Dynamic Postural Stability in Females with Chronic Ankle Instability

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ABSTRACT

BROWN, C. N., B. BOWSER, and A. ORELLANA. Dynamic Postural Stability in Females with Chronic Ankle Instability. *Med. Sci. Sports Exerc.*, Vol. 42, No. 12, pp. 2258–2263, 2010. **Purpose**: To determine whether females with chronic ankle instability (CAI) demonstrated decreased dynamic postural stability compared with controls in the anterior, lateral, and medial jump directions. **Methods**: Individuals with CAI (n = 24) reported a history of moderate to severe ankle sprain, two or more episodes of giving way in the past year, and decreased ankle function. The control group (n = 24) reported one or no previous mild to moderate ankle sprain, no episodes of giving way, and no decrease in ankle function. Maximum vertical jump height was measured in the anterior, lateral, and medial directions. Participants jumped at 50% maximum height in the three directions, landed on the involved limb, and balanced for 10 s. Ground reaction forces were collected at 1200 Hz and filtered. Stability indices for anterior–posterior, medial–lateral, and vertical and a composite index were calculated. Independent-samples t-tests compared groups on demographic data and stability indices in three jump directions, with α = 0.05. **Results**: The CAI group demonstrated significantly higher vertical (0.34 ± 0.04 vs 0.32 ± 0.03) and composite stability index scores (0.36 ± 0.04 vs 0.34 ± 0.03) in the anterior jump direction compared with the control group. Lateral jumps had similar results for vertical (0.33 ± 0.05 vs 0.30 ± 0.03) and composite scores (0.36 ± 0.04 vs 0.33 ± 0.03). **Conclusions**: Females with CAI demonstrated stability deficits compared with control group in the anterior and lateral jump directions. Multiple jump directions may be necessary to adequately capture dynamic stability measures. **Key Words:** TIME TO STABILIZATION, FUNCTIONAL ANKLE INSTABILITY, DYNAMIC POSTURAL STABILITY INDEX, STABILITY DEFICIT

Lateral ankle sprains are one of the most common sports-related injuries (10). A significant percentage of those who sprain their ankle will develop chronic ankle instability (CAI), defined as repeated, subjective episodes of giving way and spraining at the ankle, coupled with decreased self-reported function (13). Female athletes may be at a greater risk for ankle sprains than their male counterparts. Female youth soccer players had a 6% higher risk of lateral ankle sprains (18), whereas female high school and college basketball players had 25% greater risk of ankle sprain than males (17). In addition, data from the National Collegiate Athletics Association Injury Surveillance System indicate that females have a higher rate of ankle sprains than men in lacrosse and soccer (16).

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This increase in injury rate could be attributed to increased or improperly controlled landing forces and deficits in dynamic postural control (30). Neuromuscular control, as measured by dynamic postural stability, is important in maintaining joint stability (25). Measures of dynamic stability include time to stabilization (20) and the dynamic postural stability index (DPSI) (28,31). Both techniques measure ground reaction forces and determine how well an individual can accommodate forces during a single-leg landing (20,28,31).

The single-leg landing task is thought to be functional and demanding because it replicates sports activity and requires strength, proprioception, and neuromuscular control (23). DPSI is thus thought to quantify those abilities and indicate an individual's ability to maintain balance while transitioning from a dynamic to a static state as a functional measure of neuromuscular control (31). Stability indices are calculated in the anterior–posterior (APSI), medial–lateral (MLSI), and vertical directions (VSI). A composite measure is also calculated combining the three directions (DPSI). The stability indices are the mean square deviations around a zero point and measure fluctuations from stable (or no movement) points (29,31). Increased values indicate difficulty stabilizing the center of mass while transitioning from a dynamic to a static state (31). Differences in stability index scores have been demonstrated between individuals with CAI and controls (28), and it is a reliable and precise measure (30).

