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# The Effect of a 4-Week Comprehensive Rehabilitation Program on Postural Control and Lower Extremity Function in Individuals With Chronic Ankle Instability

**C**hronic ankle instability (CAI) is a common problem in athletes and among active persons. According to Peters et al,<sup>32</sup> following a lateral ankle sprain, 10% to 30% of individuals report persistent symptoms or reinjury. Those with CAI have been reported to have diminished neuromuscular control,<sup>21,34,39,41</sup> muscle weakness,<sup>44</sup> impaired joint position sense,<sup>27,44</sup> subjective reports of pain,<sup>30,45</sup> recurrent ankle sprains,<sup>1</sup> impaired performance during functional tasks,<sup>5,31</sup> and perceived difficulties with activities of daily living (ADLs) and sport-specific skills.<sup>15</sup>

Much of the current literature addresses the pathoetiology of CAI<sup>9,11,17,18,22,</sup>

<sup>24,25,27,33,36,41,44</sup> and it is well established that the pathology is complex and cannot be adequately explained through the dichotomy of mechanical instability and functional instability.<sup>17</sup> Further, CAI is

not merely a result of a single factor such as ligament laxity, muscle weakness, diminished proprioception, or postural control deficits. Rather, CAI has been found to be associated with all of these factors, as well as altered arthrokinematics and joint structure at the talocrural joint when compared to subjects without CAI.<sup>4,24,26,44</sup>

Conservative treatment of CAI is currently accepted as the primary means of managing the condition and preventing reinjury. Improvements related to proprioception and neuromuscular control have been shown following rehabilitation programs.<sup>2,6,8,11,12,35</sup> Improvements in postural control, as measured by a stability index, were also reported by Rozzi et al<sup>35</sup> as well as improvements in self-reported function following 4 weeks of balance training. Freeman et al<sup>11</sup> reported decreases in functional instability and proprioceptive deficits following 5 sessions of tilt board and wobble board training. In addition, Eils and Rosenbaum<sup>8</sup> and Docherty et al<sup>6</sup> demonstrated improved joint position sense following therapeutic exercise.

More importantly, some authors report a reduction in risk of reinjury following rehabilitation.<sup>23,38,42,43</sup> Specifically, Tropp et al<sup>38</sup> reported a decreased incidence of lateral ankle sprain among soccer players with a history of CAI following ankle disk training. Following a balance-training program, Verhagen

● **STUDY DESIGN:** Prospective, randomized controlled trial.

● **OBJECTIVE:** To examine the effects of a 4-week rehabilitation program for chronic ankle instability (CAI) on postural control and lower extremity function.

● **BACKGROUND:** CAI is associated with residual symptoms, performance deficits, and reinjury. Managing CAI is challenging and more evidence is needed to guide effective treatment.

● **METHODS AND MEASURES:** Subjects with unilateral CAI were randomly assigned to the rehabilitation (CAI-rehab, n = 16) or control (CAI-control, n = 13) group. Subjects without CAI were assigned to a healthy group (n = 19). Baseline testing included the (1) center of pressure velocity (COPV), (2) star excursion balance test (SEBT), and (3) Foot and Ankle Disability Index (FADI) and FADI-Sports Subscale (FADI-Sport). The CAI-rehab group completed 4 weeks of rehabilitation that addressed range of motion, strength, neuromuscular control, and functional tasks. After 4 weeks, all subjects were retested. Nonparametric analyses

for group differences and between-group comparisons were performed.

● **RESULTS:** Subjects with CAI demonstrated deficits in postural control and SEBT reach tasks of the involved limb compared to the uninvolved limb and reported functional deficits of the involved limb compared to healthy subjects. Following rehabilitation, the CAI-rehab group had greater SEBT reach improvements on the involved limb than the other groups and greater improvements in FADI and FADI-Sport scores.

● **CONCLUSIONS:** These results demonstrate postural control and functional limitations exist in individuals with CAI. In addition, rehabilitation appears to improve these functional limitations. Finally, there is evidence to suggest the SEBT may be a good functional measure to monitor change after rehabilitation for CAI. *J Orthop Sports Phys Ther* 2007;37(6):303-311. doi:10.2519/jospt.2007.2322

● **KEY WORDS:** ankle sprain, balance, Foot and Ankle Disability Index, star excursion balance test

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and colleagues<sup>42</sup> also found a reduction in ankle sprain risk among volleyball players with a history of ankle sprains. A reduction in risk was not seen for those players without a history of sprain. Similar findings have been reported following an acute lateral ankle sprain. Reports by Wester et al<sup>43</sup> and Holme et al<sup>23</sup> suggest that rehabilitation following acute lateral ankle sprain may reduce the number of recurrent sprains.

Despite these reports, Handoll et al,<sup>16</sup> in a systematic review, suggest that there is little evidence supporting that balance training reduces the number of ankle sprains in individuals with a history of ankle sprains. They suggest that current evidence is “preliminary...and further evidence is still required prior to widespread application.” The authors of the review also point out some methodological flaws in many studies and rate the quality of previous research as modest. Gerber et al<sup>13</sup> also suggest poor clinical outcomes despite advances in rehabilitation. Six months after the completion of a supervised rehabilitation program for a lateral ankle sprain, 40% of subjects in this study reported residual symptoms and 2.5% demonstrated at least a 20% deficit on a lateral hop test.

