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Gluteus medius activity during gait is altered in individuals with chronic ankle instability: An ultrasound imaging study☆

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ABSTRACT

Background: Altered gait mechanics are frequently reported in individuals with chronic ankle instability (CAI), and increasing information suggests proximal muscle adaptations occur in this population. Ultrasound imaging (USI) offers a visual means to evaluate muscle activity during movement, and overcomes limitations of electromyography (EMG) to detect hip muscle activity.
Research Question: A descriptive laboratory study was conducted to determine if gluteus maximus (GMAX) and medius (GMED) muscle activity differed throughout gait in patients with CAI compared to healthy counterparts.
Methods: Twenty young adults with CAI (21.6 ± 2.4 years, 10 males) and 20 healthy participants (21.2 ± 2.8 years, 10 males) walked on a treadmill at 1.35 m/s while researchers obtained 10-second clips of bilateral USI of the GMAX and GMED. USI clips were reduced to 55 frames consisting of 11 points over five full gait cycles. Muscle thickness values during walking were normalized to quiet bipedal standing USI images to obtain functional activity ratios (FARs). FARs with 90% confidence intervals (CI) were plotted as 10% interludes from 0 to 100% of the gait cycle to compare groups and limbs. Mean differences and Cohen's d effect sizes were used to assess the extent of differences. The CAI group had decreased GMED activity bilaterally from 0 to 40% of walking gait compared to healthy counterparts with large effect sizes ($d \geq 0.60$). CAI group FARs were below quiet stance levels (FARs < 1.0) throughout the entire gait cycle. There were no differences noted between groups or limbs for GMAX measures.
Significance: Proximal stabilizing musculature was altered bilaterally in CAI individuals compared to healthy counterparts, which may contribute to movement dysfunction. Previous studies using EMG have not detected this extent of bilateral gluteal muscle alterations in CAI groups during gait, however our findings suggest USI was able to detect significant proximal alterations during walking in this population.

1. Introduction

Lateral ankle sprains are among the most prevalent musculoskeletal injuries [1] with approximately 40% of cases resulting in cyclical impairments and episodes of the ankle "giving way" during activity, collectively termed Chronic Ankle Instability (CAI) [2,3]. Individuals with CAI present with a range of mechanical and sensorimotor limitations [4], shown to impact patient function during dynamic tasks that require neuromuscular control [5]. Further, individuals with CAI report kinesiophobia and have been found to take significantly fewer steps per day on average than healthy counterparts [6,7]. Investigations of gait adaptations and potential areas for clinical intervention continue to be of particular interest in this population.

It is well-documented that ankle sprains occur as the foot comes into contact with the ground, and as such initial contact and stance phases are critical timepoints during gait for this population [5,8]. Previous CAI walking analyses have identified altered peroneal activation and lateralized foot pressure [5,9,10], however it is important to consider that the ankle must also work in concert with proximal structures to produce coordinated lower extremity movement [11]. Research in other chronic musculoskeletal pathologies, such as patellofemoral pain, have highlighted that insufficient proximal activity patterns are a key link to lower extremity malalignment and dysfunction during gait [12].

Gluteal muscle function is especially important to consider during activity in CAI patients as decreased hip strength has been identified as a risk factor for sustaining lateral ankle sprains during sport [13]. Persistent hip weakness has been documented as uniquely manifesting in CAI and not ankle sprain "copers" who have more successful long-

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term outcomes [14,15]. There is mounting evidence to suggest that hip muscle alterations in individuals with CAI contribute to dysfunction down the kinetic chain during functional exercise [16,17] and dynamic balance [14,18]. Thus, there appears to be a relationship between proximal maladaptations and diminished function. As gait is a fundamental daily activity that requires pelvic stability for successful lower extremity movement, a deeper investigation of gluteal muscle activity throughout gait in individuals with CAI is warranted.

Previous studies quantifying hip muscle activity during walking in CAI populations have primarily focused on gluteus medius (GMED) surface electromyography (EMG), and have noted subtle differences between CAI and healthy cohorts [9,10,19,20]. However, this method may not be sufficient due to cross-talk from the gluteus maximus (GMAX) and tensor fascia latae muscles as reflected in the large variability in previous outcome EMG measures [20,21]. Further, previous investigations have only look**ed** at unilateral measures which may not capture the extent of centrally mediated adaptations in this population. Contralateral gluteal function is critical for hip positioning at the transition from **terminal** swing to **initial** contact phase, [22] therefore it would be important to understand if bilateral alterations exist in CAI patients.

