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Submaximal Force Steadiness and Accuracy in Patients With Chronic Ankle Instability

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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 comprehend the sensorimotor deficits associated with CAI.

Objective: To determine if participants with CAI experienced deficits in hip and ankle submaximal force steadiness and accuracy compared with healthy control participants.

Design: Case-control study.

Setting: Research laboratory.

Patients or Other Participants: Twenty-one patients with CAI and 21 uninjured individuals.

Main Outcome Measure(s): Maximal voluntary isometric contraction (MVIC) and force steadiness and accuracy (10% and 30% of MVIC) of the ankle evertors and invertors and hip abductors were assessed using the central 10 seconds (20%–87% of the total time) of the 3 trials.

Results: Relative to the control group, the CAI group demonstrated less accuracy of the invertors ($P < .001$). Across all motions, the CAI group showed less steadiness ($P < .001$) and less accuracy ($P < .01$) than the control group at 10% of MVIC. For MVIC, the CAI group displayed less force output in hip abduction than the uninjured group ($P < .0001$).

Conclusions: Patients with CAI were unable to control ongoing fine force (10% and 30% of MVIC) through a feedback mechanism during an active test. These findings suggested that deficits in sensorimotor control predisposed patients with CAI to injury positions because they had difficulty integrating the peripheral information and correcting their movements in relation to visual information.

Key Words: visual feedback, visual motor coordination, force control, proprioception, neuromuscular control

Key Points

- Patients with chronic ankle instability displayed somatosensory deficits in force steadiness in the ankle invertors and deficits in accuracy in the ankle evertors and invertors during a real-time feedback task.
- Chronic ankle instability may result in difficulty integrating peripheral information and correcting movements in relation to visual information.

Lateral ankle sprains (LASs) are common musculoskeletal injuries that are often caused by sudden inversion stress while the foot is weight bearing, plantar flexed, and inverted.[1] This results in damage to the lateral ligaments of the ankle, which reduces static and dynamic ankle stability.[2] After an initial LAS, up to 80% of people sustain repeated ankle sprains, which often develop into *chronic ankle instability* (CAI),[3] a condition characterized by pathomechanical, sensory-perceptual, and motor-behavioral impairments.[2] These impairments result in a continuum of disability, as indicated by the finding that up to 78% of those with CAI developed posttraumatic ankle osteoarthritis, which decreases the quality of life.[4]

The sensorimotor system incorporates afferent, efferent, and central integration and processing to maintain functional joint stability. Patients with LAS and CAI are known to exhibit somatosensory deficits in kinesthesia,[5] joint position sense,[6] and force sense.[6] Specifically, force sense has long been used to assess conscious proprioception.[7] Deficits in force sense could result from damage to the muscle mechanoreceptors (eg, Meissner corpuscles, Pacinian corpuscles, or Ruffini endings), deafferentation, cutaneous input, a distortion of the corollary discharge, or a combination of these.[6] However, previous studies of force sense had limitations. For example, some researchers[6,7] used only a single active replication of target force without correcting errors via visual feedback. Yet it is important to measure how steadily and accurately individuals can adjust to errors in real time, which is more relevant for functional tasks.[8] Because participants were not allowed to view a monitor that showed target force, visual feedback, which is necessary for the motor-control system, was not available.[9] Visual information plays a vital role in integrating sensory information into the central nervous system (CNS) to generate appropriate motor output.[9] Given that patients with CAI tend to rely more on visual information because of an impaired somatosensory system,[10] a measure of force control through the feedback mechanism (ie, correcting errors in real time) along with visual information is necessary to develop a comprehensive mechanism of CAI.

To accommodate the limitations of previous investigations, authors[8,11–15] have adapted a new method of measuring submaximal force steadiness and accuracy. *Submaximal force steadiness and accuracy* refer to the ability of a muscle to produce a steady and accurate contraction during a static or dynamic task.[8] Rice et al[8] demonstrated that measuring the regulation of submaximal muscle force was more relevant for daily activities (eg, walking, driving a car, stepping over obstacles, ascending and descending stairs) and sport-related activities (eg, squatting, sprinting, jumping, landing, and cutting) than earlier measures (eg, joint position sense, static force sense). During daily activities, maximal voluntary activation was used for only 56 seconds.[16] In addition, moderately active college students used 17% of their maximal quadriceps and hamstrings force in daily activities.[16] Submaximal force steadiness has been studied in various populations, including those with anterior cruciate ligament reconstruction,[11] knee and hip osteoarthritis,[14,15] a history of falling,[12] and subacute stroke.[13] Previous researchers[11–15] observed that people with these conditions had less force steadiness and accuracy than their uninjured counterparts. However, no investigators have examined force steadiness and accuracy in patients with CAI. The recently updated model of CAI[2] proposed that 6 factors contribute to motor-behavioral impairments: altered reflex, neuromuscular inhibition, muscle weakness, balance deficits, altered movement patterns, and reduced physical activity. Rice et al[8] reported that reduced force steadiness was associated with neuromuscular inhibition and muscle weakness in patients with knee pain. If those with CAI show impairment during force-steadiness measurement, this could be a key characteristic of CAI.

