Individuals With Chronic Ankle Instability Show Abnormalities in Maximal and Submaximal Isometric Strength of the Knee Extensor and Flexor Muscles

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Background: It has been shown that chronic ankle instability (CAI) leads to abnormalities in neuromuscular control of more proximal joints than the ankle. Although strength of the hip and the ankle muscles has been largely investigated providing concordant results, limited evidence with contrasting results has been reported regarding knee extensor and flexor muscles.

Purpose: To investigate maximal and submaximal isometric muscle strength in individuals with CAI.

Study Design: Controlled laboratory study.

Methods: Fifteen participants with unilateral CAI and 15 healthy matched controls were recruited. To quantify maximal strength, peak forces were recorded during a maximal isometric voluntary contraction of knee extensor and flexor muscles at 30° and 90° of knee flexion and normalized by the body weight of each participant. At both angles, submaximal isometric contractions at 20%, 50%, and 80% of the maximal voluntary isometric contraction were performed to analyze strength steadiness, in terms of coefficient of variation, and strength accuracy, in terms of absolute error. During all the assessments, knee extensor and flexor muscle activation was recorded by means of surface electromyography.

Results: Knee flexor maximal isometric strength was significantly lower in the injured limb of individuals with CAI in comparison with healthy controls at both 30° (0.15 ± 0.05 vs 0.20 ± 0.05; $P < .05$) and 90° (0.14 ± 0.04 vs 0.18 ± 0.05; $P < .05$). Knee extensor and flexor steadiness was significantly lower (higher coefficient of variation) in both the injured and the noninjured limbs of individuals with CAI in comparison with healthy individuals at 90° and at 30° for knee flexor steadiness of the injured limb. Knee extensor and flexor accuracy was lower (higher absolute error) in both the injured and noninjured limbs of individuals with CAI in comparison with healthy individuals, mainly at 30°, while at 90° it was lower only in the injured limb. No differences between the 2 groups were found for maximal isometric strength of knee extensor muscles, as well as for muscle activations.

Conclusion: Individuals with CAI show abnormalities in maximal and submaximal isometric strength of knee flexor muscles, and submaximal strength of the knee extensor muscles. Further studies should deeply investigate mechanisms leading to these abnormalities.

Clinical Relevance: Rehabilitation interventions should consider abnormalities of neuromuscular control affecting joints more proximal than the ankle in individuals with CAI.

Registration: NCT05273177 (ClinicalTrials.gov identifier).

Keywords: quadriceps; hamstrings; CAI; steadiness

A high number of individuals experiencing a first ankle sprain injury will be affected by the development of a condition known as chronic ankle instability (CAI), that is, a condition featured by recurring episodes of ankle sprains and ankle giving-way, which is usually accompanied by pain, weakness, a reduction of joint range of motion, and a reduction of self-reported function persisting for >1 year after the first episode of ankle sprain.[16-18] However, CAI-related impairment goes above and beyond these general common features as individuals affected by CAI also show several neuromuscular impairments such as abnormalities in balance,[23,30] proprioception,[54] neural excitability,[48] and impaired muscle strength[22] and activation.[33]

Interestingly, the latter alterations have been observed not only in muscles around the ankle joint but also in muscles around more proximal joints—that is, the knee and the hip.[22,29,33] Although many studies have

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investigated abnormalities in muscle strength and activation of muscles around the ankle joint,[5,6,8,10,31,34,52] and more recent studies are reporting abnormalities related to the hip muscles,[1,29,34,38,39] contrasting evidence has been provided for muscles acting on the knee.[12,13,23,41,45,51] Studies assessing knee extensor and flexor isokinetic muscle strength reported either lower muscle strength of knee extensor and flexor muscles[12,13,23] or no differences in muscle strength[41] when compared with healthy controls. Furthermore, contrasting results also arise from studies focusing on mechanisms related to neural and mechanical muscle function. In fact, while one study reported that individuals with CAI show an abnormal contractility and reduced efficiency of the stretch-shortening cycle of the quadriceps femoris,[51] another study reported a higher quadriceps muscle excitability in comparison with uninjured controls.[45] Furthermore, in the latter study arthrogenic muscle inhibition of the knee flexor muscles was reported.[45] Heterogeneity of the study samples and the methodology of assessments may have led to these contrasting results, and it seems clear that further studies are needed to better investigate if abnormalities exist in muscle strength exertion of muscles acting on the knee joint.[22]

