2015

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Matthew C. Hoch
Old Dominion University

Kelley E. Farwell
Old Dominion University

Stacey L. Gaven

Joshua T. Weinhandl
Old Dominion University

Original Publication Citation

Hoch, M. C., Farwell, K. E., Gaven, S. L., & Weinhandl, J. T. (2015). Weight-bearing dorsiflexion range of motion and landing biomechanics in individuals with chronic ankle instability. *J Athl Train, 50*(8), 833-839. doi:10.4085/1062-6050-50.5.07

Journal of Athletic Training 2015;50(8):833–839
doi: 10.4085/1062-6050-50.5.07

www.natajournals.org

original research

Weight-Bearing Dorsiflexion Range of Motion and Landing Biomechanics in Individuals With Chronic Ankle Instability

Matthew C. Hoch, PhD, ATC*; Kelley E. Farwell, MSEd, ATC*; Stacey L. Gaven, PhD, ATC†; Joshua T. Weinhandl, PhD*

*Old Dominion University, Norfolk, VA; †Franklin College, IN

Context: People with chronic ankle instability (CAI) exhibit less weight-bearing dorsiflexion range of motion (ROM) and less knee flexion during landing than people with stable ankles. Examining the relationship between dorsiflexion ROM and landing biomechanics may identify a modifiable factor associated with altered kinematics and kinetics during landing tasks.

Objective: To examine the relationship between weight-bearing dorsiflexion ROM and single-legged landing biomechanics in persons with CAI.

Design: Cross-sectional study.

Setting: Laboratory.

Patients or Other Participants: Fifteen physically active persons with CAI (5 men, 10 women; age = 21.9 ± 2.1 years, height = 168.7 ± 9.0 cm, mass = 69.4 ± 13.3 kg) participated.

Intervention(s): Participants performed dorsiflexion ROM and single-legged landings from a 40-cm height. Sagittal-plane kinematics of the lower extremity and ground reaction forces (GRFs) were captured during landing.

Main Outcome Measure(s): Static dorsiflexion was measured using the weight-bearing–lunge test. Kinematics of the ankle, knee, and hip were observed at initial contact, maximum angle, and sagittal displacement. Sagittal displacements of the ankle, knee, and hip were summed to examine overall sagittal displacement. Kinetic variables were maximum posterior and vertical GRFs normalized to body weight. We used Pearson product moment correlations to evaluate the relationships between dorsiflexion ROM and landing biomechanics. Correlations (r) were interpreted as *weak* (0.00–0.40), *moderate* (0.41–0.69), or *strong* (0.70–1.00). The coefficient of determination (r^2) was used to determine the amount of explained variance among variables.

Results: Static dorsiflexion ROM was moderately correlated with maximum dorsiflexion ($r = 0.49$, $r^2 = 0.24$), ankle displacement ($r = 0.47$, $r^2 = 0.22$), and total displacement ($r = 0.67$, $r^2 = 0.45$) during landing. Dorsiflexion ROM measured statically and during landing demonstrated moderate to strong correlations with maximum knee ($r = 0.69–0.74$, $r^2 = 0.47–0.55$) and hip ($r = 0.50–0.64$, $r^2 = 0.25–0.40$) flexion, hip ($r = 0.53–0.55$, $r^2 = 0.28–0.30$) and knee ($r = 0.53–0.70$, $r^2 = 0.28–0.49$) displacement, and vertical GRF (–0.47– –0.50, $r^2 = 0.22–0.25$).

Conclusions: Dorsiflexion ROM was moderately to strongly related to sagittal-plane kinematics and maximum vertical GRF during single-legged landing in persons with CAI. Persons with less dorsiflexion ROM demonstrated a more erect landing posture and greater GRF.