The discrepancies in the literature may be partially explained by the results in the study by Gerber et al.<sup>13</sup> They report the factor most predictive of residual symptoms is a syndesmosis sprain. Therefore, those authors who included subjects with a syndesmosis injury in their study may have found less favorable results from rehabilitation. Unfortunately, most reports in the literature do not describe the type or severity of subjects' ankle sprain.<sup>6,12,16,23,38,42,43</sup> Rather, it is often reported as a history of ankle problem or a history of ankle sprain. Others may specify an inversion mechanism but do not necessarily rule out syndesmosis sprains, making it difficult to accurately compare results.<sup>2,8,35</sup> However, it is important to note that 40% of subjects in the Gerber et al<sup>13</sup> study had

residual symptoms following rehabilitation, while only 15% had syndesmosis sprains. Therefore, although syndesmosis sprain is most predictive of residual symptoms, it does appear that residual symptoms following rehabilitation do occur in other individuals as well. Additionally, the outcome measures used in reported studies vary and may contribute to the inconsistent results reported in the literature.

Much of the literature exploring treatment interventions has examined the efficacy of a specific treatment strategy, such as balance training or strengthening, in isolation.<sup>2,8,29</sup> Due to the multifaceted nature of CAI, a more comprehensive treatment approach combining stretching, strengthening, balance training, and functional retraining may be more effective in improving lower extremity function and preventing recurrent injury. In addition, many of the outcome measures used in previous studies are at the impairment level (strength, proprioception, postural control). It is important that we also measure changes in functional limitations and disability. While a few studies have used reinjury rates as outcome measures,<sup>23,38,42,43</sup> there is limited evidence to suggest that global lower extremity function improves after rehabilitation. It is possible that improvements in strength or postural control may not result in improved function or a reduction in reinjury.

The purpose of this study was to examine the efficacy of a 4-week comprehensive rehabilitation program that addressed range of motion, muscle performance, and neuromuscular control. In addition, our outcome measures were selected to identify both impairments (postural control) and functional limitations (Foot and Ankle Disability Index [FADI] and star excursion balance test [SEBT]). It was our hypothesis that our comprehensive rehabilitation program would result in improvements in postural control, SEBT reach distances, and self-reported function.

## METHODS

### Subjects

**F**ORTY-EIGHT (28 FEMALES, 20 MALES; 29 subjects with CAI, 19 healthy subjects) recreationally active individuals from the university community (mean  $\pm$  SD age, 21.4  $\pm$  3.5 years; height, 170.6  $\pm$  11.8 cm; body mass, 73.8  $\pm$  19.5 kg) volunteered to participate in this study (FIGURE). All subjects read and signed an informed consent form approved by the Pennsylvania State University Institutional Review Board prior to participation. Subjects were excluded if they reported any of the following: (1) bilateral ankle instability, (2) history of ankle fracture, (3) ankle injury within 3 months prior to participation, (4) history of anterior cruciate ligament injury, (5) history of balance disorders, or (6) current participation in supervised physical rehabilitation.

Subjects completed a self-report questionnaire that asked about the current symptoms they were experiencing. In the event that a subject's answer was unclear, the primary investigator discussed the response with the subject to obtain a clear understanding of the response. Based on this questionnaire, subjects were classified as having CAI if they reported having all of the following: (1) a history of at least 1 unilateral ankle sprain with pain and/or limping for greater than 1 day, (2) chronic ankle weakness, pain, or instability attributed to the initial injury, and (3) self-reported giving way of the involved ankle in the last 6 months. Those subjects with CAI were then randomly assigned to the control group (CAI-control) (9 females, 4 males; mean  $\pm$  SD age, 22.2  $\pm$  4.6 years) or the rehabilitation group (CAI-rehab) (10 females, 6 males; mean  $\pm$  SD age, 21.0  $\pm$  3.1 years). Subjects without a history of CAI were assigned to the healthy group (healthy) (9 females, 10 males; mean  $\pm$  SD age, 21.1  $\pm$  3.1 years).

### Instrumentation

Postural control was measured using an AMTI Accusway force plate (AMTI, Inc, Watertown, MA) interfaced with Sway-

win software (AMTI, Inc, Watertown, MA). Three-dimensional ground reaction forces were measured at a sampling frequency of 50 Hz. Center of pressure excursion velocities (COPVs) were calculated by the Swaywin software.

### Procedures

All subjects reported to the laboratory the first day to read and sign an informed consent form and to complete a self-report questionnaire designed to identify subjects with CAI. One week later, subjects returned to the laboratory to complete baseline measures, including the COPV, SEBT, FADI, and FADI Sport Subscale (FADI-Sport). At that point, healthy subjects and control subjects with CAI were instructed to continue with their normal activities for 4 weeks then return to the laboratory for follow-up testing. Subjects in the CAI-rehab group began the 4-week rehabilitation program the following

week. The follow-up testing included the same measures that were included in the baseline testing.

