

# Isometric Hip Strength and Dynamic Stability of Individuals With Chronic Ankle Instability

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**Context:** Compared with individuals who have a history of lateral ankle sprain (LAS) without markers of chronic ankle instability (CAI; LAS copers) and healthy people, those with CAI often exhibit neuromuscular impairments and dynamic-stability deficits at the hip. However, the influence of hip-strength deficits on dynamic stability remains unknown.

**Objective:** To compare isometric hip strength and dynamic stability in individuals with or without CAI and examine the degree of dynamic-stability variance explained by isometric hip strength.

**Design:** Case-control study.

**Setting:** Research laboratory.

**Patients or Other Participants:** Sixty individuals (47 women, 13 men; age =  $23.7 \pm 4.6$  years, height =  $166.6 \pm 7.7$  cm, mass =  $70.8 \pm 15.7$  kg) separated into CAI, LAS copers, and control groups based on previously established criteria.

**Main Outcome Measure(s):** Group differences in resultant vector time to stabilization (RVTTs) and isometric hip-extension, -abduction, and external-rotation strength were determined using 1-way analyses of covariance that controlled for sex and limb (dominant or nondominant) tested and Cohen d effect sizes (95% confidence intervals). Backward linear regressions and

Cohen  $f^2$  effect sizes (95% confidence intervals) determined the amount of RVTTs variance explained by isometric hip strength. Significance was set a priori at  $P < .05$ .

**Results:** The CAI group had less isometric hip-extension strength than LAS copers ( $P = .02$ ,  $d = 0.72$  [0.06, 1.34]) and controls ( $P = .01$ ,  $d = 1.19$  [0.50, 1.84]) and less external-rotation strength than LAS copers ( $P = .03$ ,  $d = 0.78$  [0.13, 1.41]) and controls ( $P = .01$ ,  $d = 1.02$  [0.34, 1.65]). No group differences existed for RVTTs ( $F_{2,57} = 1.16$ ,  $P = .32$ ) or abduction strength ( $F_{2,57} = 2.84$ ,  $P = .07$ ). Resultant vector time to stabilization was explained by isometric hip strength for LAS copers ( $R^2 = 0.21$ ,  $f^2 = 0.27$  [0.22, 0.32],  $P = .04$ ) but not for the CAI ( $R^2 = 0.12$ ,  $f^2 = 0.14$  [0.06, 0.22],  $P = .22$ ) or control ( $R^2 = 0.10$ ,  $f^2 = 0.11$  [0.03, 0.19],  $P = .18$ ) groups.

**Conclusions:** Participants with CAI had decreased isometric hip strength, but that did not equate to dynamic-stability deficits. Clinicians should include hip-muscle strengthening in rehabilitation protocols for patients with CAI, yet these gains may not enhance dynamic stability when landing from a jump.

**Key Words:** copers, time to stabilization, handheld dynamometry

## Key Points

- Individuals with chronic ankle instability (CAI) exhibited decreased isometric strength of the posterolateral hip musculature.
- Isometric hip strength was not representative of the dynamic-stability performance of individuals with CAI.
- Hip strength and dynamic stability should be evaluated in each patient with CAI, and deficits should be corrected through rehabilitation.

Individuals with a lateral ankle sprain (LAS) commonly experience recurrent injury, episodes of “giving way,” and perceived instability, which collectively characterize chronic ankle instability (CAI).<sup>1–3</sup> Individuals with a history of LAS but without markers of CAI are commonly referred to as *LAS copers*.<sup>4</sup> Various outcomes in patients with LAS suggest that some individuals may avoid the onset of CAI through alternative recovery mechanisms or rehabilitation.<sup>5,6</sup> To understand why patients with LAS experience different outcomes, we need to expand our investigation of structural and functional impairments.

