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original research

Hip Kinematics During a Stop-Jump Task in Patients With Chronic Ankle Instability

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Context: Chronic ankle instability (CAI) commonly develops after lateral ankle sprain. Movement pattern differences at proximal joints may play a role in instability.

Objective: To determine whether people with mechanical ankle instability (MAI) or functional ankle instability (FAI) exhibited different hip kinematics and kinetics during a stop-jump task compared with "copers."

Design: Cross-sectional study.

Setting: Sports medicine research laboratory.

Patients or Other Participants: Sixty-three recreational athletes, 21 (11 men, 10 women) per group, matched for sex, age, height, mass, and limb dominance. All participants reported a history of a moderate to severe ankle sprain. The participants with MAI and FAI reported 2 or more episodes of giving way at the ankle in the last year and decreased functional ability; copers did not. The MAI group demonstrated clinically positive anterior drawer and talar tilt tests, whereas the FAI group and copers did not.

Intervention(s): Participants performed a maximum-speed approach run and a 2-legged stop jump followed by a maximum vertical jump.

Main Outcome Measure(s): An electromagnetic tracking device synchronized with a force plate collected data during the stance phase of a 2-legged stop jump. Hip motion was measured from initial contact to takeoff into the vertical jump. Group differences in hip kinematics and kinetics were assessed.

Results: The MAI group demonstrated greater hip flexion at initial contact and at maximum ($P = .029$ and $P = .017$, respectively) and greater hip external rotation at maximum ($P = .035$) than the coper group. The MAI group also demonstrated greater hip flexion displacement than both the FAI ($P = .050$) and coper groups ($P = .006$). No differences were noted between the FAI and coper groups in hip kinematic variables or among any of the groups in ground reaction force variables.

Conclusions: The MAI group demonstrated different hip kinematics than the FAI and coper groups. Proximal joint motion may be affected by ankle joint function and laxity, and clinicians may need to assess proximal joints after repeated ankle sprains.

Key Words: motion analysis, landings, ankle sprains

Key Points

- During a stop-jump task, the mechanical ankle instability group displayed greater hip flexion at initial contact and at maximum when compared with the coper group and greater total hip flexion displacement than the functional ankle instability and coper groups.
- Clinicians may need to assess the landing strategies of patients with chronic ankle instability to address any pathologic adaptations that might be occurring at the hip.

Recreational and competitive athletes at levels from high school to National Collegiate Athletic Association Division I experience high rates of ankle injury, specifically to the lateral ligaments.[1–3] People who sustain an ankle sprain are at risk for developing *chronic ankle instability* (CAI), which is defined as subjective, repeated episodes of giving way after an initial ankle sprain.[4] Of these, 47% to 73% are estimated to experience recurrent sprains.[5,6] Two potential contributing factors to CAI are *mechanical ankle instability* (MAI), which is the physiologic laxity of the lateral ankle ligaments after a sprain, and *functional ankle instability* (FAI), which refers to episodes of instability linked to possible deficits in proprioception or neuromuscular control, not physiologic ligamentous laxity.[4]

Despite potential differences in the nature of MAI and FAI, few authors to date have separated or differentiated between the two,[7] although these differences may play a role in the development of CAI.[8] A number of researchers have reported conflicting results regarding differences in proximal kinematics and landing kinetics between participants with and without CAI. Specifically, differences in knee kinematics were reported in 3 studies[9–11] but not in others.[12–14] Differences in hip kinematics were reported in one study of drop jumps[12] but not in other studies involving lateral hopping[15] or jump landing.[11] Differences in only peak lateral and peak anterior ground reaction force were reported in one study,[16] whereas greater vertical, medial, and posterior ground reaction forces were noted in another,[12] and differences in only posterior ground reaction force were seen in a third study.[15] Some of these conflicting results may be attributable to differences in the tasks, methods, and dependent variables used in these investigations. Additionally, if proximal joint differences during movement exist, they might influence the repetitive nature of CAI. Recent authors[17–19] have described impaired neuromuscular control in people with CAI, specifically in central motor programming and proximal joint motion patterns.