To measure COPV, subjects were asked to stand as still as possible in single-limb stance on the force plate for 15 seconds with their arms crossed over their chest. Subjects were instructed to visually focus on a stationary target placed on the wall 1 m in front of them. This task was repeated 3 times on each limb and the average of the 3 trials was recorded. The trials were then repeated with the subjects' eyes closed. In the event that a subject experienced a loss of balance requiring them to step-off the plate, the trial was discarded and repeated.

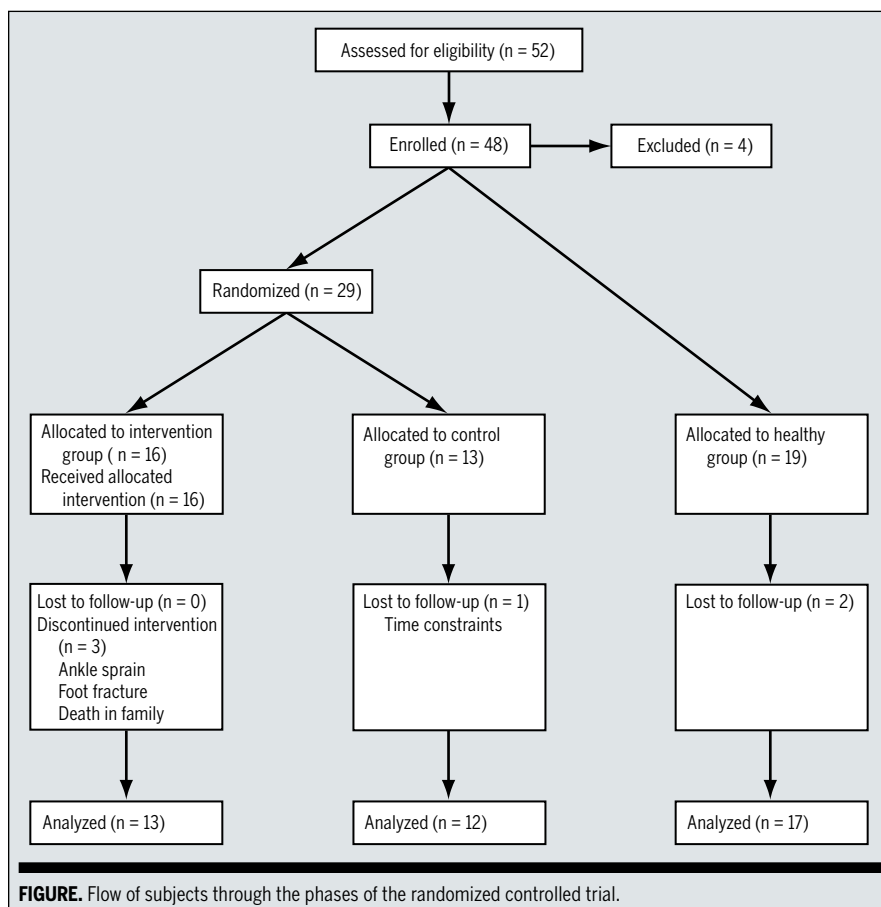
To perform the SEBT, subjects were asked to stand on 1 foot and reach as far as they could in each of 8 different directions with the other foot, touching down lightly on the line, then return to the starting position. Subjects maintained

a single-limb stance until they returned to the starting position. The 8 directions extend out in a circle and each target line is 45° from the adjacent lines. Each direction is completed as a separate trial and reach distance is recorded. As suggested by findings of Hertel et al,<sup>20</sup> 6 practice trials were permitted for each lower extremity to minimize learning effect. Subjects were then allowed to rest and completed 3 measured trials on each lower extremity. The mean reach distance for each lower extremity was normalized to limb length and recorded. Half of the subjects began by performing the test on the involved limb, while the other half of the subjects began by performing the test on the uninvolved limb. The order of reach directions was also counterbalanced by assigning each subject a starting direction and direction of rotation (clockwise or counterclockwise) to avoid order effects from contaminating the data. Trials were discarded and repeated if (1) the hands were removed from the hips, (2) the reaching limb was used for weight bearing, (3) the stance limb was displaced, or (4) there was a loss of balance.

All subjects completed the FADI and FADI-Sport to measure self-report of function. Separate surveys were completed to reflect the function of the right and left ankles. There are 26 items on the FADI and 8 items on the FADI-Sport. Each item is scored from 0 (unable to do) to 4 (no difficulty at all). The 4 pain items of the FADI are scored 0 (unbearable) to 4 (none). The FADI has a total score of 104 points, while the FADI-Sport has a total score of 32 points. The FADI and FADI-Sport are scored separately as percentages, with 100% representing no dysfunction. Both scales have been shown to be reliable over 1 week ( $ICC_{FADI} = 0.85$ ,  $ICC_{FADI-Sport} = 0.84$ ) and 6 weeks ( $ICC_{FADI} = 0.93$ ,  $ICC_{FADI-Sport} = 0.92$ ) when used for subjects with CAI.<sup>15</sup>

### Rehabilitation

The 4-week rehabilitation program consisted of 6 visits to the laboratory. During weeks 1 and 2, subjects reported to the



**FIGURE.** Flow of subjects through the phases of the randomized controlled trial.

# [ RESEARCH REPORT ]

laboratory twice a week. During weeks 3 and 4, subjects reported to the laboratory once each week. Subjects were also given a home exercise program and were instructed to perform the home program 5 times each week. Subjects were given a log to track their compliance. According to the logs, subjects completed the home exercise an average of 3.5 times each week. During the supervised laboratory rehabilitation sessions, subjects participated in flexibility, strength, and balance activities for approximately 30 minutes. The program was progressive and subjects advanced through the various stages (TABLE 1). With the exception of the few bipedal tasks (bipedal calf raise, carioca, and figure of eights), all therapeutic exercise was completed on the involved limb only. Supervised sessions were also used to review and advance the home exer-

cise program as needed to ensure proper technique and to maintain an appropriate level of difficulty.