Hip-joint neuromuscular alterations in patients with LAS or CAI have been widely reported.<sup>7–11</sup> Of note, individuals

with CAI have demonstrated deficits in posterolateral hip strength compared with LAS copers and controls.<sup>10</sup> Additionally, reduced isometric hip strength was associated with reduced dynamic postural control during a lower extremity reaching task in individuals with CAI.<sup>10</sup> Consequently, hip-muscle strength is likely important to neuromuscular control and preventing recurrent LAS.

In addition to postural-control deficits, other functional movement alterations are common among individuals with CAI. A number of investigators<sup>12–17</sup> have reported deficits in dynamic stability, marked by a longer time required to achieve a stable position after a functional movement, among those with CAI. *Time to stabilization* (TTS) is one

measure of dynamic stability that estimates the time required to reduce anterior-posterior and medial-lateral ground reaction forces (GRFs) after a single-legged landing; lower TTS values are associated with better dynamic stability.<sup>18,19</sup> Several groups<sup>12–14,16,17</sup> have demonstrated that individuals with CAI exhibit worse TTS performance than individuals without CAI. Furthermore, a number of authors<sup>12–14,17</sup> have reported that the reduced ability of individuals with CAI to attenuate GRFs during a single-legged landing is influenced by neuromuscular limitations at the ankle as well as more proximal lower extremity joints. However, no previous researchers have explored the influence of potential hip-muscle strength deficits on dynamic stability in this population.

Therefore, the purpose of our study was to compare hip-muscle strength and dynamic stability among individuals with CAI, LAS copers, and healthy controls. Furthermore, we aimed to measure the contribution of hip-muscle strength to dynamic-stability performance variance. We hypothesized that TTS performance and hip-muscle strength would be worse in individuals with CAI versus LAS copers and control groups and that hip-muscle strength would explain a significant degree of TTS performance variance in individuals with and those without CAI.

## METHODS

### Participants

We recruited 60 participants (47 women, 13 men; age =  $23.7 \pm 4.6$  years, height =  $166.6 \pm 7.7$  cm, mass =  $70.8 \pm 15.7$  kg) from the surrounding university community for a single-blinded case-control study design. Based on isometric hip-abduction (ABD) strength and dynamic-stability data from previous studies,<sup>9,16</sup> a predetermined  $\alpha$  level of .05, and an estimated power of 0.80, we estimated a sample size of 20 participants would be needed in each group (60 total). Any lower extremity injuries besides LAS in the previous 2 years or any history of lower extremity fracture or surgery was cause for exclusion. One research team member determined participants' eligibility and group placement (CAI, LAS copers, or control) based on the inclusion criteria outlined by the International Ankle Consortium (IAC)<sup>1–3</sup> and others.<sup>4</sup>

Participants were first separated by LAS history. All individuals without a history of LAS were assigned to the healthy control group. Participants reporting a previous LAS were screened using the CAI inclusion criteria as described by the IAC.<sup>1–3</sup> Members of the CAI group were required to have a history of at least 1 acute LAS resulting in swelling, pain, and a minimum of 1 day of missed physical activity.<sup>1–3</sup> At least 12 months must have passed since the initial LAS, and the previous 3 months had to be free of any significant ankle injury. Participants in the CAI group were required to report at least 2 repeated episodes of giving way, feelings of instability, or recurrent sprain within the 6 months before enrollment. Lastly, each member of the CAI group was required to answer *yes* to at least 5 questions on the Ankle Instability Instrument (AII) questionnaire, score  $\geq 11$  on the Identification of Functional Ankle Instability (IdFAI), and score  $< 24$  on the Cumberland Ankle Instability Tool (CAIT).<sup>1–3</sup> Although scores on the Foot and Ankle Ability Measure-Activities of

Daily Living and -Sports subscales were not used as inclusion criteria, they were used to quantify additional functional disability among the participants.<sup>20</sup> In the event of a bilateral LAS history, we used the participant's limb with more giving-way episodes and more severe self-reported functional limitations.