Specific changes in kinematic and kinetic patterns may place a person at risk for injury or perpetuate poor movement patterns that influence episodes of instability.[20,21] Additionally, movement pattern alterations have not been tested in a variety of daily living and sport-related tasks. Most investigators have focused on drop jumps[9,12,16] and walking.[13,14] Other common sport-related functional tasks may be needed to replicate the potential mechanisms of injury during kinematic and kinetic analysis. For example, a stop-jump maneuver is common in sports such as basketball, soccer, and volleyball and places a high demand on joints.

The aforementioned studies included control participants who had no history of ankle sprain, fracture to the lower extremity, or neuromuscular or vestibular impairment[9,12,14,15] and no lower extremity injury history.[10] A more appropriate comparison group may consist of "copers," or people who have a history of ankle sprain but did not develop CAI. These people's ability to cope after injury may reveal differences in neuromuscular control of the lower extremity.[22]

The purpose of our study was to determine whether participants with MAI or FAI exhibited different hip kinematics in 3 dimensions and ground reaction forces (GRFs) during a stop-jump task when compared with a coper group. We hypothesized that the MAI and FAI groups would demonstrate greater hip flexion and external rotation than copers but that there would be no group differences in GRFs.

METHODS

Participants

Before the study began, all volunteers provided written informed consent, as approved by the local institutional review board, which also approved the investigation. Three groups of 21 volunteers (11 men, 10 women per group) participated in this study (total n=63). Their age range was 18 to 35 years, and the groups were matched for sex, age (±2 years), height (±10%), mass (±10%), and limb dominance[23] (Table 1). We performed a priori power calculations using the conservative *t* test model to determine the sample size necessary to achieve a power of 0.80.[24] For peak GRF variables, we calculated power based on a similar study of vertical, lateral, medial, and posterior GRFs in single-legged jump landings with a sample size of 24.[12] Tabular data were used, and a sample size of 20 would result in a power of 0.80 for most variables. The same authors[12] reported differences of approximately 5° in hip rotation between the FAI and control groups (n=24) during a single-legged drop jump; however, no data were provided to calculate power or effect size. Pilot data on 4 FAI and 4 coper volunteers indicated that a sample size of 20 was adequate for a power of 0.80 in hip flexion.

All volunteers were recreationally active, participating in at least 1.5 hours per week of cardiovascular, resistance, sport-related, or other physical activity. They also reported a history of acute ankle inversion sprain within the past 5 years that necessitated non–weight bearing or immobilization for a minimum of 3 days. The MAI and FAI groups self-reported episodes of giving way at the ankle secondary to the initial sprain, with at least 2 episodes of giving way or sprains in the last 12 months. A certified athletic trainer with more than 6 years of clinical experience performed a brief orthopaedic examination using the talar tilt and anterior drawer tests to determine lateral ligament laxity.[25] The athletic trainer rated ankle laxity on a 1–5 scale, where 1 reflected *very hypomobile;* 3, *normal;* and 5, *very loose*.[26] The rater's reliability was established before screening using an intraclass correlation coefficient (2,1)[27] of more than 0.80, with a standard error of measurement of less than 0.25 points for both tests. The MAI group demonstrated clinical laxity on the anterior drawer or talar tilt test and received scores of 4 or 5. The FAI and coper groups were clinically negative on both tests and received scores of 2 or 3.[26] Exclusion criteria for all groups were a history of surgery in either leg, previous ankle fracture in either leg, a lower extremity injury in the last 3 months (other than an episode of ankle sprain or giving way in the MAI and FAI groups), or obvious swelling or discoloration. Gross limitation in range of motion, ankle pain, self-reported instability in the knee or hip, or current participation in a formal rehabilitation program were additional exclusion criteria.