It has been shown that submaximal isometric strength control, usually referred to as strength steadiness and accuracy and consisting of sustaining a long-lasting muscle contraction to a given percentage of the maximal strength, is more similar to muscle actions that feature in daily living activities with respect to isokinetic muscle actions. It has also been found that submaximal strength control is predictive of the functional performance of dynamic tasks in a number of study populations and conditions.[4,7,23,31] In addition, from a physiological point of view, this type of strength assessment may provide better information on inter- and intramuscular coordination together with sensorimotor integration,[9] which better resemble neuromuscular alterations typical for individuals with CAI.[17,18] Even though it has been reported that individuals with CAI show abnormalities in strength steadiness and accuracy of muscles acting on the ankle, but not those acting on the hip,[34] to the best of our knowledge there is no information regarding muscles acting on the knee joint. Thus, the objective of this study was to investigate maximal and submaximal isometric muscle strength of the knee extensor and flexor muscles in individuals with CAI and a matched control group of noninjured individuals. It was hypothesized that individuals with CAI would show a lower maximal isometric strength, steadiness, and accuracy of both knee extensor and flexor muscles in comparison with healthy controls.

METHODS

Participants

Fifteen participants with CAI (10 men and 5 women; mean age, 32 ± 7.1 years; mean height, 174.3 ± 8.4 cm; mean body mass, 71.1 ± 11.5 kg) were recruited to participate in the study. Individuals with an age between 20 and 40 years and a physical activity level of 2, 3, or 4 according to the Saltin and Grimby scale[14] were recruited. Inclusion and exclusion criteria to define the condition of CAI were based on the recommendations of the International Ankle Consortium,[11] as follows. Participants were included if (1) they had a history of ≥1 significant ankle sprains; (2) the initial ankle sprain occurred ≥12 months before the study enrollment, was associated with pain or swelling, and created ≥1 days of interruption of the desired physical activity; (3) the most recent injury occurred >3 months before the study enrollment; (4) they had a history of ankle joint giving-way and/or recurrent sprain and/or feelings of instability; (5) they reported ≥5 positive responses in the Ankle Instability Instrument; and (6) they had a score <90% in the Foot and Ankle Ability Measure–Activities of Daily Living and a score <80% in the Foot and Ankle Ability Measure–Sports. Participants were excluded if (1) they had a history of previous surgeries to the musculoskeletal structures (ie, bones, joint structures, and nerves) in either lower limb; (2) they had a history of a fracture in either lower limb requiring realignment; and (3) they had an acute injury to the musculoskeletal structures of other joints of the lower extremity in the previous 3 months that affected joint integrity and function (ie, sprains and fractures) resulting in ≥1 interrupted days of desired physical activity. Additional exclusion criteria for this study were neurological disorders and sedentary behavior.

Fifteen healthy volunteers (10 men and 5 women; mean age, 31.6 ± 7.1 years; mean height, 174 ± 9.5 cm; mean body mass, 69.2 ± 12.8 kg) matched for age, sex, body height, body weight, and physical activity level were recruited as a control group. Inclusion criteria were (1) absence of CAI; (2) age between 20 and 40 years; and (3) physical activity level of 2, 3, or 4 according to the Saltin and Grimby scale.[14] Exclusion criteria were (1) history of injuries or surgery to the lower limbs, (2) neurological diseases, and (3) sedentary behavior.

The study was conducted in accordance with the Declaration of Helsinki and was approved by the institutional ethics committee (PG 0002018_2021 - CE-AVEC 915/2020/Sper/IOR). Each of the participants signed an informed consent form before participating in the study.

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The study protocol was recorded on ClinicalTrials.gov (NCT05273177).