Stability index scores have been used in previous studies measuring time to stabilization, and DPSI used similar jump landing protocols: participant's maximum vertical jump height was measured using an anterior jump direction. Then, participants jumped in the same manner at 50% of their maximum height with a single-leg landing for data collection (3,20,28,29). Previous protocols used only an anterior jump direction (3,20,28,29). It is unclear if differences in dynamic stability exist if jump direction is changed. Movement in the frontal plane is common in sports and may be relevant for identifying stability deficits and for developing targeted rehabilitation programs. Previous research has identified differences in DPSI scores among anterior, lateral, and diagonal jump directions in healthy male and female control subjects (31), but it is unknown if individuals with CAI demonstrate stability deficits in jump directions other than anterior. Thus, the purpose of this study was to determine whether females with CAI demonstrated decreased dynamic postural stability compared with controls in different jump directions. We hypothesized that the CAI group would demonstrate larger DPSI scores than the controls in all three jump directions.

METHODS

Participants. Using tabled data from previous research, *a priori*–estimated sample sizes for a power of 0.80 were calculated. A study comparing controls to a CAI group indicated that a power of 0.80 could be accomplished with groups of 8–10 for APSI and DPSI for anterior jumps (29). A similar study indicated that a sample size of 26 per group was necessary for a power of 0.80 with APSI, VSI, and DPSI (28). Another study comparing jump direction indicated that 12–20 participants were needed for sufficient power in MLSI (31). On the basis of these calculations and previous studies with females, we estimated a sample size of 24 per group would be adequate for our study.

Participants were 18–35 yr old and were recreationally active, defined as performing at least 1.5 h of physical activity per week. Participants were recruited and placed into groups on the basis of selected criteria. Table 1 reports demographic data. The inclusion criterion for the CAI group was a history of at least one lateral moderate to severe ankle sprain requiring at least 3 d of immobilization or non–weight bearing, with at least two episodes of giving way in the last year (2,29). Control participants reported no more than one mild to moderate sprain in their lifetime and did not complain of repeated episodes of giving way. If control participants reported previous ankle sprain, they had returned to full activity for ≥12 months after the sprain before testing and were thus operationally defined as not having CAI. The CAI group self-reported 3.4 ± 2.4 sprains or episodes of giving way in the last 12 months, whereas the control group reported 1.0 ± 0.88 sprains or episodes of giving way in their lifetime. If the CAI participants complained of bilateral instability, the leg with the greater number of previous sprains was tested. The exclusion criterion for all participants was adiagnosis of a vestibular or balance disorder, Charcot–Marie–Tooth disorder, or other neurologic disorder. The exclusion criteria also included history of fracture or surgery in either leg, swelling, pain or discoloration at the ankle at testing, or another lower extremity injury in the last 3 months (2).

Testing procedure. Participants were recruited via flyers and announcements and completed a written informed consent as approved by the institutional review board. Demographic data were recorded, limb dominance was assessed (15), active ankle range of motion was measured (19), and participants completed the Cumberland Ankle Instability Tool (CAIT) (14). CAI and control participants were matched on test limb dominance, age (±2 yr), and height and weight (±10%) (2). Participants wore their own low-top shoes in which they were recreationally active. Participants were allowed a 10-min warm-up, including 5 min of stationary biking at a self-selected pace and 5 min of self-directed stretching. Once warm-up was complete, maximum vertical jump height was measured as previously reported (20). Participants took off with two legs using whatever arm motions desired, jumped as high as they could, and touched the flags of a vertical jump height measure (Vertec; Sports Imports, Columbus, OH), with the reaching arm's shoulder fully extended (3,20). The best height out of three trials was used. The procedure was repeated for the other two jump directions. Testing began, and the order of jump direction was randomized. The 50% height of the first direction's maximum vertical jump was calculated and set on the Vertec, adding 5% above the 50% mark to provide a target jump height range (20). Participants were instructed to stand 70 cm from the center of an inground force platform, take off with two feet, fully extend one arm and touch the target range markers, and then land on the test leg only with the test foot entirely on the force platform (20). Participants were asked to stabilize as quickly as possible and balance for 10 s. Participants completed at

TABLE 1. Participants' demographics.

