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Four-Week Ankle-Rehabilitation Programs in Adolescent Athletes With Chronic Ankle Instability

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Context: Researchers have shown that rehabilitation programs incorporating resistance-band and balance-board exercises are effective for improving clinical measures of function and patient-reported outcomes in individuals with chronic ankle instability (CAI). However, whether combining the 2 exercises increases improvement is unknown.

Objective: To determine the effectiveness of 3 rehabilitation programs on clinical measures of balance and self-reported function in adolescent patients with CAI.

Design: Randomized controlled clinical trial (Trail Registration Number: ClinicalTrails.gov: NCT03447652).

Setting: High school athletic training facilities.

Patients or Other Participants: Forty-three patients with CAI (age = 16.37 ± 1.00 years, height = 171.75 ± 12.05 cm, mass = 69.38 ± 18.36 kg) were block randomized into 4 rehabilitation groups.

Intervention(s): Protocols were completed 3 times per week for 4 weeks. The resistance-band group performed 3 sets of 10 repetitions of ankle plantar flexion, dorsiflexion, inversion, and eversion with a resistance band. The Biomechanical Ankle Platform System group performed 5 trials of clockwise and counterclockwise rotations, changing direction every 10 seconds during each 40-second trial. The combination group completed resistance-band and Biomechanical Ankle Platform System programs during each session. The control group did not perform any exercises.

Main Outcome Measure(s): Variables were assessed before and after the intervention: time-in-balance test, foot-lift test, Star Excursion Balance Test, side-hop test, figure-8 hop test, Foot and Ankle Ability Measure, and Cumberland Ankle Instability Tool. We conducted 4 separate multivariate repeated-measures analyses of variance, followed by univariate analyses for any findings that were different.

Results: Using the time-in-balance test, foot-lift test, Star Excursion Balance Test (medial, posteromedial, and posterolateral directions), and figure-8 hop test, we detected improvement for each rehabilitation group compared with the control group ($P < .05$). However, no intervention group was superior.

Conclusions: All 3 rehabilitation groups demonstrated improvement compared with the control group, yet the evidence was too limited to support a superior intervention. Over a 4-week period, either of the single-task interventions or the combination intervention can be used to combat the residual deficits associated with CAI in an adolescent patient population.

Key Words: static balance, dynamic balance, functional performance, patient-reported outcomes

Key Points

- The resistance-band, Biomechanical Ankle Platform System Board, and combination interventions improved balance and function in adolescent patients with chronic ankle instability, but evidence to support a superior intervention was limited.
- Clinicians should use both clinical measures and patient-reported outcomes when assessing rehabilitation progression.
- Clinicians can use either of the single-task interventions or the combination intervention over a 4-week period to address residual deficits in adolescent patients with chronic ankle instability.

Residual symptoms from an initial lateral ankle sprain are identified as chronic ankle instability (CAI). This condition has been reported in 18% to 71% of children with a history of ankle sprain.[1] *Chronic ankle instability* describes a combination of mechanical and functional instability with residual ankle-sprain symptoms[2,3]: pain, swelling, weakness, instability, and repeated episodes of "giving way."[4] These residual symptoms can impede young patients' physical activity, which can negatively affect their overall health and quality of life by leading to obesity and other general health problems. Whereas decreases in physical activity have been reported in the adult population, the effects on physical activity levels in the adolescent population are unknown.[5] These potential long-term consequences highlight the need to treat these conditions properly, particularly in young patients.

Nonoperative treatment via multimodal rehabilitation programs is commonly recommended for CAI.[6] The effects of these programs in the adult population with CAI have been evaluated, but little is known about their effects in the corresponding adolescent population. Most multimodal programs assessed in the adolescent population consist of 18 to 20 weeks of training (3 to 5 d/wk) focusing on 6 to 16 different exercises (20 to 35 minutes per session) and emphasize overall lower extremity injury prevention and not CAI specifically.[7–9] Moreover, major limitations of current rehabilitation programs include the time requirement and the space to perform the exercises, as well as the effort to achieve benefit. Targeting patients in the high school setting through athletic trainers (ATs) can be effective; however, these programs are not ideal for either adolescent patients or ATs implementing them. Athletic trainers in this setting do not have enough time or resources to focus on a diverse rehabilitation program for each patient they encounter daily. Given these barriers, patients may not be receiving the best level of care.

To measure the breadth of impairments associated with CAI, as well as the efficacy of rehabilitation interventions, functional task assessment via laboratory-based measures is frequently used. Although these methods focus on both the mechanical and sensorimotor aspects of CAI impairments, they often fail to address the perceptual aspect. To measure this factor, clinicians can use patient-reported outcomes (PROs), which include clinical questionnaires involving patient-specific reports of function and the level of difficulty encountered with athletic activities. In the adult population, certain self-reported instability and function questionnaires have been used and are recommended for clinical classification by the International Ankle Consortium (IAC).[4] Whereas these tools have been used in research studies to identify adult patients with CAI,[4,10,11] their use for determining self-reported rehabilitation effect has not been commonly evaluated. As clinicians move toward a patient-centered model, the use of these tools to determine self-reported effects is becoming more imperative. In addition, the long-term effects of rehabilitation have not typically been assessed in the literature and have often been cited as a study limitation due to difficulty with patient follow up.