Sample Size Calculation

Sample size was calculated a priori based on a previously published study on isokinetic assessment of knee extensor muscle strength.[12] Based on a *t* test for matched pairs and a maximum peak torque normalized by the body mass of each participant—which was 1.80 ± 0.12 N·m/kg^{-1} in the CAI group and 1.89 ± 0.12 N·m/kg^{-1} in the healthy controls, an effect size of 0.75, a significance level of .05, and a power of 95%—a minimum of 11 participants for each group was required for the study. Four additional participants were recruited for each group to allow for dropouts.

Experimental Setup and Data Analysis

Instrumentation. Participants were comfortably seated on a dynamometric chair (COR 1; OT Bioelettronica) instrumented with a load cell (model TF033; CCT Transducers) connected to an amplifier (Forza; OT Bioelettronica). Electromyographic recordings were performed with an electromyography (EMG) system (Sessantaquattro; OT Bioelettronica). Load cell and EMG were part of the same synchronized system of acquisition. All data were collected at a 2000-Hz sampling frequency. Self-adhesive pregelled bipolar surface EMG electrodes were applied to both limbs over the vastus lateralis, vastus medialis, rectus femoris, biceps femoris, and semitendinosus muscles, in accordance with the SENIAM (surface EMG for a noninvasive assessment of muscles) recommendations.[15] The skin was cleaned with ethyl alcohol and hairs were shaved to reduce impedance. Once each participant was seated on the dynamometric chair, the knee joint center of rotation was aligned with the dynamometer center of rotation by moving forward or backward and upward or downward in the seat. Then, the leg of the participant was moved together with the rotating graded limb support of the dynamometer for reaching the desired knee angle and, finally, fixed at that angle for testing. After this procedure, the knee angle was double-checked with a manual goniometer. To minimize body movements, participants were secured to the dynamometric chair with belts across the chest, waist, and lower limbs. The experimental setup is shown in Figure 1. Before the performance of strength testing, all the participants performed a general warm-up consisting of 10 minutes of cycling at a low resistance and a specific warm-up consisting of 10 knee flexor and 10 knee extensor submaximal contractions. Participants were familiarized with all the procedures.

Maximal Voluntary Isometric Contraction. Isometric knee extensor and flexor muscle strength was assessed by means of a maximal voluntary isometric contraction (MVIC) at 2 knee angles, 30° and 90° of knee flexion. Participants were asked to exert their maximal strength as fast as possible and to maintain their maximum for ≥3 seconds. For each of the 2 angles, the MVIC was performed to record the force in newtons exerted by both knee extensor and knee flexor muscles. Three trials were performed. If

Figure 1. Experimental setup.

the last trial exceeded the previous trials, a fourth trial was performed. The trial with the highest peak force value was used for further analysis. The peak force of knee extensor and flexor muscles at 30° and 90° was normalized by the body weight of each participant to calculate the maximal strength and to allow for between-participant comparisons.

Submaximal Isometric Contractions. After the MVIC, submaximal sustained contractions were performed at 20%, 50%, and 80% of the maximal force recorded during the MVIC with the aim to assess force steadiness and force accuracy. During the assessment, participants modulated their performance on a computer screen showing the target force. While exerting force, the participants were asked to match the target force and maintain it "as steady as possible" for 12 seconds. The order of the trials was randomized to minimize the potential effect of task learning or fatigue. The analysis for steadiness and accuracy was performed in the middle 8 seconds of the trace, and the first and last 2 seconds were not considered, to avoid a potential effect of the transition phases, as in previous studies.[53] Force steadiness was calculated as in previous studies[2,53] as the coefficient of variation (COV) of the force of all the submaximal contractions and expressed as a percentage of the mean force exerted: [standard deviation of the force/mean of the force × 100]. Force accuracy was calculated as the absolute error (ERR) from the target value of force for each of the submaximal contractions and for both knee extensor and knee flexor muscles, as in previous literature.[21] For both COV and ERR, a mean of the 3 contractions for each of the submaximal trials was calculated and used for further analysis.