Therefore, the purpose of our study was to examine the effect of CAI on the submaximal force steadiness and accuracy of the ankle evertors and invertors and the hip abductors. Based on the literature regarding force sense in patients with CAI, researchers[6,7] have measured the ankle evertors. Yet because musculoskeletal injuries impair cocontraction of the muscles around the joint, it is important to measure the ankle invertors in order to identify cocontraction of the ankle muscles.[17,18] It is also necessary to measure the hip abductors, because earlier authors[19–21] stated that those with CAI displayed deficits in hip neuromuscular control. We hypothesized that patients with CAI would show less force steadiness and accuracy in all 3 muscle groups compared with healthy control participants. Confirmation of our hypothesis would suggest to clinicians that rehabilitation programs for these patients should focus on restoring the proprioceptive functions of the ankle and hip along with visual training.

METHODS

Participants

A total of 42 physically active college students, consisting of 21 participants with CAI and 21 healthy control participants, were recruited from a university population. Using an a priori power analysis and previous data (isometric force steadiness) with α, β, and Cohen d values of .05, 0.2, and 0.93, respectively,[8] we determined that a sample size of 36 participants was needed. Exclusion criteria were a history of lower limb surgery or fracture, or neurologic disorder in the participant's lifetime or any sport-related injuries in the previous 3 months. Participant demographic information is shown in Table 1.

Table 1. Participant Demographics

	Group, Mean ± SD[a]	
Characteristic	Chronic Ankle Instability (n = 21)	Healthy (n = 21)
Sex, males/females	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
Foot and Ankle Ability Measure, %		
Activities of Daily Living	77.6 ± 7.2	100.0 ± 0.0
Sports	69.8 ± 4.3	100.0 ± 0.0
Ankle Instability Instrument,		
No. *yes* answers to questions 4–8	6.3 ± 1.8	0.0 ± 0.0
Previous ankle sprains, No.	4.3 ± 1.3	0.0 ± 0.0

[a] Except where indicated otherwise.

Recruits with CAI were identified based on the International Ankle Consortium guidelines.[22] We used self-reported disability questionnaires: the Foot and Ankle Ability Measure for Activities of Daily Living (FAAM–ADL), Foot and Ankle Ability Measure for Sports (FAAM–Sports), and Ankle Instability Instrument (AII). Specific inclusion criteria for participants with CAI were (1) a history of ankle sprain that occurred at least 3 months before data collection; (2) a score of <90% on the FAAM–ADL; (3) a score of <80% on the FAAM–Sports; (4) at least 5 *yes* answers, including to question 1, on the AII; and (5) a history of physical activity performed at least 3 d/wk, for a total of 90 min/wk, in the previous 3 months.[20] Specific inclusion criteria for healthy control individuals were (1) no previous ankle sprain, (2) a score of 100% on the FAAM–ADL, (3) a score of 100% on the FAAM–Sports, (4) zero *yes* answers on the AII, and (5) a history of physical activity performed at least 3 d/wk, for a total of 90 min/wk, in the previous 3 months.[20] All individuals provided informed consent, and the study was approved by the appropriate institutional review board.

Experimental Procedures

The experimental procedures are illustrated in Figure 1. A Biodex dynamometer and Advantage Software (model 3 dynamometer; Biodex Medical Systems, Inc) were used to measure the maximal voluntary isometric contraction (MVIC) and force steadiness and accuracy of the ankle evertors and invertors and the hip abductors. We measured the MVIC to permit comparisons of the maximal force of those muscles between groups. Participants were provided an opportunity to become familiar with the isokinetic dynamometer and testing procedure and to perform as many warm-up repetitions as desired (at least 5). During the practice session for the MVIC measures, they were instructed to perform the task at various force outputs (25%, 50%, 75%, and 100% of MVIC). After a 3-minute rest, participants performed 3 MVIC trials by contracting the muscles (ankle evertors and invertors and hip abductors) as hard as possible for 3 seconds while minimizing other movements. A 1-minute rest was allowed between trials. Previous authors[11–15] examined various force increments (10%, 20%, 25%, 30%, 40%, and 50% of MVIC) to measure