Participants assigned to the LAS copers group were required to report a history of 1 acute LAS resulting in swelling and pain and at least 1 day of missed physical activity a minimum of 12 months before study enrollment.<sup>1–3</sup> Each LAS copers must have experienced no episodes of giving way, feelings of instability, or recurrent LAS.<sup>4</sup> Furthermore, each LAS copers was required to answer *yes* to no more than 4 questions on the AII, score  $\leq 10$  on the IdFAI, and score  $\geq 24$  on the CAIT. Lastly, each LAS copers self-reported no change in activity or occupational involvement due to previous injury.

Participants assigned to the healthy control group were required to report no history of LAS and no episodes of giving way or feelings of instability in their ankles. Each member of the control group was required to answer *no* to all questions on the AII, score 0 on the IdFAI, and score 30 on the CAIT. Perfect scores on patient-reported outcomes ensured that each member of the control group was free of giving-way episodes, weakness, and instability in the tested ankle.

### Instrumentation

A vertical-jump tester (model Vertec; Sports Imports, Columbus, OH) measured maximum vertical-jump height and served as a target during the jump-landing task. A force plate (model FP6090-15-2000; Bertec Inc, Columbus, OH) collected GRF data. Cortex 5.5 motion-capture and processing software (Motion Analysis Corporation, Santa Rosa, CA) collected kinetic data at a sampling rate of 1000 Hz and a gain of 10. We processed kinetic data with Visual 3D software (version 5; C-motion, Inc, Germantown, MD). LabVIEW software (version 13; National Instruments, Austin, TX) calculated TTS variables from the GRF data. A portable load cell (model Evaluator; BTE, Hanover, MD) with attachments designed for handheld dynamometry was used to measure isometric hip strength.

### Procedures

On arrival for laboratory testing, each participant read and signed a written informed consent document approved by the university's institutional review board, which also approved the study. Before testing, each participant performed a 5-minute warm-up consisting of stationary cycling at a self-selected pace and self-selected stretching. For participants in the CAI and LAS copers groups, we assessed each outcome in the involved limb. The research team member responsible for determining participant eligibility and group placement identified a random testing limb for participants in the control group using a random-number generator. Investigators blinded to the participants' group memberships assessed the primary outcomes.

For the assessment of maximum vertical-jump height, the participant stood with both feet together and flat on the floor and then performed a single reach with 1 hand to touch the highest vane possible on the Vertec and establish standing maximum vertical reach. The individual jumped

vertically from a double-legged stance and reached with 1 hand to touch the highest vane possible on the Vertec. Participants used their preferred countermovement strategy (eg, squat, arm swing) before jumping and their preferred arm to reach vertically. We subtracted standing maximum vertical reach from the best of 3 maximum jumping trials to obtain each person's maximum vertical-jump height.<sup>13–15,18,19,21</sup>

During the TTS task, the participant began in a double-legged stance 70 cm from the center of the force plate.<sup>14,16</sup> The individual jumped, reaching with 1 hand to touch the Vertec vane at 50% of his or her maximum vertical-jump height. The participant landed on 1 leg in the center of the force plate.<sup>15</sup> Upon landing, he or she was required to stabilize as quickly as possible and maintain the single-legged stance for 5 seconds.<sup>13,14</sup> Additionally, we instructed them to fold their arms across their chests once they felt stable. They completed 4 practice trials and 5 successful test trials. We discarded and repeated any trial in which the participant missed the Vertec target, did not land with the entire foot on the force plate, did not maintain the test limb in contact with the force plate after initial contact, or touched down with the nontest limb.