						50% Jump Height (cm)			Range of Motion (°)			
	n	Age (yr)	Height (cm)	Weight (kg)	CAIT Score	Anterior	Medial	Lateral	Plantarflexion	Dorsiflexion	Inversion	Eversion
CAI	24	20.0 (1.3)	168.5 (6.0)	64.7 (8.4)	18.9 (3.4)[a]	17.1 (3.4)	15.5 (5.2)	16.1 (3.3)	65.6 (6.9)	5.1 (3.4)[a]	16.1 (4.7)	8.1 (3.2)
Control	24	20.3 (1.0)	166.2 (5.7)	61.6 (8.0)	27.0 (3.6)	17.9 (4.0)	15.3 (3.8)	16.1 (3.6)	63.0 (6.1)	7.1 (2.5)	17.0 (5.2)	7.6 (1.9)

[a] CAI was significantly lower score than control ($P < 0.05$).

$$APSI = \sqrt{[\Sigma(0-Y)^2/\#\,data\ points]}$$

$$MLSI = \sqrt{[\Sigma(0-X)^2/\#\,data\ points]}$$

$$VSI = \sqrt{[\Sigma(1.0-Z)^2/\#\,data\ points]}$$

$$DPSI = \sqrt{[\{\Sigma(0-X)^2 - \Sigma(0-Y)^2 - \Sigma(1.0-Z)^2\}/\#\,data\ points]}$$

FIGURE 1—Equations used to calculate stability indices. *y*-axis is anterior–posterior ground reaction force, *x*-axis is medial–lateral, and *z*-axis is vertical, all normalized to body weight.

least 3 practice trials and 10 successful test trials, with 1 min of rest between trials. A successful trial was defined as taking off 70 cm from the center of the platform, touching the target range with the shoulder fully extended, landing on the test leg with the foot entirely on the force platform, and not moving or sliding the foot after landing (20). Unsuccessful trials were discarded. The testing procedure was then repeated for the other two jump directions with 5 min of rest in between directions while the Vertec was adjusted and moved accordingly.

Data processing. An AMTI force platform (OR-6-6-0; Advanced Medical Technologies, Inc., Watertown, MA) was used to collect ground reaction force data at 1200 Hz. The global reference system was set so the anterior–posterior was in the *y*-axis direction, medial–lateral was in the *x*-axis, and vertical was in the *z*-axis direction. Analog-to-digital conversion was performed and stored on a PC using Vicon Workstation (version 5.2.4; Vicon Motion Systems Ltd., Oxford, UK). Raw ground reaction force data were exported and reduced in MatLAB (version 7.0; the MathWorks, Natick, MA). A fourth-order recursive low-pass Butterworth filter was applied with a cutoff frequency of 200 Hz on the basis of the frequency analysis. Forces were scaled to body weight. The first 3 s of data after initial contact (defined as >10 N vertical ground reaction force) was analyzed. Unitless stability index scores were calculated for APSI, MLSI, and VSI directions, along with a composite stability index (DPSI), according to previously published guidelines (Fig. 1) (28). The force plate data were normalized to body weight, so fluctuations around the anterior–posterior and medial–lateral axes are around 0, and fluctuations around the vertical are 1 or body weight (31).

Data analysis. Data analysis was performed via SPSS (version 18.0; Statistical Package for the Social Sciences, Chicago, IL). Preliminary independent-samples *t*-tests at $\alpha = 0.05$ were used to determine whether group differences existed in the demographic data (age, height, weight, CAIT score, jump height, and test ankle range of motion). Independent-samples *t*-tests at $\alpha = 0.05$ were then used to determine whether group differences existed in the APSI, MLSI, VSI, or the composite DPSI scores in each jump direction. Table 2 presents the means, SD, effect size (Cohen's d), power, and 95% confidence intervals for marginal means and effect sizes.