### Statistical Analysis

Because the data for this study were not normally distributed, Kruskal-Wallis tests were run to identify any group differences in the dependent variables at baseline. In the event of significant Kruskal-Wallis tests, a Mann-Whitney *U* test was conducted to compare means of each dependent variable for all subjects with CAI (pooled data) and those without a history of CAI, as well as each group individually. Wilcoxon signed rank tests were used to identify baseline differences between limbs for the subjects with CAI and the healthy subjects. Mann-Whitney *U* tests were also performed for all dependent variables to compare subjects that did

not complete the study to those that completed the study. Separate Kruskal-Wallis tests and Wilcoxon signed rank tests were run for eyes-open COPV, eyes-closed COPV, the SEBT (mean of all 8 directions and each individual direction), the FADI scale, and the FADI-Sport. For each subject in the healthy group, side-matching to the CAI groups was performed so that 1 limb was assigned as involved and 1 as uninvolved.

To examine the effectiveness of the rehabilitation program, the change scores (posttest score – pretest score) for each dependent variable were analyzed. Kruskal-Wallis tests were completed to look for differences in change scores among the 3 groups. When a significant difference was found for a dependent variable, a Mann-Whitney *U* test was used to identify where the between-group differences occurred.

TABLE 1	OUTLINE OF THE REHABILITATION PROGRAM		
Task	Sets/Reps (Maximum)	Progression	Home Program or Supervised Rehabilitation
Range of motion			
Gastrocnemius stretch	30 s × 3	Seated progress to standing	Both
Soleus stretch	30 s × 3	Seated progress to standing	Both
Strengthening			
Bipedal calf raise	3/15	Single limb	Both
Thera-Band resistance			
Dorsiflexion	3/15	Resistance, reps	Both
Plantar flexion	3/15	Resistance, reps	Both
Inversion	3/15	Resistance, reps	Both
Eversion	3/15	Resistance, reps	Both
Plantar flexion/inversion	3/15	Resistance, reps	Both
Plantar flexion/eversion	3/15	Resistance, reps	Both
Dorsiflexion/inversion	3/15	Resistance, reps	Both
Dorsiflexion/eversion	3/15	Resistance, reps	Both
Neuromuscular control			
Single-limb stance	60 s × 2	Eyes open progress to closed, time, perturbation	Both
Single-limb stance ball toss	3/10	Time, surface, distance from base of support	Supervised rehabilitation
Single-limb stance while kicking against resistance in 4 directions	3/10	Amount of resistance, reps	Both
Step-downs with single limb in 4 directions	2/5	Surface, height	Supervised rehabilitation
Functional tasks			
Box hop/quadrant hop	3/8	Direction, pattern	Supervised rehabilitation
Carioca	1.5 m × 2	Speed	Supervised rehabilitation
Figure of eight	4/1	Distance	Supervised rehabilitation

*Abbreviation: reps, repetitions.*

Intraclass correlation coefficients ( $ICC_{2,1}$ ) were calculated to estimate the long-term intersession reliability for each direction of the SEBT for the subject in the CAI-control group.

The significance level for all analyses was set a priori at  $P < .05$ . The SPSS 14.0 program (SPSS, Inc, Chicago, IL) was used to calculate statistics and Confidence Interval Analysis, Version 2.1.1 (University of Southampton, Southampton, UK) was used to calculate confidence intervals.

## RESULTS

**D**ATA WERE ANALYZED FOR 42 SUBJECTS. Six subjects did not complete the study. Of those 6 subjects, 3 were in the CAI-rehab group, 1 was in the CAI-control group, and 2 were in the healthy group. None of the subjects withdrew from the study secondary to an adverse response to the testing or rehabilitation protocols. When comparing these subjects to those that completed the study, they were not statistically different in terms of age, height, body mass, leg length, or baseline performances on the dependent variables ( $P > .05$ ).

### Center of Pressure Velocity

At baseline, no statistically significant differences were detected in COPV between subjects with CAI and those without CAI, when standing on the involved limb or the uninvolved limb with the eyes open or closed. There were also no significant differences between the CAI-rehab and CAI-control groups at baseline. Subjects with CAI did, however, demonstrate greater COPV under the eyes-closed ( $P = .034$ ) and eyes-open ( $P = .029$ ) conditions when standing on the involved limb as compared to the uninvolved limb. No side-to-side differences were detected within the healthy group. Means and standard deviations for all baseline scores are presented in **TABLE 2**.