Key Words: ankle sprain, drop landing, neuromuscular control, kinematics, kinetics

Key Points

- During a single-legged landing, persons with chronic ankle instability demonstrated moderate to strong relationships between dorsiflexion range of motion (ROM) and sagittal-plane kinematics at the knee and hip and vertical ground reaction forces.
- Persons with less dorsiflexion ROM exhibited a less flexed landing strategy that attenuated ground reaction forces less efficiently.
- Identifying dorsiflexion deficits may enable clinicians to implement interventions to increase ROM and potentially modify the landing biomechanics that persons with chronic ankle instability exhibit.

Ankle sprains are one of the most common injuries associated with athletics.[1] In addition, up to 73% of athletes who sustain ankle sprains experience recurrent ankle sprains, and 59% report functional loss and residual symptoms that have affected athletic performance.[2] Residual symptoms resulting from ankle sprains are often associated with a condition known as *chronic ankle instability* (CAI). This condition is characterized by repetitive ankle-sprain injuries, frequent episodes of the ankle "giving way," and decreased self-reported function stemming from an acute ankle sprain.[3] Persons with CAI have reported diminished health-related quality of life and are at greater risk for developing posttraumatic ankle osteoarthritis.[4,5] Based on the number of persons who develop CAI and the long-term consequences of the condition, a better understanding of the contributing factors is warranted to improve clinical intervention strategies.

Chronic ankle instability may be associated with several mechanical impairments in ankle function,[3] including a deficit in ankle-joint dorsiflexion range of motion (ROM).[3,6] Whereas the exact prevalence of dorsiflexion ROM deficits has not been determined, 30% to 74% of persons with CAI have at least a 5° deficit in weight-bearing dorsiflexion ROM compared with the contralateral limb.[7,8] The exact origin of dorsiflexion ROM deficits is unclear, but it likely results from arthrokinematic alterations and adaptive shortening of the triceps surae muscle group.[9,10] More importantly, dorsiflexion deficits may limit the ability to fully achieve a closed-packed, stable position of the ankle during dynamic activities, such as gait and landing, which may promote the pathomechanics associated with ankle-sprain mechanisms.[9,11,12] Therefore, a cascade of structural impairments leading to decreased dorsiflexion ROM may affect the ability to execute functional activities and ultimately contribute to the repeated ankle sprains and episodes of giving way related to CAI.

Dorsiflexion ROM plays a prominent role in the biomechanics of tasks that require landing.[13] Greater passive open chain dorsiflexion ROM has been associated with greater hip and knee flexion and lower ground reaction forces (GRFs) during a jump-landing task in healthy persons.[13] Those with greater dorsiflexion ROM land with a less erect posture by using greater sagittal-plane displacement, which allows the body to attenuate forces more efficiently.[13] Therefore, the available amount of dorsiflexion ROM may influence function not only at the ankle but also at more proximal structures in the lower extremity. Persons with CAI have demonstrated less dorsiflexion ROM during gait[11,14] and less knee flexion during landing than persons without CAI, but these findings have not been consistent in the literature.[15,16] Furthermore, persons with CAI have shown greater energy dissipation at the ankle and less energy dissipation at the knee.[17] Cumulatively, these observations suggest that alterations exist in the distal to proximal linkage of the kinetic chain of the lower extremity in persons with CAI.[17] Further examining a potential connection between dorsiflexion ROM and landing biomechanics may provide additional insight into these findings.

Persons who have CAI and less dorsiflexion ROM may also exhibit more erect landing postures and greater GRF, which may have implications for sustaining future lower extremity injuries or episodes of giving way.[18,19] Examining this relationship may further support integrating clinical intervention strategies that target dorsiflexion ROM into the rehabilitation of persons with CAI.[9] Therefore, the purpose of our study was to examine the relationship between dorsiflexion ROM and single-legged landing biomechanics in persons with CAI. We examined dorsiflexion ROM statically, using the weight-bearing–lunge test, and dynamically, using motion capture, to determine its relationship to landing biomechanics. In addition, we focused on the sagittal-plane kinematics of the lower extremity and GRFs to explore how dorsiflexion ROM may influence force attenuation in persons with CAI. Kinematics were examined in the sagittal plane because it is primarily responsible for force attenuation during landing tasks.[20] We hypothesized that persons with less dorsiflexion ROM would exhibit less sagittal-plane motion throughout the lower extremity and greater GRF during a single-legged drop-landing task.