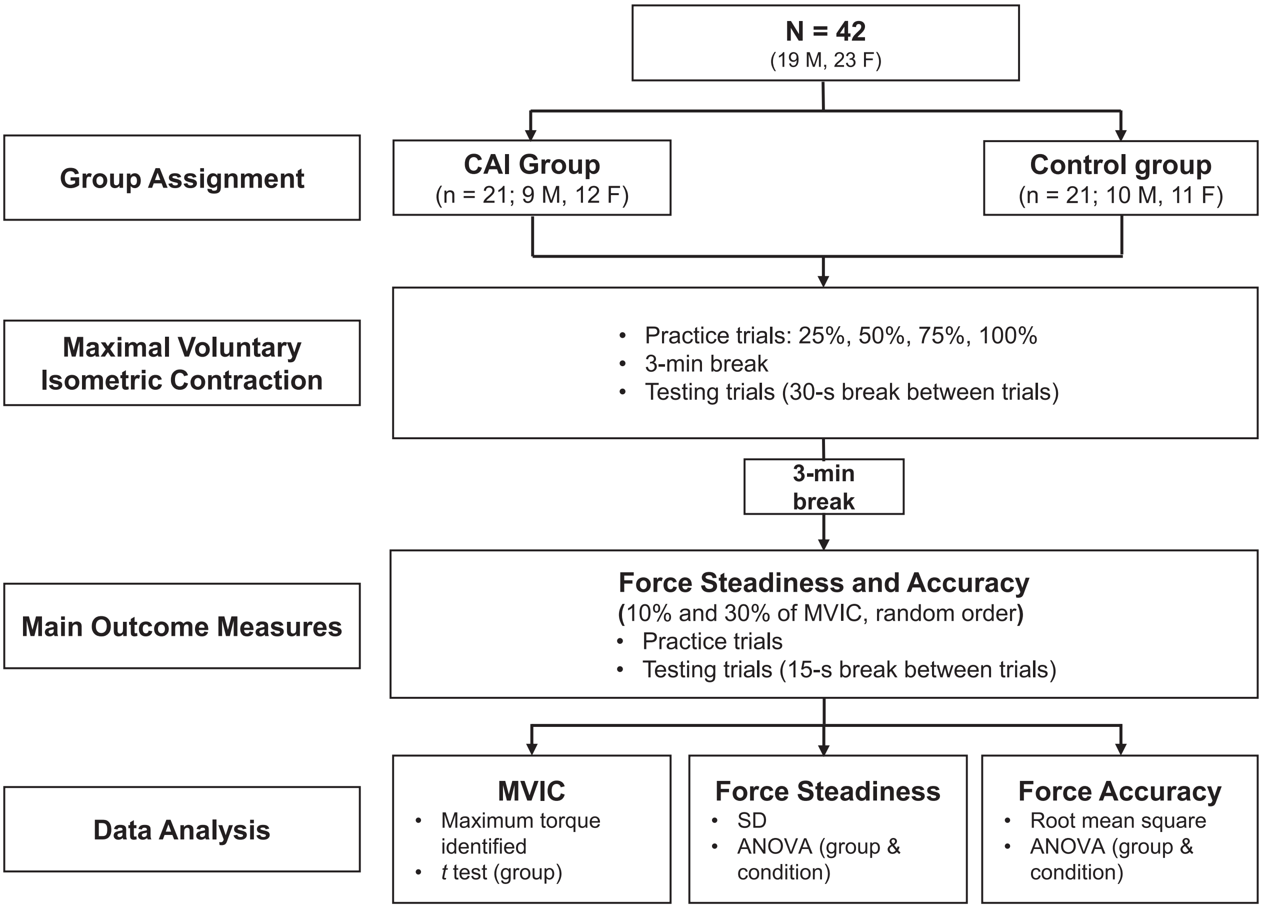

Figure 1. Flow chart of experimental procedures. Abbreviations: ANOVA, analysis of variance; CAI, chronic ankle instability; F, females; M, males; MVIC, maximal voluntary isometric contraction.

force steadiness in different joints. Because no earlier investigators measured force steadiness in patients with CAI, we chose to use 10% and 30% of each person's MVIC based on a study[6] in which the authors measured force sense for the same motions. Participants were informed of how force steadiness and accuracy would be measured. During the test, they were instructed to attempt to stay as close as possible to the target force (10% or 30% of MVIC) for 15 seconds. Five trials were performed for each muscle; the first 2 were considered practice trials. Participants were able to adjust their force using a monitor (1 m away) that showed the actual force. While participants performed the force-steadiness trials, 1 examiner indicated the target force line, so that each person easily recognized the target forces. The examiner randomly assigned a target force, 10% or 30% of MVIC, to each person.

