Received: 31 October 2023 | Revised: 3 September 2024 | Accepted: 26 September 2024

DOI: 10.1002/hsr2.70143

SYSTEMATIC REVIEW

Health Science Reports Open Access WILEY

Kinetic changes of gait initiation in individuals with chronic ankle instability: A systematic review

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Abstract

Background and Aims: Gait initiation (GI) in individuals with chronic ankle instability (CAI) has shown differences in the center of pressure (COP) and muscular measures compared to healthy controls. Some studies reported that these alterations appeared when GI was with the affected leg, while others indicated that they occurred when GI was with the non-affected leg. This systematic review aimed to understand kinetic and muscular differences between individuals with CAI, healthy controls, and the affected and non-affected legs of individuals with CAI.

Methods: PubMed, Science Direct, Web of Science, Google Scholar, and Scopus databases (1990–2023) were searched using the Population, Exposure, Comparator, and Outcome measure. The PRISMA guidelines were followed. The outcome measures were the peak and rate of COP displacement in the medial-lateral and anterior-posterior directions, and resultant plane during phases 1, 2, and 3 of COP trace during GI and the duration of each phase. The other measures included the onset time of the tibialis anterior and soleus muscle activity between individuals with CAI, healthy controls, and the affected and non-affected legs of the individuals with CAI. The studies' quality assessment was conducted based on the Strengthening the Reporting of Observational Studies in Epidemiology checklist.

Results: Five studies were included in the final evaluation. The results of included studies showed, individuals with CAI spent less time during phases 1 and 2, as well as a shorter peak of COP displacement in the lateral direction during phase 1 compared to healthy controls, regardless of whether the GI was with the affected or non-affected leg.

Conclusion: Individuals with CAI have probably adopted a strategy involving adjusting the peak of COP displacement to manage internal sway while in a single-leg stance. Overall, there was no comprehensive conclusion about differences between the two legs in individuals with CAI.

KEYWORDS

ankle sprain, center of pressure, muscular change, step initiation

Prospero code: CRD42023415770.

1 | INTRODUCTION

Lateral ankle sprains are common in sports, and they are accounted for about 15%–75% of sports injuries.[1] Following the first lateral ankle sprain, although approximately 60% of people recover, roughly 40% report disabling symptoms such as pain, swelling, a feeling of instability, and repeated sprains at least 12 months after the injury.[2] These individuals report frequent injuries and persistent episodes of the ankle giving way, known as chronic ankle instability (CAI).[3]

Studies have shown that functional and mechanical disorders contribute to CAI, leading to defects in postural control.[4] One of these challenging conditions is transitioning from double-limb support to single-limb support, similar to gait initiation (GI).[5] Reports indicate that individuals with CAI experience alterations in postural control in the affected limb.[6] Recent research has shown that both affected and unaffected limbs face challenges in controlling balance and posture.[7,8]

GI, requiring control of posture and balance, has been shown to exhibit differences in individuals with CAI compared to healthy controls.[6–10] Based on the center of pressure (COP), GI is divided into three sections. The first section (S1) begins with the auditory cue and ends with the COP located in its most posterior-lateral position toward the initial stepping foot. This posterior-lateral shift requires bilateral inhibition of the soleus, followed closely by the bilateral activation of the tibialis anterior.[11] The second section (S2) represents the movement of the COP medially toward the initial stance foot and ends at the initial stance foot on which the COP begins to move forward.[6] The third section (S3) extends from the end of the S2 until toe-off at the initial stance foot as the COP translates forward (Figure 1). The time of the auditory cue until the end of the first section is anticipatory postural adjustment (APA).[12,13] Hartley et al. demonstrated that examining the GI profile in these three phases had high repeatability and validity in individuals with CAI.[14]

