface (4–7) | When error free at each level of difficulty |
| Single-limb stance | Single-limb stance, eyes open Hard floor 60 s → foam pad 30 s → 60 s → 90 s Ball toss on foam 30 s → 60 s → 90 s with 20 throws/time Single-limb stance, eyes closed Arms out 30 s → arms across 30 s → 60 s Arms out foam pad 30 s → arms across foam pad 30 s → 60 s → 90 s | Eyes open/closed at 7 levels of difficulty | When able to perform 3 error-free reps at each level of difficulty |

Abbreviation: reps, repetitions.

resistance in 4 directions, 3 times, with 5 kicks in each direction; and step-downs on a 6-in (15.2-cm) step with the single limb in 4 directions, including 2 sets of 5 repetitions in each direction. Progression was based on the exercise component used and varied with the number of tosses and surfaces, increasing resistance, or the height of the step. An error occurred when the participant touched down with the opposite limb, demonstrated excessive trunk motion ($>30^\circ$ lateral flexion), removed the arms from across the chest during specified activities (components 1, 3, and 4), or braced the nonstance limb against the stance limb. For this intervention, participants did not complete the programs in their entirety. Participants in this group went up to step-down with single-limb stance.

Statistical Analysis

The analysis was conducted using an intent-to-treat approach and included all randomized participants. Descriptive statistics were means and standard deviations. Two 2×2 repeated-measures analyses of variance (ANOVAs; time \times group) were used for the FAAM-ADL and the FAAM-Sports scores. Three 2×2 repeated-measures ANOVAs (time \times group), 1 in each direction, were used for the SEBT measurements. Four 2×2 repeated-measures ANOVAs (time \times group) were used, 1 in each direction, for the JPS blocks. Post hoc tests were conducted if warranted. The α level for all analyses was .05. Effect sizes with bias-corrected Hedges g were calculated to offset the small sample size and to report on

Table 3. Single-Limb Balance Program²⁰

| Exercise | Description | Start | Progression |
|-----------------------------------|---|--|-------------------------------------|
| Single-limb stance | Stand for 60 s for 2 reps | Eyes open → eyes closed → perturbations | Complete exercise set without error |
| Single-limb stance with ball toss | Single-limb stance while tossing a ball and adding a foam pad | 3 times with 10 tosses → adding a foam pad → distance from base of support | Complete exercise set without error |
| Single-limb stance with kicking | Single-limb stance while kicking against resistance in 4 directions | Green surgical tubing → blue → ↑ reps | Complete exercise set without error |
| Step-down with single-limb stance | Standing on 1 limb, step down with other limb in 4 directions | 2 sets/5 reps on 6-in (15.24-cm) step → add foam pad → ↑ height of step to 10 in (25.4 cm) | Complete exercise set without error |

Abbreviation: reps, repetitions.

Table 4. Self-Reported Function Scores and Hedges *g* Group Effect Sizes^a

| Foot and Ankle Ability Measure | Mean ± SD, % | | | | Time | Group | Group × Time | Group Effect Size (95% Confidence Interval) |
|--------------------------------|---------------------|------------|--|------------|-------|-------|--------------|---|
| | Single-Limb Balance | | Progressive Hop to Stabilization Balance | | | | | |
| | Pretest | Posttest | Pretest | Posttest | | | | |
| Activities of Daily Living | 84.3 ± 3.1 | 87.0 ± 2.4 | 83.6 ± 5.2 | 88.8 ± 4.7 | <.001 | .765 | .081 | 0.56 (−0.38, 1.51) ^b |
| Sports | 75.6 ± 5.7 | 82.6 ± 5.1 | 65.5 ± 8.4 | 71.6 ± 9.4 | <.001 | .006 | .683 | −0.13 (−1.05, 0.80) ^c |

^a Time and group reflect main effects with *P* value and group × time reflects interaction with *P* value; group effect calculated from each group's pretest-to-posttest change score divided by each group's pooled standard deviation; effect size = *small* (0.20), *moderate* (0.50), or *large* (0.80).

^b Favors the progressive hop-to-stabilization balance group.