METHODS

Design

With this cross-sectional study, we evaluated the relationship between dorsiflexion ROM and single-legged drop-landing biomechanics in persons with CAI. The dependent variables were weight-bearing dorsiflexion ROM and sagittal-plane kinematics at the ankle, knee, and hip, as well as GRF, recorded during single-legged drop landings.

Participants

Fifteen physically active persons with CAI (5 men, 10 women; age = 21.9 ± 2.1 years, height = 168.7 ± 9.0 cm, mass = 69.4 ± 13.3 kg) were recruited from a large public university over the course of 6 months to participate in this study. The inclusion criteria were consistent with the International Ankle Consortium's position statement on selection criteria for patients with CAI.[21] Specifically, participants had to report a history of at least 1 substantial ankle sprain and at least 1 episode of giving way in the 3 months before the study (ankle sprains = 2.7 ± 2.4, time since last sprain = 25.2 ± 25.2 months, incidences of giving way in the 3 months before the study = 4.9 ± 5.5). *Ankle sprain* was defined as an incident in which the rearfoot was inverted or supinated and resulted in a combination of swelling, pain, and time missed or modification of normal function for at least 1 day. An episode of *giving way* was described as an incident in which the rearfoot suddenly rolled, felt weak, or lost stability; however, the person could continue with normal function. Participants also had to give an affirmative answer to at least 4 items on the Ankle Instability Instrument[22] (6.3 ± 1.5) and report at least moderate levels of physical activity on the NASA Physical Activity Scale[23] (6.1 ± 1.8). To further describe the level of activity limitation and participation restriction, each participant completed the Foot and Ankle Ability Measure (FAAM) Activities of Daily Living (90.6% ± 5.4%) and FAAM Sport (79.0% ± 12.5%) instruments.[24] To supplement FAAM scores, participants completed a global rating of function scale at the end of each FAAM subscale; function was rated from 0% to 100%, with 100% representing the level of function before injury (FAAM Activities of Daily Living = 89.4% ± 8.3%, FAAM Sport = 81.6% ± 12.7%). Participants were excluded if they had experienced an ankle sprain in the 6 weeks before the study, had a history of lower extremity fracture or surgery, had sustained any other lower extremity injury in the 6 months before the study, or reported any other conditions that might affect landing. If a participant reported bilateral ankle instability, the limb with the lower FAAM scores was used for testing. All participants provided written informed consent, and the study was approved by the Institutional Review Board of Old Dominion University.

Instrumentation

An 8-camera motion analysis system (model MX40; Vicon Motion Systems, Denver, CO) collected kinematic data at 200 Hz. Three-dimensional force data were collected at 1000 Hz using a force plate (model 4060-10; Bertec Corp, Columbus, OH).

Procedures

Participants reported to the laboratory for a single testing session lasting approximately 1.5 hours. They performed a weight-bearing–lunge test (WBLT) and a single-legged drop-landing task on the involved limb. All measures were taken by the same investigator (S.L.G.). After completing the WBLT, participants were outfitted with retroreflective markers for tracking motion during the drop-landing task. To accurately capture motion-analysis data, we required all participants to wear spandex shorts and low-cut socks, men to wear no shirts, and women to wear sports bras. Participants also wore Nike sneakers (Air Max Glide; Nike, Beaverton, OR) provided by the investigators to eliminate variables introduced by various shoe types or brands. Participants selected their shoe size in men's or women's sizes.