Chronic ankle instability is a major concern for individuals with a history of ankle sprains. Multimodal interventions are effective; however, most take too long to be practical in a high school setting. Clinician-friendly assessments and PROs focused on an adolescent population are scarcely used in the current literature. Therefore, the purpose of our study was to compare the effects of single and multimodal interventions in adolescents with CAI on clinical measures of balance and PROs at the point of care.

METHODS

Design

We performed a single-blinded randomized controlled clinical trial (registry NCT03447652, clinicaltrials.gov) to evaluate the effects of 3 ankle-rehabilitation programs on clinical measures of balance and PROs for physically active adolescents with CAI. This study was approved by the Institutional Review Board of Georgia State University, and all patients provided a signed parental permission form and child assent form.

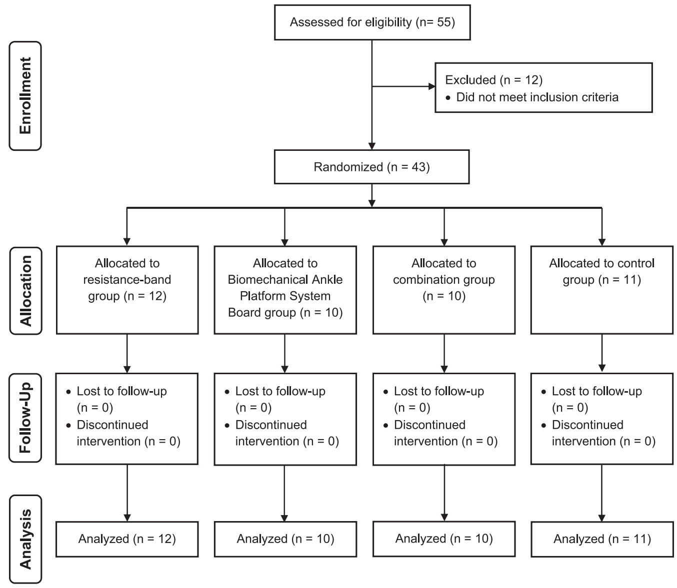

Figure 1. Consolidated Standards of Reporting Trials (CONSORT) flow diagram.

Participants

An a priori sample-size calculation using estimated effect sizes from previously published data[12] and pilot data from our laboratory resulted in an estimate of 6 to 8 patients required per group—24 to 32 total participants—to obtain power of 0.80 for all dependent variables at an α level of .05 (G*Power 3.1; G*Power, Heinrich-Heine-Universität, Düsseldorf, Germany). We oversampled to protect against participant attrition.

From 10 high schools, 55 adolescent patients (age range = 15–18 years) with CAI were recruited and screened for eligibility. Of those patients, 12 were determined to be ineligible, leaving 43 (Figure 1). All patients were similar anthropometrically, and group characteristics can be found in Table 1. Patients reported a minimum of 5 hours of moderate activity per week, and inclusion and exclusion criteria were based on recommendations from the IAC.[4] Volunteers were included if they had a history of at least 1 substantial ankle sprain that required medical intervention; repeated symptoms of pain, swelling, weakness, and instability; repeated episodes of giving way[4]; and a Cumberland Ankle Instability Tool (CAIT) questionnaire score $\leq$25.[13] Recruits were excluded if a medical professional had diagnosed any lower extremity injury within the previous 3 months with symptoms present at the time of the study or an acute ankle sprain in the 6 weeks before the study, they had undergone previous surgery to either lower extremity, or they had a history of ankle fracture or dislocation.[4]

Procedures

Patient age, height, mass, sex, limb length, and test limb were recorded. The test limb was identified by the lower CAIT score. Limb length was measured from the anterior-

Table 1. Patient Characteristics

Variable	Group			
	Resistance Band (n = 12)	Biomechanical Ankle Platform System Board[a] (n = 10)	Combination (n = 10)	Control (n = 11)
	Mean ± SD			
Age, y	16.42 ± 1.00	16.40 ± 0.97	16.20 ± 1.14	16.45 ± 1.04
Height, cm	171.24 ± 10.13	178.69 ± 9.87	170.69 ± 12.14	166.96 ± 14.20
Mass, kg	65.75 ± 11.16	77.57 ± 21.54	67.99 ± 16.49	67.17 ± 22.94
	No.			
Sex, males/females	5/7	8/2	3/7	4/7
Test foot, right/left	7/5	5/5	5/5	7/4
Positive anterior drawer test	12	10	10	11
Positive talar tilt test	12	10	10	11

[a] System Spectrum Therapy Products, LLC, Adrian, MI.

superior iliac spine to the distal aspect of the medial malleolus. Assessments of ankle-ligament laxity, including the anterior drawer and talar tilt tests, were conducted by an AT using the methods of Ryan[14] but were not used for inclusion. All patients performed a variety of static and dynamic balance and functional performance assessments and completed 2 PRO questionnaires to evaluate any changes due to the interventions for ankle function. We counterbalanced test administration using an automated list randomizer, and all data-collection scoring was performed by a single investigator (R.J.B.) blinded to group allocation. After the baseline assessment, patients were randomized to 1 of 4 groups and underwent their assigned intervention as described in this section. After the intervention, patients completed the same assessments (posttest). Each patient who received rehabilitation reported within 3 days of the last rehabilitation session, and the patients who served as controls reported within 3 days of the end of the initial 4-week timeframe.