There were also no significant between-group differences in change scores for COPV with the eyes open or closed for

either limb. Means and 95% confidence limits of all change scores are reported in **TABLE 3**.

### Star Excursion Balance Test

The reach measurement for each direction of the SEBT was found to be reliable over the 4-week period for the CAI-control group. ICC values ranged from 0.80 to 0.93.

At baseline, no statistically significant differences were found in reach distances when comparing subjects with and without CAI, standing on the uninvolved limb or the involved limb. There were also no

significant differences between the CAI-rehab and CAI-control groups at baseline. Significant differences were found between the involved and uninvolved limbs for the subjects with CAI. Subjects with CAI reached further while standing on the uninvolved limb in the posteromedial ( $P = .047$ ), posterolateral ( $P = .007$ ), and lateral ( $P = .025$ ) directions when compared to the involved limb. No side-to-side differences in reach distance were noted in the healthy group ( $P = .171, .658$ ). Means and standard deviations for all baseline scores are presented in **TABLE 2**.

When examining performance on the

TABLE 2		DATA AT BASELINE FOR THE SEBT, THE COPV, AND THE FADI*		
Measure	Side	CAI-Rehab (n = 16)	CAI-Control (n = 13)	Healthy (n = 19)
SEBT anterior reach	Involved	0.71 ± 0.08	0.69 ± 0.12	0.71 ± 0.10
	Uninvolved	0.73 ± 0.06	0.71 ± 0.11	0.71 ± 0.08
SEBT anteromedial reach	Involved	0.75 ± 0.08	0.74 ± 0.11	0.78 ± 0.10
	Uninvolved	0.78 ± 0.05	0.77 ± 0.09	0.75 ± 0.11
SEBT medial reach	Involved	0.82 ± 0.07	0.82 ± 0.14	0.87 ± 0.09
	Uninvolved	0.85 ± 0.07 <sup>†</sup>	0.85 ± 0.11 <sup>†</sup>	0.85 ± 0.08
SEBT posteromedial reach	Involved	0.80 ± 0.09	0.80 ± 0.16	0.84 ± 0.11
	Uninvolved	0.85 ± 0.10	0.82 ± 0.13	0.85 ± 0.13
SEBT posterior reach	Involved	0.76 ± 0.11	0.74 ± 0.13	0.79 ± 0.12
	Uninvolved	0.79 ± 0.13	0.76 ± 0.15	0.81 ± 0.13
SEBT posterolateral reach	Involved	0.74 ± 0.10	0.73 ± 0.11	0.77 ± 0.13
	Uninvolved	0.78 ± 0.08 <sup>†</sup>	0.77 ± 0.13 <sup>†</sup>	0.78 ± 0.12
SEBT lateral reach	Involved	0.65 ± 0.07	0.66 ± 0.13	0.66 ± 0.12
	Uninvolved	0.70 ± 0.10 <sup>†</sup>	0.70 ± 0.11 <sup>†</sup>	0.67 ± 0.14
SEBT anterolateral reach	Involved	0.66 ± 0.07	0.62 ± 0.11	0.67 ± 0.09
	Uninvolved	0.68 ± 0.07	0.65 ± 0.12	0.66 ± 0.08
SEBT mean reach	Involved	0.74 ± 0.07	0.73 ± 0.12	0.76 ± 0.09
	Uninvolved	0.77 ± 0.07	0.75 ± 0.10	0.76 ± 0.10
COPV eyes open (cm/s)	Involved	4.17 ± 1.30	3.61 ± 1.31	3.57 ± 0.80
	Uninvolved	3.64 ± 0.63 <sup>‡</sup>	3.18 ± 0.94 <sup>†</sup>	3.56 ± 0.73
COPV eyes closed (cm/s)	Involved	10.21 ± 3.81	9.04 ± 3.81	8.70 ± 2.49
	Uninvolved	9.40 ± 2.94 <sup>†</sup>	8.21 ± 2.68 <sup>†</sup>	8.62 ± 2.24
FADI (%)	Involved	88.49 ± 11.38	90.96 ± 5.82	99.90 ± 0.30 <sup>†</sup>
	Uninvolved	99.19 ± 1.90	98.54 ± 3.18	99.80 ± 0.52
FADI-Sport (%)	Involved	80.31 ± 12.87	79.40 ± 13.20	99.84 ± 0.71 <sup>†</sup>
	Uninvolved	98.10 ± 3.47	97.46 ± 4.88	99.18 ± 2.29

*Abbreviations: CAI, chronic ankle instability; COPV, center of pressure velocity; FADI, Foot and Ankle Disability Index; SEBT, star excursion balance test.*

*\* Data expressed as mean ± SD; SEBT represented as proportion of leg length.*

*<sup>†</sup> Statistically significant difference when compared to involved side with both CAI groups pooled together.*

*<sup>‡</sup> Statistically significant difference when compared to CAI-rehab group and CAI-control group individually and all ankles with CAI pooled.*

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SEBT following the training period, between-group differences were found for change scores in the posteromedial ( $P = .027$ ), posterolateral ( $P = .01$ ), and lateral ( $P = .009$ ) directions on the involved limb. Between-group differences were also found for change scores when using the mean reach distance on the involved limb for all directions ( $P = .026$ ). Post hoc testing revealed that the CAI-rehab group had greater improvements than the CAI-control group and the healthy group in the posteromedial ( $P = .013$ ,  $.038$ ), posterolateral ( $P = .011$ ,  $.007$ ), and lateral ( $P = .018$ ,  $.004$ ) directions as well as the mean of all 8 reach directions ( $P = .019$ ,  $.018$ ). No between-group differ-

ences were found between the CAI-control group and the healthy group. No between-group differences were noted for the uninvolved limb. Means and 95% confidence limits of all change scores are reported in **TABLE 3**.