Maximum weight-bearing ankle dorsiflexion ROM was assessed statically using the WBLT as described by Hoch and McKeon.[25] To perform the WBLT, the participant was positioned facing a wall with the involved foot in front, parallel with a tape measure secured to the floor, and the great toe touching the wall while the uninvolved foot was placed comfortably behind the involved foot. The WBLT uses a knee-to-wall principle that requires the participant to perform a lunge in which the knee flexes to a point where the anterior knee makes contact with the wall while the test heel remains firmly planted on the floor. Participants initially were progressed backward in 1-cm increments until heel or knee contact could no longer be maintained during the lunge. Subsequent changes in distance from the wall were made in smaller increments until the maximum lunge distance was identified. Maximum lunge distance was measured from the tip of the great toe to the wall to the nearest 0.1 cm.[25] Maximum dorsiflexion ROM was assessed 3 times for each participant and averaged for analysis. The WBLT has demonstrated strong intratester and intertester reliability (intraclass correlation coefficient > 0.90).[26,27] We selected this method of assessing maximum dorsiflexion ROM over traditional open chain goniometric techniques because it has been correlated with functional activities and has identified dorsiflexion deficits in persons with CAI.[6]

Upon completion of the WBLT, we prepared participants for motion capture by applying retroreflective markers bilaterally[28] over the following locations using double-sided tape for standing calibration: acromioclavicular joint, anterior-superior iliac spine, posterior-superior iliac spine, iliac crest, greater trochanter, lateral and medial femoral condyles, lateral and medial malleoli, base of the fifth metatarsal, and base of the first metatarsophalangeal joint. Cluster plates comprising 4 markers on semirigid, molded Orthoplast (Johnson & Johnson, New Brunswick, NJ) were attached by hook-and-loop fasteners at the heel of the shoe and on foam wraps snugly fit around the lower leg, thigh, and midthoracic region on the back. Participants were instructed to stand on the force plate and raise their upper extremities for calibration. Once calibration was completed, all markers except those on the anterior-superior iliac spine and posterior-superior iliac spine and cluster plates were removed for dynamic motion capture.

To perform the drop-landing task, participants stood on a 40-cm box with the uninvolved limb and were instructed to drop on the involved limb onto the force plate located 10 cm in front of the box.[29] They performed 3 to 5 practice trials until they were comfortable with the drop-landing task. We also informed participants that a successful landing trial required them to drop down on the force plate without propelling forward, avoid contact with the ground on the uninvolved foot, maintain the upper extremities folded across the chest, land with the entire foot on the force plate, and avoid any subsequent hops or sliding of the foot. This position had to be maintained long enough for full weight acceptance to occur on the single limb. Data were captured from the initiation of the drop until the participant had successfully completed the landing for further data reduction and analysis. Trials deemed unsuccessful were discarded and repeated until 5 successful trials were captured and subsequently used for data analysis.

Data Reduction

Data were postprocessed through Vicon Nexus software (version 1.8.5; Vicon Motion Systems) to identify and fill any missing trajectories less than 10 frames. These gaps were pattern filled using a marker collocated on the same cluster. Data were transferred to Visual 3D (version 5.0; C-Motion, Inc, Rockville, MD) to reconstruct the model and calculate both kinematic and kinetic variables from marker and force-plate data. Raw 3-dimensional marker coordinate and GRF data were low-pass filtered using a fourth-order, zero-lag, recursive Butterworth filter with cutoff frequencies of 12 Hz and 50 Hz, respectively.[30] A kinematic model comprising 8 skeletal segments (trunk; pelvis; and bilateral thighs, shanks, and feet) was created from the standing calibration trial.[28,31] *Hip-joint center* was defined as 25% of the distance from the ipsilateral to the contralateral greater trochanter marker,[32] *knee-joint center* was defined as the midpoint between the lateral and medial markers on the condyles of the femur,[33] and *ankle-joint center* was defined as the midpoint between the medial and lateral malleoli markers.[34] Three-dimensional ankle, knee, and hip angles were calculated using a joint coordinate system approach.[33,34] *Initial contact* was identified as the point in the trial when the vertical GRF exceeded 10 N, and the *end of the landing phase* was defined as maximum knee flexion.[28] Kinematics for the ankle, knee, and hip were observed at initial contact, maximum angle, and total displacement in the sagittal plane. *Total displacement* of the ankle, knee, and hip was defined as the final angular position of the joint minus the initial angular position of the joint. We also summed the sagittal-plane displacements observed at the ankle, knee, and hip to examine overall sagittal-plane displacement. Kinetic variables were maximum posterior and vertical GRFs, which were normalized to body weight. Posterior GRF was included because this measure was associated with dorsiflexion ROM in a previous study[13] and is often examined when investigating lower extremity injury.[35,36] The average of 5 successful trials was used to create each variable and entered into analyses.