Ultrasound imaging (USI) is a reliable clinical tool to visualize superficial and deep muscle layers to determine activity during dynamic conditions [21,23,24]. Functional activity ratios (FARs) in which muscle thickness measures during activity are normalized to resting thickness have been used to detect altered lumbopelvic-hip muscle activity throughout a variety of tasks [23,25]. However, USI has not previously been used to determine gluteal muscle function throughout the entire walking gait cycle.

The purpose of this study was to investigate GMAX and GMED FARs bilaterally throughout treadmill walking in individuals with CAI compared to healthy counterparts. Based on previous USI investigations in a group at increased risk for lower extremity injury [23] and reported hip muscle deficits in CAI patients [14,15], we hypothesized that the CAI group would present with decreased bilateral GMED activity throughout stance compared to the healthy cohort.

2. Methods

2.1. Study design

Bilateral gluteal muscle thickness measures were obtained through video clips captured during treadmill walking in individuals with and without CAI using a descriptive laboratory study design. B-mode ultrasound images were taken in quiet bipedal stance as a normative measure, and 10-second USI clips were recorded while participants walked at a standardized speed. USI video clips were processed to obtain still screen images across each gait cycle. Independent variables were participant group and limb, and dependent variables were GMAX and GMED FARs at 10% intervals over the gait cycle.

2.2. Participants

Participants aged 18–35 were recruited through convenience sampling in a university setting. Inclusion and exclusion criteria for selecting CAI participants followed the guidelines set forth by the International Ankle Consortium: [8] individuals were screened to ensure they had at least one significant ankle sprain 12 months or more prior to enrollment, no current ankle injuries $\leq$3 months of the study, < 90% on the Foot and Ankle Ability Measure Activities of Daily Living Subscale (FAAM-ADL) and < 85% on the Sport subscale (FAAM-Sport), $\geq$11 on the Identification of Functional Instability scale (IdFAI), and < 24 on the Cumberland Ankle Instability Tool (CAIT) questionnaires. Individuals with bilateral ankle sprain history were instructed to respond for their perceived worse side. Healthy participants were included if they were recreationally active ($\geq$30 min of moderate activity 5 times/week) without a history of ankle sprains. Exclusion criteria for both groups consisted of any lower extremity/back injuries/surgeries, neuropathy, muscular abnormalities, and/or current pregnancy. All participants provided informed consent prior to participation, and the study was approved by the University's Institutional Review Board.

Upon reporting for testing, all participants completed additional patient-reported outcomes including general health history, Tegner Activity Level Scale, Fear Avoidance Belief Questionnaire (FABQ), Tampa Scale for Kinesiophobia (TSK-17), and the Patient-Specific Functional Scale (PSFS). Demographic information is reported in Table 1.

Table 1
. Participant Demographics.

	HEA (Mean ± SD)	CAI (Mean ± SD)	*p*-value
Height (cm)	173.18 ± 15.16	172.74 ± 11.28	0.930
Weight (kg)	70.89 ± 12.18	74.26 ± 15.24	0.402
Age (years)	21.20 ± 2.79	21.70 ± 2.32	0.605
Tegner	5.50 ± 1.32	6.00 ± 1.91	0.190
TSK-17	20.75 ± 5.71	37.65 ± 5.29[a]	< 0.001
FABQ	1.45 ± 3.07	15.50 ± 9.84[a]	< 0.001
IdFAI	1.00 ± 1.00	21.20 ± 4.05[a]	< 0.001
CAIT	30.00 ± 0.00	17.80 ± 4.43[a]	< 0.001
FAAM – ADL	100.00 ± 0.00	83.94 ± 4.57[a]	< 0.001
FAAM – Sport	100.00 ± 0.00	72.83 ± 5.56[a]	< 0.001

Abbreviations: HEA, healthy group; CAI, Chronic Ankle Instability group; Tegner, Tegner Activity Level Scale; TSK-17, Tampa Scale for Kinesiophobia; FABQ, Fear Avoidance Belief Questionnaire; CAIT, Cumberland Ankle Instability Tool; IdFAI, Identification of Functional Ankle Instability; FAAM – ADL, Foot and Ankle Ability Measure Activities of Daily Living Subscale; FAAM – Sport, Foot and Ankle Ability Measure Sport Subscale.
aSignificant at $p \leq 0.05$.