Knee Extensor and Flexor Muscle Activation. During both maximal and submaximal strength testing, EMG was recorded from knee extensor and flexor muscles as previously described. Signals were band-pass filtered between 20 and 500 Hz using a fourth-order zero-phase Butterworth filter in accordance with previous studies.[53] To quantify muscle activation during the submaximal contractions, the root mean square (RMS) of the signal was calculated over 1 second corresponding to the highest value of strength recorded during the MVIC, and over the middle 4 seconds of each of the submaximal contractions. Then, to quantify the level of muscle activation during the submaximal contractions, the RMS of each of the knee extensor muscles (vastus lateralis, rectus femoris, and vastus medialis) was expressed as a percentage of the RMS recorded during the MVIC of the same muscles at the same knee angle (30° or 90°), and the RMS of each of the knee flexor muscles (biceps femoris and semitendinosus) was expressed as a percentage of the RMS recorded during the MVIC of the same muscles at the same knee angle (30° or 90°). The mean of the 3 trials performed for each of the submaximal contractions was used for further analysis.

Statistical Analysis

Descriptive statistics were used to summarize data. The Shapiro-Wilk test was used to test data distribution. A 2-way analysis of variance (ANOVA) was conducted to analyze the effect of group and limb on maximal voluntary isometric strength of knee extensor and flexor muscles. A 3-way ANOVA was carried out to analyze the effect of group, limb, and condition for strength steadiness (COV) and accuracy (ERR) recorded during submaximal isometric contraction and for muscle activations. If F was significant, a Student t test was used to locate the significant differences and a Bonferroni correction was used for multiple comparisons. A significance level of $P < .05$, or $P < .016$ in case of Bonferroni correction, was adopted. All analyses were performed using SPSS Version 23 (IBM Corp).

RESULTS

Maximal Voluntary Isometric Contraction

Regarding maximal strength, a significant effect of group was found in knee flexor muscles at both 30° (F = 5.884; $P < .05$) and 90° (F = 4.798; $P < .05$). Participants in the CAI group showed a lower knee flexor maximal strength of the injured limb when compared with healthy controls at both 30° and 90°. No significant between-limb and between-group differences were found for maximal strength of the knee extensor muscles at 30° and 90°. The mean values and standard deviations of the 2 groups, together with statistical differences after post hoc analysis, are reported in Table 1.

TABLE 1
Peak Forces (N) Normalized by Body Weight (N) of Knee Extensor and Flexor Muscles Recorded During the MVIC at 30° and 90°[a]

Group	30°	90°
Knee extensor MVIC		
Control group		
Dominant	0.36 ± 0.12	0.39 ± 0.13
Nondominant	0.33 ± 0.11	0.37 ± 0.14
CAI group		
Injured	0.28 ± 0.08	0.31 ± 0.11
Noninjured	0.30 ± 0.08	0.39 ± 0.13
Knee flexor MVIC		
Control group		
Dominant	0.20 ± 0.05	0.18 ± 0.05
Nondominant	0.18 ± 0.05	0.16 ± 0.04
CAI group		
Injured	0.15 ± 0.05[b]	0.14 ± 0.04[b]
Noninjured	0.16 ± 0.06	0.17 ± 0.05

[a]Data are presented as mean ± SD. CAI, chronic ankle instability; MVIC, maximal voluntary isometric contraction.
[b]Significantly different from control group.

Submaximal Isometric Contractions

For knee extensor muscles at 30°, significant effects of group (F = 13.239; $P < .001$) and testing condition (F = 5.821; $P < .001$) were found for COV. Significant effects of group (F = 26.247; $P < .001$) and testing condition (F = 15.120; $P < .001$) were also found for ERR. The mean values and standard deviations of the 2 groups, together with between-group statistical differences after post hoc analysis, are reported in Figures 2A and 3A. Regarding the COV, post hoc comparisons across testing conditions showed a significant difference between 20% and 50% ($P < .05$) in the CAI group. Regarding the ERR, post hoc comparisons across testing conditions showed a significant difference between 20% and 50% ($P < .01$) and 20% and 80% ($P < .001$) in the CAI group, and between 20% and 80% ($P < .05$) in the control group.

