Chronic Ankle Instability Impairs Submaximal Force Steadiness and Accuracy

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Abstract

Context: Patients with chronic ankle instability (CAI) have demonstrated sensorimotor impairments. Submaximal force steadiness and accuracy measure sensory, motor, and visual function via a feedback mechanism, which helps researchers and clinicians to comprehend sensorimotor deficits associated with CAI. Objective: To determine if participants with chronic ankle instability experience deficits in hip and ankle submaximal force steadiness and accuracy compared to healthy controls. Design: A case-controlled study Setting: Research Laboratory

Patients and Other Participants: Twenty-one CAI patients and 21 uninjured controls participated in this study. Intervention(s): n/a. Main Outcome Measure(s): Maximal voluntary isometric contraction (MVIC), force steadiness and accuracy (10% and 30% of their MVIC) of ankle evertors, invertors, and hip abductors. The central 10-sec (20-87% of the total time) of the 3 trials were analyzed. An independent t-test was used to assess MVIC. Two-way, 2 × 3, ANOVAs were used to assess force steadiness and accuracy. Results: Relative to controls, the CAI group demonstrated lower accuracy in invertors ($p = .0006$). Across all motions, the CAI group showed less steadiness ($p = .0005$) and lower accuracy ($p = .0074$) than the controls in 10% MVIC. In terms of MVIC, the CAI group showed less force output in hip abduction compared with the control group ($p < .0001$). Conclusions: CAI patients showed an inability to control ongoing fine force (10% and 30% of their MVIC) through a feedback mechanism during an active test. These findings suggest deficits in sensorimotor control that lead CAI patients to be more susceptible to injury positions since they have difficulty integrating the peripheral information and correcting their movement in relation to visual information.
24 **Key Words:** Chronic ankle instability; Force steadiness; Force accuracy; Sensorimotor system

25

26 **Key Points**

27 - CAI patients showed somatosensory deficits in force steadiness in invertors and deficits in accuracy in both evertors and invertors during a real-time feedback task.

28 - CAI patients may have difficulty integrating the peripheral information and correcting their movement in relation to visual information.
1. Introduction

Lateral ankle sprains (LASs) are common musculoskeletal injuries that are often caused by sudden inversion stress while the foot is weight bearing, plantarflexed, and inverted. This results in damage to the lateral ligaments of the ankle, which reduces static and dynamic ankle stability. After an initial LAS, up to 80% of people suffer repeated ankle sprains, which often develop into chronic ankle instability (CAI), a condition characterized by pathomechanical, sensory-perceptual, and motor-behavioral impairments. These impairments result in people entering a continuum of disability as proved by the statistic that up to 78% of CAI develop into post-traumatic ankle osteoarthritis (OA) which decreases the quality of life.

The sensorimotor system incorporates afferent, efferent, and central integration and processing maintaining functional joint stability. Patients with LAS and CAI are known to exhibit somatosensory deficits including kinesthesia, joint position sense, and/or force sense. Specifically, force sense has long been one of the measurements that assesses conscious proprioception. Deficits in force sense could result from damage to the muscle mechanoreceptors (e.g., meissner's corpuscle, pacinian corpuscle, or ruffini ending), deafferentation, cutaneous input, and/or a distortion of the corollary discharge. However, previous studies on force sense have some limitations. For example, some researchers have used only a single active replication for target force without correcting errors via visual feedback. However, it is important to measure how steadily and accurately individuals can adjust from errors in real time, which is more relevant for functional tasks. Since subjects were not allowed to look at a monitor that showed target force, there was also no visual feedback, a factor which is important for the motor control system. Visual information plays an important role in integrating sensory information into the central nervous system (CNS) to generate appropriate
motor output.\textsuperscript{9} Given that CAI patients tend to rely more on visual information due to an impaired somatosensory system,\textsuperscript{10} a measure of force control through the feedback mechanism (correcting errors in real time) along with visual information is necessary to appreciate a comprehensive mechanism of CAI.