2.3. Instruments

A dual-belt treadmill with imbedded force plates (Bertec Corporation, Columbus, OH, USA) sampled at 1000 Hz was used for walking procedures and ground reaction force data for marking initial contact events. A 12-camera Vicon Motion Capture System (Vicon Motion Systems, Inc., Lake Forest, CA, USA) sampled at 250 Hz with MotionMonitor™ software (Innovative Sports Training, Chicago, IL, USA) was used to track participants' movement throughout gait.

A portable Siemens ACUSON Freestyle Ultrasound System (Siemens Medical Inc., Mountain View, CA, USA) with an 8 MHz wireless linear transducer secured with a custom Velcro belt with foam block was used to collect B-mode GMAX and GMED quiet standing images and walking videos.

2.3.1. Procedures

Participants reported to the laboratory for a single session. Following systems set-up and calibration, participants were outfitted with eight clusters of retroreflective markers placed bilaterally on the foot dorsum, lateral shank, lateral thigh, and on the sacrum and thorax [26]. A stylus was used to indicate bony landmarks for joint center identification to complete participant digitization.

The ultrasound transducer placement methods have been described and published elsewhere [21,23]. In brief, the wireless transducer with aqueous gel was placed in the custom block and belt, then secured around the participants' right hip such that the sound head was oriented between the greater trochanter and posterior superior iliac spine. Depth of penetration was adjusted until a clear view of the superior and inferior fascial borders of the GMAX and GMED were visualized without exiting the screen frame during walking.

Participants were instructed to maintain a still bipedal stance and a

single investigator with 2 years of USI experience (AFD) obtained three quiet images. The treadmill speed was then increased to a 1.35 m/s walking pace for a 5-minute acclimation period. MotionMonitor with force plate data acquisition and a USI clip were synchronously recorded through intra-examiner communication controlling each system to collect 10 s of walking data, equating to approximately nine full gait cycles and 150 frames (Supplementary Video). The transducer was then switched to the left hip and walking collection procedures were repeated, and participants were dismissed.

2.4. Data processing

USI video clips were analyzed using QuickTime Player software (Version 7.7.9, Apple, Inc., 2016©) in conjunction with ground reaction force data on a separate monitor to reference initial contact events, such that a change in ground reaction from zero to greater than 20 Ns indicated the change from **terminal** swing to initial contact timing on the USI clip [27]. The first three gait cycles were purposefully omitted to ensure clean walking data. At the fourth initial contact, the USI video frames were recorded as data "start" frames. The USI and motion capture videos were then played in tandem for the middle five gait cycles until the ground reaction force fell below a 20 N threshold, and at this time the videos were paused and frames were noted as the end timepoints for USI data reduction.

Equation 1 was used to calculate the USI video frames in 10% intervals from 0 to 100% for an 11-point gait cycle reduction. The resultant value was added sequentially to the start video frame value until the end video frame was reached, yielding 55 images for measurement (11 frames each for 5 consecutive steps). Each video clip was reduced to still images using the Macintosh screenshot function (macOS High Sierra, Version 10.13.6, Apple Inc.© 2018), and procedures were repeated for all participants' limb videos (Supplementary Video).

Equation 1: [23] $\textbf{\textit{Frame Intervals}} = \frac{(End\ Frame - Start\ Frame) + 1}{55}$

All ultrasound images were measured using ImageJ software (ImageJ 1.50i, National Institutes of Health, USA) by an investigator blinded to participant group at the time of measurement (AFD). GMAX and GMED thicknesses were measured from the superior to inferior fascial border in the thickest muscle portion. Average muscle thickness was obtained for each 10% increment of the five gait cycles for each limb (Fig. 1). FARs (Equation 2) were used to normalize thicknesses during gait to quiet stance.

Equation 2: [25] $\textbf{\textit{Functional Activity Ratio}} = \frac{muscle\ thickness_{during\ activity}}{muscle\ thickness_{quiet}}$

2.5. Statistical analysis

Based on current USI literature, the expected mean gluteal muscle thickness difference between groups was 1.65 mm with a 1.70 mm standard deviation [28]. An *a priori* sample size estimate with alpha set ≤0.05 and 80% power accounting for 15% attrition reflected the need for 40 total participants. Participants' CAI limbs (N = 8), or the self-reported worse limb in individuals with bilateral sprains (N = 12), were designated as "affected", with the contralateral limb as "unaffected" for all analyses. Healthy participants' limbs were matched as the same side to affected and unaffected CAI limbs based on participant sex and height to ensure an equal group comparison.