Instrumentation

A Flock of Birds electromagnetic tracking device (Ascension Technology Corporation, Burlington, VT) was coupled with a piezoelectric nonconductive force plate (model 4060-NC; Bertec Corporation, Columbus, OH), controlled by MotionMonitor software (version 6; Innovative Sports Training, Chicago, IL). We used the standard range transmitter (182.88 cm) with 6 sensors, 1 of which was movable and attached to a stylus for digitization of joints. The electromagnetic field, stylus, force plate, and global axis system were established before data collection. The transmitter was placed 32 cm from the force plate at a height of 42 cm. The axis system was positive (x) in the direction the participant faced, positive (y) to the right, and positive (z) in the vertical direction. Kinematic and GRF data were sampled at 144 Hz and 1440 Hz, respectively.[28]

Testing Procedures

Participants' demographic data, anthropometric measurements (range of motion and limb dominance),[23] ankle injury history, and Foot and Ankle Disability Index (FADI) and Sport Subscale (FADI-S)[29] scores were recorded (Table 1). The FADI scores are reported as a percentage of 104 points and FADI-S scores as a percentage of 32 points. Thus, lower scores on the FADI and FADI-S indicate decreased ankle function.[29] The previously injured ankle was tested for all participants. If both ankles were previously injured, the ankle with the lower FADI and FADI-S score was tested. The test limb was defined as dominant or nondominant,[23] and limb dominance was matched between groups.

Sensor placement and setup were performed as previously described.[28] Sensors were attached over areas of minimal muscle mass to decrease potential skin movement and secured with surgical tape, underwrap, and athletic tape. Each lower extremity joint and segment was digitized by marking the proximal and distal ends of the segment's longitudinal axis, a third point on the plane, a fourth point above and on the positive side, and the origin as a centroid, or calculated midpoint between 2 bony landmarks at a joint using the sites previously listed. A final visual check and real-time view were used to ensure proper setup. Each participant's height was measured using the movable sensor and entered into the software, and each person stood in anatomic position for a 3-second static calibration trial to define neutral positions for the joints. The force plate recorded body mass.

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Table 1. Participant Demographics (Mean ± SD)

Group	Sex	Age, y	Height, cm	Mass, kg	Foot and Ankle Disability Index Score	Foot and Ankle Disability Index Sport Subscale Score
Mechanical ankle instability	Male	23.00 ± 5.12	179.81 ± 10.02	76.73 ± 13.80	90.50 ± 8.36	78.10 ± 13.12
	Female	21.70 ± 3.30	166.33 ± 5.47	65.73 ± 9.75	87.62 ± 7.98	75.00 ± 11.67
Functional ankle instability	Male	22.45 ± 4.27	178.08 ± 6.45	77.59 ± 12.00	93.75 ± 4.76[a]	77.52 ± 9.10[b]
	Female	21.80 ± 3.49	165.10 ± 7.72	67.91 ± 13.01	94.68 ± 3.92[a]	85.95 ± 10.02[b]
Copers	Male	21.27 ± 4.17	182.10 ± 4.16	75.38 ± 7.65	96.67 ± 5.53[c]	89.45 ± 12.42[c]
	Female	22.20 ± 5.69	167.70 ± 5.48	63.92 ± 10.55	97.45 ± 1.90[c]	92.65 ± 5.75[c]

[a] The mechanical ankle instability and functional ankle instability groups were different ($P < .05$).
[b] The functional ankle instability and coper groups were different ($P < .05$).
[c] The mechanical ankle instability and coper groups were different ($P < .05$).