^c Favors the single-limb balance group.

pre-intervention to postintervention group comparisons. Between-groups effect sizes compared each group's pretest-to-posttest change score divided by each group's pooled standard deviation. Hedges *g* was interpreted as *small* = 0.20, *moderate* = 0.50, or *large* = 0.80.³⁶ We used SPSS (version 24; IBM Corp, Armonk, NY) to analyze the data.

RESULTS

All randomized participants completed the entire study as allocated (Figure 1) and none were harmed in the process. Descriptive statistics and effect sizes for the pretest and posttest data (FAAM-ADL, FAAM-Sports, SEBT, and JPS) by group are shown in Tables 3 to 6 and Figure 3. The groups were similar at baseline for all dependent variables except for FAAM-Sports score (*P* = .009).

Patient-Oriented Outcomes

For the FAAM-ADL, no interactions or group main effects were observed. However, for the FAAM-Sports, despite no interaction, the SLB group showed more improvement (SLB posttest = 82.65 ± 5.1 versus PHSB posttest = 71.69 ± 9.4; *P* = .006). A time main effect was noted. After completing the programs, both groups improved from pre-intervention to postintervention for the FAAM-ADL (SLB pretest = 84.3 ± 3.1, posttest = 87.0 ± 2.4; PHSB pretest = 83.6 ± 5.2, posttest = 88.8 ± 4.7; *P* < .001) and FAAM-Sports (SLB pretest = 75.6 ± 5.7, posttest = 82.6 ± 5.1; PHSB pretest = 65.5 ± 8.4, posttest = 71.6 ± 9.4; *P* < .001). Large time effect sizes were present for FAAM-ADL, while for FAAM-Sports, the SLB group demonstrated a large effect size

and the PHSB group, a moderate effect size. Between-groups effect sizes were small to moderate for both patient-oriented outcomes, and all 95% confidence intervals (CIs) crossed zero.

Clinically Oriented Outcomes

Star Excursion Balance Test (SEBT). No interactions or group main effects were evident for any SEBT normalized reach distance in the 3 directions. A significant time main effect for both groups in all 3 reach directions from pre-intervention to postintervention occurred: reach distances increased for the A (SLB pretest = 83.93% ± 5.71%, posttest = 87.93% ± 5.17%; PHSB pretest = 87.43% ± 4.39%, posttest = 92.42% ± 4.50%; *P* < .001), PM (SLB pretest = 95.8% ± 6.71%, posttest = 99.93% ± 6.18%; PHSB pretest = 97.98% ± 4.36%, posttest = 101.14% ± 4.33%; *P* < .001), and PL (SLB pretest = 89.31% ± 5.21%, posttest = 94.38% ± 6.21%; PHSB pretest = 88.96% ± 3.50%, posttest = 93.08% ± 3.80%; *P* < .001) directions. Reach distances increased after both balance-training interventions with large (PL) and moderate to large (A and PM directions) time effect sizes. Between-groups effect sizes were small for all directions of the SEBT, and all 95% CIs crossed zero.

Joint Position Sense. No interactions or group main effects were seen for JPS absolute error in any of the 4 directions, nor was there a time main effect for EV. A time main effect for both groups in 3 directions from pre-intervention to postintervention was noted, as absolute error decreased for DF (SLB pretest = 1.87° ± 0.30°, posttest = 1.58° ± 0.30°; PHSB pretest = 2.22° ± 0.83°, posttest = 1.89° ± 0.68°; *P* < .001), PF (SLB pretest = 2.21° ± 0.95°,

Table 5. Star Excursion Balance Test and Hedges *g* Group Effect Sizes^a

| Star Excursion Balance Test Direction ^b | Normalized Reach Distance (Mean ± SD), % | | | | Time | Group | Group × Time | Group Effect Size (95% Confidence Interval) |
|--|--|--------------|--|---------------|-------|-------|--------------|---|
| | Single-Limb Balance | | Progressive Hop-to-Stabilization Balance | | | | | |
| | Pretest | Posttest | Pretest | Posttest | | | | |
| Anterior | 83.93 ± 5.71 | 87.93 ± 5.17 | 87.43 ± 4.39 | 92.42 ± 4.50 | <.001 | .103 | .204 | 0.20 (−0.72, 1.13) ^b |
| Posteromedial | 95.8 ± 6.71 | 99.93 ± 6.18 | 97.98 ± 4.36 | 101.14 ± 4.33 | <.001 | .519 | .181 | −0.20 (−1.13, 0.73) ^c |
| Posterolateral | 89.31 ± 5.21 | 94.38 ± 6.21 | 88.96 ± 3.50 | 93.08 ± 3.80 | <.001 | .718 | .210 | −0.18 (−1.11, 0.75) ^c |