To ensure there was no influence of bilateral *versus* unilateral ankle sprains on within CAI group limb comparisons, a sub-analysis of the bilateral history patient's worse and contralateral limb mean GMAX and GMED thickness measures against unilateral CAI patients were compared using 90% confidence intervals (CI) at each gait cycle increment.

Mean GMAX and GMED FARs were calculated across the five complete gait cycles over an 11-point gait cycle (0%, 10%…100%), and were analyzed by comparing group means with 90% CI. Cohen's *d* effect sizes were calculated to determine the extent of gluteal muscle thickness change, with < 0.2-0.49 interpreted as a small effect, 0.5-0.79 as moderate, and > 0.8 as large [29].

3. Results

The CAI group had significantly decreased CAIT, FAAM-ADL, and FAAM-Sport scores and increased IdFAI scores compared to the healthy group (Table 1). The CAI group also had significantly increased kinesiophobia compared to the healthy group (Table 1). CAI participants used the PSFS to designate activities they felt limited in based on their ankle function, and frequently reported problems with running (N = 17), field/court sports (N = 15), cutting (N = 6), and jumping (N = 5). Groups were similar in terms of anthropometric measures and activity (Table 1).

There were no significant differences when comparing limbs within the bilateral ankle sprain history group against the unilateral CAI group for any gluteal outcome measure throughout the gait cycle, ensuring a reasonable CAI group limb comparison for gait outcomes.

3.1. GMED outcomes

When comparing the CAI and healthy groups, the CAI affected limbs had decreased GMED FAR measures from 0 to 40% of gait with moderate to large effect sizes (MD: 0.16-0.17; *d*: 0.62-0.68; Fig. 2A, Fig. 3A). Similar outcomes were found for the CAI unaffected limb compared to the healthy group (MD: 0.14-0.17; *d*: 0.76-0.95; Figs. 2B, 3 B). There were no significant differences identified between limbs within healthy or CAI group. The CAI group presented with GMED thickness values below quiet standing levels throughout the entire gait cycle (FARs < 1.0, Fig. 3).

3.2. GMAX outcomes

There were no significant differences in GMAX activity at any point in the gait cycle when comparing CAI and healthy participants' affected and unaffected limbs (Fig. 4A&B), nor between limbs within the CAI

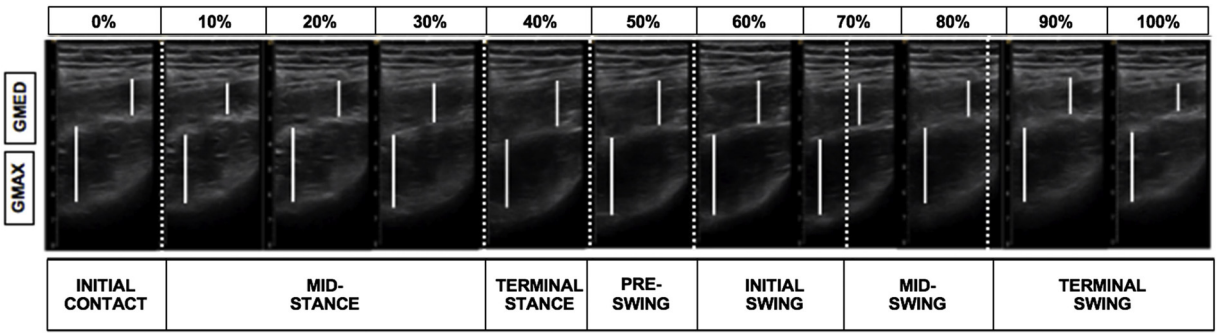

Fig. 1. 11-Point Frame Reduction of Gluteal Ultrasound Images. Images Plotted Across the Walking Gait Cycle.[30.]
Abbreviations: GMAX, gluteus maximus; GMED, gluteus medius.