Statistical Analysis

We calculated descriptive statistics, including means and standard deviations, for all dependent variables. Pearson product moment correlations were conducted to evaluate (1) the relationship between maximum dorsiflexion on the WBLT and the kinematic and kinetic variables associated with the drop-landing task and (2) the relationship between maximum dorsiflexion angle during the drop-landing task and the hip kinematics, knee kinematics, and kinetic variables associated with the drop-landing task. Pearson product moment correlation coefficients (*r*) were interpreted as *weak* (0.00–0.40), *moderate* (0.41–0.69), or *strong* (0.70–1.00).[37] We also calculated the coefficient of determination (r^2) to examine the explained variance exhibited for each analysis.

RESULTS

Descriptive statistics for all dependent variables are presented in Table 1. Dorsiflexion ROM on the WBLT was positively, moderately correlated with maximum ankle dorsiflexion, knee and hip flexion, ankle and hip displacement, overall sagittal-plane displacement, and vertical GRF and was positively, strongly correlated with knee displacement. All other relationships were considered weak. Pearson product moment correlation coefficients, coefficients of determination, and probability statistics between maximum weight-bearing dorsiflexion ROM and all kinematic and kinetic variables are presented in Table 2.

Maximum dorsiflexion angle during the drop-landing task was positively, moderately correlated with maximum hip flexion, knee and hip displacement, and vertical GRF and was positively, strongly correlated to knee flexion at initial contact and maximum knee flexion. All other relationships were considered weak. Pearson product moment correlation coefficients, coefficients of determination, and probability statistics between maximum dorsiflexion angle during the drop-landing task and all other kinematic and kinetic variables are presented in Table 3.

DISCUSSION

The main finding of our study was that weight-bearing dorsiflexion ROM measured statically using the WBLT and dynamically during the drop-landing task was moderately to strongly associated with sagittal-plane kinematics throughout the lower extremity and vertical GRF during a single-legged drop-landing task in persons with CAI. These observations indicated that persons with less dorsiflexion ROM exhibited more erect postures during the drop-landing task. Overall, dorsiflexion ROM seemed to have a lesser influence on kinematics at initial contact and a greater association with maximum angles and displacements. This observation suggests that the available weight-bearing dorsiflexion ROM may have a greater effect on landing biomechanics as the lower extremity attempts to attenuate forces during the later stages of landing in persons with CAI.

Our observations are supported by those of previous researchers who examined the relationship between passive open chain measures of dorsiflexion ROM and single-legged jump-landing kinematics in healthy adults.[13] Fong et al[13] reported that greater extended-knee dorsiflexion ROM was associated with greater knee ($r^2 = 0.21$) and hip ($r^2 = 0.13$) displacement during jump landing in healthy persons, and we determined that the WBLT and maximum dorsiflexion angle were also associated with greater knee ($r^2 = 0.28$–0.49) and hip ($r^2 = 0.28$–0.30) displacement during a drop-landing task in persons with CAI. Whereas the results of Fong et al[13] support our observations, several

Table 1. Dependent Variable Descriptive Statistics[a]