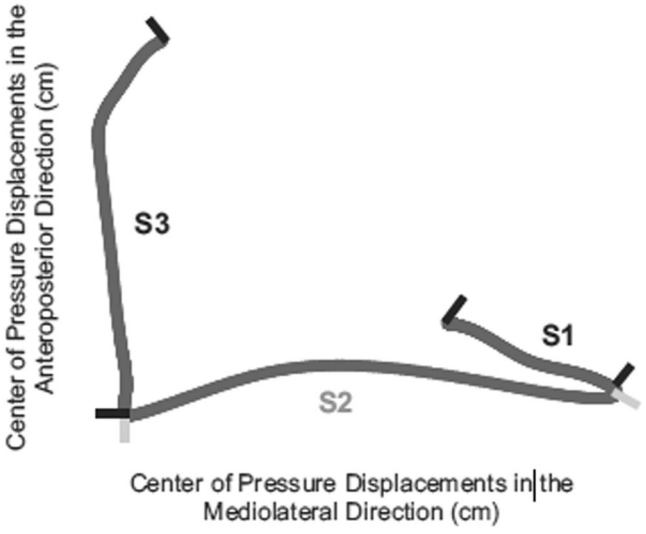

FIGURE 1 COP trace in GI.[14] COP, center of pressure; GI, gait initiation.

GI is the transition from quiet stance to continuous gait, measuring postural control and global functioning of the feed-forward neuromuscular control system defined by time-invariant features.[11] Recent studies on GI have shown changes in its different phases in individuals with CAI compared to healthy controls.[6–10] These individuals spend a shorter time during phases 1 and 2 with the GI.[9] It seems that individuals with CAI adopted the worst changes in GI parameters to reduce postural instability.[15,16] In addition, the maximum shift in the medial-lateral (ML) displacement of the COP and its rate were slower in individuals with CAI when compared to healthy controls.[8] Some studies reported that these alterations appeared when GI was with the affected leg,[7,8] while others demonstrated that these differences occurred when GI was with the non-affected leg.[6,10]

Previous systematic reviews have examined the gait parameters of individuals with CAI throughout the whole gait cycle.[17,18] Other reviews have also evaluated the effects of therapeutic interventions such as balance exercises, proprioception, Kinesio-tape, and whole-body vibration on the individuals' performance with CAI.[17–21] Another systematic review reported that individuals with CAI had delayed activation of the peroneus longus in response to sudden inversion disorders in the transition from the double-limb position to the single-limb stance position.[22] As it is well known, muscular and kinetic changes exist in the transition between double- and single-limb stance positions.[22] Recent studies have discussed GI changes in individuals with CAI,[6–10] as previously mentioned. Despite the importance of GI in individuals with CAI that requires postural control and balance, to our knowledge, no comprehensive review has been conducted on this topic. Thus, this study aimed to understand the kinetic and muscular differences between individuals with CAI, healthy controls, and the affected and non-affected legs of individuals with CAI. It was hypothesized that there would be differences with kinetic and muscular measures in GI between individuals with CAI, healthy controls, and the affected and non-affected legs of individuals with CAI.

2 | METHODS

The protocol for this systematic review was already registered in the PROSPERO database with the number CRD42023415770. After identifying studies, the process followed the PRISMA guidelines (Supporting Information S1: Appendix S1).

2.1 | Evidence acquisition

Several databases, including PubMed, Science Direct, Web of Science, Google Scholar, and Scopus (1990–2023), were searched using the Population, Exposure, Comparator, and Outcome (PECO) method. Keywords I and II were “chronic ankle instability” or “ankle sprain” or “ankle instability” and “gait initiation or “gait start” or “step initiation” or “step start”, respectively. Combinations of “Keyword-I

AND Keyword-II" were utilized to inquire databases for studies involving GI in CAI (Supporting Information S1: Appendix S2). All the records extracted from the databases were imported into EndNote software, and duplicates were removed from the list. Next, two evaluators (Marzieh Mortezanejad and Aliyeh Daryabor) independently screened the titles and abstracts for eligibility, and the full text of the studies was then acquired. The author was contacted in cases where there was ambiguity in the study. Finally, two evaluators (Marzieh Mortezanejad and Zahra Ebrahimabadi) initiated eligibility for the remaining full-text articles. The details of the study selection process are depicted in Figure 2.

Articles were included in this review if they included individuals with CAI who had experienced at least one unilateral ankle sprain at least 12 months before the test day that required protected weight-bearing or immobilization for a minimum of 3 days or 1 week. Additionally, participants needed to report at least two episodes of giving way within three to 6 months before enrolling in the study. The control group in these studies included healthy controls with no history of ankle sprains, and outcome measures were kinetic changes, including changes in the peak of COP displacement, the rate of COP displacement in different directions, and electromyography changes of tibialis anterior and soleus muscle activity. Studies that included populations secondary to post-concussion injuries or other diseases were excluded from the investigation.