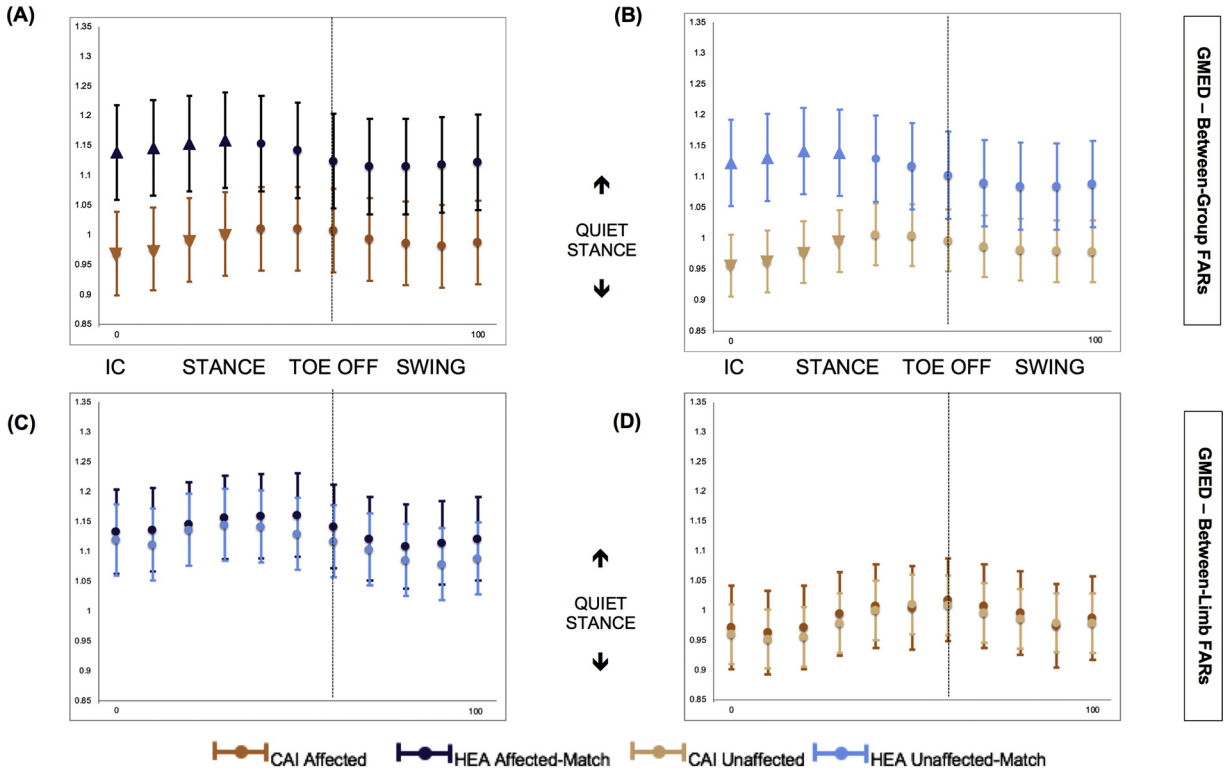

Fig. 2. (A&B) Between-Group and **(C&D)** Between-Limb Gluteus Medius Functional Activity Ratios Throughout the Gait Cycle.
Abbreviations: IC, initial contact; CAI, chronic ankle instability; HEA, healthy; GMED, gluteus maximus; FARs, functional activity ratios.
Arrows signify statistically significant differences between groups.

and healthy groups (Fig. 4C&D). GMAX activity was increased above quiet standing measures from **terminal** stance to **mid-swing** for all group and limb outcomes. (FARs > 1.0, Fig. 4)

4. Discussion

4.1. Gluteal muscle outcomes

The results of this study confirmed our hypothesis; the CAI group had significantly decreased GMED activity with moderate to large effect sizes from initial contact to terminal stance. To our knowledge, this is the first study to quantify gluteal activity throughout the entire gait cycle using dynamic USI. Previous investigations using USI during gait have identified gluteal alterations at phases of gait in a dynamic knee valgus risk factor population [23]. Based on this previous analysis and increasing evidence of proximal maladaptations in CAI patients, we anticipated amplified gluteal alterations in this injured population. Our findings not only support that the CAI limb had significantly decreased GMED activity throughout the majority of stance, but these findings manifested in the contralateral limb as well. Analyses of CAI subgroups suggested gluteal alterations were independent of laterality of ankle sprain history, which supports that these are centrally mediated proximal adaptations [30].