Test Tasks

Volunteers performed a stop-jump task using previously published guidelines.[30] They took a 3- or 4-step approach run at 2.5 to 3.5 m/s, took off on 1 foot, landed with both feet at the same time (test foot on the force plate, other foot off the force plate), and then performed a maximal vertical jump and landed in approximately the same position, so as to minimize horizontal movement. The stop jump was performed in a continuous, rapid motion, similar to motions used in basketball and soccer.[30] To minimize coaching effects, the only instructions provided were a verbal description of the task and a request to make contact with the force plate using the entire foot. Anterior linear velocity of the sacral sensor measured running speed during the trial, and real-time data were presented as feedback to keep performance within the acceptable speed range. Only trials within the range and with the foot landing entirely on the force plate were defined as successful and analyzed. Each participant practiced the stop jump at least 3 times, followed by 8 successful test trials,[31] with at least 30 seconds' rest between trials.

Data Processing

Euler angles were used, and the order of rotation at the hip was *y, x,* and *z,* or extension, abduction, and external rotation, all of which were positive, as in previously published guidelines.[28,32] Data were aligned to this configuration regardless of limb side. Impact artifacts 1 to 3 frames long were observed for some variables and trials. A custom MATLAB program (The MathWorks, Inc, Natick, MA) was used to visually identify artifacts and connect the beginning and end of the artifact using linear interpolation. No more than 2 artifacts appeared in each trial. The GRFs were normalized to body weight.[28]

A low-pass, fourth-order, nonrecursive Butterworth filter at a cutoff frequency of 15 Hz[33] was applied to the kinematic data using a custom DataPac 2K2 program (version 3.11; Run Technologies Co, Mission Viejo, CA). No filtering was performed on the GRF data.[12,15] The dependent variables were identified during the stance phase, defined as initial contact (force plate registering vertical GRF >10 N) to toe-off into the maximal vertical jump (force plate registering vertical GRF <10 N). Kinematic dependent variables were hip flexion, abduction, and rotation at initial contact, at maximum (greatest value), and displacement (total range of motion from minimum to maximum joint angle). The GRF dependent variables were normalized peak magnitude in the vertical, anterior, posterior, medial, and lateral directions. Kinematic data were demeaned using the static calibration trial. The data were averaged over the 8 trials, initially explored for descriptive qualities, and checked for validity.[28]

Data Analysis and Interpretation

Reduced data were transferred to SPSS (version 17.0; SPSS Inc, Chicago, IL) for analysis. One-way analyses of variance were applied to determine group differences on each variable, using an alpha level of 0.05 and Tukey post hoc testing ($\alpha = .05$) where indicated. Observed power, effect sizes, and 95% confidence intervals were reported to indicate the magnitude of the differences. Effect sizes (partial η^2 values) were included to aid in interpretation of group differences. These values may be interpreted as small (0.01 to 0.059), moderate (0.06 to .139), and large (>.14). We calculated preliminary 1-way analyses of variance and Tukey post hoc tests for group differences in age, height, mass, and ankle function as reported in the FADI and FADI-S. We also tested for differences among groups in sacral sensor run speed to determine whether the groups were running at similar speeds.

RESULTS

Preliminary Analyses

The groups were not different in age, height, or mass ($F_{2,60} = 0.127$ to 0.632, $P = .54$ to .88), but the MAI and FAI groups reported differences in ankle function on the FADI and FADI-S. The MAI group scored lower than the FAI and coper groups on the FADI ($F_{2,60} = 9.99$, $P = .017$ and $P < .001$, respectively). No difference was noted between the FAI and coper groups on the FADI ($P = .258$). The MAI and FAI groups also scored lower than the coper group on the FADI-S ($F_{2,60} = 9.58$, $P < .001$ and $P = .017$, respectively). There was no difference between the MAI and FAI groups on the FADI-S ($P = .311$) or in approach run speed (sacral sensor speed) ($F_{2,60} = 1.21$, $P = .31$). The MAI group self-reported an average total of 8.4 ± 6.5 episodes of giving way in the test ankle, whereas the FAI group reported 5.7 ± 5.11 episodes since the initial sprain. The MAI and FAI groups were not different in the number of episodes of giving way ($F_{2,60} = 9.5$, $P = .16$). The coper group reported no complaints of instability or repeated episodes of giving way at the ankle, no more than a single episode of giving way or sprain in the past 12 months, and no acute sprain in the past 3

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months. The mean time since the initial sprain was 3.35 ± 3.45 years (range, 1 to 14 years).