For knee extensor muscles at 90°, significant groups by testing condition interaction were found for both COV (F = 8.427; $P < .001$) and ERR (F = 13.560; $P < .001$). The mean values and standard deviations of the 2 groups, together with between-group statistical differences after the post hoc analysis, are reported in Figures 2C and 3C. Regarding the COV, post hoc comparisons across testing conditions showed a significant difference between 20% and 50% ($P < .05$) in the control group. Regarding the ERR, post hoc comparisons across testing conditions showed a significant difference between 20% and 80% ($P < .01$) in the control group.

For knee flexor muscles at 30°, significant groups by testing condition interaction were found for both COV (F = 11.708; $P < .001$) and ERR (F = 14.805; $P < .001$). The mean values and standard deviations of the 2 groups, together with between-group statistical differences after the post hoc analysis, are reported in Figures 2B and 3B. A significant difference between 20% and 50% ($P < .05$) was found for COV in the control group.

For knee flexor muscles at 90°, a significant group by testing condition interaction was found for COV (F = 11.883; $P < .001$), and a group by limb by testing condition interaction was found for ERR (F = 6.766; $P < .01$). The mean values and standard deviations of the 2 groups, together with between-group statistical differences after the post hoc analysis, are reported in Figures 2D and 3D. A significant difference between 20% and 80% ($P < .05$) was found for ERR in the CAI group. In addition, significant differences between the CAI limb and the contralateral limb were found for ERR at 50% ($P < .05$) and 80% ($P < .01$) in the CAI group.