Peroneal, GMAX, and GMED strength deficits are frequently

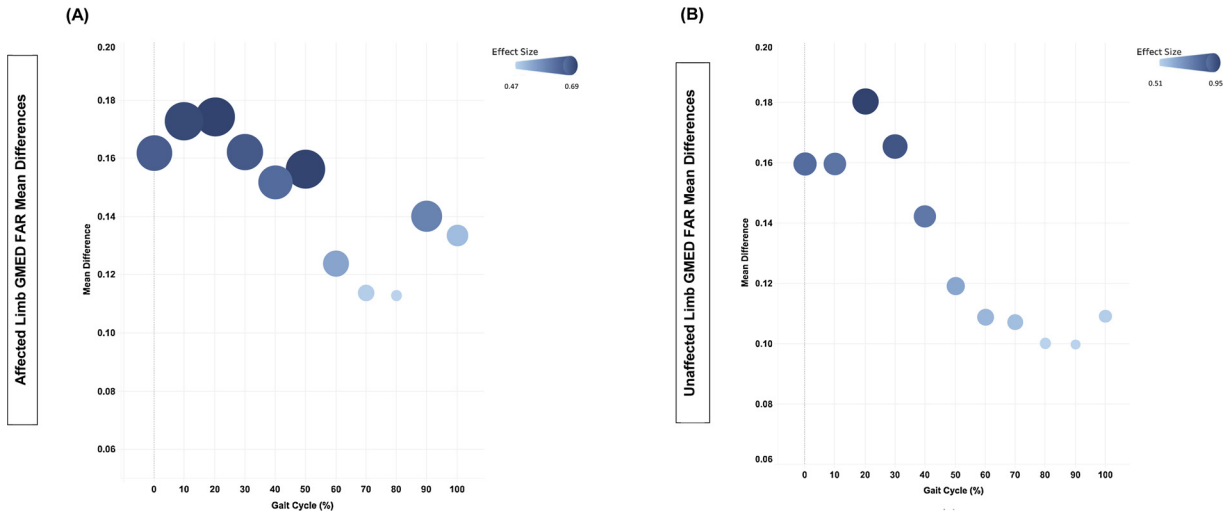

Fig. 3. Group GMED **(A)** Affected and **(B)** Unaffected Mean Differences and Effect Sizes Throughout the Gait Cycle.
Abbreviation: GMED, gluteus medius; FAR, functional activity ratio.