2.2 | Assessment of methodological quality

The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist was used by two independent evaluators (Marzieh Mortezanejad and Aliyeh Daryabor) to assess the methodological quality of observational cohort, case-control, and cross-sectional studies. This checklist consists of 22 items. Each item assesses a specific aspect of the study report, such as the study design, sampling strategy, or statistical methods, with each item scoring "fully reported" (2 points), "partially reported",[14] and "no reported" (0). The total score for the study was calculated by using the sum of the 22 scored items. The maximum

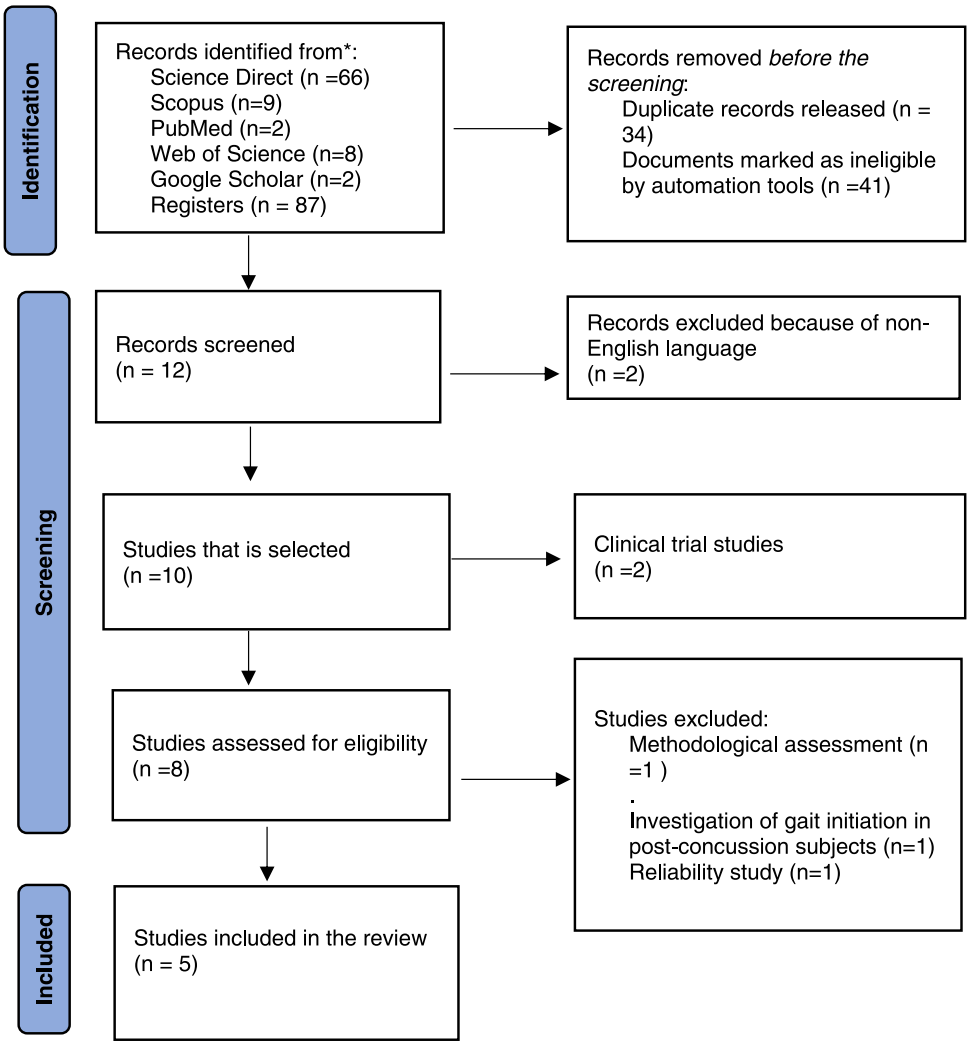

FIGURE 2 Flowchart indicating the selection of articles through the PRISMA method.

possible score was 44 (two points for each item), indicating that all items were fully reported.[23] The quality status of the studies had a scientific rigor of 36 (medium or fair) and ranged from 33 (low or poor) to 41 (high or good) (Tables 1 and 3). The results of the quality assessment of the studies are provided in Table 1. Of the remaining five studies, two received a poor grade,[8,10] while two received a fair grade,[6,9] and only one received a high grade[8] using the STROBE criteria (Table 3). If the STROBE score was under 22, the study would be excluded from further analysis.