Variable	Mean ± SD
Dorsiflexion range of motion, cm	9.03 ± 2.33
Initial contact angle, °	
Ankle plantar flexion-dorsiflexion	−26.24 ± 7.70
Knee flexion-extension	13.21 ± 5.35
Hip flexion-extension	6.39 ± 6.96
Maximum angle, °	
Ankle plantar flexion-dorsiflexion	18.48 ± 6.49
Knee flexion-extension	56.11 ± 12.06
Hip flexion-extension	22.56 ± 11.23
Sagittal-plane displacement, °	
Ankle	44.73 ± 8.77
Knee	42.90 ± 9.11
Hip	16.16 ± 9.81
Total	103.79 ± 23.77
Ground reaction forces, normalized to body weight	
Posterior	0.46 ± 0.08
Vertical	3.94 ± 0.41

[a] Positive values for kinematic variables indicate ankle dorsiflexion, knee flexion, and hip flexion.

Table 2. Correlations Between Maximum Weight-Bearing Dorsiflexion Range of Motion and Lower Extremity Kinematics and Normalized Maximum Ground Reaction Forces

Variable	*r*	r^2	*P* Value
Initial contact angle			
Ankle dorsiflexion	−0.12	0.01	.67
Knee flexion	0.35	0.12	.20
Hip flexion	0.25	0.06	.36
Maximum angle			
Ankle dorsiflexion	0.49	0.24	.06
Knee flexion	0.69	0.47	.005
Hip flexion	0.64	0.40	.01
Sagittal-plane displacement			
Ankle	0.47	0.22	.08
Knee	0.70	0.49	.003
Hip	0.55	0.30	.04
Total	0.67	0.45	.006
Normalized peak ground reaction forces			
Posterior	0.02	0.001	.93
Vertical	−0.47	0.22	.08

Table 3. Correlations Between Maximum Dorsiflexion Angle and Lower Extremity Kinematics and Normalized Maximum Ground Reaction Forces

Variable	*r*	r^2	*P* Value
Initial contact angle			
Knee flexion	0.76	0.58	.001
Hip flexion	0.10	0.01	.74
Maximum angle			
Knee flexion	0.74	0.55	.002
Hip flexion	0.50	0.25	.06
Sagittal-plane displacement			
Knee	0.53	0.28	.04
Hip	0.53	0.28	.045
Normalized peak ground reaction forces			
Posterior	0.05	0.003	.86
Vertical	−0.50	0.25	.06

methodologic differences should be considered when making comparisons. Fong et al[13] used traditional open chain measures of dorsiflexion ROM with a long-arm goniometer, and we used the WBLT and motion capture to measure weight-bearing dorsiflexion ROM. In addition, Fong et al[13] incorporated a jumping component into the landing task, and we instructed participants to perform a drop landing with no jumping component. Regardless of the methodologic differences, we and Fong et al[13] determined that clinical assessments of dorsiflexion ROM are related to landing biomechanics. This observation suggests that dorsiflexion ROM may have a meaningful influence on lower extremity kinematics regardless of CAI status.

We determined that dorsiflexion ROM measured on the WBLT explained more than 20% of the variance in maximum dorsiflexion and ankle displacement. In contrast to these results, Fong et al[13] reported a weak correlation, which explained only 2% of the variance between dorsiflexion ROM and ankle displacement in healthy adults. This discrepancy may in part be related to the amount of variability in the ankle angle at initial contact. We observed a wide ROM at initial contact (standard deviation = 7.70°, range = 28.87°), but Fong et al[13] reported nearly double the variability (standard deviation = 15°, range = 60°). It is unclear whether these differences are methodologic in nature, but this narrower range of variability may be an aspect of landing biomechanics that warrants further investigation in persons with CAI. Whereas the implications for less variability in dorsiflexion angle at initial contact are unclear, Terada et al[17] determined that persons with CAI demonstrated greater energy dissipation at the ankle, which may be due to ankle stiffness during landing. Researchers should continue to examine ankle sagittal-plane motion in persons with CAI and determine if this motion contributes to reinjury mechanisms.

