Clinical Research

Effect of Foot Orthotics on Single- and Double-Limb Dynamic Balance Tasks in Patients With Chronic Ankle Instability

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Abstract: *Deficits have been observed in patients with chronic ankle instability while performing dynamic balance tasks. Foot orthotic intervention has demonstrated improvements in static balance following lateral ankle sprain, but the effect is unknown in patients with chronic ankle instability during dynamic balance tasks. Twenty patients with self-reported unilateral chronic ankle instability volunteered for participation. They completed a familiarization session and 2 test sessions separated by 4 weeks. The familiarization session consisted of practice trials of the Star Excursion Balance Test (SEBT) and Limits of Stability (LOS) test, orthotic fitting, and the Cumberland Ankle Instability Tool (CAIT) questionnaire. Patients were instructed to wear the custom-fitted orthotics for at least 4 hours a day to a preferred 8 hours a day for the 4 weeks between sessions. There was an increase in distance reached in the posterolateral direction over the 4-week period in the orthotic condition. There was an increase in distance reached in the medial direction, demonstrating an improvement on the injured side in the orthotic condition after 4 weeks of orthotic intervention. No consistent, meaningful results were observed in the LOS. The involved leg had a significantly lower CAIT score than the uninvolved leg during both sessions, but the involved leg CAIT scores significantly improved over 4 weeks compared with the baseline measure. Orthotic intervention may prove beneficial for improving dynamic balance as measured by the SEBT in individuals with chronic ankle instability and may be a useful adjunct to clinical and sport interventions.*

Keywords: ankle instability; dynamic balance; orthotics

Injuries to the lateral ankle complex are among the most common in an athletic population.[1] Residual disability and pain are often present in patients after a lateral ankle sprain.[2] Chronic ankle instability (CAI) is a broad term used to describe the occurrence of repetitive ankle sprains and residual symptoms following lateral ankle sprain.[3] Patients with CAI are more prone to inversion injuries or the feeling of "giving way" during activities in which ankle-stable individuals would not have an injury.[4] CAI can occur regardless of mechanical ankle instability and has been attributed to alterations in static and dynamic postural control deficits.[5-8] Deficits in dynamic balance, as measured by the Star Excursion Balance Test (SEBT), have consistently been demonstrated in those with CAI.[5,6,8,9] However, differences in static single-limb stance measures between patients with chronic ankle instability and controls have not always been observed.[5] It has been theorized that static single-limb stance tasks may not challenge the postural control system such that identifiable differences between patients with unstable ankles and healthy individuals may be observed.[8,10] The SEBT is an inexpensive testing protocol that is purported to assess dynamic balance. The SEBT requires a patient to maintain stable single-limb stance while reaching with the non-weight-bearing foot. The farther the patient can reach without losing balance indicates the integrity of dynamic balance maintenance.

An instrumented test that assesses dynamic balance in double-limb stance is known as the Limits of Stability (LOS) test from the NeuroCom Balance Master (Clackamas, Oregon). In this test, patients maintain double-limb stance while swaying as far as possible without taking a compensatory step in 8 directions, similar

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to the SEBT. The LOS test provides information using a computerized force platform that requires patients to maintain upright bilateral stance while attempting to move the center of balance to the outermost directional boundaries. Diminished excursions toward the limits of stability and decreased directional control have been shown to be predictive of those who are at increased risk of ankle sprains.[11,12]

The Cumberland Ankle Instability Tool (CAIT) has been developed by Hiller et al[13] to measure self-reported functional deficits associated with CAI. The CAIT has been demonstrated to be a valid and reliable tool in quantifying self-reported functional deficits associated with CAI. Hiller et al[13] also proposed the CAIT to be useful for measuring rehabilitation or treatment progress and discriminating between ankles.