^a Time and group reflect main effects with *P* value and group × time reflects interaction with *P* value; group effect calculated from each group's pretest-to-posttest change score divided by each group's pooled standard deviation; effect size = *small* (0.20), *moderate* (0.50), or *large* (0.80).

^b Favors the progressive hop-to-stabilization balance group.

^c Favors the single-limb balance group.

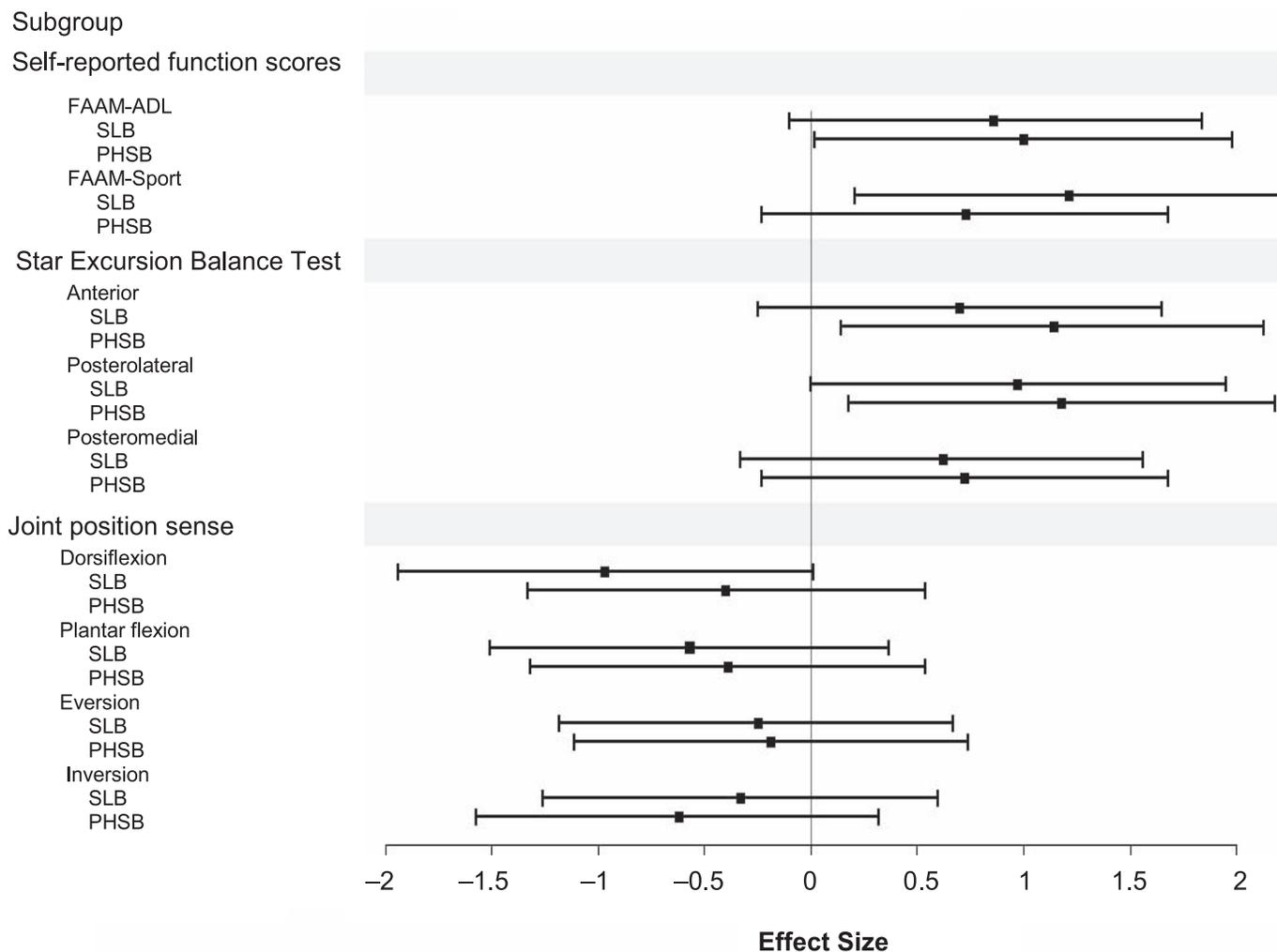


Figure 3. Time effect sizes for single-limb balance (SLB) and progressive hop-to-stabilization (PHSB) groups (95% confidence intervals). Effect size indicates an improvement from pretest to posttest for all dependent variables. Effect size = *small* (0.20), *moderate* (0.50), or *large* (0.80). Abbreviations: ADL, Activities of Daily Living; FAAM, Foot and Ankle Ability Measure.

posttest = $1.67^\circ \pm 0.73^\circ$; PHSB pretest = $1.94^\circ \pm 0.69^\circ$, posttest = $1.67^\circ \pm 0.54^\circ$; $P < .001$), and INV (SLB pretest = $2.20^\circ \pm 0.97^\circ$, posttest = $1.88^\circ \pm 0.68^\circ$; PHSB pretest = $2.05^\circ \pm 0.81^\circ$, posttest = $1.67^\circ \pm 0.32^\circ$; $P < .001$). Each absolute error measurement decreased, indicating improvement, after both balance-training interventions with small to moderate (PF, INV, and EV) and small to large (DF)

time effect sizes. Between-groups effect sizes were small for all directions for JPS, and all 95% CIs crossed zero.

DISCUSSION

After completing either a PHSB or SLB intervention program, individuals with CAI improved in self-reported function (FAAM-ADL and FAAM-Sports), dynamic pos-

Table 6. Joint Position Sense and Hedges *g* Group Effect Sizes^a

| Joint Position Sense | Mean \pm SD, $^\circ$ | | | | Time | Group | Group \times Time | Group Effect Size (95% Confidence Interval) |