In order to accommodate the limitations in previous studies, researchers have adapted a new method to measure submaximal force steadiness and accuracy.\textsuperscript{8,11-15} Submaximal force steadiness and accuracy refer to the ability of a muscle to produce an accurate and steady contraction during a static or dynamic task.\textsuperscript{8} One study demonstrated that the regulation of submaximal muscle force is more relevant for daily activities (e.g., walking, driving a car, stepping over obstacles, ascending and descending stairs) and sports-related activities (e.g., squatting, sprinting, jumping, landing, and cutting) compared to previously studied methods (e.g., joint position sense and/or static force sense).\textsuperscript{8} In daily activities, maximal voluntary activation is used only for 56 seconds in a day.\textsuperscript{16} In addition, moderately active college students use 17\% of their maximum force in the quadriceps and hamstrings in daily activities.\textsuperscript{16} Submaximal force steadiness has been used in various populations including anterior cruciate ligament reconstruction,\textsuperscript{11} knee and hip osteoarthritis,\textsuperscript{14,15} history of falling,\textsuperscript{12} and subacute stroke.\textsuperscript{13} The results of the previous studies\textsuperscript{11-15} identified that people with these conditions have less force steadiness and accuracy than their counterparts. However, no study has examined force steadiness and accuracy in CAI patients. Based on the recently updated model of CAI,\textsuperscript{2} there are 6 factors that contribute to motor-behavioral impairments including altered reflex, neuromuscular inhibition, muscle weakness, balance deficits, altered movement patterns, and reduced physical activity. A previous study reported that reduced force steadiness is associated with neuromuscular inhibition and muscle weakness in patients with knee pain.\textsuperscript{8} If CAI patients...
show impairments during the force steadiness measurement, it could be a key characteristic of CAI.

The purpose of this study was to examine the effect of CAI on submaximal force steadiness and accuracy of ankle evertors, invertors, and hip abductors. Based on the literature that measured force sense in patients with CAI, researchers have previously measured ankle evertors.\textsuperscript{6,7} However, since musculoskeletal injuries in joints impair co-contraction of muscles around the joint, it is important to measure ankle invertors to identify co-contraction of ankle muscles.\textsuperscript{17,18} It is also important to measure hip abductors, since previous studies stated that CAI patients demonstrated deficits in hip neuromuscular control.\textsuperscript{19-21} We hypothesized that CAI patients would show less force steadiness and accuracy of all three muscle groups compared to a group of healthy control subjects. If we confirm our hypothesis, we would suggest to clinicians that rehabilitation programs for CAI patients should focus on restoring proprioceptive function of the ankle and hip along with visual training.

2. Methods

2.1. Subjects

A total of 42 physically active collegiate students, consisting of 21 CAI subjects and 21 healthy controls, were recruited from a university population. A feasible sample size of 36 subjects was determined by a power analysis, a priori, using previous data (isometric force steadiness) with alpha, beta, and Cohen’s d values of 0.05, 0.2, and 0.93, respectively.\textsuperscript{8} Subject exclusion criteria included a history of lower limb surgery, fracture, or neurological disorders in
their lifetime and any sports-related injuries within the previous 3 months. Subject demographic information is shown in Table 1.

CAI subjects were identified based on the International Consortium Guidelines. We used self-reported disability questionnaires including a Foot and Ankle Ability Measure for Activities of Daily Living (FAAM ADL), FAAM Sports, and Ankle Instability Instrument (AII). Specific subject inclusion criteria for CAI included (i) a history of ankle sprain injury that occurred at least 3 months prior at the time of data collection, (ii) a score of < 90% on the FAAM ADL, (iii) a score of < 80% on the FAAM Sports, (iv) at least 5 “yes” answers including question 1, plus 4 others on the AII, and (v) a history of physical activity at least 3 days/week for a total of 90 min/week in the previous 3 months. Healthy controls were defined using aforementioned self-reported disability questionnaires including the FAAM ADL, FAAM Sports, and AII. Specific subjects inclusion criteria for healthy controls included (i) no previous ankle sprain injury, (ii) a score of 100% on the FAAM ADL, (iii) a score of 100% on the FAAM Sports, (iv) no “yes” answers on the AII, and (v) a history of physical activity at least 3 days/week for a total of 90 min/week in the previous 3 months. All participants provided informed consent prior to their participation, and the study was approved by the appropriate institutional review board.