Foot orthotics have been used as an intervention that is placed in a person's shoe to reduce or eliminate biomechanical stresses to the foot or other portions of the lower kinetic chain.[14-17] It has been suggested that orthotic intervention following ankle sprain may place the subtalar joint in a more mechanically stable position and allow ligaments to heal at an optimal length.[18] Several investigators have demonstrated improvements in postural control during a single-limb stance and decreased pain in patients following acute lateral ankle sprain.[19-21] Foot orthotics also had a positive effect on resting standing foot posture in patients with a malaligned rearfoot over a 6-week period.[22]

To date, no studies have examined the effects of foot orthotics on dynamic balance, as measured by the SEBT and LOS over time. Therefore, our purpose was to determine the effect of orthotics following immediate application, as well as following a 4-week acclimation period, on self-reported function and the ability to maintain single-limb stance and double-limb stance dynamic balance tasks in patients with CAI. The knowledge obtained from this research will provide evidence of the effectiveness of orthotics as an intervention in patients with CAI. Our research hypotheses were that there would be an immediate improvement in SEBT reach distances on the injured limb but not the uninjured limb and that reach distances, as assessed with the SEBT, would increase following 4 weeks of orthotic use. In addition, we hypothesized that directional control and endpoint excursion measures of the LOS would improve. Concurrently, we hypothesized that there would be an improvement in self-reported function, as measured by the CAIT score following the 4-week intervention.

Methods

Patients

Twenty patients were recruited from a sample of convenience from the general community of a large public university. Patients' mean age, height, and weight were 24.15 ± 7.73 years, 170.33 ± 10.14 cm, and 75.25 ± 16.9 kg, respectively. The inclusion criteria for participation in this study were self-reported chronic ankle instability, including a history of more than 1 lateral ankle sprain and a recurrent feeling of giving way. Patients completed a health history questionnaire as well as the CAIT questionnaire to determine their inclusion. This questionnaire has been shown to be valid and reliable in detecting self-reported functional deficits associated with CAI. Exclusion criteria for all patients included an ankle sprain during the past 6 weeks, previous use of orthotics, any balance or vestibular disorder, any lower leg fracture within the past year, previous knee surgery, and/or current head injury. A consent form approved by the Institutional Review Board of our institution was read and signed by all participants.

Instrumentation

Foot orthotics were custom-fitted for each patient using a foam impression kit from Foot Management, Inc (Pittsville, Maryland). Neutral semirigid orthotics were fabricated from the mold formed with the impression kit. The NeuroCom Balance Master was used to perform the LOS test. The NeuroCom consists of a dual-force plate, integrated with a Dell computer (Dell Computer Corporation, Austin, Texas), a visual surround around the force plate, and a safety harness.

Procedure

Familiarization Session

All patients reported to the University of Kentucky Musculoskeletal Laboratory for orthotic fitting and familiarization of the SEBT and LOS. Participants read and signed an informed consent and completed a health history and CAIT questionnaire. If the participant met the inclusion criteria, they were fitted for orthotics, and their height, leg length, and weight were measured. Stretches for the quadriceps, hamstrings, and calves were demonstrated to each participant, and they were instructed to perform them before beginning the SEBT. Participants were then provided verbal instructions on how to perform the LOS and completed 3 practice trials.

Orthotic Construction

Participants were seated on a stool with their hips, knees, and ankles in a 90-degree flexed position. The examiner used a palpation method to determine subtalar joint neutral position (STJNP).[23] Once this position was determined, the examiner guided the foot downwards to the foam impression box. The participant was instructed to not apply any pressure and stay completely relaxed. The examiner pressed the heel into the foam and then the rest of the foot while maintaining STJNP. The same procedure was repeated for both feet.