Static Balance

Time-in-Balance Test. Patients stood facing forward in a normal erect stance with their hands on their hips and their eyes closed. They were instructed to balance on their test limb while the examiner recorded the time held in seconds. Each trial could last a maximum of 60 seconds. Moving the test foot or touching the floor with the contralateral foot was not permitted and ended the trial. A single practice trial for patient familiarization was allowed before the test trials. The test was conducted 3 times, with 30 seconds of rest provided after each trial. The longest trial was used for analysis. This test is valid and responsive to rehabilitation (intraclass correlation coefficient [ICC] = 0.99).[12] The methods were consistent with those previously reported.[15]

Foot-Lift Test. Patients maintained a single-limb stance on their test foot with their hands on their hips, facing forward in an erect stance, and their eyes closed. The test was performed for 30 seconds, and the number of foot lifts during each trial was recorded. A *foot lift* was defined as any part of the foot leaving the floor. Touching the floor with the contralateral foot was recorded as an error. Patients were instructed to refrain from removing their hands from their hips, opening their eyes, and touching their stance limb with the contralateral foot; however, these actions were not recorded as errors. A single practice trial for participant familiarization was allowed before the test trials. The test was conducted 3 times, with a 30-second rest provided between trials. The average of 3 trials was used for analysis. This test is valid and responsive to rehabilitation (ICC = 0.99).[12] The methods were consistent with those previously reported.[15]

Dynamic Balance

For the Star Excursion Balance Test, patients stood on the test limb and reached as far as possible in each direction while maintaining balance. Five reach directions were evaluated: anterior, anteromedial, medial, posteromedial, and posterolateral. Each reach took place over a cloth tape measure that was taped securely to the floor. Distance was measured by the investigator in centimeters and normalized to the patient's nontest limb length. Patients performed 4 practice trials in each direction with a 5-minute rest period before the test sessions.[15] The test was conducted 3 times in each direction. Patients were given a 10-second rest between trials. An average of the 3 trials for each direction was used for analysis. This test is valid and responsive to rehabilitation[16] (ICC range = 0.81–0.93).[17] The methods were consistent with those previously reported.[18]

Functional Performance

Side-Hop Test. Patients stood on their involved limb and hopped 30 cm laterally, side to side, for 10 repetitions as fast as possible. Time needed to perform the test was recorded to the nearest 0.01 second using a handheld stopwatch (model AX725 Pro Memory; Accusplit, Pleasanton, CA). A single practice trial for patient familiarization was allowed before the test trials. The test was conducted twice on the involved limb, with a 60-second rest provided between trials. The shortest trial was used for analysis. The test is valid and responsive to rehabilitation (ICC = 0.99).[12] The methods were consistent with those previously reported.[19]

Figure-8 Hop Test. Patients stood on their test limb and hopped over a 5-m distance in a figure-8 pattern. Time to perform the test was recorded to the nearest 0.01 second using a handheld stopwatch. A single practice trial for patient familiarization was allowed before the test trials. The test was conducted twice on the involved limb, with a

60-second rest provided between trials. The shortest trial was used for analysis. This test is valid and responsive to rehabilitation (ICC = 0.98).[12,20] The methods were consistent with those previously reported.[19]

Patient-Reported Outcomes

Foot and Ankle Ability Measure. The Foot and Ankle Ability Measure (FAAM) is used to assess general self-reported levels of function in patients with leg, ankle, and foot musculoskeletal injuries and disorders.[21] It consists of 2 subscales (Activities of Daily Living [ADL] and Sport [S]), both of which are scored on a 0% to 100% scale, with a higher percentage indicating a better level of function.[21] The FAAM is a valid questionnaire for assessing function in adult patients with CAI.[10] Minimal detectable change (MDC) scores of 3.9% to 4.8% and 7.6% to 7.9% have been reported for the FAAM-ADL and FAAM-S, respectively.[22,23] Minimal clinically important difference (MCID) scores of 8 and 9 points for the FAAM-ADL and FAAM-S, respectively, have also been reported for an adult population receiving treatment for a leg, ankle, or foot musculoskeletal disorder.[21]

Cumberland Ankle Instability Tool. The CAIT is used to focus on the severity of functional problems in patients with ankle instability.[11] It consists of 9 items that together are rated on a 30-point scale. A higher response score indicates a better level of overall function. The CAIT is a valid and reliable questionnaire that can be used to measure the severity of functional difficulties in adults with CAI.[11] An MDC score of 3.08 and an MCID score $\geq$3 points have been reported in an adult population with CAI.[24]

Rehabilitation Interventions

Each patient was randomized to 1 of 4 rehabilitation groups: resistance band, Biomechanical Ankle Platform System (BAPS) Board (Spectrum Therapy Products, LLC, Adrian, MI), combination, or control. We used a concealed cluster randomization for each site to allow blinding of the investigator responsible for data analysis (M.S.C.). Before any rehabilitation intervention sessions were conducted, we gave specific instructions and training to the study personnel responsible for administration and supervision at each clinical site. This training included oral instructions with physical demonstrations, as well as written instructions that could be referenced to ensure proper technique. We held periodic meetings with the rehabilitation administrators to ensure consistency in delivery of the programs. After the pretest assessments were completed, patients reported to their respective athletic training facility for the 12 rehabilitation intervention sessions. They were required to complete all 12 sessions in 4 to 6 weeks: no fewer than 2 sessions per week and no more than 3 sessions per week. A study investigator (S.W.L.) tracked each patient's completion and documented both progress and setbacks. Each week, the difficulty of the exercises was increased.