We hypothesized that persons with less dorsiflexion ROM would exhibit greater GRF. Dorsiflexion ROM explained 22% to 25% of the variance in vertical GRF, which is consistent with the results of Fong et al,[13] who determined that extended-knee dorsiflexion ROM explained 17% of the variance in healthy adults. However, our results explained very little variance (<1%) in posterior GRF, which contradicts the 9% of explained variance reported in healthy participants.[13] Secondary analyses from our data indicated that maximum hip and knee flexion, hip and knee displacement, and overall displacement explained large proportions of the variance ($r^2 = 0.29–0.52$) associated with vertical GRF, indicating that more erect postures resulted in greater vertical GRF. Therefore, static or dynamic weight-bearing dorsiflexion values may provide information that could aid in identifying persons who are more likely to land with less sagittal-plane displacement and subsequently higher vertical GRF. In future studies with larger sample sizes, researchers should consider examining how lower extremity kinematics and dorsiflexion ROM may interact to predict the absorption of vertical GRF during landing. This research may provide future directions for examining not only the pathomechanics associated with CAI but also lower extremity injury mechanisms in general.

Overall, static and dynamic measures of weight-bearing dorsiflexion ROM demonstrated relationships similar to the kinematics of more proximal joints and GRFs. Both measures demonstrated moderate to strong correlations with maximum knee and hip angle, knee and hip displacement, and vertical GRF. The most distinctive difference was the strong relationship exhibited between maximum ankle-dorsiflexion angle during landing and knee-flexion angle at initial contact, which may be related to the direct linkage between these joints during landing. The similar pattern of correlation demonstrated by the static and dynamic measures of weight-bearing dorsiflexion indicated that the less instrumented static measure may be suitable for future studies in which researchers are interested in identifying persons who land with more erect postures and greater vertical GRF. Whereas the value of this measure certainly needs to be confirmed with additional systematic investigation, it could be very beneficial, as the WBLT provides a more feasible approach to clinically implementing maximum dorsiflexion ROM measures into injury evaluation and prevention.

Persons with CAI demonstrated correlations between dorsiflexion ROM and landing biomechanics that were similar to what has been reported in healthy persons.[13] This observation is encouraging because it suggests that persons with CAI, who commonly exhibit dorsiflexion deficits,[3,6] may fall along the same continuum of function regarding the relationships that we examined. Therefore, when efforts are made to increase dorsiflexion ROM in persons with deficits, a reciprocating improvement in landing biomechanics may also be anticipated. This concept is supported by DiStefano et al,[38] who determined that limiting ankle sagittal-plane ROM with an ankle brace resulted in immediate decreases in ankle and knee sagittal-plane ROM during landing. In addition, the presence of a dorsiflexion ROM deficit is accompanied by decreased self-reported function associated with activities of daily living and sport-related activities in persons with CAI[39] and patients who have sustained acute ankle sprains.[40] Therefore, when dorsiflexion deficits are present, alterations in lower extremity function may follow. The similarities between our study and the study of Fong et al[13] are also important because they indicate that the influence of dorsiflexion ROM on landing biomechanics may transcend specific clinical populations and have implications for lower extremity injury mechanisms in general. Studies in which investigators directly compare persons with CAI and healthy persons and studies in which investigators seek to increase dorsiflexion ROM and examine landing biomechanics are logical next steps to advance this theory and this line of inquiry.