Star Excursion Balance Testing

Performance of the SEBT was demonstrated to each participant by one of the examiners. The foot was aligned in the center of the asterisk design on the floor, and his or her reaching foot was placed down next to it. Participants were instructed to reach with their nonstance limb down the test line as far as possible while maintaining their hands on their hips and their stance heel on the ground. The examiner marked the point on the line where the most distal part of the foot touched, and that distance was measured from the center of the asterisk. Each participant performed 3 reaches for each of the 8 directions of the SEBT. A trial was discarded and repeated if a participant placed excessive weight on the reaching limb, removed the stance foot from the starting position, or lost balance. Reach distance was normalized to the participant's leg length in accordance to previously established methods. The mean of 3 trials for each direction was used for analysis. All participants performed the SEBT while wearing their usual athletic shoes (Figure 1).

Limits of Stability Test

The LOS is a double-limb stance task consisting of leaning the body in the same 8 directions as the SEBT (Figure 2). The participant was positioned on the NeuroCom according to the manufacturer's instructions. All participants were attached to the safety harness provided. The safety harness was attached to the participant and to the metal frame above the NeuroCom force plate. A computer monitor placed in front of the participant provided visual feedback of his or her center of gravity (COG) movement as a cursor in the center box on the screen. When instructed, participants leaned their body to displace their COG toward a given target. There were 8 targets around the COG in the same directions as the SEBT (Figure 3). Two practice trials were provided for the LOS test.

Testing Session 1

All participants reported back to the Musculoskeletal Lab when their orthotics were fabricated. They performed a 5-minute warm-up on a stationary bike and stretches for their quadriceps, hamstrings, and calves. The order of testing and shoe condition was randomly chosen for each participant. Participants completed 6 practice trials of the SEBT on each leg for each direction and then rested for 5 minutes.[24] Three test trials of the SEBT were then performed in each direction on each leg with a 10-second rest between each direction. The participant then performed 2 test trials of the LOS. The shoe condition was then changed, and the participant either removed or inserted orthotics.

Figure 1.

Demonstration of the posteromedial direction of the Star Excursion Balance Test.

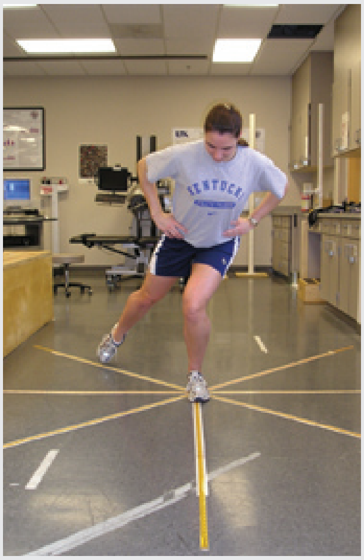
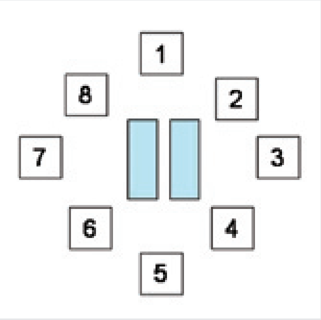


Figure 2.

The 8 directions of the Limits of Stability (LOS) test.



The same SEBT and LOS testing procedures were completed in the other shoe condition. Upon departure, participants were instructed to wear their orthotics in their shoes for at least 4 hours per day, acclimating to a maximum of 8 hours every day for 4 weeks.

Testing Session 2

All participants returned for their final testing session 4 weeks after the first session. Participants completed a follow-up CAIT questionnaire. The same testing procedures were performed as testing session 1, and the shoe condition and testing order were counterbalanced from the first session.

Figure 3.

Demonstration of the Limits of Stability (LOS) test, direction 2.

Design and Analysis

The SEBT research design consisted of 3 within-factors (time, limb, and orthotic) repeated-measures analyses of variance (ANOVAs) for each reach direction. Eight 2 × 2 × 2 ANOVAs were conducted for each reach direction. The independent variables were time (session 1 vs session 2), limb (injured vs uninjured), and condition (orthotic vs no orthotic). The dependent variable was normalized reach distance expressed as a percentage of each participant's leg length. The LOS research design consisted of 2 within-factors (orthotic and time) repeated-measures ANOVAs for all 4 dependent variables for each direction. Separate 2 × 2 ANOVAs were conducted for the 3 dependent variables of endpoint excursion, maximum excursion, and directional control for each test direction.