2.2. Experimental procedures (Fig. 1)

A Biodex dynamometer and Biodex Advantage Software (Biodex Medical Systems Inc, Shirley, New York, USA) were used to measure maximal voluntary isometric contraction (MVIC), force steadiness, and accuracy of ankle evertors, invertors, and hip abductors. MVIC was measured to compare maximum force of those muscles between groups. Subject were provided an opportunity to become familiarized with the isokinetic dynamometer and the testing
procedure and to perform as many warm-up repetitions as desired at least 5 times. In the practice session for MVIC measures, subjects were instructed to perform the task at varying force outputs (25%, 50%, 75%, and 100% of their MVIC). After a 3 min rest, subjects performed 3 trials of MVIC by contracting the muscles (evertors, invertors, and hip abductors) as hard as possible for 3 seconds. In addition, they were instructed to minimize other movements during testing. There was a 1 min rest between trials. Once participants measured their MVICs, an examiner calculated 10% and 30% of each subject’s MVIC. Previous studies have examined various force increments (10, 20, 25, 30, 40, and 50% of MVIC) to measure force steadiness for different joints.\textsuperscript{11-15} Since there is no study that measures force steadiness in patients with CAI, investigators chose to use 10 and 30% of MVIC based on a previous study that measured force sense for the same motions as the current study in patients with CAI.\textsuperscript{6} Subjects were instructed how force steadiness and accuracy were measured. During the test, they were instructed to attempt to stay at the target force (10% and 30% of MVIC) as closely as possible for 15 seconds. There were 5 trials for each muscle and the first two trials were considered as practice trials. Participants were able to adjust their forces through a monitor (1-m away from subjects) showing their actual forces. While subjects performed force steadiness trials, one of the examiners indicated the target force line, so that they easily recognized where their target forces were. The examiner randomly assigned a target force, 10% and 30% of MVIC, to each subject.

2.3. Subject position on a dynamometer

All subjects wore athletic shoes (Nike T-Lite XI, Beaverton, Oregon, USA) during testing, which were tightly secured to the footplate to minimize unnecessary movement between the shoe sole and footplate surface for the ankle measurements (Fig. 2). For the hip measurements, subjects were positioned on their side on the dynamometer chair facing the
dynamometer, thus giving less space for compensatory movements (Fig. 2). This position
provided a backrest and allowed participants to hold the handhold in front of them, thereby
minimizing trunk and pelvic rotation during testing. The position was referenced by the Biodex
System 3 application and operation manual.

2.4. Data processing and statistical analysis

All three trials of MVIC were processed using custom-written Matlab software to
determine maximum torque. Submaximal force steadiness and accuracy were also analyzed
using the Matlab software. For all the conditions, the first two trials were discarded and the
central 10 seconds of data (20-87% of the total time) were analyzed for the remaining three trials
(Fig. 3). The force steadiness and accuracy were calculated based on a previous study. Specifically, the standard deviation across the 10 seconds of data provides the response signal of
the participant without reference to the target force level, which is force steadiness. Force
accuracy is calculated as the root mean square (RMS) of the difference between the subject-
generated force and target force. MVIC was analyzed by an independent t-test for group effect
(CAI vs. Healthy controls). Force steadiness and accuracy were analyzed by a two-way (2 groups
(CAI and Healthy controls) × 3 motions (eversion, inversion, and hip abduction)) ANOVA for
the group effect, motion effect, and group x motion interaction. A Tukey’s Honestly Significant
Difference (HSD) post-hoc test was performed for pairwise comparisons. The experiment-wise
type I error rate for all tests was set at $p < .05$. Cohen’s d effect sizes were calculated to provide
the magnitude of differences between groups (from 0.21 to 0.5 as small, from 0.51 to 0.8 as
moderate, and $> 0.8$ as large).
3. Results