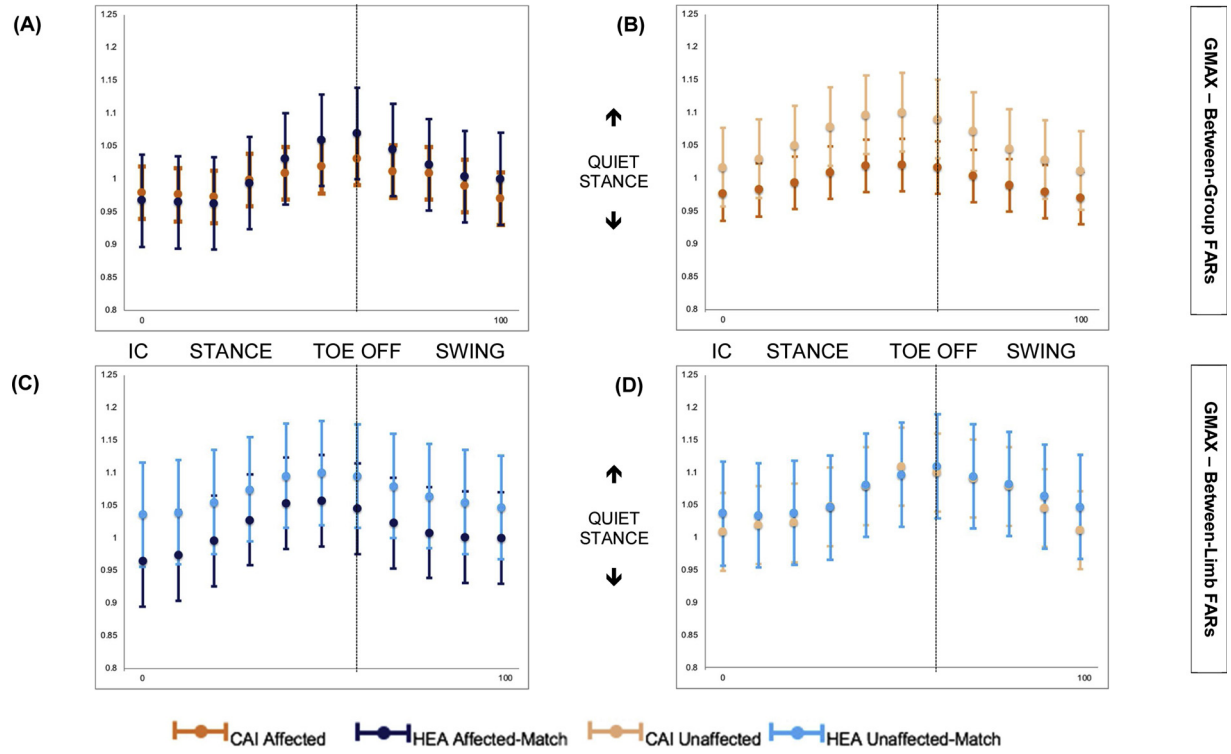

Fig. 4. (A&B) Between-Group and **(C&D)** Between-Limb Gluteus Maximus Functional Activity Ratios Throughout the Gait Cycle.
Abbreviations: IC, initial contact; CAI, chronic ankle instability; HEA, healthy; GMAX, gluteus maximus; FARs, functional activity ratios.

reported for CAI patients. Although each of these lower extremity muscles are innervated by different peripheral nerves, there are nerve root commonalities for the superior gluteal (L4-S1), inferior gluteal (L5-S1), and superficial peroneal (L4-S2) nerves. Based on the descending pain modulation theory, there may be a top-down effect of centrally mediated deficits associated with chronic pain leading to muscle activity and strength deficits [31]. Further, arthrogenic muscle inhibition (AMI) influences motor function following joint injury. Though CAI patients primarily present with AMI of the peroneal muscles [32], there is evidence of AMI in proximal musculature in this group as well [33]. We hypothesize these phenomena contributed to the bilateral GMED deficits observed throughout gait in this cohort. Previous work has found USI GMAX deficits during an increasingly demanding stabilization task [34]; thus, centrally-mediated adaptations may play a role in activities requiring increased hip muscle activity and may help explain the comparable GMAX outcomes across groups during gait in the present findings.

Although previous studies using EMG during walking have found subtle alterations in gluteal function during gait, these investigations were limited in interpretation and clinical impact due to high variability in the outcome measures [20]. Conversely, our findings reflect that USI revealed significant changes in GMED activity throughout movement. Given that we did not find GMAX alterations, we speculate that EMG investigations may have been subject to cross-talk from this larger muscle [21]. These findings are similar to examinations in other lumbopelvic-hip muscles in which EMG was insufficient for detecting muscular action, such as the transverse abdominis [21]. Previous authors have suggested that USI provides insight into the types of contractions and morphological changes as opposed to electrical recruitment, and offers a different picture of muscle activity [21,35]. Our outcomes support the use of USI to quantify deep muscle activity, and provide compelling evidence of altered movement patterns in this CAI group.

Although hip extension and external rotation strength deficits are reported in CAI populations [14,15], we did not expect differences in GMAX activity patterns throughout walking in CAI participants as ankle sprains and "giving way" episodes are often a result of excessive frontal plane motion [5]. Healthy reference gait data reflects minimal hip frontal plane motion, typically within a 10-degree window from approximately five degrees of adduction during stance and five degrees of abduction during swing phases [36]. Thus, pelvic stability is needed for frontal plane control and does not require extensive GMAX activity for global movement [22]. Conversely, the GMED is closer to the hip center of rotation for fine movement control [22]. The results of this study supported the hypothesis that GMED activity would be compromised in this population due to insufficient stabilization, and aligns with the theoretical construct suggesting GMED is critical for lower extremity alignment during gait [11].

Interestingly, the CAI cohort appeared to have similar GMAX and GMED activity patterns throughout gait with relatively increased FARs around terminal and pre-swing phases. Meanwhile, the healthy cohort had expectedly increased GMED FARs during stance with lesser contributions from the GMAX (FAR $<$ 1.0), and the inverse relationship during swing [36]. This alteration seen in CAI patients may be reflective of a synergistic gluteal recruitment pattern to compensate for proximal control deficits. The transducer was placed over the upper GMAX and posterior GMED fibers, which serve slightly different primary actions; the GMAX primarily serves to extend the hip, while the GMED externally rotates the hip with extension as a secondary action [22]. It appears that the CAI cohort had delayed activity of the GMED and incorporated muscular actions during hip extension demands, which may be attributed to altered neuromuscular control.