Figure 4.

Interaction between time, limb, and orthotic in the medial direction. The time 2 injured orthotic condition was significantly higher than all other conditions except for the time 2 uninjured no-orthotic condition. The time 1 uninjured no-orthotic condition was significantly lower than the time 2 injured no-orthotic condition, the time 2 uninjured orthotic condition, and the time 2 uninjured no-orthotic condition.

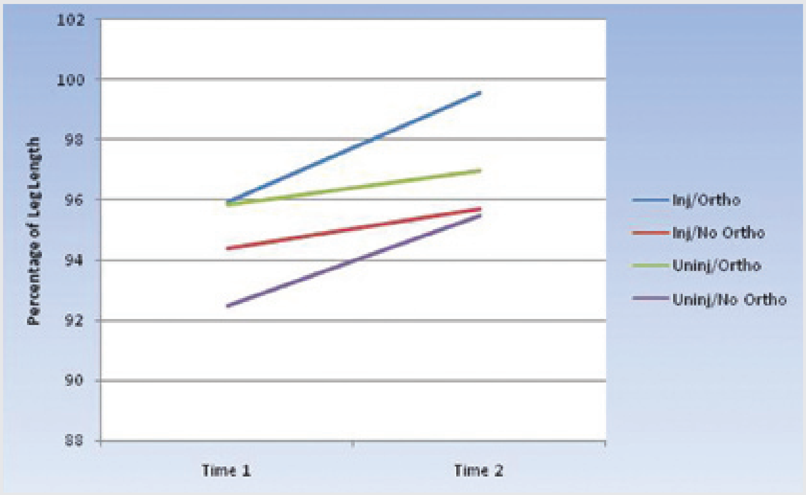
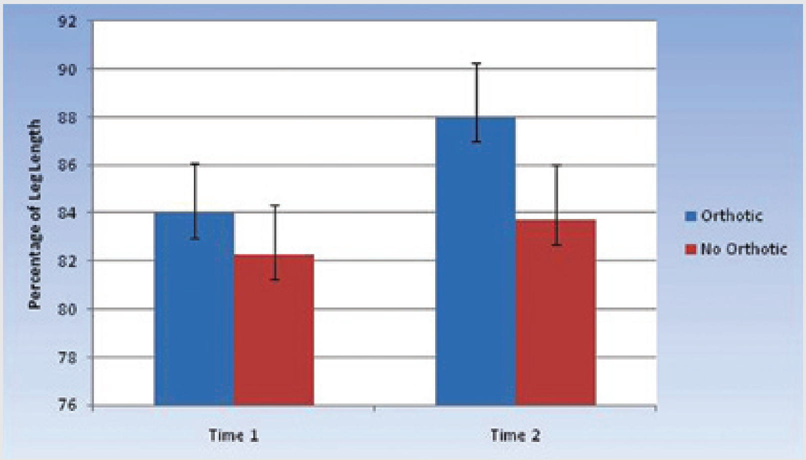


Figure 5.

Posterolateral direction interaction between time and orthotic. The time 2 orthotic condition was significantly higher than all other conditions ($P < .05$).



A 2 × 2 repeated-measures ANOVA was used to compare the CAIT scores between the involved and uninvolved extremities. The independent variables were time (session 1 vs session 2) and limb (injured vs uninjured). Tukey post hoc honestly significant difference (HSD) test was used to determine the minimum significant difference employed for all post hoc testing. An alpha level of $P \leq .05$ was determined to be statistically significant for all statistical comparisons.