### Foot and Ankle Disability Index, and Foot and Ankle Disability Index-Sports Subscale

Subjects without CAI reported greater functional ability on the FADI and FADI-Sport for the assigned involved limb, when compared to those with CAI at baseline ( $P < .0005$ ). No differences were detected between the subjects with and without CAI for the uninvolved limb.

No statistically significant differences between the CAI-rehab and CAI-control groups were noted at baseline. Subjects with CAI reported a functional deficit for the involved limb compared to the uninvolved limb at baseline, when measured by the FADI ( $P < .0005$ ) and the FADI-Sport ( $P < .0005$ ). Means and standard deviations for all baseline scores are presented in **TABLE 2**.

Between-group differences were noted for FADI change scores ( $P < .0005$ ). Post hoc testing revealed that the CAI-rehab group demonstrated more improvement at follow-up than did the CAI-control group ( $P = .003$ ) and the healthy group ( $P < .0005$ ). Similarly,

<b>TABLE 3</b>		<b>PREINTERVENTION-TO-POSTINTERVENTION CHANGE SCORES (95% CONFIDENCE INTERVALS) FOR THE SEBT, THE COPV, AND THE FADI*</b>		
Measure	Side	CAI-Rehab (n = 13)	CAI-Control (n = 12)	Healthy (n = 17)
SEBT anterior reach	Involved	0.03 (-0.01, 0.07)	-0.03 (-0.07, 0.01)	0.01 (-0.03, 0.05)
	Uninvolved	0.01 (-0.02, 0.04)	-0.04 (-0.09, 0.01)	0.01 (-0.02, 0.04)
SEBT anteromedial reach	Involved	0.04 (-0.01, 0.08)	-0.02 (-0.08, 0.04)	-0.03 (-0.07, 0.01)
	Uninvolved	0.00 (-0.02, 0.02)	-0.01 (-0.05, 0.03)	0.04 (-0.01, 0.09)
SEBT medial reach	Involved	0.04 (-0.01, 0.09)	-0.02 (-0.07, 0.03)	-0.03 (-0.07, 0.01)
	Uninvolved	0.02 (0.00, 0.04)	0.00 (-0.04, 0.04)	0.00 (-0.03, 0.03)
SEBT posteromedial reach	Involved	0.07 (0.02, 0.12) <sup>†</sup>	-0.02 (-0.08, 0.04)	0.01 (-0.01, 0.04)
	Uninvolved	0.03 (-0.01, 0.07)	0.01 (-0.05, 0.07)	0.00 (-0.04, 0.04)
SEBT posterior reach	Involved	0.05 (-0.02, 0.12)	0.00 (-0.06, 0.06)	-0.01 (-0.03, 0.05)
	Uninvolved	0.03 (-0.04, 0.10)	0.00 (-0.06, 0.06)	0.01 (-0.04, 0.06)
SEBT posterolateral reach	Involved	0.12 (0.06, 0.18) <sup>†</sup>	0.02 (-0.03, 0.07)	0.02 (-0.02, 0.06)
	Uninvolved	0.04 (0.00, 0.08)	-0.02 (-0.06, 0.02)	0.02 (-0.02, 0.06)
SEBT lateral reach	Involved	0.09 (0.04, 0.14) <sup>†</sup>	0.01 (-0.04, 0.06)	0.02 (-0.02, 0.06)
	Uninvolved	0.04 (-0.01, 0.09)	0.01 (-0.04, 0.06)	0.05 (-0.01, 0.10)
SEBT anterolateral reach	Involved	0.02 (-0.03, 0.07)	-0.01 (-0.04, 0.02)	0.01 (-0.01, 0.03)
	Uninvolved	0.03 (-0.01, 0.07)	-0.03 (-0.08, 0.02)	0.03 (0.00, 0.06)
SEBT mean reach	Involved	0.06 (0.02, 0.10) <sup>†</sup>	-0.01 (-0.05, 0.03)	0.00 (-0.02, 0.02)
	Uninvolved	0.03 (-0.01, 0.05)	-0.01 (-0.05, 0.03)	0.02 (0.00, 0.04)
COPV eyes open (cm/s)	Involved	-0.38 (-0.97, 0.21)	-0.14 (-0.62, 0.34)	-0.11 (-0.40, 0.18)
	Uninvolved	-0.11 (-0.40, 0.18)	-0.12 (-0.47, 0.23)	0.05 (-0.39, 0.29)
COPV eyes closed (cm/s)	Involved	-1.09 (-2.99, 0.81)	-0.92 (-2.27, 0.43)	-0.03 (-0.55, 0.49)
	Uninvolved	-1.07 (-2.64, 0.50)	0.21 (-1.04, 0.62)	0.37 (-0.44, 1.18)
FADI (%)	Involved	7.30 (2.47, 12.13) <sup>†</sup>	-0.68 (-3.17, 1.81)	0.11 (-0.05, 0.27)
	Uninvolved	0.46 (-0.45, 1.37)	0.17 (-0.97, 1.31)	-0.05 (-0.45, 0.35)
FADI-Sport (%)	Involved	11.10 (6.35, 15.86) <sup>†</sup>	2.63 (-2.28, 7.54)	0.00 (0.00, 0.00)
	Uninvolved	1.11 (-2.03, 4.52)	-0.10 (-2.65, 2.45)	0.17 (-0.21, 0.55)