RESULTS

There were no group differences in any demographic data, jump height in any direction, or test ankle active plantarflexion, inversion, and eversion range of motion ($P > 0.05$) (Table 1). The CAI group scored significantly lower on the CAIT than the control group, indicating decreased ankle joint function in the test limb (Table 1). The CAI group also demonstrated significantly less ankle dorsiflexion range of motion than the control group (Table 1).

In the anterior jump direction, the CAI group demonstrated significantly greater VSI and DPSI scores than the

TABLE 2. Independent-samples *t*-test for stability indices in three jump directions.

Jump Direction	Stability Indices	Group	Mean (SD)	95% Confidence Interval for Mean		*P*	Power	Effect Size	95% Confidence Interval for Effect Size	
				Lower Limit	Upper Limit		(1 − *b*)	(Cohen's *d*)	Lower Limit	Upper Limit
Anterior	APSI	CAI	0.11 (0.01)	0.10	0.11	0.96	0.05	0.00	−0.57	0.57
		Control	0.11 (0.01)	0.10	0.11					
	MLSI	CAI	0.03 (0.01)	0.03	0.04	0.63	0.08	0.00	−0.57	0.57
		Control	0.03 (0.01)	0.03	0.04					
	VSI	CAI*	0.34 (0.04)	0.33	0.36	0.04	0.56	0.57	−0.02	1.13
		Control	0.32 (0.03)	0.30	0.34					
	DPSI	CAI*	0.36 (0.04)	0.35	0.38	0.04	0.56	0.57	−0.02	1.13
		Control	0.34 (0.03)	0.32	0.35					
Lateral	APSI	CAI	0.11 (0.01)	0.10	0.11	0.32	0.16	1.00	0.38	1.58
		Control	0.10 (0.01)	0.10	0.11					
	MLSI	CAI	0.04 (0.01)	0.05	0.05	0.50	0.10	−1.00	−1.58	−0.38
		Control	0.05 (0.01)	0.05	0.05					
	VSI	CAI*	0.33 (0.05)	0.31	0.35	0.04	0.53	0.73	0.13	1.30
		Control	0.30 (0.03)	0.29	0.32					
	DPSI	CAI*	0.35 (0.05)	0.33	0.37	0.04	0.53	0.49	−0.10	1.05
		Control	0.33 (0.03)	0.31	0.34					
Medial	APSI	CAI	0.11 (0.01)	0.10	0.11	0.29	0.18	1.00	0.38	1.58
		Control	0.10 (0.01)	0.10	0.11					
	MLSI	CAI	0.05 (0.01)	0.05	0.06	0.94	0.05	0.00	−0.57	0.57
		Control	0.05 (0.01)	0.05	0.06					
	VSI	CAI	0.34 (0.04)	0.32	0.35	0.18	0.27	0.57	−0.02	1.13
		Control	0.32 (0.03)	0.31	0.34					
	DPSI	CAI	0.35 (0.04)	0.34	0.37	0.16	0.29	0.28	−0.29	0.85
		Control	0.34 (0.03)	0.33	0.36					

control group (Table 2). In the lateral jump direction, the CAI group also demonstrated significantly greater VSI and DPSI scores than the control group. There were no other group differences in the anterior–posterior or the medial–lateral index scores in the anterior and lateral jumps and no group differences in any stability index scores in the medial jump direction.

DISCUSSION

The most important finding of this study was that the CAI group demonstrated statistically significantly greater VSI and DPSI scores than the control group in the anterior and lateral jump directions. This indicates that the CAI group had decreased postural stability in both jump directions. Our hypotheses were partially supported in that the CAI group did demonstrate decreased dynamic stability (increased stability index scores) compared with the control group in selected tasks. Our hypotheses were not supported in that there were no differences in dynamic stability between the CAI and the control groups in the medial jump direction and there were no group differences in the APSI and MLSI in the anterior or lateral jump directions.