|----------------------|-------------------------|-----------------|--|------------------|------|-------|---------------------|---|
| | Single-Limb Balance | | Progressive Hop-to-Stabilization Balance | | | | | |
| | Pretest | Posttest | Pretest | Posttest | | | | |
| Dorsiflexion | 1.87 \pm 0.30 | 1.58 \pm 0.30 | 2.22 \pm 0.83 | 1.89 \pm 0.680 | .002 | .223 | .786 | 0.45 (–0.48, 1.39) ^b |
| Plantar flexion | 2.21 \pm 0.95 | 1.67 \pm 0.73 | 1.94 \pm 0.69 | 1.67 \pm 0.54 | .004 | .696 | .289 | –0.07 (–0.99, 0.86) ^c |
| Inversion | 2.20 \pm 0.97 | 1.88 \pm 0.68 | 2.05 \pm 0.61 | 1.67 \pm 0.32 | .003 | .563 | .784 | –0.07 (–1.0, 0.85) ^c |
| Eversion | 1.60 \pm 0.83 | 1.39 \pm 0.28 | 1.32 \pm 0.38 | 1.25 \pm 0.0 | .269 | .287 | .578 | –0.27 (–0.65 to 1.20) ^c |

^a Time and group reflect main effects with *P* value and group \times time reflects interaction with *P* value; group effect calculated from each group's pretest-to-posttest change score divided by each group's pooled standard deviation; effect size = *small* (0.20), *moderate* (0.50), or *large* (0.80).

^b Favors the progressive hop-to-stabilization balance group.

^c Favors the single-limb balance group.

tural control (SEBT), and JPS when angle and direction were self-reported. This was a superiority study, so our goal was to determine whether the PHSB or the SLB group would improve more than the other on patient-oriented or clinically oriented outcome measures. We observed no difference between groups for patient- or clinically oriented outcomes except on the FAAM-Sports in favor of the SLB group. However, pre-intervention differences between the groups for the FAAM-Sports did not factor into the ability to improve, as the change in neither group reached the minimally clinically important difference. Thus, neither training regimen appeared to enhance patient- or clinically oriented outcomes.