Participant Position on the Dynamometer

All participants wore athletic shoes (model T-Lite XI; Nike, Inc) during testing. The shoes were tightly secured to the footplate to minimize unnecessary movement between the shoe sole and footplate surface during the ankle measurements (Figure 2A). For the hip measurements, participants were positioned on their side in the dynamometer chair facing the dynamometer, thereby allowing less space for compensatory movements (Figure 2B). This position provided a backrest and allowed each person to use the handhold in front, thereby minimizing trunk and pelvic rotation during testing. The position was referenced using the Biodex System 3 application and operation manual.

Data Processing and Statistical Analysis

The data for all 3 MVIC trials were processed using custom-written MATLAB software (The MathWorks, Inc) to determine maximal torque. We also used the MATLAB software to analyze submaximal force steadiness and accuracy. For all conditions, the first 2 trials were discarded and the central 10 seconds of data (20%–87% of the total time) were assessed for the remaining 3 trials (Figure 3). Force steadiness and accuracy were obtained following the methods of an earlier study.[8] Specifically, the SD across the 10 seconds of data provided the participant's response signal without reference to the target force level, which was force steadiness. We calculated force accuracy as the root mean square of the difference between the participant-generated force and the target force. The MVIC was analyzed using an independent t test for group effect (CAI versus healthy control). Force steadiness and accuracy were evaluated using a 2-way (2 groups [CAI and healthy control] $\times$ 3 motions [ankle eversion and inversion and hip abduction]) analysis of variance for the group effect, motion effect, and group $\times$ motion interaction. We conducted Tukey honestly significant difference (HSD) post hoc tests for pairwise comparisons. The experiment-wise type I error rate for all tests was set at $P < .05$. Cohen d effect sizes were calculated to provide the magnitude of

Figure 2. Testing position. A, Ankle measurement. B, Hip measurement.

differences between groups (from 0.21 to 0.5, *small*; 0.51 to 0.8, *moderate*; >0.8, *large*).

RESULTS

Force Steadiness (SD)

The force-steadiness data at 10% and 30% of MVIC for ankle eversion and inversion and hip abduction for both the CAI and control groups are shown in Table 2. No interaction was present between group and muscle at either 10% or 30% of MVIC ($F_{5,120} = 1.42$, $P = .25$, and $F_{5,120} = 1.32$, $P = .27$, respectively). A group main effect was noted at 10% of MVIC for force steadiness ($F_{5,120} = 12.67$, $P < .001$) but not at 30% of MVIC ($F_{5,120} = 1.76$, $P = .19$). We observed motion main effects at 10% and 30% ($F_{5,120} = 136.09$, $P < .0001$, and $F_{5,120} = 100.77$, $P < .0001$, respectively) of MVIC. A Tukey HSD post hoc test indicated that the hip abductors demonstrated less steadiness than the ankle evertors and invertors at 10% and 30% of MVIC ($P < .0001$). Even though no interaction was present between group and muscle, the Cohen d showed a large effect size (1.18) between groups at 10% of MVIC in inversion. In summary, patients with CAI displayed less steadiness in inversion than the control group.

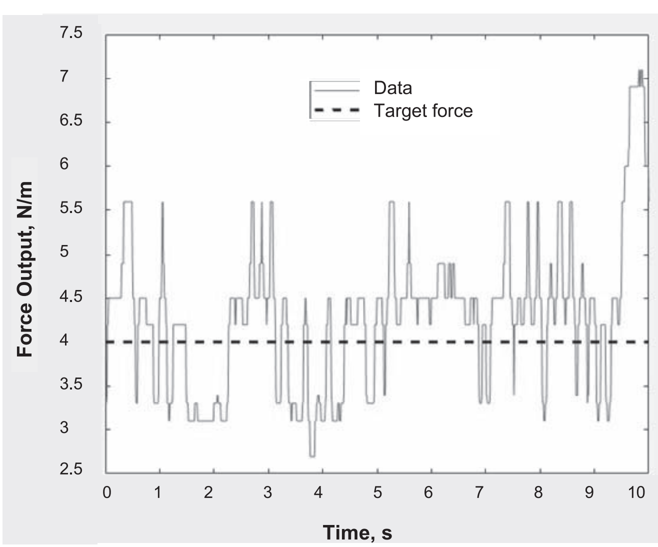

Figure 3. Sample 10 seconds of data. *Force steadiness* was defined as the SD across the 10 seconds of data. *Force accuracy* was defined as the root mean square of the difference between the data and the target force.