Results

Star Excursion Balance Test

There was a 3-way interaction between time, limb, and orthotic for the medial direction (P = .023; Figure 4). The largest change over time occurred with the injured limb at time 2 while wearing orthotics. The time 2 injured limb orthotic condition reach distance (99.6 ± 9.7 cm) was significantly greater than all other conditions, except for the time 2 uninjured orthotic condition. The time 1 uninjured no-orthotic condition (92.5 ± 7.8 cm) was significantly less than all the time 2 conditions. The time 1 injured orthotic condition (95.9 ± 8.0 cm) was significantly greater than the time 1 uninjured no-orthotic condition (92.5 ± 7.8 cm). There was a significant increase between the time 1 uninjured no-orthotic condition (92.5 ± 7.8 cm) and the time 1 uninjured orthotic condition (95.9 ± 8.0 cm).

There was also a 3-way interaction in the anterolateral direction (P = .038). The time 1 uninjured no-orthotic condition was significantly higher than the time 1 injured no-orthotic condition (P = .05). The time 2 uninjured orthotic condition was significantly higher than the time 1 injured no-orthotic condition (P = .01).

In the posterolateral direction, a 2-way interaction between time and orthotic was observed. Time 2 with orthotics was significantly greater than time 1 with and without orthotics and time 2 without orthotics (Figure 5).

Significant main effects were observed over time in the posteromedial direction (P = .003) and the lateral direction (P = .038; Figure 6). Reach distances improved over time in these directions regardless of limb or condition.

Reach distances on the injured limb were significantly less than the uninjured limb in the posterolateral direction (P = .04) and the lateral direction (.033) when both testing sessions were pooled (Figure 7).

There were significant main effects for orthotics for the anterior, anteromedial, posteromedial, posterior, and lateral directions (Table 1). Reach distances for the orthotic conditions were greater than for the no-orthotic condition when both limbs and times were pooled.

Figure 6.

Main effect for time in the posteromedial, posterolateral, and lateral directions. Time 2 reach distances are significantly larger than time 1 in the posteromedial, posterolateral, and lateral directions.

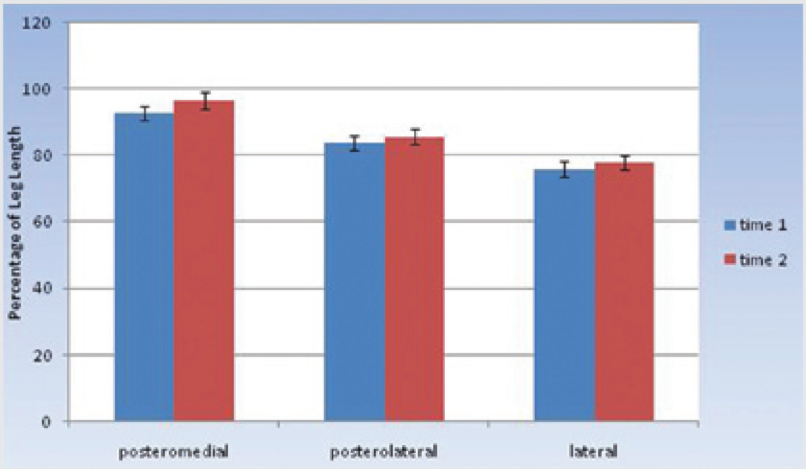
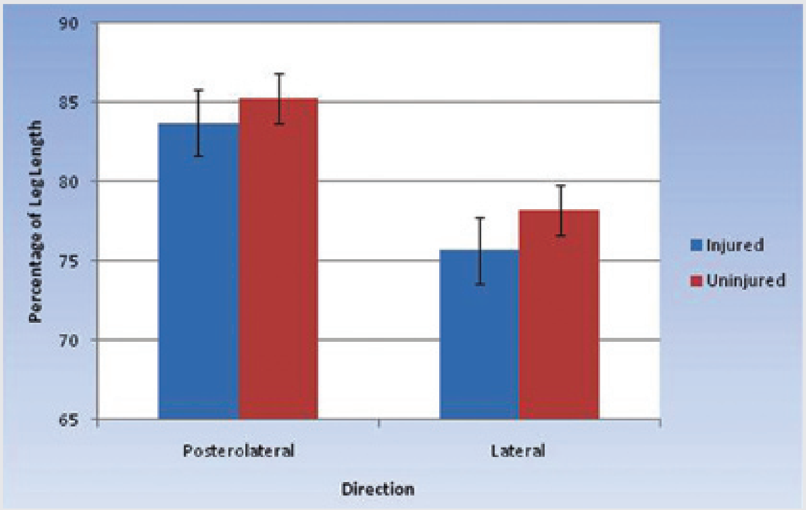