Within a brief treatment period of 4 weeks, the PHSB and SLB groups improved from pre-intervention to postintervention, but neither group performed better than the other statistically. Yet the effect sizes from pretest to posttest were moderate to large for most variables. It appears that participants were trending toward clinically meaningful changes with these interventions, providing clinical relevance. During the 4-week time period, changes were becoming evident for both patient- and clinically oriented outcomes. As this study is the first, to our knowledge, to compare the PHSB designed by McKeon et al¹⁰ with a modified SLB used by Hale et al²⁰ for individuals with CAI, it is difficult to directly compare our results with those of other studies in this area.

The FAAM Questionnaire

Scores on the FAAM-ADL and FAAM-Sports increased from pre-intervention to postintervention based on group membership, but the groups did not differ. Despite the increase in the pre-intervention to post-intervention scores and the moderate to large effect sizes, clinically relevant changes over the course of the 4 weeks were not noted in the 2 groups, as minimally clinically important difference values were not reached with the FAAM-ADL (PHSB = 5%, SLB = 2.6%) or FAAM-Sports (PHSB = 6.1%, SLB = 7%) based on values reported by Martin et al.²⁸ Except for the magnitude of change, these changes were somewhat consistent with the results of other researchers who studied balance training using the FAAM-Sports or the Foot and Ankle Disability Index-Sport. Hale et al²⁰ demonstrated more improvement in the CAI rehabilitation group than the CAI control group for the Foot and Ankle Disability Index-Sport. However, the magnitude of change was greater at 20% improvement compared with the 7% improvement we found. We used a modified Hale et al program (lacking stretching, strengthening, functional tasks, and a home exercise program), so it is plausible to consider including these components, in addition to neuromuscular control, in a traditional rehabilitation program.³⁷ Improvement was consistent with what McKeon et al¹⁰ reported using the dynamic balance-training program, but again, the magnitude of change was greater at 15%. Although the dynamic balance-training program used in the McKeon et al program was identical to ours, the participants were different. We studied high school athletes with CAI, whereas McKeon et al¹⁰ studied recreationally active collegiate participants with perhaps a longer history of

CAI. Also, our participants may not have experienced greater environmental or task constraints related to CAI, which would have left little opportunity for improvement. Even though both interventions lasted 4 weeks, it appeared that the participants were starting to trend toward a clinically meaningful change.

Dynamic Postural Control

Both groups increased their pretest to posttest normalized reach distances in all directions, but neither group increased more than the other. This result is similar to the findings of Hale et al²⁰ and McKeon et al,¹⁰ who reported improvements in SEBT reach distances after a 4-week rehabilitation program for participants with CAI. In the dynamic balance-training group, McKeon et al¹⁰ showed that reach distances improved in the PM and PL directions of the SEBT but not in the A direction. In the Hale et al²⁰ study, participants with CAI improved after a self-designed traditional 4-week rehabilitation program; they displayed greater SEBT reach improvements for the PL, PM, and lateral directions versus the uninvolved limb and healthy participants. Improvements were evident in both training groups: the balance-training programs incorporated single-limb stance, especially the PHSB program with a hop to stabilization and then a reach back to the starting point. This exercise mimics the reach task on the SEBT. To enhance range of motion (ROM) and increase reach distances, further studies are needed. Although not used in this study, grade III joint mobilizations as described by Hoch et al³⁷ have increased ROM and reach distances in the A, PM, and PL directions of the SEBT. We incorporated isolated exercises, whereas a more comprehensive rehabilitation program³⁸ addressing mechanical restrictions, plantar cutaneous deficits, strength, and static postural control³⁹ may both improve reach distances and result in better functional outcomes.