Group Differences

Hip flexion at initial contact, hip flexion maximum, hip external rotation maximum, and hip flexion displacement during stance were different among the groups (all $P < .05$) (Table 2). Tukey post hoc testing revealed that the MAI group displayed greater values than the coper group on all significant variables and a greater value than the FAI group on hip flexion displacement. No group differences were demonstrated in hip abduction variables (Table 2) or in any other GRF variables (Table 3).

DISCUSSION

Our principal finding was that the MAI group displayed different hip motion patterns than the coper group during a stop-jump task. Overall, the MAI group showed greater hip flexion at initial contact and greater maximum hip flexion than the coper group and greater total hip flexion displacement than the FAI and coper groups. The MAI group also demonstrated greater maximum hip external rotation than the coper group, but no differences in GRFs were observed. All groups performed the stop jump at approximately the same speed and, therefore, differences cannot be attributed to velocity of travel. The MAI group was primarily different from the FAI and coper groups. We will discuss the possible reasons laxity at the lateral ankle ligaments and lower self-reported functional scores may be related to differences in hip kinematics during a stop jump.

Possible Role of Laxity

Laxity at the lateral ankle may be one explanation for differences in hip kinematics in the MAI group and could involve proximal joint differences evident after injury and changes in balance strategy from ankle to hip. Previous authors[34,35] have noted that people with a history of severe unilateral ankle sprain demonstrate slower gluteus maximus activation, differences in hip extensor muscle activity, and less vibration perception at the ankle compared with a control group. The authors hypothesized that proximal joint changes occurred after injury,

Table 2. Hip Kinematic Variables

Variable	Motion, °	Group	Mean ± SD	$F_{2,60}$ Value	*P* Value	Power Level (1 − β)	Effect Size (η_p^2)	Tukey Post Hoc Test[a]	95% Confidence Interval
Initial contact	Hip flexion	MAI	−42.76 ± 13.47	3.51	.04	0.63	0.11	MAI, Coper	−48.29, −37.31
		FAI	−38.62 ± 13.44						−44.07, −33.16
		Coper	−32.60 ± 10.33						−38.06, −27.15
	Hip abduction	MAI	−2.67 ± 22.18	1.61	.21	0.33	0.05	None	−12.77, 7.42
		FAI	6.50 ± 15.00						−0.33, 13.33
		Coper	4.77 ± 14.63						−1.89, 11.42
	Hip rotation	MAI	9.06 ± 16.78	1.02	.37	0.22	0.03	None	1.06, 17.06
		FAI	6.43 ± 12.72						−1.58, 14.43
		Coper	1.12 ± 23.77						−6.89, 9.12
Maximum	Hip flexion	MAI	−63.04 ± 24.28	4.56	.01	0.75	0.13	MAI, Coper	−70.90, −55.19
		FAI	−50.21 ± 13.65						−58.06, −42.36
		Coper	−47.29 ± 13.98						−55.15, −39.44
	Hip extension	MAI	−15.64 ± 11.74	1.19	.31	0.25	0.04	None	−19.63, −11.65
		FAI	−11.83 ± 8.58						−15.82, −7.84
		Coper	−11.91 ± 6.27						−15.90, −7.92
	Hip abduction	MAI	7.37 ± 17.05	0.96	.39	0.21	0.03	None	−0.39, 15.13
		FAI	13.66 ± 12.77						7.85, 19.47
		Coper	11.36 ± 14.51						4.76, 17.97
	Hip adduction	MAI	−10.57 ± 22.369	1.35	.27	0.28	0.04	None	−20.75, −0.39
		FAI	−3.67 ± 15.59						−10.77, 3.42
		Coper	−2.24 ± 13.59						−8.43, 3.94
	Hip internal rotation	MAI	2.93 ± 15.37	1.35	.27	0.28	0.04	None	−5.22, 11.08
		FAI	−1.97 ± 13.52						−10.12, 6.18
		Coper	−6.53 ± 25.02						−14.68, 1.61
	Hip external rotation	MAI	21.93 ± 21.96	3.32	.04	0.61	0.10	MAI, Coper	13.78, 30.08
		FAI	12.77 ± 9.15						4.62, 20.92
		Coper	7.23 ± 21.91						−0.92, 15.38
Displacement	Hip flexion	MAI	47.41 ± 17.10	5.56	.01	0.84	0.16	(1) MAI, Coper	−52.72, −42.10
		FAI	38.38 ± 7.85					(2) MAI, FAI	−43.69, −33.07
		Coper	35.38 ± 9.47						−40.69, −30.07
	Hip abduction	MAI	17.94 ± 9.33	1.68	.20	0.34	0.05	None	13.69, 22.19
		FAI	17.33 ± 9.21						13.14, 21.52
		Coper	13.61 ± 5.85						10.95, 16.27
	Hip rotation	MAI	19.00 ± 14.89	1.53	.26	0.31	0.05	None	−23.50, −14.49
		FAI	14.74 ± 7.05						−19.24, −10.24
		Coper	13.76 ± 6.92						−18.26, −9.26