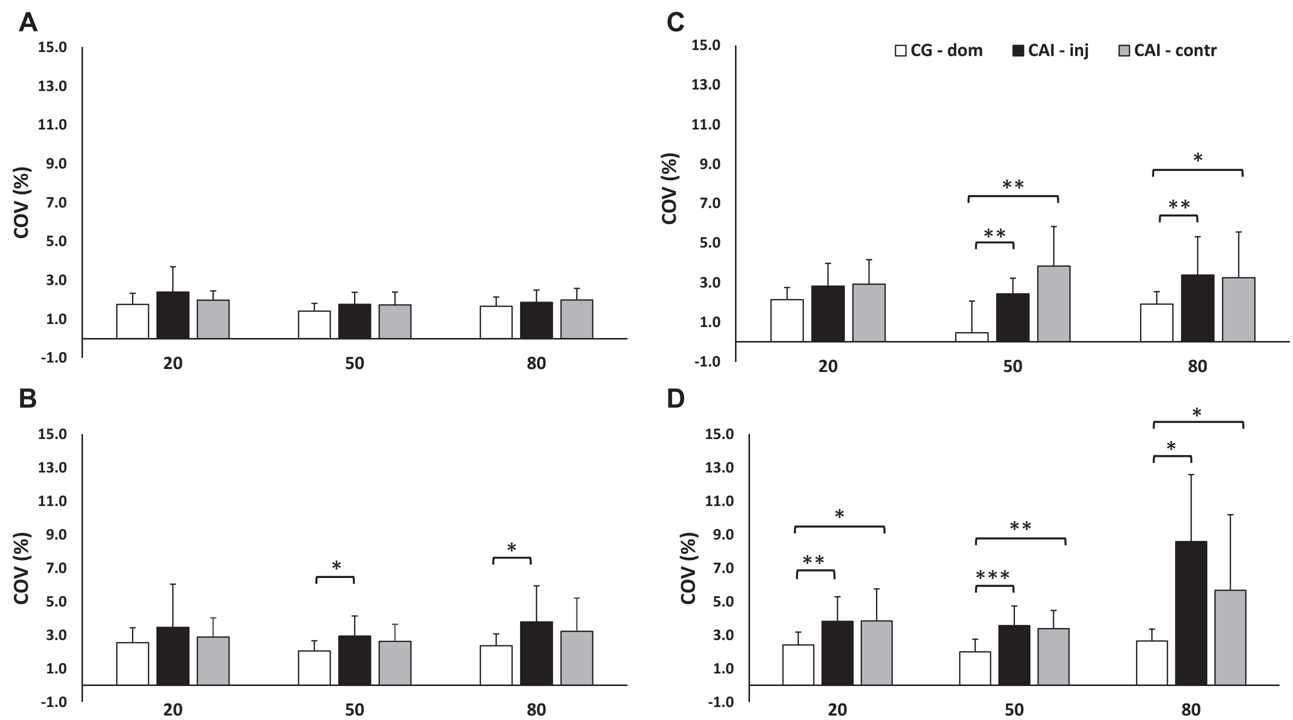

Figure 2. Force steadiness. Coefficient of variation (COV) of muscle strength exerted during submaximal isometric contraction at 20%, 50%, and 80% of the maximal voluntary isometric contraction in knee extensor muscles at (A) 30° and (C) 90° and knee flexor muscles at (B) 30° and (D) 90°. Because no between-limb differences were found in participants of the control group (CG), only data related to the dominant limb have been used to show between-group comparisons. *$P < .05$; **$P < .01$; ***$P < .001$. CAI, chronic ankle instability; contr, control; dom, dominant; inj, injured.

Knee Extensor and Flexor Muscle Activation

The ANOVA showed an effect of testing condition on all muscle activations except for vastus medialis during knee flexor muscle submaximal contractions at 30° and 90° and vastus lateralis and rectus femoris during knee flexor muscle submaximal contractions at 90°. The mean values and standard deviations of the RMS of knee extensor and flexor muscle activations expressed as a percentage of maximal activations during all the testing conditions in the 2 groups, together with the ANOVA results and the statistical differences after the post hoc analysis, are reported in Appendix Table A1 (available in the online version of this article).

DISCUSSION

The main results of this study partially confirm our hypothesis and show that maximal isometric strength of the knee flexor muscles was lower in the injured limb of individuals with CAI in comparison with healthy individuals; maximal isometric strength of knee extensor muscles was not different between individuals with CAI and healthy individuals, as well as between the injured and the contralateral limbs in individuals with CAI; knee extensor and flexor muscle steadiness and accuracy were impaired in individuals with CAI compared with healthy individuals; and no differences between individuals with CAI and healthy individuals were found for muscle activations during submaximal contractions.

It is known that after a joint injury, several alterations of function can be seen in the muscles acting on that joint by way of neural inhibition or facilitation. The main explanation of these phenomena relies on reflex mechanisms elicited by the abnormal afferent information arising from the joint related to damage to joint receptors, as in the case of ligament ruptures,[27,35] or abnormal receptor stimulation, as in the case of joint instability, inflammation, or swelling.[43] In line with this, an inhibition of the peroneal and soleus muscles has been found in individuals with CAI.[40,48] Although the mechanisms leading to the inhibition of muscles directly acting on the ankle have been largely clarified, it seems much more complicated to explain why abnormalities in muscle strength can also be observed in muscles acting on the knee joint.

It could be speculated that the lower muscle strength of knee flexor muscles observed in individuals with CAI in comparison with healthy controls in the present study and in previous investigations[12,23] may be related to a combination of mechanical, functional, and neural factors. From a mechanical and functional point of view, damage to ankle ligaments and ongoing joint instability leads the lower limb to rely on an unstable base of support[3] and to an abnormal displacement of the tibia, thus also affecting the knee joint function.[46] Several studies investigating