3.1. Force Steadiness (Standard Deviation)

Table 2 shows force steadiness data at 10% and 30% MVIC of eversion, inversion, and hip abduction for both CAI and control groups. There was no interaction between group and muscle in both 10% and 30% MVIC (F<sub>5,120</sub> = 1.42, p = .25; F<sub>5,120</sub> = 1.32, p = .27, respectively). There was group main effect in 10% MVIC force steadiness (F<sub>5,120</sub> = 12.67, p = .00), but no effect in 30% MVIC (F<sub>5,120</sub> = 1.76, p = .19). There were motion main effects in 10 and 30% MVIC (F<sub>5,120</sub> = 136.09, p < .0001; F<sub>5,120</sub> = 100.77, p < .0001, respectively). A Tukey’s HSD post-hoc test indicated that hip abductors showed less steadiness than evertors and invertors in 10% (p < .0001, both) and 20% MVIC (p < .0001, both). Even though there was no interaction between group and muscle, Cohen’s d showed large effect size in 10% inversion between groups (ES = 1.18). In summary, CAI patients demonstrated less steadiness in inversion compared with the control group.

3.2. Force Accuracy (Root Mean Square)

Table 2 shows force accuracy error data at 10% and 30% MVIC of eversion, inversion, and hip abduction for both CAI and control groups. There was interaction between group and muscle in both 10% and 30% (F<sub>5,120</sub> = 7.57, p = .01; F<sub>5,120</sub> = 4.22, p = .02, respectively). A Tukey’s HSD post-hoc test indicated that the CAI group showed less inversion accuracy than the control group in 10% MVIC (p = .00) There was group main effect in 10% MVIC force accuracy (F<sub>5,120</sub> = 7.42, p = .00), but no effect in 30% MVIC (F<sub>5,120</sub> = 3.74, p = .06). There were motion main effects in 10 and 30% MVIC (F<sub>5,120</sub> = 25.08, p < .0001; F<sub>5,120</sub> = 15.46, p < .0001, respectively). A Tukey’s HSD post-hoc test indicated that hip abductors showed less accuracy than evertors and invertors in 10% (p < .0001, both) and 20% MVIC (p < .0001, both). In
addition, Cohen’s $d$ showed medium effect size in 10% eversion between groups (ES = 0.65). In summary, CAI patients had lower accuracy in eversion and inversion compared with the control.

### 3.3. Maximal Voluntary Isometric Contraction (MVIC)

Table 3 shows MVIC data for eversion, inversion, and hip abduction for both CAI and control groups. There was no group difference in MVIC of eversion and inversion ($T_{1,124} = 2.25$, $p = .14$; $T_{1,124} = 1.39$, $p = .24$, respectively). Contrary to eversion and inversion, CAI patients showed less force output in hip abduction compared with the control group. ($T_{1,124} = 58.06$, $p < .0001$)

### 4. Discussion

The purpose of this study was to examine the effect of CAI on submaximal force steadiness and accuracy of ankle evertors, invertors, and hip abductors. The primary finding of this study was that CAI subjects have impairments in submaximal force steadiness on ankle invertors, and in force accuracy on ankle evertors and invertors. In addition, CAI subjects showed less maximum force than the control group in hip abductors.

Measuring submaximal force steadiness and accuracy is a novel technique to assess proprioceptive function. This new technique assesses the ability of feedback-based force adjustment through visual information and sensorimotor function. Previous studies demonstrated that people who have impaired proprioceptive function caused by anterior cruciate ligament reconstruction, knee and hip osteoarthritis, falling, and subacute stroke showed less submaximal force steadiness. The current findings reinforce the existing body of literature since there is no previous literature linking CAI and force steadiness.
4.1 Differences Between Groups in Force Steadiness and Accuracy