We filtered the raw GRF data using a low-pass, fourth-order Butterworth filter at a frequency of 12 Hz. LabVIEW software calculated the anterior-posterior TTS (APTTS) and medial-lateral TTS (MLTTS) from the anterior-posterior and medial-lateral GRFs, respectively. To calculate TTS, an unbounded third-order polynomial curve-fit line was superimposed over the rectified raw GRF graph.<sup>21</sup> We analyzed the control group's GRFs during the single-legged stance after initial contact to produce a normal reference of stability. A mean range of variation was calculated from the control group's smallest absolute GRF ranges during the final 3 seconds of the 5 TTS trials.<sup>21</sup> The mean range of variation, plus 3 standard deviations, was normalized to each participant's body weight and then superimposed on the curve-fit line.<sup>21</sup> The TTS values were determined as the amount of time from initial ground contact to the instant when the curve-fit line crossed the normalized range-of-variation line. Initial ground contact was the instant in which the vertical GRF exceeded a threshold of 10 N. After calculating APTTS and MLTTS, we calculated a singular resultant vector TTS (RVTTTS) variable using the following formula:  $RVTTTS = \sqrt{APTTS^2 + MLTTS^2}$ .<sup>16</sup> We also documented the number of failed TTS trials as a secondary outcome to control for the potential effects of fatigue from the jump-landing attempts.

Before assessing isometric hip strength, we measured lower extremity segment lengths as estimates of moment arm length. The distance (in meters) from the center of the greater trochanter to the lateral femoral epicondyle represented femur length. The distance (in meters) from the medial knee joint line to the distal end of the medial malleolus represented tibia length. We measured isometric hip-extension (EXT), ABD, and external-rotation (ER) strength in random order using previously described techniques.<sup>22</sup> Patient and examiner positions for each test are depicted in the Figure. The examiner placed the dynamometer a standard distance of 5.08 cm proximal to the knee joint line for EXT and ABD and 5.08 cm proximal to the most distal point of the medial malleolus for ER.<sup>23</sup>

During each test, the participant contracted against the dynamometer for 5 seconds, ramping up force during the first 3 seconds and then providing maximal effort for the final 2 seconds. The participant completed 1 practice trial and 3 test trials with 30-second rest intervals between trials. We recorded peak force (in pounds) for each trial. Previous authors<sup>22</sup> established good to excellent test-retest reliability for EXT (intraclass correlation coefficient [ICC] = 0.98), ABD (ICC = 0.76), and ER (ICC = 0.95).

We averaged peak force from 3 trials of each isometric hip-strength test and then converted that value to newtons. To account for differences between the measured moment arm lengths and the position of the dynamometer, we subtracted 5.08 cm from each participant's segment lengths. To identify the center of force application, we subtracted an additional 1.90 cm (half of the dynamometer's width of application) from the segment length. We then multiplied newtons by the corrected length of the corresponding moment arm (in meters) and divided by body mass (in kilograms) to calculate normalized torque (in newton meters per kilogram). Femur length acted as the moment arm for EXT and ABD, and tibia length acted as the moment arm for ER.