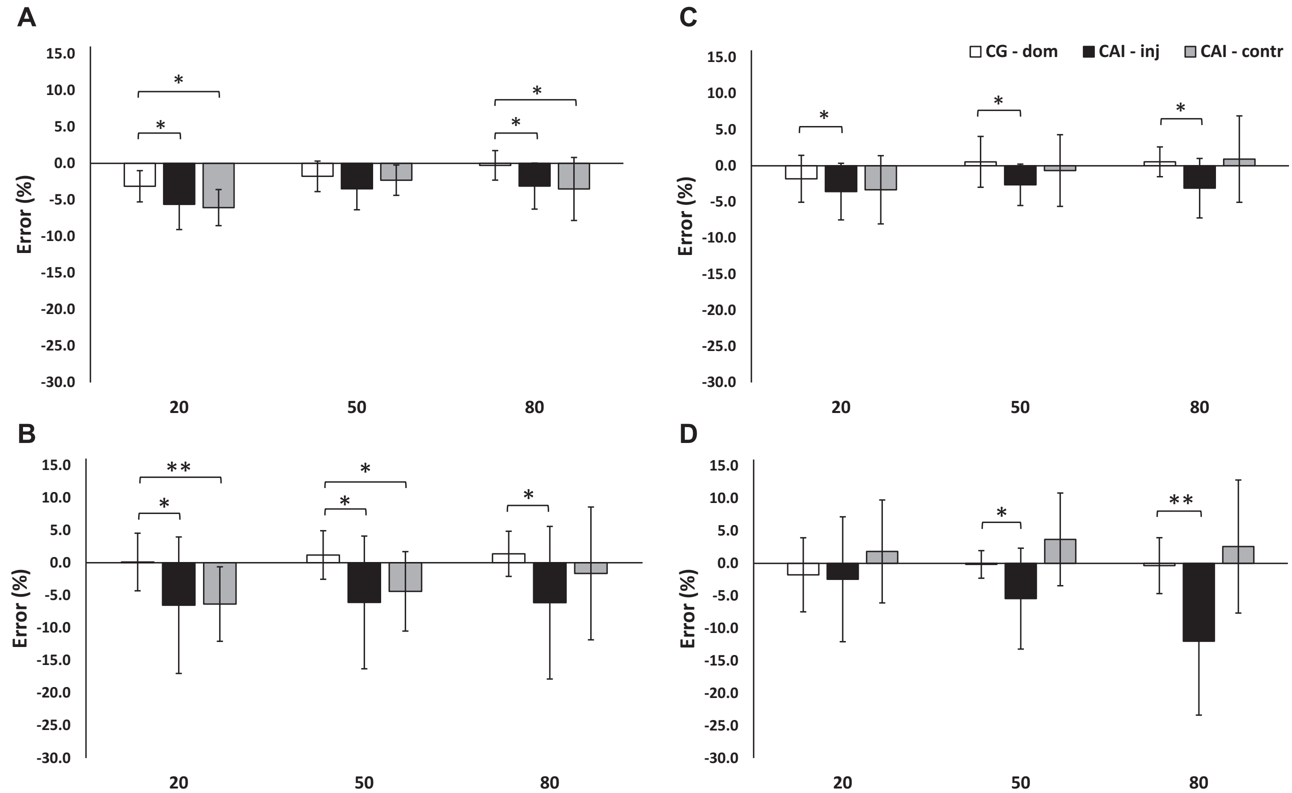

Figure 3. Force accuracy. Absolute error with respect to the target value (20%, 50%, and 80% of the maximal voluntary isometric contraction) of muscle strength exerted during submaximal isometric contractions of the knee extensor muscles at (A) 30° and (C) 90° and the knee flexor muscles at (B) 30° and (D) 90°. Because no between-limb differences were found in participants of the control group (CG), only data related to the dominant limb have been used to show between-group comparisons. *$P < .05$; **$P < .01$. CAI, chronic ankle instability; contr, control; dom, dominant; inj, injured.