Figure 7.

Main effect for limb in the posterolateral and lateral directions. The uninjured leg reach distances were significantly greater than the injured reach distances in the posterolateral and lateral directions.



Limits of Stability

Maximum Excursion

There was a 2-way interaction between time and condition for direction 4. Tukey post hoc analysis revealed that the session 1 no-orthotic condition (95.95% ± 1.90%) was greater than the session 2 no-orthotic condition (91.6% ± 2.5%). Direction 5 also demonstrated a time-by-condition interaction in which the session 1 no-orthotic condition (80.1% ± 2.7%) was greater than the session 2 no-orthotic condition (74% ± 3.3%). In direction 1, the no-orthotic condition (73.3% ± 1.9%) was significantly greater than the orthotic condition (70.2% ± 1.9%; *P* = .007).

Directional Control

There was a 2-way interaction between time and condition for direction 2, revealing that the time 1 orthotic condition (82.4% ± 1.48%) was significantly greater than the time 2 orthotic condition (76.5% ± 2.6%). The time 2 no-orthotic condition (82.7% ± 1.6%) was also significantly greater than the time 2 orthotic condition (76.5% ± 2.6%).

Cumberland Ankle Instability Tool

There was a significant difference between the involved versus uninvolved extremity in sessions 1 and 2 (*P* = .001; Figure 8). CAIT scores for session 1 for the involved and the uninvolved ankle were 14.4 and 24.2, respectively. CAIT scores for session 2 for the involved and uninvolved ankle were 17.1 and 24.1, respectively. There was a significant improvement over time for the involved ankle (*P* < .05) between session 1 (14.03) and session 2 (17.1). There was no difference for the uninvolved ankle between session 1 and session 2 (*P* > .05).

Discussion

The results observed in our study demonstrate that orthotics may be effective in improving performance of the SEBT in certain directions, including the anterolateral, posterolateral, and medial directions in patients with ankle instability.

Participants performed significantly better with orthotics at time 2 then any other condition for the posterolateral direction (Figure 5). We feel that the orthotic provided structural support to the medial arch and allowed for more control and increased reach distances when moving from supination to pronation as the foot does during the posterolateral directions due to a shift in body weight to the support foot.

We observed a significant main effect for time in the posteromedial, posterolateral, and lateral directions (Figure 6). A 3-way interaction for the medial direction

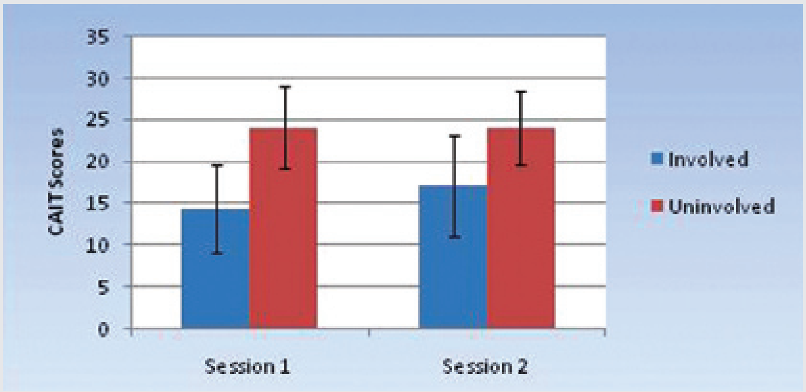
Table 1.