Force Accuracy (Root Mean Square)

The force accuracy error data at 10% and 30% of MVIC for ankle eversion and inversion and hip abduction for both the CAI and control groups appear in Table 2. Group × muscle interactions were noted at both 10% and 30% of MVIC ($F_{5,120} = 7.57$, $P = .01$, and $F_{5,120} = 4.22$, $P = .02$, respectively). A Tukey HSD post hoc test indicated that the CAI group showed less inversion accuracy than the control group at 10% of MVIC ($P < .001$). There was a group main effect at 10% of MVIC in force accuracy ($F_{5,120} = 7.42$, $P < .001$), but no effect at 30% of MVIC ($F_{5,120} = 3.74$, $P = .06$). Motion main effects were evident at 10% and 30% of MVIC ($F_{5,120} = 25.08$, $P < .0001$, and $F_{5,120} = 15.46$, $P < .0001$, respectively). A Tukey HSD post hoc test indicated that the hip abductors showed less accuracy than evertors and invertors at 10% ($P < .0001$) and 30% of MVIC ($P < .0001$). In addition, the Cohen d showed a medium effect size (0.65) between groups at 10% MVIC for eversion. In summary, the patients with CAI exhibited less accuracy in eversion and inversion compared with the control individuals.

Maximal Voluntary Isometric Contraction

The MVIC data for ankle eversion and inversion and hip abduction for both the CAI and control groups appear in Table 3. No group difference was present for MVIC in eversion and inversion ($t_{1,124} = 2.25$, $P = .14$, and $t_{1,124} = 1.39$, $P = .24$, respectively), but participants with CAI showed less force output in hip abduction than control participants ($t_{1,124} = 58.06$, $P < .0001$).

DISCUSSION

The purpose of our study was to examine the effect of CAI on the submaximal force steadiness and accuracy of the ankle evertors and invertors and hip abductors. Our primary finding was that the CAI group had impairments in submaximal force steadiness for the ankle invertors and in

Table 2. Force-Steadiness and Force-Accuracy Errors

Test, N/kg	Load, % of MVIC	Motion	Group: Mean ± SD: Chronic Ankle Instability (n = 21)	Control (n = 21)	Cohen d	Analysis of Variance: Group Effect: $F_{5,120}$ Ratio	P Value	Motion Effect: $F_{5,120}$ Ratio	P Value	Group × Muscle Interaction: $F_{5,120}$ Ratio	P Value
Force steadiness	10	Ankle eversion	0.26 ± 0.24	0.18 ± 0.13	0.41	12.67	<.001	136.09[a]	<.001	1.42	.25
		Ankle inversion	0.33 ± 0.24	0.11 ± 0.11	1.18						
		Hip abduction	0.93 ± 0.31	0.83 ± 0.30	0.33						
	30	Ankle eversion	0.33 ± 0.17	0.37 ± 0.22	0.20	1.76	.19	100.77[a]	<.001	1.32	.27
		Ankle inversion	0.43 ± 0.25	0.23 ± 0.14	1.36						
		Hip abduction	1.29 ± 0.54	1.21 ± 0.49	0.15						
Force accuracy	10	Ankle eversion	0.61 ± 0.67	0.29 ± 0.14	0.65	7.42	<.001	25.08[a]	<.001	7.57[b]	.01
		Ankle inversion	1.06 ± 0.54	0.26 ± 0.29	1.83						
		Hip abduction	1.23 ± 0.84	1.46 ± 0.79	0.28						
	30	Ankle eversion	0.97 ± 0.96	0.49 ± 0.33	0.68	3.74	.06	15.46[a]	<.001	4.22	.02
		Ankle inversion	1.26 ± 1.47	0.47 ± 0.52	0.72						
		Hip abduction	1.59 ± 0.93	1.92 ± 0.87	0.37						

Abbreviation: MVIC, maximal voluntary isometric contraction.

[a] Hip abduction showed less steadiness and accuracy than both ankle eversion and inversion at 10% and 30% of MVIC (*P* values < .00101).

[b] The chronic ankle instability group displayed less inversion accuracy than the control group at 10% of MVIC (*P* = .0006).

force accuracy for the ankle evertors and invertors. In addition, the maximal force of their hip abductors was less than in the control group.

Evaluating submaximal force steadiness and accuracy is a novel technique for assessing proprioceptive function.[8] This new technique measures feedback-based force adjustment via visual information and sensorimotor function. Previous authors[11–15] demonstrated that people with proprioceptive function impaired by anterior cruciate ligament reconstruction, knee or hip osteoarthritis, falling, or subacute stroke displayed less submaximal force steadiness. The current findings add to the existing body of literature because CAI has not been linked with force steadiness to date.