Resistance-Band Intervention. During each session, patients completed resistance training using a Theraband resistance band (The Hygenic Corp, Akron, OH) in 4 directions of ankle motion (plantar flexion, dorsiflexion, inversion, eversion) to perform 3 sets of 10 repetitions. Patients were seated on the floor with the knee extended and instructed to perform the movement at the ankle joint

Figure 2. Participant setup. A, Resistance band. B, Biomechanical Ankle Platform System Board (Spectrum Therapy Products, LLC, Adrian, MI).

without allowing extraneous movement at other joints (ie, hip and knee). A bolster was placed under the heel to lift the foot off the floor. The resistance band was doubled and securely attached to the base of a treatment table (Figure 2A). The training resistance was determined using the methods of Kaminski et al[25] by calculating 70% of the resting length of the resistance band and adding this distance to the resting length of the resistance band. Using

Table 2. Dependent Variable Main Effects and Interactions

Category	Multivariate Time Main Effect F Value	Multivariate Time Main Effect P Value	Multivariate Group Main Effect F Value	Multivariate Group Main Effect P Value	Multivariate Time × Group Interaction F Value	Multivariate Time × Group Interaction P Value	Variable	Univariate Time Main Effect $F_{1,39}$ Value	Univariate Time Main Effect P Value	Univariate Group Main Effect $F_{3,39}$ Value	Univariate Group Main Effect P Value	Univariate Time × Group Interaction $F_{3,39}$ Value	Univariate Time × Group Interaction P Value
Static balance	5.03	.01[a]	0.87	.52	4.22	.001[a]	Time-in-balance test	0.02	.88	0.77	.52	5.92	.002[a]
							Foot-lift test	9.74	.003[a]	0.52	.67	3.44	.03[a]
Dynamic balance	10.15	<.001[a]	0.98	.48	1.71	.06	SEBT anterior-reach direction	2.81	.10	0.76	.52	1.01	.40
							SEBT anteromedial-reach direction	14.79	<.001[a]	0.34	.79	1.42	.25
							SEBT medial-reach direction	25.98	<.001[a]	1.10	.36	4.74	.007[a]
							SEBT posteromedial-reach direction	40.47	<.001[a]	0.95	.43	3.64	.02[a]
							SEBT posterolateral-reach direction	51.23	<.001[a]	0.93	.44	3.35	.03[a]
Functional performance	21.23	<.001[a]	2.54	.03[a]	3.58	.004[a]	Side-hop test	18.53	<.001[a]	1.93	.14	2.64	.06
							Figure-8 hop test	43.09	<.001[a]	1.54	.22	4.48	.009[a]
Patient-reported outcomes	4.87	<.001[a]	0.61	.79	1.00	.48		NA	NA	NA	NA	NA	NA

Abbreviations: NA, not applicable; SEBT, Star Excursion Balance Test.

[a] Indicates difference ($P < .05$).

this calculated distance, the examiner placed a mark to which the resistance band was stretched during exercise performance on the floor. This distance was maintained regardless of the color (resistance) of the band. Each week, the patient progressed to the next resistance-band color level (from red to green, blue, and black). For the set and repetition count, patients could go at their own pace; however, they were instructed to move through their entire range of motion for the direction of each exercise.

Biomechanical Ankle Platform System Board Intervention. Patients stood near a wall where they could only use their fingertips against the wall for stability (Figure 2B). They performed a 1-legged stance using their test limb on the BAPS Board while completing clockwise and counterclockwise circles. Training started at the lowest progression (level 1 of 5), with each level increasing in half-dome size underneath the board. Level 1 allowed for the smallest amount of motion at the ankle. As the patient progressed, the allowed range of motion increased, and the training volume intensified. The initial rotation of direction was selected by the patient and changed every 10 seconds in the 40-second trial. Five 40-second trials were completed with 1-minute rest intervals between trials. Progression was determined by the supervising clinician and was based on the patient's ability to make smooth transitions between directional changes and completion of smooth circular rotations in both directions. The methods were consistent with those previously reported.[26]

Combination Intervention. Patients assigned to the combination protocol completed both the resistance-band and BAPS Board protocols during each session. The order of exercise completion was counterbalanced for each session. Progressions for each protocol were as described in the previous paragraphs.

Control Intervention. Patients in the control group did not perform any rehabilitation exercises. Over the intervention timeframe, they were required to check in with a member of the research team each week to discuss any changes in their ankle or report any incidence of *injury*, which was defined as any injury that caused them to miss >1 day of participation. For this study, no injuries were reported during the intervention timeframe.