Descriptive Data for Orthotic Conditions in the Star Excursion Balance Test When Side and Time Were Pooled

Direction	Condition	Mean	Standard Error	*F*	Significance Level
Anterior	No orthotic	93.28	0.74	10.691	.004
	Orthotic	94.6	0.777		
Anteromedial	No orthotic	96.8845	0.809	8.965	.007
	Orthotic	98.496	1.002		
Medial	No orthotic	94.517	1.651	21.026	.001
	Orthotic	97.079	1.72		
Posteromedial	No orthotic	93.581	2.163	22.072	.001
	Orthotic	95.76	2.1		
Posterior	No orthotic	88.464	2.412	26.15	.001
	Orthotic	90.874	2.219		
Posterolateral	No orthotic	82.972	2.127	27.001	.001
	Orthotic	85.997	2.059		
Lateral	No orthotic	75.355	2.092	23.619	.001
	Orthotic	78.597	1.897		
Anterolateral	No orthotic	79.277	1.11	4.748	.042
	Orthotic	80.432	1.22		

Figure 8.

Main effect for session and limb for the Cumberland Ankle Instability Tool (CAIT) scores. There was a significant difference between the involved versus uninvolved extremity in sessions 1 and 2 ($P = .001$). There was a significant improvement over time for the involved ankle ($P < .05$) between session 1 and session 2.



demonstrated that the session 2 injured orthotic condition was significantly greater than all other conditions, except for the session 2 uninjured orthotic condition (Figure 4). These findings suggest that following the intervention with orthotics, participants were able to increase reach distances in certain directions when performing the tasks while wearing the orthotics. There is a lack of previous research investigating the effects of orthotics over time on dynamic balance measures, so a direct comparison is not possible. However, Olmsted and Hertel[25] found significant increases in reach distances with orthotic intervention over a 2-week period in patients with cavus feet in the anterolateral, lateral, and posterolateral directions. The authors proposed that increased medial support to the arch may provide enhanced plantar cutaneous sensation. This increased sensation may increase efferent activity and enhance neuromuscular control, leading to increases in reach distances.[25] These findings are similar to our results in that improvements were observed in the posterolateral and lateral directions over time with the orthotic intervention. Hale et al[26] observed improvements with rehabilitation in patients with CAI compared with CAI control participants and healthy participants in the posteromedial, posterolateral, and lateral directions. We observed a main effect for orthotics in every direction when both limbs and times were combined. Reach distances were greater in the orthotic condition when compared with the no-orthotic condition in all directions (Table 1). There are several postulated reasons why the orthotics may have improved the ability to reach while performing the SEBT. We feel that the medial support may have provided stability and somatosensory feedback such that participants were able to perform better with the use of orthotics than without the use of orthotics. The lateral reaching directions require the stance leg to maintain stability while the reaching leg actually reaches behind the stance leg to the opposite side of the body. This movement requires the stance foot to pronate and dorsiflex in relation to the tibia to maintain balance. If subtalar instability is present, the added support to the medial portion of the foot provided by the orthotic helps to stabilize the foot and provide sensory afferent feedback. The orthotic may also allow for more diffuse pressure of the foot,[23] which would explain the increased reach distances in all directions. Most patients with CAI learn to adopt strategies to maintain their balance. This could include placing more pressure on their first metatarsophalangeal (MTP) joint and toes. Placing a custom orthotic in the patient's shoe allows for more contact of the foot to the ground and spreads out the forces, allowing for a more stable base of support and the ability to reach further during the SEBT.