In the current study, CAI subjects maintained less force steadiness in their invertors during isometric contractions. In addition, they showed significantly less accuracy in eversion and inversion. The increased variability in force steadiness and accuracy represents altered motor unit recruitment and firing rates, impaired proprioceptive information, increased activation of synergist and antagonist muscles, and altered spinal interneuron modulation of motoneuron firing. We propose that the presently observed alterations in force steadiness and accuracy may be due to impaired proprioceptive function in CAI patients. Proprioceptive sensory inputs from muscles, tendons, and ligaments are transmitted from the peripheral nervous system (PNS) to the CNS; this is necessary for appropriate neuromuscular control. Neuromuscular control can be affected by (i) less peripheral information collected because of damaged proprioception, (ii) an inability to integrate the peripheral information in the CNS, or (iii) an inability to send out the centrally-mediated information to the motor units. Thus, our results may be attributed to one or more of the aforementioned factors. Moreover, one study explained that less steadiness in force output may be caused by presynaptic inhibition of Ia afferents. Due to the depolarization of primary afferent fibers by interneuron, input from Ia afferents to the active motor neuron pool may be inhibited and consequently affect the activation of the motor units to maintain certain force. Accordingly, CAI patients may have an inability to regulate presynaptic inhibition compared with healthy controls. Furthermore, Docherty et al suggested a significant relationship between ankle instability and force sense. Their results showed that individuals with functional ankle instability have deficits in precise force sense and joint position sense. Since CAI patients have impaired proprioception, strength, and postural control caused by repeated lateral ankle sprains, reduced force accuracy could be a consequence of the injury.
In this study, CAI subjects showed less steadiness and accuracy only in the invertors, but not evertors, compared to controls. A possible explanation for this result is that invertors have deficits in motor control and a larger degree of freedom in movement during force generation than evertors. Specifically, previous studies reported that there are deficits in motor control such as neuromuscular inhibition and muscle weakness not only in evertors, but also in invertors.\textsuperscript{2,18} Inversion is a motion that has a larger range of motion and more muscle fibers for force generation than eversion. Given that, invertors may have less steadiness and accuracy because inversion has more range of motion to generate force than eversion. There is no direct relationship between force control and the degree of freedom in force generation based on the literature. However, several studies were used to compare absolute error between different joints in the lower extremity during force steadiness.\textsuperscript{13-15} A combination of the previous studies and our results support that the greater the motion during force generation a lower extremity joint has, the greater the error the joint makes during force control (the order in which joints have less error: eversion < inversion < hip abduction < knee extension). Both impaired motor control and the large degree of freedom in invertors resulted in impaired force steadiness and accuracy.

4.2. A Novel Measurement for CAI Patients: Force Steadiness and Accuracy

Unlike previous studies measuring force steadiness and accuracy,\textsuperscript{6,7} subjects were allowed to look at a monitor to check their force steadiness and accuracy output, and allowed to adjust their target force during the task in this study. Thus, this feedback allowed subjects to adjust their force to get closer to the target forces. Previous studies demonstrated that the visual feedback can enhance not only isokinetic muscle force,\textsuperscript{26} but also neuromuscular control, such as inter-limb coordination.\textsuperscript{27} However, CAI subjects had more difficulty maintaining target forces than controls in this study. This result suggests that CAI patients have difficulties in reducing
force error. In other words, the ability to integrate sensory information into the CNS to produce appropriate motor output may be impaired in CAI patients. A future study is needed to examine the effect of visual information on force steadiness and accuracy to strengthen this idea. Practically, deficits in the ability to integrate sensory information could easily result in alternations to movement, loads, and, ultimately, increase injury risk.28

4.3. Changes in the Neuromuscular Control in the Proximal Joint.

Researchers have studied hip joint neuromuscular alternations in those with LAS and CAI.19,21 Hip biomechanics were altered in CAI patients, which could be due to deficits in altered neuromuscular control.21 Decreased hip strength also influenced dynamic postural control, which needs appropriate neural muscular control in the CAI population.19 In concord with previous studies,19,21 our results indicate that CAI patients demonstrated less maximal voluntary isometric contraction (MVIC) of hip abduction than controls. However, there was no difference in submaximal force steadiness and accuracy between CAI subjects and controls. The task in this study was submaximal force steadiness, which is less dynamic than the jump-landing task and star excursion balance test.20,21 The measures of force steadiness and accuracy may be less demanding tasks to induce a difference between two conditions. Additionally, we measured isometric hip abductor force. If we measure concentric or eccentric force, which is a more dynamic task than isometric force, it may elicit a difference between conditions. Thus, a future study is needed to measure force steadiness and accuracy during concentric or eccentric contractions.