Differences Between Groups in Force Steadiness and Accuracy

Our participants with CAI maintained less force steadiness in their ankle invertors during isometric contractions. In addition, they were less accurate in ankle 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 motor-neuron firing.[8] We propose that the observed alterations in force steadiness and accuracy may be due to impaired proprioceptive function in these patients. Proprioceptive sensory inputs from muscles, tendons, and ligaments are transmitted from the peripheral nervous system to the CNS; this process is necessary for appropriate neuromuscular control.[23] Neuromuscular control can be affected by (1) the collection of less peripheral information because of damaged proprioception, (2) an inability to integrate the peripheral information in the CNS, or (3) an inability to send out the centrally mediated information to the motor units.[9] Thus, our results may be attributed to one or more of the aforementioned factors. Moreover, Chung-Hoon et al[24] explained that less steadiness in force output may be caused by presynaptic inhibition of Ia afferents. Because of the depolarization of primary afferent fibers by interneurons, the input from Ia afferents to the active motor-neuron pool may be inhibited and consequently affect motor-unit activation in maintaining a certain force.[25] Accordingly, patients with CAI may be unable to regulate presynaptic inhibition compared with healthy control individuals.[25] Furthermore, Docherty and Arnold[7] suggested a significant relationship between ankle instability and force sense. They showed that patients with functional ankle instability had deficits in precise force sense and joint position sense.[7] Because CAI is associated with impaired proprioception, strength, and postural control as a result of repeated LASs,[2] reduced force accuracy could be a consequence of the injury.

Compared with the control group, our CAI group demonstrated less steadiness and accuracy in the ankle invertors but not the evertors. A possible explanation is that the invertors had deficits in motor control and more degrees

Table 3. Maximal Voluntary Isometric Contractions

Test, N/kg	Group, Mean ± SD: Chronic Ankle Instability (n = 21)	Control (n = 21)	$t_{1,124}$ Ratio	*P* Value	Cohen d
Ankle eversion	0.26 ± 0.07	0.29 ± 0.08	2.25	.14	0.33
Ankle inversion	0.44 ± 0.14	0.41 ± 0.12	1.39	.24	0.18
Hip abduction	0.94 ± 0.39	1.52 ± 0.34	58.06	<.0001[a]	1.59

[a] Indicates a statistical difference.

of freedom in movement during force generation than the evertors. Specifically, previous authors[2,18] reported deficits in motor control such as neuromuscular inhibition and muscle weakness not only in the evertors but also in the invertors. Inversion has a larger range of motion and involves more muscle fibers for force generation than eversion. Thus, the invertors may display less steadiness and accuracy because inversion has a greater range of motion to generate force than eversion. Based on the literature, no direct relationship exists between force control and the degrees of freedom in force generation. However, absolute error was compared among different joints in the lower extremity during force steadiness in several investigations.[13–15] The earlier results combined with ours support the idea that the greater the lower extremity joint during force generation, the greater the error during force control (error increases from eversion to inversion to hip abduction to knee extension). Both impaired motor control and the greater degrees of freedom in the invertors led to impaired force steadiness and accuracy.

A Novel Measurement for Patients With CAI: Force Steadiness and Accuracy

Unlike previous authors[6,7] who measured force steadiness and accuracy, we allowed our participants to view their force steadiness and accuracy output on a monitor and adjust their target force to approach the target forces. Earlier investigators demonstrated that visual feedback enhanced not only isokinetic muscle force[26] but also neuromuscular control, such as interlimb coordination.[27] However, we found that the CAI group had more difficulty than the control group maintaining target forces. Thus, patients with CAI may have difficulty reducing force error. In other words, their ability to integrate sensory information in the CNS to produce the appropriate motor output may be impaired. To explore this idea, more work is needed to examine the effect of visual information on force steadiness and accuracy. Practically, deficits in the ability to integrate sensory information could easily result in alterations in movement and loads and ultimately increase the injury risk.[28]

Changes in Neuromuscular Control in the Proximal Joint

Researchers[19,21] have studied hip-joint neuromuscular alterations in those with LAS and CAI. In those with CAI, hip biomechanics were altered, which could have been caused by deficits in neuromuscular control.[21] Decreased hip strength also influenced dynamic postural control, which needs appropriate neuromuscular control in the CAI population.[19] In accord with previous studies,[19,21] our results indicated that the CAI group demonstrated a smaller MVIC in hip abduction than the control group. However, submaximal force steadiness and accuracy did not differ between the groups. 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] This less demanding task may be insufficient to induce differences in force steadiness and accuracy. Additionally, we measured isometric hip-abductor force. If we were to measure concentric or eccentric force, which is a more dynamic task, we might elicit a difference between conditions. Thus, future work is needed to measure force steadiness and accuracy during concentric or eccentric contractions.