## Statistical Analysis

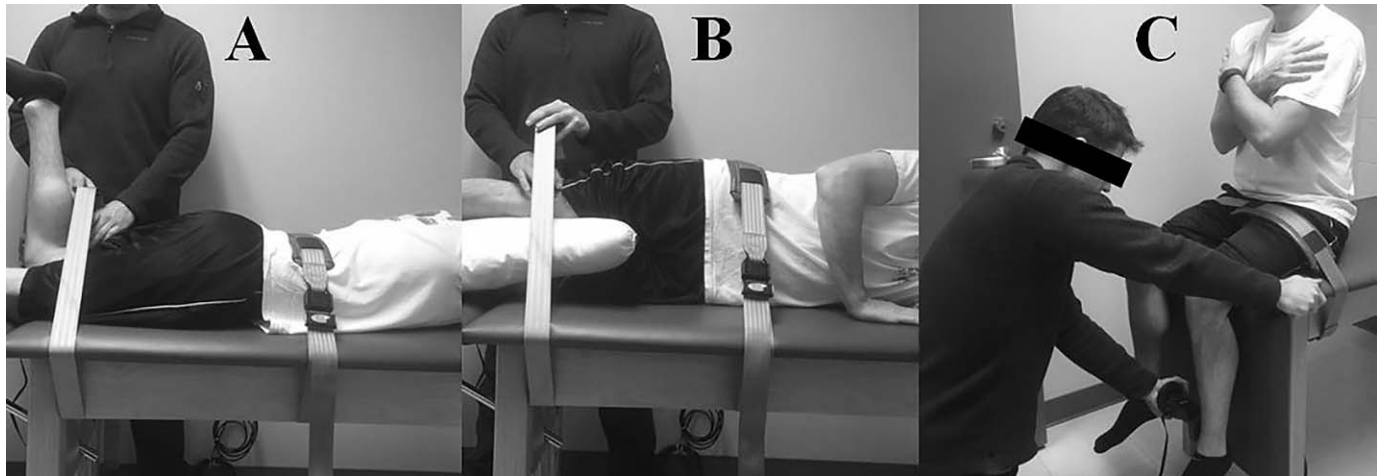
A Pearson  $\chi^2$  test assessed distributions of sex and dominant (DOM) and nondominant (NON) limbs tested in each group to ensure there was no influence on the between-groups comparisons of the primary outcomes. We conducted between-groups comparisons of demographics and injury history characteristics using separate 1-way analyses of variance. We performed between-groups comparisons of the primary outcomes using separate 1-way analyses of covariance, correcting for sex and limb. We used least-squares difference tests for pairwise comparisons in the event of a significant 1-way analysis of covariance. Cohen  $d$  effect sizes with 95% confidence intervals were included to estimate the magnitude of significant group differences.<sup>24</sup> We interpreted effect sizes using previously established criteria: *small*,  $d = 0.20$ – $0.49$ ; *moderate*,  $d = 0.50$ – $0.79$ ; and *large*,  $d > 0.80$ .<sup>24</sup> Confidence intervals that did not cross 0 indicated the effect size was statistically significant.

Backward linear regression analyses assessed the contribution of each group's isometric hip strength to RVTTTS variance. We used Cohen  $f^2$  effect sizes with 95% confidence intervals to describe the magnitude of each predictor variable's effect on the regression model. Effect sizes were interpreted as *small* ( $f^2 = 0.02$ – $0.14$ ), *moderate* ( $f^2 = 0.15$ – $0.34$ ), or *large* ( $f^2 \geq 0.35$ ).<sup>25</sup> Significance was set a priori at  $P < .05$ . We conducted all statistical analyses with SPSS (version 23; IBM Corp, Armonk, NY).

## RESULTS

After group placement, a Pearson  $\chi^2$  test indicated that the distributions of men and women did not differ among the CAI (women = 17, men = 3), LAS coper (women = 16, men = 4), and control (women = 14, men = 6;  $\chi^2_2 = 1.38$ ,  $P = .50$ ) groups and, thus, likely did not affect the primary statistical analyses. Additionally, the distributions of DOM and NON limbs tested did not differ among the CAI (DOM = 12, NON = 8), LAS coper (DOM = 14, NON = 6), and





**Figure.** Patient and examiner positioning for A, isometric hip-extension, B, -abduction, and C, external-rotation strength testing.

control (DOM = 14, NON = 6;  $\chi^2_2 = 0.60$ ,  $P = .74$ ) groups. The CAI (age =  $24.8 \pm 4.0$  years, height =  $166.8 \pm 7.7$  cm, mass =  $76.7 \pm 15.5$  kg), LAS copers (age =  $23.9 \pm 5.7$  years, height =  $165.7 \pm 8.1$  cm, mass =  $69.8 \pm 18.3$  kg), and control (age =  $22.6 \pm 3.8$  years, height =  $167.2 \pm 7.5$  cm, mass =  $65.9 \pm 11.2$  kg) groups did not differ in age ( $F_{2,57} = 1.18$ ,  $P = .32$ ), height ( $F_{2,57} = 1.18$ ,  $P = .83$ ), or mass ( $F_{2,57} = 1.18$ ,  $P = .09$ ). Group differences in injury history characteristics are presented in Table 1.