Data Analysis and Reduction

Preliminary correlation analyses were conducted on groupings of the dependent variables (static balance, dynamic balance, functional balance, and PROs). Given that variables for each group were correlated, we conducted 4 separate multivariate analyses of variance (ANOVAs) to determine the effect of time (pretest, posttest) and group (resistance band, BAPS Board, combination, control) on the constructs of static balance, dynamic balance, functional balance, and self-reported function. If multivariate ANOVA interactions were observed, we calculated follow-up univariate ANOVAs to determine which specific variables drove the interaction for the construct in question. Pairwise comparisons using the Tukey HSD test were evaluated when univariate interactions were noted. Hedges *g* effect sizes with 95% confidence intervals (CIs) were also calculated and interpreted as *small* (0.2), *moderate* (0.5), or *large* (0.8). We also calculated MDC values from the control group pretest-posttest data using the standard error of the measurement (SEM = baseline standard deviation × $[\sqrt{1 - ICC}]$) and multiplied by $\sqrt{2}$ for each variable with a univariate interaction to determine the amount of change needed to surpass the typical measurement error for each variable.[27] The α level was set a priori at .05, and SPSS (version 24.0; IBM Corp, Armonk, NY) was used for all statistical analyse.

RESULTS

Corresponding main effects for both multivariate and applicable univariate ANOVAs for all variables are reported in Table 2. Dependent variable values, MDC values, and group effect sizes are reported in Table 3.

Balance and Performance Outcomes

In summary, univariate time-by-group interactions were detected for time-in-balance, foot-lift, and figure-8 hop tests and the SEBT in the medial-, posteromedial-, and posterolateral-reach directions (P values $< .05$). Univariate time main effects (P values $< .05$) were detected for each of the dependent variables except the time-in-balance test

Table 3. Dependent Variable Minimal Detectable Change, Mean ± SD, and Hedges *g* Effect Size Continued on Next Page

Variable	Minimal Detectable Change	Pretest	Posttest	Δ After 4 wk	Effect Size (95% Confidence Interval) Versus Control Group [a]	Effect Size (95% Confidence Interval) Versus Combination Group Δ[b]
Static balance						
Time-in-balance test	15.16 s					
Resistance band		29.03 ± 23.63	40.84 ± 23.80	11.81 ± 15.33	1.68 (−4.64, 8.01)	0.44 (−5.38, 6.27)
BAPS Board		29.86 ± 22.61	28.33 ± 23.61	−1.53 ± 20.07	0.73 (−6.91, 8.38)	−0.40 (−7.65, 6.85)
Combination		21.15 ± 21.12	26.56 ± 16.06	5.41 ± 12.02	1.41 (−4.59, 7.41)	
Control		33.80 ± 20.71	18.59 ± 12.20	−15.21 ± 15.63		
Foot-lift test	3 errors					
Resistance band		7.42 ± 4.41	6.42 ± 4.51	1.00 ± 3.08	0.34 (−0.82, 1.50)	−0.91 (−2.00, 0.19)
BAPS Board		7.60 ± 4.67	7.17 ± 4.89	0.43 ± 2.30	0.17 (−0.87, 1.21)	−1.37 (−2.30, −0.44)
Combination		8.93 ± 2.88	5.47 ± 2.34	3.46 ± 1.91[d]	1.46 (0.49, 2.44)	
Control		5.64 ± 3.29	5.64 ± 2.79	0.00 ± 2.56		
Dynamic balance						
SEBT anterior-reach direction	5.33%					
Resistance band		77.57 ± 5.17	80.11 ± 5.76	2.53 ± 6.12	0.42 (−2.13, 2.97)	−0.08 (−2.48, 2.33)
BAPS Board		75.29 ± 6.18	75.62 ± 5.80	0.33 ± 3.18	0.10 (−2.09, 2.29)	−0.58 (−2.49, 1.33)
Combination		76.64 ± 7.58	79.63 ± 6.12	2.99 ± 5.28	0.52 (−2.00, 3.03)	
Control		78.38 ± 6.82	78.20 ± 6.29	−0.18 ± 6.38		
SEBT anteromedial-reach direction	3.82%					
Resistance band		79.91 ± 5.51	84.79 ± 5.18	4.88 ± 6.56[c]	0.74 (−1.65, 3.13)	0.20 (−2.18, 2.59)
BAPS Board		79.81 ± 6.66	83.62 ± 5.66	3.81 ± 4.82	0.67 (−1.41, 2.76)	0.03 (−2.00, 2.06)
Combination		79.62 ± 8.02	83.29 ± 6.39	3.67 ± 4.42	0.67 (−1.34, 2.68)	
Control		83.72 ± 6.67	84.11 ± 6.61	0.39 ± 4.93		
SEBT medial-reach direction	5.05%					
Resistance band		81.03 ± 8.75	89.93 ± 9.59	8.90 ± 8.12[c]	1.32 (−1.71, 4.35)	0.37 (−2.76, 3.51)
BAPS Board		81.23 ± 5.60	90.17 ± 7.93	8.94 ± 7.81[c]	1.37 (−1.71, 4.35)	0.39 (−2.79, 3.57)
Combination		79.36 ± 8.53	85.36 ± 6.53	6.00 ± 6.65[c]	1.06 (−1.70, 4.43)	
Control		88.81 ± 8.64	87.54 ± 8.52	−1.27 ± 6.55		
SEBT posteromedial-reach direction	6.58%					
Resistance band		82.42 ± 8.96	94.04 ± 10.33	11.62 ± 7.79[c]	1.25 (−2.05, 4.55)	0.21 (−3.07, 3.49)
BAPS Board		85.78 ± 8.89	94.37 ± 9.89	8.59 ± 8.49[c]	0.85 (−2.76, 4.46)	−0.15 (−3.75, 3.44)
Combination		80.15 ± 10.73	90.06 ± 10.47	9.91 ± 7.90[c]	1.03 (−2.46, 4.52)	
Control		91.32 ± 13.10	92.45 ± 11.53	1.13 ± 8.39		
SEBT posterolateral-reach direction	7.04%					
Resistance band		74.57 ± 12.04	85.92 ± 12.45	11.35 ± 8.17[c]	0.96 (−2.40, 4.33)	−0.23 (−3.32, 2.86)
BAPS Board		77.23 ± 13.37	84.58 ± 9.27	7.35 ± 8.91[c]	0.47 (−3.21, 4.15)	−0.72 (−4.10, −2.66)
Combination		67.46 ± 11.45	80.59 ± 9.05	13.13 ± 6.29[c]	1.29 (−1.88, 4.47)	
Control		78.70 ± 12.42	81.84 ± 9.11	3.14 ± 8.30		
Functional performance						
Side-hop test	0.97 s					
Resistance band		14.94 ± 5.82	10.94 ± 2.47	4.00 ± 5.09[c]	1.05 (−0.51, 2.61)	0.26 (−1.58, 2.10)
BAPS Board		11.70 ± 4.46	8.41 ± 1.45	3.29 ± 4.01[c]	1.13 (−0.14, 2.39)	0.13 (−1.50, 1.75)
Combination		12.43 ± 3.64	9.63 ± 1.09	2.80 ± 3.39[c]	1.12 (0.03, 2.21)	
Control		10.84 ± 2.78	11.01 ± 3.27	−0.17 ± 1.45		
Figure-8 hop test	0.98 s					
Resistance band		14.59 ± 2.92	13.02 ± 1.85	1.57 ± 1.64[c]	0.70 (0.11, 1.29)	−0.71 (−1.56, 0.14)
BAPS Board		13.42 ± 1.58	12.09 ± 1.61	1.33 ± 0.76[c]	0.77 (0.33, 1.20)	−0.93 (−1.71, −0.14)
Combination		16.27 ± 3.26	13.20 ± 1.82	3.07 ± 2.42[c]	1.30 (0.50, 2.11)	
Control		14.17 ± 2.23	13.65 ± 1.77	0.52 ± 1.20		
Patient-reported outcomes						
Foot and Ankle Ability Measure–Activities of Daily Living	10.68%					
Resistance band		87.40 ± 8.07	89.68 ± 9.24	2.28 ± 7.43	0.03 (−3.92, 3.99)	−0.56 (−3.21, 2.09)
BAPS Board		89.40 ± 8.39	92.86 ± 9.10	3.46 ± 6.58	0.15 (−3.96, 4.26)	−0.42 (−2.92, 2.08)
Combination		85.36 ± 11.42	91.31 ± 8.80	5.95 ± 4.66	0.42 (−3.45, 4.30)	
Control		89.07 ± 10.14	91.02 ± 9.38	1.95 ± 11.67		
Foot and Ankle Ability Measure–Sport	9.51%					
Resistance band		69.01 ± 11.73	81.25 ± 12.29	12.24 ± 13.62[c]	0.43 (−5.25, 6.12)	0.12 (−5.31, 5.55)
BAPS Board		77.50 ± 13.24	84.38 ± 14.95	6.88 ± 10.91	0.07 (−5.39, 5.52)	−0.31 (−5.37, 4.75)
Combination		74.06 ± 14.44	84.69 ± 17.21	10.63 ± 12.17[c]	0.34 (−5.34, 6.02)	
Control		71.02 ± 15.51	76.99 ± 19.93	5.97 ± 14.21		