Abbreviations: CAI, chronic ankle instability; COPV, center of pressure velocity; FADI, Foot and Ankle Disability Index; FADI-Sport, FADI Sports Subscale; SEBT, star excursion balance test.  
 \*Data expressed as mean (lower limit, upper limit); SEBT represented as proportion of leg length.  
 † Significant difference compared to CAI-control group and healthy group.

there were between-group differences for the FADI-Sport change scores ( $P < .0005$ ). The CAI-rehab group showed more improvement than did the CAI-control group ( $P = .009$ ) and the healthy group ( $P < .0005$ ). Means and 95% confidence limits of all change scores are reported in **TABLE 3**.

## DISCUSSION

**T**HE RESULTS OF THIS STUDY DEMONSTRATE that there are postural sway and functional performance deficits in the involved limb when compared to the uninvolved limb among subjects with CAI at baseline. There are also greater perceived functional limitations among those with CAI compared to those without CAI at baseline. In addition, it appears that rehabilitation does serve to decrease function limitations, as the CAI-rehab group demonstrated greater improvements in the SEBT, FADI, and FADI-Sport than all other subjects.

At baseline, subjects with CAI demonstrated greater COPV when standing on the involved limb compared to the uninvolved limb. These side-to-side differences were not seen in the healthy group, however. Between-group differences were not found when comparing the COPV data for the healthy group and the CAI groups at baseline. Previous literature examining the correlation between CAI and static postural control show inconsistent results. While some authors have reported static postural control deficits among subjects with CAI,<sup>7,10,21,28,37,40</sup> others report no differences in static balance between stable and unstable ankles.<sup>21,34,37</sup>

There are many possible reasons for the inconsistent results, including the sensitivity of the measures chosen. These studies did not all use the same measurement tool. However, Hertel and Olmsted-Kramer<sup>21</sup> examined the ability of various postural measures to detect differences among subjects with CAI. They reported that traditional center-of-pressure measures, such as COPV used in our study,

were not as sensitive to detect CAI-related postural control deficits as the time-to-boundary measures were.

The severity of CAI may also contribute to some of the inconsistencies. Subjects in our study needed only to have had 1 previous ankle sprain and the presence of giving way in the last 6 months. Therefore, it is possible that our subject pool included subjects with less severe instability, which may have resulted in static balance measures similar to those of the healthy population. Similarly, there are not well-established, objective measures to clearly diagnose CAI. This too may prevent a homogeneous group of subjects being compared among studies. The variable pathoetiology also limits the homogeneity of the group. As discussed previously, CAI is a multifaceted problem. It may be that static postural control deficits were not the primary cause of symptoms in some subjects, while others have static postural control deficits resulting in the sensations of giving way.

Finally, because failed trials or “touch-downs” were discarded and repeated in this study, it is possible that our data for the CAI group are skewed and subjects received an artificially superior score when compared to the healthy group. Theoretically, if the healthy subjects did not have failed trials, the recorded COPV was representative of 3 random trials. However, if the CAI group had several failed trials, the 3 recorded trials are representative of the 3 best performances. It is also plausible that the CAI group had multiple failed trials bilaterally as bilateral deficits have been reported following ankle sprain.<sup>9</sup> This would essentially level the playing ground between limbs for the CAI group. This may explain why we did not discover between-group differences; but we did find differences between the involved and uninvolved limbs in the CAI group.

In our study, we also found conflicting results regarding functional performance deficits. While subjects with CAI did not demonstrate a significant deficit in performance on the SEBT, as compared

to healthy subjects, we did identify side-to-side differences in subjects with CAI. Previous literature examining the effects of CAI on functional performance is inconclusive. Demeritt et al<sup>9</sup> reported that CAI does not adversely affect performance on the shuttle run, agility hop tests, and cocontraction. In contrast, Docherty et al<sup>5</sup> reported deficits in a side-hop test and figure-of-eight hop for subjects with CAI. Functional performance deficits have also been reported as measured by the SEBT in subjects with CAI when compared to controls.<sup>14,21,31</sup> Again, the inconsistency in the literature may be related to the definition of CAI, differences in outcome measures, or individual differences among subjects.

The baseline differences in reported functional improvements between subjects with and without CAI is consistent with other studies that have utilized similar subjective scales such as the Ankle Joint Functional Assessment Tool.<sup>35</sup>

Our results indicate that no significant change occurred in COPV following rehabilitation, which is in contrast with findings reported in other studies.<sup>2,8,11,12,35</sup> Eils and Rosenbaum,<sup>8</sup> however, reported no greater improvement in postural control among subjects who completed rehabilitation when compared to controls.