4.2. Implications for gait-training

Although we did not measure hip strength, previous research suggests that strength does not necessarily transfer to outcomes throughout dynamic movement, such as during a stabilization task [14]. Further, previous gait-training literature suggests that strengthening alone proves unsuccessful for impacting gait, with the conclusion that

neuromuscular education during movement is necessary to effectively change gait patterns [37]. The CAI group FAR findings reflect decreased GMED activity below healthy values throughout stance, and below quiet standing thickness as all values were below 1.0 (Fig. 3). Although strength may have played a role, these results are more suggestive of an avoidance pattern which are similar to findings seen in the dynamic knee valgus population [23]. Thus, using tactics to increase GMED activity and enhance neuromuscular education during walking may be beneficial to this population. Given that USI successfully identified these trends through a visual interface, future research should investigate the effects of muscle activity feedback throughout movement.

Previous CAI gait analyses have continually found altered peroneal muscle activation and lateralized foot pressure throughout stance phases of walking, and as such gait-training measures have focused on addressing these alterations [38,39]. Researchers used an elastic band around participants' lower limbs and connected to a central track during treadmill walking to medialize foot pressure and target peroneal and gluteal activation. [39] This band positioning was similar to exercises targeting the GMED, such as monster walks, as the hip muscles have to prevent against medial and internal rotation [40]. The researchers found that gait measures and self-reported function improved in the CAI patients. Though the researchers did not identify gluteal EMG alterations, they noted being under-powered for these analyses and potentially ran into aforementioned EMG limitations. Therefore, there may be additional benefits to implementing this sort of gait-training to target multiple facets of pathological gait in this population. The band positioning would bilaterally target proximal muscles in addition to lateralizing foot pressure and increasing peroneal activation throughout gait. Future research is warranted to understand how gait-training interventions may improve proximal muscular activity.

4.3. Patient-reported outcome measures

It is well-documented that individuals with CAI engage in less physical activity and report kinesiophobia [6,7]. The CAI group in this study did not report decreased physical activity compared to the healthy group, however these outcomes were blunt estimates taken at a single timepoint compared to longitudinal studies using physical activity monitors in previous investigations [6]. The CAI group presented with increased levels of kinesiophobia, and used the PSFS to report decreased self-reported function on increasingly demanding tasks. Few participants reported issues with walking on uneven surfaces (N = 3). Future investigations of proximal muscle function are warranted during walking on a variety of surfaces, and during running to understand how activity patterns may differ during more strenuous tasks that are limited by ankle dysfunction.

4.4. Limitations

This study had several limitations. As mentioned previously, we did not account for muscle strength measures and thus we only were able to describe the extent of muscle activity above quiet standing thickness values. Further, we did not examine kinematic data with this study and cannot conclude how activity measures related to lower extremity joint angles. Given that USI video clips were obtained for a comprehensive visual understanding of gluteal activity throughout movement, there was some inconsistency with image quality inherent to the tool [21]. However, measures were taken to ensure minimal shifting of the ultrasound probe, and the same investigator collected all data to ensure consistency and minimize error. Initial contact was also used as a reference point during gait to ensure measurement consistency across participants. Finally, we did include CAI participants that reported a bilateral ankle sprain history which may have influenced the bilateral hip muscle alterations; however, statistical analyses reflected that unilateral CAI and bilateral sprain participant outcomes did not significantly differ.

5. Conclusion

Individuals with CAI demonstrated decreased GMED activity bilaterally throughout the majority of stance during walking compared to healthy counterparts, while GMAX activity was similar between groups and limbs. GMED activity patterns fell below resting levels suggestive of a hip muscle avoidance pattern in the CAI group. USI was able to detect gluteal muscle activity changes that have not previously been detected using EMG techniques. Due to the influence of the gluteal muscles on gait in CAI patients, proximal musculature should be considered during gait-training in this population.

Disclosures

Nothing to disclose.

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Conflicts of interest

None

CRediT authorship contribution statement

Alexandra F. DeJong: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Validation, Visualization, Writing - original draft. **L. Colby Mangum:** Investigation, Methodology, Project administration, Resources, Validation, Writing - review & editing. **Jay Hertel:** Conceptualization, Data curation, Supervision, Writing - review & editing.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.gaitpost.2019.04.007.

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