4.4. Differences Between Muscle Groups in Force Steadiness and Accuracy
In this investigation, hip abductors showed more errors in force steadiness and accuracy than evertors and invertors. The results suggest that as more muscle fibers were recruited, subjects’ steadiness performance decreased. Since limited data are available in force steadiness between large and small muscle groups, an explanation for this current finding was assumed based on previous studies. The mass of knee extensors are higher than hip abductors, and hip abductors’ mass are higher than evertors or invertors. In the current study, the absolute error of 10% MVIC force steadiness for ankle eversion and inversion were less than 0.4. However, absolute error of force steadiness for quadriceps in patients with knee and hip osteoarthritis were higher than 1.3. (2.13 ± 1.51 and 1.3 ± 0.94, respectively). Therefore, we suggest that the number of muscle fibers may affect the ability to maintain submaximal force steadiness. A relationship between the number of muscle fibers and force steadiness and accuracy would be valuable to study in the future.

4.5. Clinical Implication

The current findings of impaired ankle and hip force steadiness and accuracy in chronic ankle instability (CAI) patients provide useful insights for clinicians in developing rehabilitation protocols. The current results indirectly indicate that CAI patients had proprioceptive deficits in force steadiness and accuracy of ankle inversion and eversion. This impaired proprioception might lead CAI patients to be more susceptible to injury positions as they have difficulty integrating the peripheral information and correcting their movement in relation to visual information. Restoring proprioceptive function of the ankle and hip along with visual training may be a key to improving clinical outcomes for this CAI population. Our data suggest that clinicians should continue to focus on restoring proprioceptive function in both distal and proximal joints in conjunction with visual information to improve force control in various
movements. Moreover, movement-related functional rehabilitation exercises are necessary to adjust and correct their movement errors and increase the ability to produce appropriate force in a given task.

4.6. Limitation

One limitation of this study is that we only measured an isometric contraction of ankle evertors, invertors, and hip abductor. The isometric contraction measure may not be sufficient to fully understand somatosensory function of the involved joints during sports and/or activities of daily living. Although errors of force steadiness and accuracy in concentric and eccentric contractions of the knee extensor were not different between concentric and eccentric conditions, ankle musculature may show different results.

5. Conclusion

In conclusion, CAI subjects showed somatosensory deficits in force steadiness in invertors and deficits in accuracy in both evertors and invertors during a real-time feedback task. This is the first study observing the effect of CAI on submaximal force steadiness and accuracy in CAI patients. The results suggest that clinicians should focus on improving proprioceptive function by using rehabilitative exercises in conjunction with visual training for CAI patients to reduce further injuries.

Authors’ contributions

AAA participated in the design of the study, contributed to data collection, data reduction/analysis, and interpretation of results. BBB, CCC, DDD participated in the design of
the study and contributed to the interpretation of results. EEE participated in the design of the study and contributed to data collection. FFF contributed to the manuscript writing. All authors have read and approved the final version of the manuscript.

Competing interests

The authors declare that they have no competing interests.
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Table 1. Subject Demographics

| Characteristic               | Group, Mean ± SD |
|-----------------------------|------------------|
|                             | CAI (n = 21)     | Healthy (n = 21) |
| Sex, male/female            | 9/12             | 10/11            |
| Age, y                      | 22.2 ± 3.2       | 22.7 ± 2.3       |
| Height, cm                  | 177.7 ± 10.2     | 176.5 ± 12.1     |
| Mass, kg                    | 83.3 ± 25.1      | 71.3 ± 14.9      |
| FAAM ADL, %                 | 77.6 ± 7.2       | 100.0 ± 0.0      |
| FAAM Sports, %              | 69.8 ± 4.3       | 100.0 ± 0.0      |
| AII, No. of yes†            | 6.3 ± 1.8        | 0.0 ± 0.0        |
| Previous ankle sprains, No. | 4.3 ± 1.3        | 0.0 ± 0.0        |