Our study provided insight into possible contributing factors to CAI from not only a biomechanical or disease-oriented perspective but also a patient-oriented perspective. Based on the results of the FAAM Sport, most participants reported functional deficits associated with sport activities. Closer examination of the individual FAAM Sport items determined that 13 of the 15 participants reported at least slight difficulty with landing activities and 1 of the participants who did not report difficulty had the greatest dorsiflexion ROM (14 cm). Researchers targeting dorsiflexion ROM and landing biomechanics using clinical interventions should examine treatment effects from disease-oriented and patient-oriented perspectives. This work may provide complementary data that can be used more readily in clinical settings for patient evaluation and goal setting.

Finally, our results support incorporating interventions that target dorsiflexion ROM into the rehabilitation strategy for persons with CAI and potentially persons with dorsiflexion deficits in general. More specifically, improving dorsiflexion ROM by increasing the extensibility of capsular tissues or the flexibility of the triceps surae muscle group through manual therapies or stretching techniques may enhance landing biomechanics by reducing erect postures. This is important for persons with CAI, as increased plantar flexion at the ankle during landing from a jump has been identified as a risk factor for ankle sprain, particularly in persons with a history of sprain.[41] Recent evidence[42] has indicated that persons with CAI can achieve more dorsiflexed positions at the point of initial contact during a jump-landing task immediately after a single session of joint mobilization focused on improving dorsiflexion ROM. Delahunt et al[42] did not report hip or knee kinematics, GRFs, or how long the effects of manual therapy treatments may last but did provide preliminary evidence that sagittal-plane kinematics could be influenced by readily available clinical interventions for increasing dorsiflexion ROM. In addition, after 2 weeks of talocrural-joint mobilization, persons with CAI reported an improvement in self-reported landing ability and concurrent increases in dorsiflexion ROM.[43,44] This observation supports the importance of examining changes in function with a combination of patient-, clinician-, and laboratory-oriented measures. Other interventions and the long-term effects of treatment should be investigated more.

Our study had limitations. We used a 40-cm box for the drop landings to create a standard height for all participants. This box height may be more or less difficult for participants depending on height, lower extremity length, or jumping capability. Researchers may consider normalizing drop height by making the box height a percentage of the participant's height or maximum vertical-jump height to have a more consistent level of difficulty across participants. The kinematics exhibited during drop landing were similar to those reported in previous studies in some respects but very different in others. For example, the ankle kinematics demonstrated in our study were similar to those in previous studies[12,42,45]; however, Caulfield and Garrett[16] reported considerably greater dorsiflexion values. Similar differences were noted with knee kinematics, as considerable variations are present in knee-flexion and knee-displacement values during landing in persons with CAI across the literature.[15,16,45] Kinematic variations may be due to differences in landing tasks, collection methods, or participant inclusion criteria. In addition, our retrospective study could not generate any cause-and-effect conclusions regarding dorsiflexion, landing biomechanics, and the progression of CAI. Whereas the WBLT has demonstrated good reliability,[27] we did not establish the reliability of the investigator in our study. We also did not conduct an a priori power analysis. However, post hoc power analyses indicated that the relationships, which were moderate to strong, had powers of 0.35 to 0.96 at an α level of .05. Finally, we focused only on kinematics in the sagittal plane and GRFs during drop landing in persons with CAI. Future researchers may consider providing a more comprehensive examination of kinematics and joint moments to determine if dorsiflexion ROM is related to alterations in other planes of movement or the forces experienced at individual joints in participants with CAI and healthy control participants.

CONCLUSIONS

Persons with CAI exhibited moderate to strong relationships between weight-bearing dorsiflexion ROM and sagittal-plane kinematics at the knee and hip and vertical GRF during a single-legged drop landing. Persons with less dorsiflexion ROM demonstrated a less flexed landing strategy that was less efficient at attenuating GRF. Identifying dorsiflexion deficits in persons with CAI may allow clinicians to implement interventions to increase ROM and potentially modify the landing biomechanics that these persons exhibit.

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Address correspondence to Matthew C. Hoch, PhD, ATC, Old Dominion University, 102 Health Science Annex, Norfolk, VA 23529. Address e-mail to mhoch@odu.edu.