Abbreviations: FAI, functional ankle instability; MAI, mechanical ankle instability.
[a] Significant at the $P \leq .05$ level.

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Table 3. Ground Reaction Force Variables[a]

Direction	Group	Peak Ground Reaction Force × Body Weight (Mean ± SD)	$F_{2,60}$ Value	P Value	Power Level ($1-\beta$)	Effect Size (η_p^2)	Tukey Post Hoc Test[b]	95% Confidence Interval
Vertical	MAI	2.21 ± 0.76	0.05	.95	0.06	<0.01	None	1.89, 2.53
	FAI	2.23 ± 0.72						1.91, 2.55
	Coper	2.16 ± 0.73						1.84, 2.48
Anterior	MAI	0.55 ± 0.21	1.10	.34	0.24	0.04	None	0.47, 0.63
	FAI	0.63 ± 0.13						0.55, 0.71
	Coper	0.59 ± 0.19						0.52, 0.67
Posterior	MAI	0.15 ± 0.10	0.07	.93	0.06	<0.01	None	0.10, 0.20
	FAI	0.15 ± 0.12						0.09, 0.20
	Coper	0.14 ± 0.13						0.09, 0.19
Medial	MAI	0.23 ± 0.16	1.22	.30	0.26	0.04	None	0.17, 0.29
	FAI	0.17 ± 0.12						0.11, 0.23
	Coper	0.17 ± 0.13						0.11, 0.23
Lateral	MAI	0.23 ± 0.12	0.73	.48	0.17	0.02	None	0.16, 0.30
	FAI	0.28 ± 0.18						0.21, 0.35
	Coper	0.22 ± 0.19						0.15, 0.29

Abbreviations: FAI, functional ankle instability; MAI, mechanical ankle instability.

[a] The peak vertical, medial, lateral, anterior, and posterior ground reaction force data are reprinted from *Clinical Biomechanics,* 23(6), Brown CN, Padua DA, Marshall SW, Guskiewicz KM, Individuals with mechanical ankle instability exhibit different motion patterns than those with functional ankle instability and ankle sprain copers, 822–831, copyright (2008) with permission from Elsevier.

[b] Significant at $P \leq .05$.

were bilateral, and changed hip extensor activity. This finding could help explain why we noted greater hip flexion at initial contact, maximum, and total displacement in the MAI group. If the MAI group experienced slower hip extensor activity, they might have demonstrated greater hip flexion kinematics in response to laxity and proprioceptive changes at the lateral ankle. Although we did not measure surface electromyography, this suggestion could help to explain our findings.