2.3 | Evidence synthesis

Data on the design of the studies, sample size, selected population (age, gender, injury frequency, activity level, Foot and Ankle Ability Measure (FAAM) questionnaire score (daily performance questionnaire score and sports activity questionnaire score), evaluated leg, outcome measures, and main results are presented in Table 3. The authors were contacted for missing information, clarification, or both, where appropriate.

3 | RESULTS

Out of 87 studies identified, 10 articles remained after removing conference abstracts, theses, book chapters, reports, and articles without full text. Out of the 10 selected studies, two were excluded due to differences in study type (clinical trials), one study was excluded due to the methodology used, which focused on motion analysis of the foot and leg without COP analysis, and another was excluded because it focused on a population secondary to post-concussion injury. The reliability study about CAI was also excluded from the investigation. Finally, five articles were selected for the final evaluation (Figure 2).

The analysis was narratively performed since meta-analysis could not be performed because of the limitation in the number of studies for each outcome.

3.1 | Outcome measures

There were mainly two types of outcome measures in the GI discussed in the present review. The first type included COP-related variables such as the peak and rate of COP displacement in the ML and AP directions, as well as in the resulting plane during phases 1, 2,[6–10] and 3.[6,7] The duration of each phase was also taken into consideration.[9,10] The second type of discussed outcome measures were electromyography variables, specifically the amount and onset of activity in the tibialis anterior and soleus muscles.[9]

Among the five studies, all examined the changes during GI between individuals with CAI and healthy controls,[6–10] and three

TABLE 1 Evaluation of the quality of studies.

	Q1A/B	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12A/B/C/D/E	Q13 A/B/C	Q14A/B	Q15	Q16 A/B/C	Q17	Q18	Q19	Q20	Q21	Q22	summation
Eebrahimabadi et al.[10]	2	2	2	2	2	2	2	2	1	0	2	2	0	2	21	2	2	2	2	2	2	Not reported	34
Yousefi et al.[9]	0	2	2	2	1	2	2	2	2	0	2	2	0	2	2	2	2	2	2	2	2	Not reported	36
Ebrahimabadi et al.[7]	2	2	2	2	2	2	2	2	0	2	2	2	2	2	2	2	2	2	2	2	2	Not reported	41
Ebrahimabadi et al.[8]	0	2	2	2	2	2	2	2	0	2	2	2	0	2	2	2	2	2	2	2	2	Not reported	33
Hass et al.[6]	0	2	2	2	2	2	2	2	2		2	2	0	2	2	2	2	2	2	2	2	Not reported	36

studies compared the changes during GI in the individuals with CAI between the affected and non-affected legs[6–8] (Table 2).

3.2 | The peak and rate of COP displacement during phases 1 and 2 between individuals with CAI and healthy controls

Three studies analyzed the peak of COP displacement during phase 1 or 2, separately[6–8] while two studies looked at the peak of COP displacement during phase 1 and 2.[9,10] Yousefi et al. reported that there was no significant difference in the peak of COP displacement during the combination of phases 1 and 2 of GI among individuals with CAI and healthy controls ($p > 0.05$). They used the affected leg as the initial swing leg.[9] Ebrahimabadi et al. found no differences in peak COP displacement between individuals with CAI and healthy controls in both ML and AP directions during the combination of phases 1 and 2 ($p > 0.05$). They utilized the affected leg as the initial stance leg.[10] Studies performed by Ebrahimabadi et al. noted that individuals with CAI exhibited a shorter peak of COP displacement in the lateral direction during phase 1 compared to healthy controls.[7,8] They employed both the affected and non-affected leg as the initial swing leg ($p < 0.001$ and $p = 0.049$, respectively). Hass et al. demonstrated that the peak of COP displacement during phase 1 in the posterior-lateral direction ($p < 0.05$) and resultant plane, during phase 2 in the ML direction ($p < 0.05$) was shorter in individuals with CAI compared to healthy controls when GI was with the affected leg as an initial stance limb.[6] They applied both the affected and non-affected legs as the initial swing leg.[6]

According to Ebrahimabadi et al., the COP displacement rate in the lateral direction was similar for individuals with CAI and healthy controls ($p = 0.164$).[8]

3.3 | The peak and rate of COP displacement during phases 1 and 2 between the affected and non-affected legs of individuals with CAI