Again, the authors' decision to discard and repeat failed COPV trials may have inflated the baseline scores of the CAI group, resulting in no detected improvements in COPV following rehabilitation. It is plausible that fewer failed trials occurred at the follow-up when compared to the baseline testing.

Another contributing factor may be that our program was only 6 sessions over 4 weeks and that static postural control tasks were only a small portion of the program. In contrast, other authors have reported training programs that were 3<sup>2</sup> to 5<sup>12</sup> times per week for 6<sup>2,8</sup> to 8<sup>12</sup> weeks and focused on balance training.<sup>2,8,12</sup>

Although we are unaware of any previous research to suggest that rehabilitation improves lower extremity performance among subjects with CAI, as measured by functional performance tests, we did find

increased reach distances on the SEBT following rehabilitation. Interestingly, we found a significant increase in the mean of all 8 reach directions, but significant changes were not seen in some reach directions. It is also of interest to note the large standard deviations in our study. This suggests that there are large variations among subjects and may possibly support the idea that CAI is multifaceted and the pathoetiology may vary among individuals. The change in self-reported function following rehabilitation is consistent with Rozzi et al.<sup>35</sup>

In addition to supporting rehabilitation as a means of improving lower extremity function among subjects with CAI, these data suggest the SEBT may be a good performance-based measure of neuromuscular control to monitor change after rehabilitation. Prior to this study, researchers have examined the ability of the SEBT to assess deficits related to CAI<sup>19,31</sup> but have not examined the ability of the SEBT to detect improvements following rehabilitation. These findings suggest that the SEBT is reliable over 4 weeks when used among subjects with CAI, and the sensitivity of the SEBT to detect changes attributed to rehabilitation is restricted to certain directions. Although changes were not noted in all 8 directions, change was detected when the mean reach distance was analyzed. Future research aiming to demonstrate validity may provide further support for using the SEBT as a functional performance measure. In addition, future research investigating the sensitivity to change of the SEBT for each direction may increase the clinical utility of this tool. It is also important to examine why specific directions are more sensitive to deficits and improvements in function. Larger studies replicating these results may also strengthen the current evidence supporting the use of the SEBT as a functional outcome measure.

When interpreting the results of this study there are several limitations to consider. The follow-up data were collected within 1 week of completion of the rehabilitation period. Therefore, we

are unable to examine long-term outcomes (symptoms and reinjuries) of this rehabilitation program. Now that there is evidence to suggest that this program may produce functional improvements, it is important to answer the question of whether or not these improvements carry over to a long-term reduction in symptoms of CAI and reinjuries.

One must also consider the possibility of a placebo effect, particularly when examining the improvements in the FADI and FADI-Sport, which are self-reports of function. Although we did have a control group, the control group did not participate in any rehabilitation and, therefore, it is possible that some of the effects noted may be related to a placebo effect. Specifically, it is possible that the administration of a prescribed exercise program or the weekly contact with a therapist may have resulted in subjective reports of improvement. While it would be beneficial to include a control group that participated in a sham treatment, developing such a treatment with therapeutic exercise may not be feasible.

Because impairment-based measures were not recorded in this study, it is not possible to clearly identify the mechanism underlying these improvements. We must again consider the complex pathoetiology of CAI. There are many possible contributing factors to CAI, including weakness, postural-control deficits, impaired proprioception, arthrokinematic changes, ligamentous laxity, and neuromuscular control deficits. In contrast to many other training protocols in the literature, our protocol was comprehensive. While we believe the breadth of our program may better address the complexity of CAI, it makes it challenging to identify the exact mechanism behind the improvements. Our program incorporated range-of-motion, strengthening, balance-training, and functional exercises. Therefore we must consider the potential contribution of each of these interventions. Future research may serve to identify the mechanism by which rehabilitation improves lower extremity performance. It may also

be beneficial to further study CAI and develop either a treatment- or impairment-based classification system that addresses the multifactorial nature of CAI. Classification of individuals with CAI into different groups based on impairments or treatment response may lead to more efficient conservative management.

Repeating this study with a larger sample size may also serve to establish greater statistical power and more clearly determine the sensitivity and specificity of COPV measures, the SEBT, and the FADI and FADI-Sport. Future research should also focus on identifying the most effective parameters of the rehabilitation protocol. It is plausible that a change in the frequency, duration, or intensity of rehabilitation may have a clinically important effect on the outcomes. While this protocol required the subjects to participate in rehabilitation once or twice each week, this does not reflect the typical frequency of rehabilitation seen in the traditional athletic training setting. It is, however, reflective of many physical therapy clinics where the number of visits is typically only a few times per week.

## CONCLUSION

**T**HE RESULTS OF THIS STUDY SUGGEST that progressive, comprehensive rehabilitation may serve to minimize lower extremity reach deficits and perceived deficits in ADLs and sport-specific skills. However, at this time the exact mechanism that underlies the benefits of rehabilitation is not clear. Additionally, the findings reported in this study indicate that the SEBT is reliable, able to detect functional limitations between sides in subjects with CAI, and sensitive to change following rehabilitation among subjects with CAI.

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