Additionally, the stop-jump task requires rapid deceleration with fixed feet and a transition to a vertical jump. Laxity of the static lateral ankle ligaments may necessitate greater dynamic stabilizer action at the ankle. Chronic ankle instability may be viewed as a constraint on the sensorimotor system.[36] Degrees of freedom of movement at the ankle may be decreased as a strategy to improve stability.[36,37] Less ankle sagittal-plane displacement[28] and ankle movement variability[37] were reported in an MAI group during similar tasks, and more out-of-phase movement, indicating less movement stability, was noted in a CAI group during running.[38] Compensation for limited motion and variability at the ankle joint may occur with differences in hip kinematics in the sagittal plane, especially given that we observed no changes in GRF variables. Previous investigators using similar jumping tasks reported no differences in hip sagittal-plane kinematics between those with FAI and a control group during a lateral hop,[15] after initial contact during a drop jump,[12] or before or at initial contact during an anterior jump.[10,11] These similar hip flexion kinematic findings are consistent with the lack of differences we report between those with FAI and copers. The MAI group's ankle laxity and decreased function may explain the differences we saw; however, the previous authors did not specify whether laxity was present, making comparisons difficult.

Finally, use of a hip-centered balance strategy may explain the hip kinematic differences we noted. Typically, to maintain balance, healthy young adults use an ankle strategy in which the center of gravity rotates around the ankle joint with minimal hip and knee movement. Small amounts of sway from small, slow perturbations can be addressed with an ankle strategy.[39,40] Alternatively, when a quicker postural correction is needed for a larger, faster perturbation, a hip strategy is used in which the center of gravity is adjusted through flexion or extension of the hips.[39,40] Although we did not investigate strategy, the increased hip flexion may be a result of a hip strategy of balance. Previous researchers[41] indicated that after induced somatosensory loss at the ankle in healthy control participants, a hip strategy was used more frequently during anterior and posterior postural translations. Participants with chronic ankle sprains and ankle hypermobility used a hip-based strategy after sudden ankle inversion, which the authors[42] attributed to compensation for deafferentation at the ankle coupled with proximal joint reactions to overcome the distal deficit. The authors argued that the deafferentated ankle is unable to deal with sudden perturbation, and the central nervous system responds by using the hip musculature instead.[42]

Joint somatosensory information from the ankles appears to be important in postural responses to perturbation.[41] Researchers[43] studying postural responses to translational platform disturbances indicated that horizontal platform disturbance at the ankle was approximately 40 times the effect of disturbance at the knee and several hundred times larger than the effect of disturbance at the hip. Thus, the ankle is subject to the largest excursion, and the authors[43] hypothesized that when the ankle is unable to produce sufficient torque, hip strategies must be used instead of ankle strategies. Ankle laxity associated with inversion hypermobility[42] or somatosensory loss[41] may be viewed as a constraint on the sensorimotor system that might have caused the MAI group to use a more hip-centered balance strategy. Large postural adjustments, with inability to efficiently use the ankle, may provide a rationale for the greater hip flexion displayed by the MAI group during a stop jump.

It is not entirely clear why the MAI group demonstrated greater hip external rotation. In the anterior cruciate ligament injury literature, greater hip flexion is often associated with greater hip external rotation or a "better" landing motion.[44,45] Because the MAI group demonstrated greater hip flexion, the

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hip external rotation may be a corollary. Previous authors[12] reported less hip external rotation in an FAI group before initial contact during a drop jump but no differences during the stance phase. Other investigators[13–15] also reported no differences in hip rotation before initial contact or during stance. The effect sizes are unknown, so the lack of differences might be attributable to low power or a large amount of variability.