Table 3. Continued From Previous Page

Variable	Minimal Detectable Change	Pretest	Posttest	Δ After 4 wk	Effect Size (95% Confidence Interval) Versus Control Group [a]	Versus Combination Group Δ[b]
Cumberland Ankle Instability Tool	5 points					
Resistance band		16.08 ± 4.68	20.50 ± 2.61	4.42 ± 4.36	0.94 (−1.25, 3.13)	0.31 (−1.55, 2.16)
BAPS Board		16.30 ± 4.79	22.10 ± 4.58	5.80 ± 3.43[c]	1.24 (−0.95, 3.43)	0.67 (−1.10, 2.43)
Combination		18.40 ± 3.20	21.40 ± 5.13	3.00 ± 4.55	0.66 (−1.70, 3.03)	
Control		17.45 ± 4.46	16.64 ± 5.50	−0.81 ± 6.27		

Abbreviations: BAPS, Biomechanical Ankle Platform System (Spectrum Therapy Products, LLC, Adrian, MI); SEBT, Star Excursion Balance Test.

[a] Effect sizes were calculated based on the change in the intervention group compared with the change in the control group from pretest to posttest.

[b] Effect sizes were calculated based on the change in the intervention group compared with the change in the combination intervention group from pretest to posttest.

[c] Indicates a group mean that surpassed the minimal detectable change score.

($P = .88$) and the SEBT in the anterior-reach direction ($P = .10$). Group main effects were not detected for any of the dependent variables (P values $> .05$). Tukey post hoc testing showed that each rehabilitation group performed better than the control group at posttest; however, no rehabilitation group performed better than any other rehabilitation group. Each group difference compared with the control group was supported by small to large effect sizes for both static balance (Hedges g range = 0.17–1.68) and dynamic balance (Hedges g range = 0.10–1.37) and moderate to large effect sizes for functional performance (Hedges g range = 0.70–1.30).