Group differences existed for EXT and ER when controlling for sex and limb (Table 2). The CAI group had lower EXT scores than the LAS copers ( $P = .02$ ,  $d = 0.72$  [0.06, 1.34]) and control ( $P = .01$ ,  $d = 1.19$  [0.50, 1.84]) groups. The CAI group also had lower ER scores than the LAS copers ( $P = .03$ ,  $d = 0.78$  [0.13, 1.41]) and control ( $P = .01$ ,  $d = 1.02$  [0.34, 1.65]) groups. The LAS copers and control groups did not differ in EXT ( $P = .63$ ) or ER ( $P = .59$ ). We identified no group differences in ABD, RVTTS, or the number of failed jump-landing trials when controlling for sex and limb.

We found a significant final linear regression model, in which greater EXT was associated with a shorter RVTTS score in the LAS copers group (Table 3). This relationship was associated with a moderate effect size. The final backward linear regression models that emerged for the CAI and control groups were nonsignificant.

## DISCUSSION

Our primary finding was that individuals with CAI had isometric hip-muscle strength deficits, specifically in EXT and ER, compared with LAS copers and controls. We are aware of only 1 other group<sup>10</sup> that has reported isometric hip-strength deficits in individuals with CAI versus individuals without CAI. Our CAI group's proximal neuromuscular impairments may support the theory that peripheral musculoskeletal injuries can affect centrally regulated motor control<sup>26</sup> and ultimately result in extensive lower extremity neuromuscular impairments. This theory is supported by a number of other investigators<sup>7-9,11,27,28</sup> who have noted neuromuscular alterations at the hip in individuals with CAI. However, we did not assess isometric hip strength before the index LAS, so we cannot confirm whether the impairments were preexisting or arose because of the LAS injuries. Nevertheless, reduced isometric hip strength has been associated with an increased risk of distal lower extremity injuries,<sup>29,30</sup> likely because of the decreased ability to safely position the lower extremity during functional tasks.

Isometric hip strength explained 21% of dynamic-stability variance in the LAS copers group only, with greater EXT equating to more favorable dynamic stability. A moderate effect size indicated that the LAS copers' isometric hip strength influenced dynamic stability to a

**Table 1.** Between-Groups Comparisons of Injury History Characteristics

Characteristic	Group, Mean $\pm$ SD			1-Way Analysis of Variance $F_{2,57}$ Value	<i>P</i> Value
	Chronic Ankle Instability (n = 20)	LAS Copers (n = 20)	Control (n = 20)		
Ankle Instability Instrument score	5.8 $\pm$ 2.2	2.5 $\pm$ 1.0	0.0 $\pm$ 0.0	82.68	<.01
Identification of Functional Ankle Instability score	18.3 $\pm$ 5.7	5.2 $\pm$ 4.2	0.0 $\pm$ 0.0	106.21	<.01
Cumberland Ankle Instability Tool score	15.3 $\pm$ 6.1	26.7 $\pm$ 3.4	30.0 $\pm$ 0.2	72.05	<.01
Foot and Ankle Ability Measure score					
Activities of Daily Living	89.3 $\pm$ 7.1	99.0 $\pm$ 1.9	99.9 $\pm$ 0.5	38.01	<.01
Sports	75.6 $\pm$ 14.0	94.9 $\pm$ 8.2	99.8 $\pm$ 0.8	37.26	<.01
Previous LAS, No.	5.0 $\pm$ 4.4	1.7 $\pm$ 1.1	0.0 $\pm$ 0.0	18.50	<.01
Time since previous LAS, mo	44.3 $\pm$ 46.9	83.2 $\pm$ 83.5	0.0 $\pm$ 0.0	11.32	<.01
Giving-way episodes in last 6 months, No.	10.8 $\pm$ 17.9	0.1 $\pm$ 0.3	0.0 $\pm$ 0.0	7.20	<.01
Time since previous giving-way episode, mo	1.3 $\pm$ 1.4	NA	NA	NA	NA

Abbreviation: LAS, lateral ankle sprain; NA, not applicable.