During session 1, there was a significant difference observed between limbs in the anterolateral direction. Reach distance was significantly less for the injured side in the anterolateral direction when compared with the uninjured side. However, after 4 weeks of orthotic use, this difference between sides was reduced and was nonsignificant. The difference observed in this direction were not in agreement with previously reported data by Hertel et al,[7] who observed decreased reaches in the anteromedial, medial, and posteromedial directions in patients with CAI compared with their uninjured side and a matched control. Hale et al[26] observed significant differences between injured and uninjured limbs in the posteromedial, posterolateral, and lateral directions. Cote et al[27] observed that patients with supinated feet had increased reach distances in the lateral and posterolateral directions when compared with pronators. They attribute this finding to mechanical or neuromuscular advantages or disadvantages resulting from joint range of motion present in different foot types.[27] It is possible that patients with CAI have a neuromuscular disadvantage due to articular deafferentation[28] or decreased proprioception that limits their reach ability in these directions, but it is not clear why we found differences in the anterolateral direction when compared with previous studies. Therefore, the difference in the anterolateral direction may be a spurious finding as we compare our findings with others.

> "Potentially, an orthotic intervention may be used in conjunction with rehabilitation programs to improve outcomes for those individuals with CAI."

Limits of Stability

Review of the LOS results only demonstrated one consistent interaction between time and orthotic for the maximum excursion variable. The time 1 no-orthotic condition was significantly greater than the time 2 no-orthotic condition in directions 4 and 5. This finding is difficult to interpret and may be due to a spurious effect as there were no consistent orthotic effects in any of the other variables or directions. This may be due to the fact that the LOS is a double-limb stance task, and patients may have been able to compensate for any deficits that exist in the injured limb during double-limb stance. This would indicate that the LOS does not adequately challenge the sensorimotor system to detect postural control deficits in patients with unilateral CAI. Therefore, assessing the ability to move the COG in directions using the LOS test may not be clinically useful to determine difference in patients with CAI.

Cumberland Ankle Instability Tool

Hiller et al[13] define an unstable ankle with a score ≤24 on the CAIT. Our participants had an average score of 14.4 on the involved leg in session 1, whereas the uninvolved leg scored 24.2. There was an improvement over time in the involved ankle during the 4 weeks that participants wore the orthotics. However, the scores were still below the cutoff score of 24 used to discriminate between stable and unstable ankles.[13,29] The CAIT is designed to classify patients with CAIT and to be used to measure treatment and rehabilitation progress.[13] Our results support that the CAIT was useful in documenting improvement in the involved ankle with the orthotic intervention. Although the involved ankle improved over 4 weeks, it was still remained below the cutoff score or 24. Therefore, our intervention provided an improvement over time with the realization that the ankle is still unstable according to this subjective evaluation.

Clinical Significance

Our results support that orthotic invention can improve performance on the SEBT in patients with CAI. Whether these improvements transfer to more functional activities is unclear. Our results indicate that self-reported function is improved as measured by the CAIT following a 4-week orthotic intervention. However, the magnitude of the improvement did not change the status of those with CAI. Specifically, individuals with CAI were classified as having a self-reported functional deficit as assessed via the CAIT even after 4 weeks of wearing custom-fitted orthotics.

Potentially, an orthotic intervention may be used in conjunction with rehabilitation programs to improve outcomes for those individuals with CAI.

Limitations

Our lack of a control group is a limitation to this study. However, previous research has demonstrated significant differences between injured and uninjured sides in patients with CAI,[8,26] and therefore, we felt that a within-subject comparison would provide a sufficient model.

Conclusion

Our findings demonstrate that foot orthotics are effective in improving reach distances during the SEBT in patients with CAI over time but have no effect on the LOS variables. The CAIT scores also improved over time in the involved ankle with orthotic intervention. Our findings support the use of orthotics as an adjunct in the rehabilitation protocol for individuals with CAI.

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The University of Kentucky Institutional Review Board approved the protocol for this investigation.

We affirm that we have no financial affiliation or involvement with any commercial organization that has a direct financial interest in any matter included in this manuscript, except as cited in the manuscript. FAS

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