Patient-Reported Outcomes

In summary, time main effects were detected for the PRO category of dependent variables (P values $< .001$), but no time-by-group interaction ($P = .48$) or group main effects ($P = .79$) were detected. Whereas each of the rehabilitation groups reported better outcomes than the control group, we found limited evidence regarding a superior rehabilitation group. Group differences compared with the control group were supported by small to large effect sizes (Hedges g range = 0.03–1.24).

DISCUSSION

Previous Rehabilitation Programs

Multimodal rehabilitation has been recommended for patients with CAI.[6] Although these types of programs are often used for both acute and chronic ankle rehabilitation, the effectiveness of this type of training is less than ideal, as which exercises are necessary and offer positive adaptations to biomechanical function and which exercises provide no benefit is unknown. Given the high volume of patients seen daily in a high school athletic training facility, ATs often do not have enough time to properly monitor patients performing rehabilitation programs. Therefore, identifying an intervention that does not require much equipment or clinician supervision can be helpful. The purpose of our study was to evaluate 2 common rehabilitation interventions used in high school settings and determine whether a single or dual technique offered the most benefit to adolescent athletes with CAI. Each intervention focused on common tasks in multimodal ankle-rehabilitation plans that used minimal equipment and needed minimal clinician supervision. Our most important observation was that all 3 rehabilitation-intervention groups showed improvements across clinical balance and performance outcomes compared with the control group; however, no rehabilitation group performed better than another. For PROs, we found only a time main effect for the grouping of outcomes, showing all groups' scores improved over time. Our results are similar to those reported by previous researchers[12,26,28] who evaluated these tests after a 4-week intervention.

Balance and Performance Outcomes

Static Balance Assessments. The time-in-balance and foot-lift tests were used to assess the patients' static balance and ability to maintain their center of gravity on a stable surface. The effects of the interventions used in this study allowed for beneficial changes in the patients' balance-strategy patterns, as detected from an increase in the length of time balance was held and a decrease in foot-lift compensations. These changes were supported by small to large effect sizes. Similar results have been reported by previous researchers after a 4-week intervention in both the general[26,28] and adolescent[12] populations. None of the intervention-group means surpassed the MDC score (15.16 seconds) for the time-in-balance test. Whereas intervention improvements were noted, most did not surpass the MDC. These differences, therefore, should be interpreted with caution, as the control group had a large decline in the length of time balance was held from pretest to posttest. For the foot-lift test, only the combination group mean surpassed the MDC score (3 errors). Overall, the combination intervention may be viewed as a superior intervention based on the MDC score comparison for static balance assessments (Appendix).

Dynamic Balance Assessments. The SEBT was used to assess patients' dynamic balance and ability to maintain their center of gravity while completing a reach task with the opposite foot. Although we did not observe a multivariate ANOVA interaction for the dynamic balance grouping of variables, we chose to follow up with univariate statistics to determine which reach directions were responsible for the group trend. The detected increases in reach distance offered insight into the beneficial changes in dynamic balance that can be attained from performing 1 or both types of interventions used in this study and were supported by small to large effect sizes. These changes allow patients to be more functional during single-limb stance that is accompanied by a multiplanar reach task, which is commonly present during athletic activity. Similar results have been reported in the posteromedial-reach direction among the general adult population performing 4 weeks of either wobble board[26,28] or resistance training,[28] as well as in the medial- and posteromedial-reach directions in an adolescent population performing a 4-week BAPS Board protocol.[12] No group means surpassed the calculated MDC for the anterior-reach direction (5.33%), and only the resistance-band group mean surpassed the MDC for the anteromedial-reach direction (3.82%). All 3 intervention-group means surpassed the calculated MDC scores for the medial (5.05%)-, posteromedial (6.58%)-, and posterolateral (7.04%)-reach directions, which included roughly 50% to 80% of all intervention participants. Our MDC scores were higher than those previously stated[23]; however, this difference was most likely due to the population evaluated. Overall, limited evidence was available to support a superior intervention based on MDC score comparison for dynamic balance assessments (Appendix).

Functional Performance Assessments. The side-hop and figure-8 hop tests were used to assess functional performance and patients' ability to maintain their center of gravity in an efficient manner while reacting to perturbations from landing and takeoff tasks. The rehabilitation interventions we used benefitted patients' hopping and landing abilities, as indicated by a decreased time needed to complete the hopping tasks. Our results were supported by moderate to large effect sizes. Similar findings have been described for the figure-8 hop test in both the general adult[26,28] and adolescent[12] populations with CAI who performed similar programs. All 3 intervention-group means surpassed calculated MDC scores for the side-hop test (0.97 seconds) and figure-8 hop test (0.98 seconds), which included 50% to 80% of all intervention participants. Our MDC scores were slightly higher than those reported in the literature for the figure-8 hop test.[20] Overall, limited evidence supported a superior intervention based on MDC score comparison for functional performance assessments (Appendix).