Differences Between Muscle Groups in Force Steadiness and Accuracy

The hip abductors showed more errors in force steadiness and accuracy than did the ankle evertors and invertors. This finding suggests that as more muscle fibers were recruited, participants' steadiness decreased. Because limited data are available regarding force steadiness in large and small muscle groups, we based our explanation on earlier investigations.[14,15,29] The mass of the knee extensors is greater than that of the hip abductors, and the mass of the hip abductors is greater than that of the ankle evertors or invertors.[29] Our absolute error at 10% of MVIC force steadiness for ankle eversion and inversion was less than 0.4 N/kg. However, absolute errors of force steadiness for the quadriceps in patients with knee[15] or hip osteoarthritis[14] were higher than 1.3 N/kg (2.13 $\pm$ 1.51 and 1.3 $\pm$ 0.94 N/kg, respectively). Therefore, we propose that the number of muscle fibers recruited may affect the ability to maintain submaximal force steadiness. A relationship between the number of muscle fibers and force steadiness and accuracy would be a valuable area of future examination.

Clinical Implications

Our findings of impaired ankle and hip force steadiness and accuracy in patients with CAI provide useful insights for clinicians developing rehabilitation protocols. An indirect indication was that the CAI group had proprioceptive deficits in the force steadiness and accuracy of ankle eversion and inversion. This impaired proprioception might lead these 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 plus visual training may be key to improving clinical outcomes for this population.[21,30] Our data suggest that clinicians should continue to focus on restoring proprioceptive function in both the distal and proximal joints in conjunction with visual information to improve force control in various movements. Moreover, movement-related functional rehabilitation exercises are necessary for adjusting and correcting movement errors and increasing the ability to produce appropriate force during a given task.

Limitations

We only measured an isometric contraction of the ankle evertors and invertors and the hip abductors. This measure may have been insufficient to fully understand the somatosensory function of the involved joints during sports or activities of daily living. Although errors in force steadiness and accuracy during concentric and eccentric contractions of the knee extensor were not different between concentric and eccentric conditions,[8] the ankle musculature may show different results.

CONCLUSIONS

The CAI group demonstrated somatosensory deficits in force steadiness in the ankle invertors and deficits in accuracy in both the ankle evertors and invertors during a real-time feedback task. To our knowledge, this is the first observation of the effect of CAI on submaximal force steadiness and accuracy. Our results suggest that clinicians should focus on improving proprioceptive function in patients with CAI by using rehabilitative exercises in conjunction with visual training to reduce the risk of further injuries.