The PHSB group demonstrated greater changes based on the large time effect sizes for the A and PL directions; the SLB group had a large time effect only for the PL direction. McKeon et al¹⁰ found a large group effect for the PM and PL directions and a minimal to small effect in the A direction.^{10,20} Thus, effect sizes may be less informative than the pre-intervention to postintervention improvement in all 3 directions, which ranged from 3.16 to 5.0 in the PHSB group and from 3.99 to 5.07 in the SLB group. These values are fairly consistent with those of other studies^{20,38} after a 4-week rehabilitation program.

Joint Position Sense

Previous authors^{16,18,19} hypothesized that CAI was associated with disrupted mechanoreceptors^{13,22,23} in the articular surfaces, cutaneous surfaces, lateral ankle ligaments, and joint capsules of the talocrural and subtalar joints. Disruption of JPS is partially due to damaged mechanoreceptors sending corrupt signals to the central nervous system.¹¹ This sensorimotor impairment may become evident when the individual bears weight and the efferent responses are received by the muscles. Upon loading, there may be an alteration in foot biomechanics, leading to a lack of adaptability of the joint to change in surface, predisposing the body to become more unstable and leading to incorrect foot landing.²⁴ This may result in

an underestimation or overestimation of foot position on landing.

Deficits in JPS have been noted with aging²³ and in healthy participants.²⁴ When healthy participants with no history of LAS were evaluated for JPS using the weight-bearing, sloped-surface block method, PF and INV were underestimated.²⁴ Thus, because the mechanism of injury for an LAS may involve moments that include PF and INV,⁴⁰ underestimation may be more apparent in a participant with CAI. We observed a decrease in angle error for PF and INV. This is important clinically because the most common positions for the foot and ankle during an LAS are PF and INV.²⁴ With less absolute-angle error underestimation, the positions of the foot and ankle may be more compressed, thereby reducing the risk of injury when moving from an unloaded to a loaded condition upon landing.⁴⁰

Joint position sense has not been evaluated previously using the 2 balance-training programs compared here. Over the course of the 4-week training period, participants became more aware of the differences between the actual angle and the estimated angle. This may be related to the stationary kicking, the hops to stabilization in the sagittal and frontal planes, or the step-downs in 4 directions while in stationary or dynamic single-limb stance. Joint position sense was assessed in a weight-bearing, single-legged stance on the block as the angle and the position of the block changed in randomized order for each trial. This was similar to the single-limb stance maintained during the intervention and perhaps aided in postintervention improvement.

Clinical Implications and Limitations

Both experimental groups improved from pretest to posttest on all patient- and clinically oriented outcomes, which may have more relevance than statistical significance in the clinical setting when considering which rehabilitation program to use. In 4-week programs for participants with CAI, improvements were evident in self-reported ADL and sport function, dynamic postural control, and JPS. Thus, the isolated static and dynamic exercises used in this study should be incorporated into a program when only 1 area of impairment, namely sensorimotor impairment, is present. Combining multiple treatment techniques, as is normally done in the clinical setting, should be the mainstay of rehabilitation for patients with CAI. Therefore, we advocate for other areas of impairment to be addressed, including functional activities, ROM, joint mobilization, strength, gait retraining,³⁸ plantar cutaneous deficits,³⁹ and static postural control.

The primary limitation of our study is that the results cannot be generalized to other participants with CAI due to the sample size. Our sample of convenience consisted of injured, physically active individuals from only 1 high school and 1 university. Scheduling sessions during data collection was challenging due to snow days and poor road conditions, which prevented the participants from keeping some of their appointments. A 1-week delay occurred between pretesting and the start of the 2 programs because of school closures, during which the participants were inactive; when school resumed, the 4-week program proceeded as planned. Adaptations of traditional and

dynamic balance-training programs might vary based on individual factors including previous injury, rehabilitation history, and current fitness level. Although the lengths of the traditional and dynamic balance-training programs were similar to those tested in previous studies, more randomized controlled studies evaluating the 2 programs as well as other multiple treatment techniques for patients with CAI should be conducted.

CONCLUSIONS

Both the SLB and the PHSB groups improved from pretest to posttest on the FAAM-ADL, FAAM-Sports, SEBT, and JPS. In both groups, large to moderate effect sizes for time were evident. Both programs resulted in equally improved outcomes. Therefore, whether SLB or PHSB training has the greatest effect on improving postural control and function is currently unknown.

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