**Table 2. Between-Groups Comparisons of Primary Outcomes, Controlling for Sex and Limb**

Variable	Group, Mean $\pm$ SD			1-Way Analysis of Covariance $F_{2,57}$ Value	<i>P</i> Value
	Chronic Ankle Instability ( <i>n</i> = 20)	Lateral Ankle Sprain Coper ( <i>n</i> = 20)	Control ( <i>n</i> = 20)		
Resultant vector time to stabilization, s	1.50 $\pm$ 0.04	1.49 $\pm$ 0.03	1.50 $\pm$ 0.04	1.16	.32
Failed resultant vector time to stabilization trials, No.	2.40 $\pm$ 3.00	2.50 $\pm$ 2.90	2.70 $\pm$ 3.60	0.02	.98
Isometric hip torque, N·m/kg					
Extension	0.98 $\pm$ 0.33 <sup>a,b</sup>	1.30 $\pm$ 0.54	1.38 $\pm$ 0.34	4.59	.01
Abduction	1.29 $\pm$ 0.36	1.46 $\pm$ 0.48	1.63 $\pm$ 0.38	2.84	.07
External rotation	0.47 $\pm$ 0.08 <sup>a,b</sup>	0.55 $\pm$ 0.12	0.58 $\pm$ 0.13	4.33	.02

<sup>a</sup> Statistically different from the lateral ankle-sprain coper group.

<sup>b</sup> Statistically different from the control group.

meaningful degree, and thus, they may have used a compensatory, hip-inclusive stabilization strategy. However, the hypothesized association between dynamic stability and isometric hip strength would be most beneficial for developing rehabilitation protocols for individuals with CAI. Considering the dynamic-systems model,<sup>31</sup> we anticipated that hip-muscle weakness would limit the CAI group's ability to use alternative movement strategies to stabilize the lower extremity in the presence of neuromuscular dysfunction at the ankle joint. As the observed association was not present in the participants with the greatest need for rehabilitation (ie, the CAI group), we cannot conclude that reduced isometric hip strength is indicative of reduced dynamic stability in patients with CAI. However, we must note that the association between ABD strength and dynamic stability in the CAI group had a moderate effect size and a level of statistical significance. Therefore, this association warrants further exploration.

Although the CAI group was potentially unable to adopt a more hip-inclusive dynamic stability strategy, their RVTTS scores did not suffer, suggesting they had an alternative stabilization strategy. However, we did not quantify muscular function at any other joint and therefore cannot infer what alternative stabilization strategy they used. Another potential reason for the lack of a significant association in the CAI group is that the landing task involved a dynamic movement, whereas we measured strength statically. Isotonic strength or activation amplitude might more accurately represent hip-muscle function during a dynamic-stability task. Although isometric hip-muscle strength may be a poor indicator of dynamic stability in patients with CAI, isometric hip strength may influence other outcomes, such as dynamic postural control.<sup>10</sup> Future authors should explore which other functional impairments and activity limitations may be improved by increasing isometric hip strength in patients with CAI.

We did not find differences in dynamic stability among the 3 groups. This result was unexpected, as RVTTS performance has previously differed between individuals with and those without CAI.<sup>13,16</sup> The mean RVTTSs of our 3 groups were similar ( $\sim$ 1.50 seconds) to the mean RVTTS of the stable ankle group described by Ross et al,<sup>16</sup> suggesting that our CAI group displayed unimpaired dynamic stability. To our knowledge, we are the first to examine RVTTS in individuals with and those without CAI under the inclusion guidelines outlined by the IAC,<sup>1-3</sup> which allow participants with fewer episodes of giving