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REFERENCES

1. Baumhauer JF, Alosa DM, Renström AF, Trevino S, Beynnon B. A prospective study of ankle injury risk factors. *Am J Sports Med*. 1995;23(5):564–570. doi:10.1177/036354659502300508.
2. Hertel J, Corbett RO. An updated model of chronic ankle instability. *J Athl Train*. 2019;54(6):572–588. doi:10.4085/1062-6050-344-18.
3. Petersen W, Rembitzki IV, Koppenburg AG, et al. Treatment of acute ankle ligament injuries: a systematic review. *Arch Orthop Trauma Surg*. 2013;133(8):1129–1141. doi:10.1007/s00402-013-1742-5.
4. Harrington KD. Degenerative arthritis of the ankle secondary to long-standing lateral ligament instability. *J Bone Joint Surg Am*. 1979;61(3):354–361.
5. Hertel J. Sensorimotor deficits with ankle sprains and chronic ankle instability. *Clin Sports Med*. 2008;27(3):353–370. doi:10.1016/j.csm.2008.03.006
6. Docherty CL, Arnold BL, Hurwitz S. Contralateral force sense deficits are related to the presence of functional ankle instability. *J Orthop Res*. 2006;24(7):1412–1419. doi:10.1002/jor.20195
7. Docherty CL, Arnold BL. Force sense deficits in functionally unstable ankles. *J Orthop Res*. 2008;26(11):1489–1493. doi:10.1002/jor.20682
8. Rice DA, McNair PJ, Lewis GN, Mannion J. Experimental knee pain impairs submaximal force steadiness in isometric, eccentric, and concentric muscle actions. *Arthritis Res Ther*. 2015;17(1):259. doi:10.1186/s13075-015-0768-1
9. Riemann BL, Lephart SM. The sensorimotor system, part II: the role of proprioception in motor control and functional joint stability. *J Athl Train*. 2002;37(1):80–84.
10. Song K, Burcal CJ, Hertel J, Wikstrom EA. Increased visual use in chronic ankle instability: a meta-analysis. *Med Sci Sports Exerc*. 2016;48(10):2046–2056. doi:10.1249/MSS.0000000000000992
11. Bryant AL, Pua YH, Clark RA. Morphology of knee extension torque-time curves following anterior cruciate ligament injury and reconstruction. *J Bone Joint Surg Am*. 2009;91(6):1424–1431. doi:10.2106/JBJS.H.01335
12. Carville SF, Perry MC, Rutherford OM, Smith ICH, Newham DJ. Steadiness of quadriceps contractions in young and older adults with and without a history of falling. *Eur J Appl Physiol*. 2007;100(5):527–533. doi:10.1007/s00421-006-0245-2
13. Chow JW, Stokic DS. Force control of quadriceps muscle is bilaterally impaired in subacute stroke. *J Appl Physiol (1985)*. 2011;111(5):1290–1295. doi:10.1152/japplphysiol.00462.2011
14. Hortobagyi T, Garry J, Holbert D, Devita P. Aberrations in the control of quadriceps muscle force in patients with knee osteoarthritis. *Arthritis Rheum*. 2004;51(4):562–569. doi:10.1002/art.20545
15. Pua YH, Clark RA, Bryant AL. Physical function in hip osteoarthritis: relationship to isometric knee extensor steadiness. *Arch Phys Med Rehabil*. 2010;91(7):1110–1116. doi:10.1016/j.apmr.2010.04.001
16. Kern DS, Semmler JG, Enoka RM. Long-term activity in upper-and lower-limb muscles of humans. *J Appl Physiol (1985)*. 2001;91(5):2224–2232. doi:10.1152/jappl.2001.91.5.2224
17. Chmielewski TL, Hurd WJ, Rudolph KS, Axe MJ, Snyder-Mackler L. Perturbation training improves knee kinematics and reduces muscle co-contraction after complete unilateral anterior cruciate ligament rupture. *Phys Ther*. 2005;85(8):740–749; discussion 750–754.
18. Wilkerson GB, Pinerola JJ, Caturano RW. Invertor vs evertor peak torque and power deficiencies associated with lateral ankle ligament injury. *J Orthop Sports Phys Ther*. 1997;26(2):78–86. doi:10.2519/jospt.1997.26.2.78
19. Friel K, McLean N, Myers C, Caceres M. Ipsilateral hip abductor weakness after inversion ankle sprain. *J Athl Train*. 2006;41(1):74–78.
20. Kim H, Son SJ, Seeley MK, Hopkins JT. Kinetic compensations due to chronic ankle instability during landing and jumping. *Med Sci Sports Exerc*. 2018;50(2):308–317. doi:10.1249/MSS.0000000000001442
21. McCann RS, Crossett ID, Terada M, Kosik KB, Bolding BA, Gribble PA. Hip strength and star excursion balance test deficits of patients with chronic ankle instability. *J Sci Med Sport*. 2017;20(11):992–996. doi:10.1016/j.jsams.2017.05.005
22. Gribble PA, Delahunt E, Bleakley C, et al. Selection criteria for patients with chronic ankle instability in controlled research: a position statement of the International Ankle Consortium. *Br J Sports Med*. 2014;48(13):1014–1018. doi:10.1136/bjsports-2013-093175
23. Sousa AS, Leite J, Costa B, Santos R. Bilateral proprioceptive evaluation in individuals with unilateral chronic ankle instability. *J Athl Train*. 2017;52(4):360–367. doi:10.4085/1062-6050-52.2.08
24. Chung-Hoon K, Tracy BL, Dibble LE, Marcus RL, Burgess P, LaStayo PC. The association between knee extensor force steadiness, force accuracy, and mobility in older adults who have fallen. *J Geriatr Phys Ther*. 2016;39(1):1–7. doi:10.1519/JPT.0000000000000044
25. Baudry S, Maerz AH, Gould JR, Enoka RM. Task- and time-dependent modulation of Ia presynaptic inhibition during fatiguing contractions performed by humans. *J Neurophysiol*. 2011;106(1):265–273. doi:10.1152/jn.00954.2010
26. O'Sullivan A, O'Sullivan K. The effect of combined visual feedback and verbal encouragement on isokinetic concentric performance in healthy females. *Isokinet Exerc Sci*. 2008;16(1):47–53.
27. Cortis C, Pesce C, Capranica L. Inter-limb coordination dynamics: effects of visual constraints and age. *Kinesiology*. 2018;50(suppl 1):133–139.
28. Delahunt E, Remus A. Risk factors for lateral ankle sprains and chronic ankle instability. *J Athl Train*. 2019;54(6):611–616. doi:10.4085/1062-6050-44-18
29. Zheng L, Wei H, He P, et al. Effects of supplementation of branched-chain amino acids to reduced-protein diet on skeletal muscle protein synthesis and degradation in the fed and fasted states in a piglet model. *Nutrients*. 2016;9(1):17. doi:10.3390/nu9010017
30. Burcal CJ, Sandrey MA, Hubbard-Turner T, McKeon PO, Wikstrom EA. Predicting dynamic balance improvements following 4-weeks of balance training in chronic ankle instability patients. *J Sci Med Sport*. 2019;22(5):538–543. doi:10.1016/j.jsams.2018.11.001

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