Abbreviations: CAI = chronic ankle instability; FAAM ADL = Foot and Ankle Ability Measure for Activities of Daily Living; AII = Ankle Instability Instrument; No. = number; SD = standard deviation; y = years; †: questions 4-8 on the MAII.
Table 2. Force Steadiness and Accuracy Errors for Both Group

| Test       | Load | Motion       | Group, Mean±SD (N/kg) | ANOVA                      |
|------------|------|--------------|-----------------------|----------------------------|
|            |      |              | CAI (n=21)            | Control (n=21)             | Cohen’s d | Group effect | Motion effect | Group x Muscle Interaction |
| Force      | 10%  | Eversion     | 0.26 ± 0.24           | 0.18 ± 0.13                | 0.41      | 12.67        | 136.09†        | 1.42                       |
| Steadiness |      | Inversion    | 0.33 ± 0.24           | 0.11 ± 0.11                | 1.18      |               |               | P < .00        |
|            |      | Hip abduction| 0.93 ± 0.31           | 0.83 ± 0.30                | 0.33      |               |               | P = .25        |
|            | 30%  | Eversion     | 0.33 ± 0.17           | 0.37 ± 0.22                | 0.2       |               |               |               |
| Force      | 10%  | Inversion    | 0.43 ± 0.25           | 0.23 ± 0.14                | 1.36      | 1.76         | 100.77†        | 1.32                       |
| Accuracy   |      | Hip abduction| 1.29 ± 0.54           | 1.21 ± 0.49                | 0.15      |               |               | P = .27        |
|            | 30%  | Eversion     | 0.61 ± 0.67           | 0.29 ± 0.14                | 0.65      |               |               |               |
|            |      | Inversion    | 1.06 ± 0.54           | 0.26 ± 0.29                | 1.83      | 7.42         | 25.08†        | 7.57‡                       |
|            |      | Hip abduction| 1.23 ± 0.84           | 1.46 ± 0.79                | 0.28      |               |               | P = .01        |
|            |      | Eversion     | 0.97 ± 0.96           | 0.49 ± 0.33                | 0.68      |               |               |               |
|            | 30%  | Inversion    | 1.26 ± 1.47           | 0.47 ± 0.52                | 0.72      | 3.74         | 15.46†        | 4.22                       |
|            |      | Hip abduction| 1.59 ± 0.93           | 1.92 ± 0.87                | 0.37      |               |               | P = .02        |

Table 2. Force Steadiness and Accuracy Errors for Both Group

†Hip abduction showed less steadiness and accuracy than both eversion and inversion in 10% and 30% MVIC (p < .0001 for all comparisons)

‡The CAI group showed less inversion accuracy than the control group in 10% MVIC (p = 0.0006)
| Test               | Group, Mean ± SD | T-test | P value | Cohen’s d |
|-------------------|------------------|--------|---------|-----------|
|                   | CAI (n=21)       | Control (n=21) | T<sub>1,14</sub> ratio |          |
| Eversion, N/kg    | 0.26 ± 0.07      | 0.29 ± 0.08   | 2.25    | P = .14   | 0.33     |
| Inversion, N/kg   | 0.44 ± 0.14      | 0.41 ± 0.12   | 1.39    | P = .24   | 0.18     |
| Hip Abduction, N/kg| 0.94 ± 0.39      | 1.52 ± 0.34   | 58.06   | P < .00*  | 1.59     |

Table 3. Maximal Voluntary Isometric Contraction (MVIC) for Both Groups

* Significant difference
Figure 1. A Flow Chart
(a) Eversion and Inversion  (b) Hip abduction

**Figure 2. Testing Position**
Figure. 3. Example of 10-s data. Force steadiness was defined as a standard deviation across the 10-s of the data. Force accuracy was defined as the root mean square of the difference between the data and the target force.