way, feelings of instability, and recurrent sprains compared with previous studies.<sup>13,16</sup> Although the intent of the guidelines was to establish homogeneity in CAI cohorts, previous researchers<sup>32,33</sup> who identified different functional impairments among subcategories of CAI patients supported the existence of heterogeneity within CAI. Our results and those of others<sup>17</sup> may provide evidence that greater group heterogeneity can result in an absence of RVTTS differences between CAI and LAS coper groups. Wright et al<sup>17</sup> compared dynamic stability between individuals with functional ankle instability (FAI), LAS copers, and controls, using group classification guidelines very similar to the IAC's. The FAI group did have higher MLTTS scores compared with controls, yet these did not differ from those of LAS copers. Additionally, LAS copers had higher APTTS scores compared with FAI and control groups. Lastly, our selected sampling rate, data filter, and trial length also may have influenced our findings.<sup>34</sup> Wide variations in these factors have been used to assess TTS in individuals with CAI but have likely caused TTS scores to vary across studies.<sup>34</sup>

### Clinical Application

Our findings build on limited evidence<sup>9-11</sup> suggesting that hip strength is deficient in individuals with CAI. Clinicians treating patients with LAS or CAI are encouraged to assess hip-strength impairments and dedicate time to resolving deficits with therapeutic exercise.<sup>35</sup> Two groups<sup>36,37</sup> have investigated hip strengthening in patients with CAI, and both reported improvements in clinical outcomes. Smith et al<sup>37</sup> examined the effects on dynamic postural control, noting that hip strengthening improved the Star Excursion Balance Test scores of patients with CAI. We did not find an association between isometric hip strength and dynamic stability in individuals with CAI, which suggests that

**Table 3. Backward Linear Regression Models (Outcome Variable: Resultant Vector Time to Stabilization)**

Group	Predictor Variable (Isometric Hip Torque)	$\beta$	$R^2$	$f^2$ (95% Confidence Interval)	<i>P</i>
Chronic ankle instability	Abduction	.34	0.12	0.14 (0.06, 0.22)	.14
Lateral ankle sprain coper	Extension	-.45	0.21	0.27 (0.22, 0.32)	.04
Control	Abduction	.31	0.10	0.11 (0.03, 0.19)	.18

increasing isometric hip-muscle strength may not be an effective means of enhancing dynamic stability. However, more work is needed in this area, as we did not assess the relationship between changes in hip strength and changes in dynamic stability after a rehabilitation protocol. Typically, hip-strengthening protocols involve isotonic exercise as opposed to isolated isometric exercise. Therefore, more investigation is needed to determine if other components of a hip-strengthening protocol may positively affect dynamic stability. Additionally, decreased dynamic stability is one of many deficiencies that have been identified in individuals with CAI, and hip strengthening may have more effects on other functional impairments and self-reported outcomes.

Surprisingly, RVTTS performance was unimpaired in our participants with CAI, signifying that dynamic stability during single-limb landing may be less of a concern for CAI rehabilitation than previously thought. Although group heterogeneity or data-collection and -processing factors may have reduced the apparent differences between the groups with and without CAI, clinicians should understand that CAI cohorts may include some individuals with substantial dynamic-stability impairments. Therefore, although our results might suggest that dynamic stability could be considered of secondary importance, this outcome may need to be evaluated on an individual basis<sup>35</sup>; correcting possible deficits is still a potentially valuable component of rehabilitation for some patients with CAI.

## Limitations

Notable limitations in this study include the retrospective study design that prevented us from determining whether isometric hip-strength impairments in the CAI group were present before the initial LAS or resulted from acute injury. Also, we only measured hip-muscle strength isometrically, with the intention of improving the clinical applicability. However, these measures may have inadequately gauged the role of hip musculature in dynamic stability.

## CONCLUSIONS

Participants with CAI displayed reduced isometric hip strength compared with the LAS coper and control groups but no deficits in dynamic stability. Isometric hip strength was a significant influence on RVTTS for the LAS coper group only, suggesting that isometric hip strength is a poor indicator of dynamic-stability performance in patients with CAI. Nevertheless, hip-muscle strengthening may be a valuable rehabilitation component for patients with CAI. Future authors must establish the most effective means of improving hip strength in this population.

## ACKNOWLEDGMENTS

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