Numerous publications have reported that individuals with CAI demonstrate decreased postural stability compared with control groups, as evidenced by a longer time to stabilization or greater stability index scores in the anterior jump directions (1,3,20,23,28,29). Our study supports these findings for the most part. Previous studies reported increased DPSI (28,29) and VSI (28) compared with controls in anterior jumps. This matches our results in the anterior and lateral directions. Overall, our values for the directional and composite stability index scores were close to those previously reported values (28,29). A previous study on controls reported increased VSI scores in an anterior jump compared with a lateral jump, which our results support, although we did not make that comparison (31). These greater stability index scores in CAI participants may be attributable to laxity or damage in the anterior talofibular ligament. The anterior talofibular ligament is the most commonly injured of the lateral ankle joint ligaments and has the lowest load to failure (24). An *in vivo* study of physiologic loading in patients with "lateral ankle instability" reported that anterior talofibular ligament deficiency increased anterior translation of the talus during an anterior step (4). The authors attributed the increased anterior translation to the orientation of the ligament, which indicates that it normally restricts the anterior translation of the lateral side of the talus but would be unable to accomplish that when damaged (4). An anterior jump would likely load the anterior talofibular ligament similar to the anterior step, and the ligament may be unable to accommodate the rapid rise in forces during landing in the CAI population. Increased anterior translation of the talus may play a role in increasing DPSI scores. This situation may also occur in the lateral jump because we report similar findings to the anterior jump, but to our knowledge, there are no *in vivo* studies that could support that assertion.

We did not find differences in APSI scores, which do not support the previous literature (27,28). Other research, using time to stabilization instead of DPSI, also reported that CAI groups demonstrated longer AP times (3,20–22). Our results do not support these findings, but differences in collecting and in calculating DPSI, participants' degree of instability, and equipment could explain the lack of agreement. For example, our higher collection rate for ground reaction forces could have led to higher peak values, thus increasing DPSI. A previous study indicated that DPSI scores were not changed when sampling rate was at 200, 500, or 1000 Hz (32); however, our range was higher than that.

Our findings in the lateral jump direction were similar to those in the anterior direction. The lateral jump may warrant inclusion in dynamic postural stability testing because it generated group differences. It could be more challenging than anterior jumps for frontal plane motion (31). A previous study assessing the influence of jump direction on DPSI scores in healthy individuals indicated that lateral and diagonal jump directions produced increased MLSI scores compared with anterior jump directions (31). Although we did not test for differences between jump directions, on average between the groups, our participants also demonstrated greater MLSI scores in the lateral jump direction compared with the anterior jump direction, supporting previous results in controls (31). We hypothesized that the CAI group would have greater MLSI scores in the lateral jump direction, but our results did not support this. Previous research has reported that MLSI scores were not significantly different between CAI and control groups in an anterior jump (29), supporting our results. However, other studies reported medial-lateral time to stabilization was greater in the CAI group than in the control group during an anterior jump (20,21). Our stability score values are similar to those reported in a previous study in which the equations and data processing procedures closely match (29). The lack of precise agreement and some variability in range of values could be due to the differences in stability indices' calculation, instrumentation, testing procedures, collection rate, filtering, and participants' degree of instability.

We did not find differences between groups in any stability index scores in the medial jump direction. In the medial jump, participants displayed similar VSI scores to an anterior jump, but they displayed greater MLSI scores than the anterior jump. Because no differences were revealed, this jump direction may not need to be included in the dynamic stability testing.

The differences we observed in DPSI scores may be due to the centrally mediated changes that influence neuromuscular control (11). CAI could be viewed as a constraint to the sensorimotor system, and individuals with CAI may be unable to adopt a movement strategy to deal with an unstable or dynamic landing situation (2), thus increasing the time needed to stabilize after landing. Applying nonlinear