Patient-Reported Outcomes

Researchers who used the FAAM[28,29] and CAIT[28] questionnaires demonstrated improved scores after the rehabilitation intervention. Whereas we did not find interaction effects for the PROs, improvements were present over time. Wright et al[28] noted improved outcomes on both the FAAM and CAIT questionnaires for time after a single-task 4-week rehabilitation intervention; however, they did not include a control group for comparison and focused on an adult population. Our results were consistent with those of Wright et al[28] for the effect of a single-task intervention study, yet the variability of the control group and the differences in patient populations should be acknowledged. Hall et al[30] also showed improvements in PROs regardless of the type of intervention over a 6-week period, which further supports our observations. None of the intervention-group means surpassed the MDC for the FAAM-ADL (10.68%), both resistance-band and combination group means surpassed the MDC for the FAAM-S (9.51%), and only the BAPS Board group mean surpassed the MDC for the CAIT (5 points). Our PRO-calculated MDC scores were slightly different from those reported in the literature.[21–24] These variations were most likely due to differences in the populations evaluated.

The PRO results can be further compared with the published recommendations of the IAC. These recommendations provide inclusion scores for controlled research and offer further comparisons of instability.[4] These values are specific to the adult population, and any comparisons with our adolescent population need to be interpreted with care. Scores of $<90\%$ for the FAAM-ADL and $<80\%$ for the FAAM-S are recommended for patient inclusion.[4] All 4 groups started at or below the inclusion value and completed the 4-week rehabilitation program with FAAM-ADL scores $>90\%$ and FAAM-S scores $>80\%$. For the CAIT, an inclusion score ≤ 24 points has been recommended by the IAC,[4] and a recalibrated inclusion score ≤ 25 has been recommended by Wright et al.[13] All 4 of our groups began with average total scores <19 points. Each intervention group increased its average total score at posttest to ≥ 20 points, with the BAPS Board group reporting the highest score (22.10 points); however, none of the group scores surpassed the IAC inclusion value.

The inability to determine a superior intervention because of a lack of group effects for all dependent variables was an interesting result. Using MDC score comparisons, we detected improvements in the intervention groups, but the evidence was insufficient to identify a superior intervention (Appendix). Whereas MDC score comparisons offers insight into the amount of change needed to surpass the typical measurement error for each variable, our findings demonstrated that a combined program of both exercises did not improve balance in this population more than a single-task intervention.

LIMITATIONS

Patient blinding to treatment was not possible. Although the PRO questionnaires we selected are valid and reliable in the adult population, their use in the adolescent population may be limited due to developmental changes and adolescent awkwardness. Improvements were detected for the rehabilitation groups; however, the control group also reported some score improvements in the absence of rehabilitation. This improvement could be due to an association of functional improvement with questionnaire familiarity and respondent learning. The goal of our study was to determine an intervention that required minimal clinician supervision for this age group, but more supervision may be necessary to ensure appropriate mechanics for beneficial outcomes.

CONCLUSIONS

All 3 rehabilitation interventions used in our study improved balance and function. However, the evidence to support a superior intervention was limited. Our work offered insight into active adolescent patients with CAI via 3 easily administered rehabilitation interventions that showed improvement in clinical measures of function and PROs after only 4 weeks. Clinicians should use both clinical measures and PROs when assessing rehabilitation progression. Either of the single-task interventions or the combination intervention can be used over a 4-week period to combat the residual deficits that affect adolescent patients with CAI.

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Appendix. Group Change-Score Means (%) That Exceeded the Minimal Detectable Change

Variable	Minimal Detectable Change	Group Change-Score Mean (%)[a]				
				Intervention Split		
		Control (n = 11)	Combined Interventions (n = 32)	Resistance Band (n = 12)	Biomechanical Ankle Platform System Board[b] (n = 10)	Combination (n = 10)
Time-in-balance test	15.16 s	0 (0)	6 (18.75)	4 (33.33)	0 (0)	2 (20.00)
Foot-lift test	3 errors	2 (18.18)	12 (37.50)	3 (25.00)	2 (20.00)	7 (70.00)
Star Excursion Balance Test reach direction						
Anterior	5.33%	1 (9.09)	8 (25.00)	3 (25.00)	1 (10.00)	4 (40.00)
Anteromedial	3.82%	3 (27.27)	15 (46.88)	7 (58.33)	4 (40.00)	4 (40.00)
Medial	5.05%	1 (9.09)	20 (62.50)	7 (58.33)	7 (70.00)	6 (60.00)
Posteromedial	6.58%	3 (27.27)	23 (71.88)	10 (83.33)	6 (60.00)	7 (70.00)
Posterolateral	7.04%	5 (45.45)	21 (65.63)	8 (66.67)	5 (50.00)	8 (80.00)
Side-hop test	0.97 s	2 (18.18)	19 (59.38)	7 (58.33)	7 (70.00)	5 (50.00)
Figure-8 hop test	0.98 s	4 (36.36)	21 (65.63)	6 (50.00)	7 (70.00)	8 (80.00)
Foot and Ankle Ability Measure						
Activities of Daily Living subscale	10.68%	2 (18.18)	6 (18.75)	2 (16.67)	2 (20.00)	2 (20.00)
Sport subscale	9.51%	4 (36.36)	12 (37.50)	5 (41.67)	2 (20.00)	5 (50.00)
Cumberland Ankle Instability Tool	5 points	1 (9.09)	13 (40.63)	5 (41.67)	6 (60.00)	2 (20.00)

[a] Values represent the applicable number from the specified sample with accompanied percentage based on the total group sample size.
[b] Spectrum Therapy Products, LLC, Adrian, MI.