Possible Role of Impaired Function

The MAI group also self-reported less function at the ankle compared with the FAI and coper groups. With feelings of less stability at the ankle and less confidence in the joint's ability to perform, the MAI group might have relied more on the hip joint to complete the stop jump, revealing differences in hip kinematics. The FADI-S questionnaire specifically asks about difficulty at the ankle with running, jumping, landing, quick starts, and "normal movement technique." The stop jump probably incorporated these constructs, and the difficulty the MAI group self-reported was demonstrated through altered kinematics. The MAI and FAI groups probably exist on a continuum of instability and function, and the MAI group in this study was lower on the continuum in terms of function. We noted changes only in the MAI group, not the FAI group, so the lower level of function may play a role in promoting hip joint kinematic differences. The FAI group might not have had significant limitations in function given their higher self-reported function scores. Statistically significant differences were evident in group self-reported function and clinically significant differences in joint laxity, but no statistically significant difference was demonstrated in the number of self-reported episodes of giving way of the test ankle between the MAI and FAI groups. Laxity and the level of self-reported function may play roles in proximal kinematic motions.

We observed no differences in frontal-plane hip motion between the groups in hip abduction at initial contact, maximum, minimum, or displacement. This result supports the lack of hip frontal-plane angular displacement differences reported previously in drop jumping[12] and lateral hopping.[15] Frontal-plane movement appears similar between groups with and without ankle instability. The effect sizes for these comparisons were small, indicating a minor magnitude of group differences. Caulfield and Garrett[16] reported a shorter time to peak in participants with FAI in the lateral and anterior GRFs in a single-legged drop jump but no differences in peak medial-lateral, anterior-posterior, or vertical GRF. Delahunt et al[12] showed greater peak vertical GRF and shorter time to peak vertical GRF in participants with FAI in a similar drop-landing task. In a lateral hop, participants with FAI displayed a lower peak posterior GRF; all other peak GRFs were equivalent.[15] Our results support the lack of group differences in peak GRF reported previously, but the literature is divided. It is difficult to directly compare our results with those of previous studies because we looked separately at participants with clinical laxity, and the other authors did not. The previous researchers also compared averaged data in distinct windows of time before and after initial contact, not absolute peak values, as we did.

Clinical Consequences

Clinicians may need to assess the landing strategies of CAI populations to make sure no pathologic adaptations are occurring and, if people with MAI exhibit differences, that the hip joint is able to withstand those differences. It is also important for clinicians to evaluate proximal joint strength and range of motion and address those issues at the hip during ankle rehabilitation in case proximal joint kinematic changes occur. People with laxity and decreased ankle function may be more likely to display proximal joint differences, although our results tend to indicate positive differences in landing motion at the hip.

Limitations

The limitations of this study include the use of self-reported complaints of instability and clinical laxity measures. A high degree of variability always exists in self-reported symptoms and initial injury severity, and no widely accepted instrument or criterion standard is available to identify CAI.[46] Therefore, the FAI group might not have had severe functional limitations. Additionally, the reported power for testing group differences in GRF was low, never greater than 0.26, increasing the risk of a type II error. However, the effect sizes reported were also low (0.01–0.04); as a result, differences in peak GRF between the groups may not be clinically relevant. Based on the study design, we cannot tell whether the changes observed were present before or after ankle instability developed. Finally, the absence of a control group, the differences in number of episodes of giving way between the MAI and FAI groups, and the lack of comparisons between limbs may also be limitations. Future authors should focus on including uninjured control participants and using objective measures of laxity.

CONCLUSIONS

The MAI group displayed greater hip flexion at initial contact and at maximum than the coper group and greater total hip flexion displacement than the FAI and coper groups. Ankle joint laxity and decreased function may be constraints on the sensorimotor system, contributing to hip kinematic changes in the stop-jump task through alterations in balance strategy and a shift from relying on the ankle joint to relying on the hip joint to complete the movement.

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