lower limb kinematics in individuals with CAI have reported a less flexed knee position during a number of functional tasks, such as walking[47] or landing from a jump,[50] together with an increase in hip flexion. All this adaptation seems to be a strategy for the reduction of energy absorption by avoiding load on the unstable ankle joint. However, these strategies increase forces acting on the knee and hip.[24] It is not surprising that individuals with CAI are at risk of anterior cruciate ligament injury during tasks such as landings[42,49] and hamstring injuries in the long term.[36] Thus, it could be speculated that the lower knee flexor muscle strength observed in individuals with CAI in comparison with healthy controls might be related, first, to an abnormal stimulation of the knee joint receptors leading to hamstring reflex inhibition and, second, to the "underuse" of the knee flexors and the "overuse" of the quadriceps, which may further respectively weaken and strengthen those muscles. In addition, regarding neural mechanisms related to inhibition of the knee flexor muscles, previous literature has reported that the inhibition seen in hamstring muscles can be related to the soleus muscle inhibition. In fact, it has been shown that there is a link between the motoneurons innervating the soleus and the motoneurons innervating the quadriceps muscles.[20,25,26] Thus, an inhibition of the soleus muscle may lead to a facilitation of the quadriceps and vice versa.[19,21] The quadriceps facilitation in turn, as a consequence of the antagonist inhibition phenomenon, leads to hamstring inhibition. In addition, it has been shown that a marked decrease in hamstring muscle strength can be seen early after a severe ankle sprain,[13] as well as in individuals with chronic instability of the ankle.[45] Taken together, these results suggest that a likely immediate reflex inhibition is seen in the muscles directly acting on the ankle and that, at the same time or as a longer-term adaptation, inhibition and facilitation mechanisms arise in muscles acting on more proximal joints. However, participants with CAI in this study did not show significant differences in absolute muscle strength of the quadriceps when compared with the noninjured limb or with matched controls. Previous studies assessing quadriceps muscle strength have reported contrasting results.[13,23,41] The contrasting results may be related to heterogeneity in strength-testing methodology as well as characteristics of the study sample. Thus, further research is needed to clarify this point. On the other hand, even if no deficit was found in absolute quadriceps muscle strength, abnormalities were found in steadiness and accuracy.

To the best of the our knowledge, this is the first study to investigate submaximal strength steadiness and accuracy in knee extensor and flexor muscles of individuals with CAI. Thus, it is not possible to compare our results with previous investigations. However, it has been reported that muscle strength steadiness and accuracy are related to a number of factors, such as motor unit recruitment, motor unit firing rate, impaired proprioceptive information, activation of synergistic/antagonist muscles,[9,44] and joint angle of testing.[32] Individuals with CAI show abnormalities in proprioception mainly in the ankle joint,[54] and even if ankle instability may lead to alteration in forces acting on the knee, it is unlikely that these forces alter the proprioceptive signal arising from the knee joint receptors to such an extent that muscle force control is directly impaired. Furthermore, the results of this study did not show differences in the level of muscle activation during submaximal tasks between individuals with CAI and healthy controls. For these reasons, it seems plausible that abnormalities in knee extensor and flexor muscle strength steadiness and accuracy are more related to motor unit recruitment than abnormalities in proprioception or activation of the antagonist muscles.

It should also be mentioned that the abnormalities in quadriceps muscle strength steadiness in CAI compared with healthy controls were observed at 90° but not at 30°. In this regard, previous literature has reported impairments in the contractility and efficacy of the stretch-shortening cycle[51] of the quadriceps muscle of individuals with CAI. Furthermore, the 90° knee joint position represents a mechanical disadvantage for the quadriceps muscle to create muscle protein crossing bridges in comparison with a 30° position, and previous literature has reported a lower quadriceps steadiness at knee angles near 90°.[32] It is plausible to think that the mechanical disadvantage together with impairments in muscle contractility is the determinant of the results observed in this study. Some of the abnormalities in muscle strength steadiness and accuracy were observed in both limbs of individuals with CAI. Previous literature has reported bilateral abnormalities in neuromuscular control despite a unilateral injury.[28] In addition, because CAI is a chronic condition, it cannot be ruled out that adaptations at a central level may have affected neuromuscular control of both the injured limb and the contralateral limb.[37] Further research is needed to clarify these points.

From a clinical perspective, the results of this study suggest that a distal injury leading to a chronic condition such as CAI may lead to strength abnormalities in muscles acting on joints more proximal than the ankle. Clinicians and other professionals dealing with CAI should thus consider focusing their exercise and rehabilitation interventions not only on the ankle joint, but also on neuromuscular control of the other joints of the lower limb.

Limitations

The major limitation of this study is that it was conducted only on young and physically active individuals. Thus, the results cannot be generalized to other age ranges or sedentary individuals. Another limitation is that muscle activations were recorded by means of surface bipolar EMG electrodes, which do not allow analysis of motor unit recruitment. Finally, it should be mentioned that the design of this study is unable to prove a cause-effect relationship between CAI and abnormalities in muscle strength.

CONCLUSION

Individuals with CAI show abnormalities in maximal and submaximal isometric strength of knee flexor muscles as well as submaximal strength of the knee extensor muscles.

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