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dynamics theory, individuals with CAI may lack the flexibility to adopt a motor program to a changing situation such as dynamic postural stability testing (29). Previous research has demonstrated that only the involved limb in CAI participants demonstrated decreased knee flexion at initial contact from a jump landing and increased anterior–posterior time to stabilization (11). The authors interpreted this finding as a pattern stemming from the central nervous system affected by CAI (11). In addition, decreases in the center of pressure excursion during gait initiation were attributed to the centrally mediated changes to motor control (12). Another study reported differences in hip rotation in the CAI group and attributed the differences to neuromuscular impairments and central neural adaptations to distal joint injury (9). The feedback and feed-forward control capability could be compromised in individuals with CAI, leading to repetitive injury (1,26). Control of the ankle during activity is attributed to an "interplay" between the central nervous system and peripheral feedback, not reflex control, thus underlining the importance of precontact movement (7). We may interpret our findings, when coupled with other research, as evidence for this centrally mediated change in CAI participants. However, we cannot make that claim directly because we did not collect bilateral data to make the comparison directly. Motion analysis may assist with this undertaking.

Several previous studies used motion analysis during jump landings to determine whether motion patterns may influence stability and episodes of giving way. Several studies have reported differences in CAI groups compared with controls in ankle kinematics (7–9), knee kinematics (7), hip kinematics (9), as well as ground reaction forces (GRF) (5,6,8,9) and ankle muscle activity (5,8,9). Altered kinematics, kinetics, muscle activity, and ground reaction forces may influence landing mechanics and lead to decreased dynamic stability. However, there are no consistent patterns between studies with similar jump landing tasks. Only one study to date seems to have combined stability measures with kinematics (11). In this case, the CAI group demonstrated decreased knee flexion at initial contact, as well as decreased dynamic stability compared with controls (11). Thus, it seems there may be a link between landing movement patterns and decreased stability.

The clinical application of this study is that incorporating other jump directions into dynamic postural stability testing may reveal deficits in neuromuscular control, better assess effects of multiplanar rehabilitation strategies, and better assess the participants' ability to stabilize in more chaotic real-life environments. Clinicians may need to address landing strategy and the ability to return to a steady state of balance by adapting to demanding situations. Rehabilitation may need to address motor programming.

The limitations of this study include subjects and sample size. We included only females, and this may not generalize the results to males. The sample size could be increased, which would likely increase the power observed. However, the effect sizes for APSI in the lateral and medial jumps and for MLSI in the lateral jumps were large, with 95% confidence intervals that did not cross zero. Despite not finding statistical significance at the 0.05 level, the effect sizes may indicate differences in these directions that are clinically relevant. Alternately, for VSI and DPSI in the anterior and lateral directions, where we did note statistically significant differences between the groups, we observed only medium effect sizes. In addition, the 95% confidence intervals for those effect sizes all crossed zero, except for VSI in the lateral jump direction. This may indicate that these differences are not particularly strong or clinically relevant.

It is difficult to compare our research with previous studies because slightly different inclusion and exclusion criteria were used, along with different data collection and processing methods. Participants likely exist along a continuum of instability and may display more or less disability than participants in other studies. This is evidenced by the difference in self-reported number of sprains and scores on functional questionnaires. We used the CAIT questionnaire to determine the level of ankle dysfunction (14), a valid and reliable instrument. Previous studies have used other questionnaires, such as the Foot and Ankle Disability Index (11) or the Ankle Joint Functional Assessment Tool (22). Other studies used injury criteria and complaints of giving way only (6,9). Although the inclusion and exclusion criteria are similar in many regards, there are differences in the level of function with various activities and wide ranges in the number of episodes of giving way. There are many different ways to measure dynamic postural stability, and the best measure is yet to be established. Future research should continue to incorporate kinematics and EMG with dynamic postural stability to help identify mechanism(s) that may be contributing to instability at landing. Identifying those mechanisms could help develop targeted rehabilitation programs. Finally, the relationship between injury risk and DPSI should be identified to bolster this technique in clinical practice.

CONCLUSIONS

The CAI group demonstrated greater VSI and DPSI scores than controls in both the anterior and lateral jump directions. Anterior jumps seem to be appropriate for stability testing, although lateral jumps may also be important and useful because they also demonstrated differences. The medial jump does not seem to delineate group differences in dynamic postural stability, and likely, it would not need to be incorporated into stability testing protocols.

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