Among the five studies, only three investigated the comparative changes of COP in the AP, ML directions, and resultant plane during phase 1 with GI in individuals with CAI, between the affected and non-affected legs.[6–8] Ebrahimabadi et al. reported that the peak of COP displacements during phase 1 was shorter in individuals with CAI when GI was with the affected leg as an initial swing leg, respectively ($p < 0.01$ and $p = 0.002$, respectively).[7,8]

Hass et al. showed that the peak of COP displacement in the resulting plane during phase 1 and in the ML direction during phase 2 was shorter when the GI was with the non-affected leg compared to the affected leg ($p < 0.05$).[6]

Ebrahimabadi et al. indicated that the rate of COP displacement during phase 1 to the lateral side was similar between individuals with CAI and healthy controls.[8]

3.4 | The peak and rate of COP displacement during phase 3 between individuals with CAI and healthy controls

Two studies evaluated changes in COP displacement and rate during phase 3.[6,7] Hass et al. indicated that the peak of COP displacement in the ML direction during phase 3 was shorter when GI was with the affected leg as an initial swing limb compared to healthy controls.[6]

The rate of COP displacement during phase 3 in the ML direction was slower in individuals with CAI in comparison to healthy controls when GI was with the non-affected leg as an initial swing limb ($p < 0.05$).[6] Ebrahimabadi et al. stated that the rate of COP displacement in the AP direction during phase 3 was higher in individuals with CAI compared to healthy controls when GI was with the affected leg as an initial swing limb ($p = 0.039$).[7]

3.5 | The peak and rate of COP displacement during phase 3 in individuals with CAI between affected and non-affected legs

Hass et al. reported that individuals with CAI had a greater peak of COP displacement in the ML direction during phase 3 when GI was with the non-affected leg as an initial swing limb than when GI was with the affected leg as an initial swing limb ($p < 0.05$).[6] In another study, Ebrahimabadi et al. demonstrated that individuals with CAI showed a higher velocity displacement of COP during phase 3 in the AP direction when GI was with the affected leg as an initial swing limb compared to the time GI was with the non-affected leg ($p = 0.037$).[7]

3.6 | Duration of each phase and muscle response between CAI individuals and healthy controls

Yousefi et al. and Ebrahimabadi et al. indicated that individuals with CAI spend a shorter time in the sum of phases 1 and 2 than healthy controls ($p < 0.048$ and $p = 0.015$, respectively).[9,10] Yousefi et al. concluded that the soleus muscle activated earlier in individuals with CAI compared to healthy controls when GI was with the affected leg as the initial swing leg, while the tibialis anterior muscle represented no differences between the two populations ($p = 0.044$).[9]

4 | DISCUSSION AND IMPLICATIONS

This review assumed that there would be differences in kinetic and muscular measures in GI between individuals with CAI, healthy controls, and the affected and non-affected legs of individuals with CAI. The results of the two included studies (Quality: poor and fair) supported the first part of the hypothesis and showed that individuals with CAI spend less time during phases 1 and 2 compared to healthy controls, whether the GI was with the affected[9] or

TABLE 2 The summary of outcome measures reported in the studies.

Outcome measures	Eebrahimabadi et al.[10]	Yousefi et al.[9]	Ebrahimabadi et al.[7]	Ebrahimabadi et al.[8]	Hass et al.[6]
The legs considered as initial swing leg for GI	One leg(non-affected leg)	One leg (affected leg)	Both legs	Both legs	Both legs
Displacement of the COP in the medial-lateral direction during S1, S1 and S2	*	*	*	*	*
Displacement of the COP in the anterior-posterior direction during S1, S1 and S2	*	*	*	*	*
Displacement of the COP in the resultant plane during S1 and S2	*	*	*	*	*
Displacement of the COP in the medial-lateral direction during S3					*
Displacement of the COP in the anterior-posterior direction during S3					
Displacement of the COP in the resultant plane during S3					
Rate of COP displacement in the medial-lateral direction during S1, S1 and S2	*	*	*	*	*
Rate of COP displacement in the anterior-posterior direction during S1, S1 and S2	*	*	*	*	*
Rate of COP displacement in the resulting plane during S1, S1 and S2	*	*	*	*	*
Rate of COP displacement in the media-llateral direction during S3					*
Rate of COP displacement in the anterior-posterior direction during S3			*		
Rate of COP displacement in the resulting plane during S3					
S1and S2 phase time	*	*			
EMG activity		*			

Abbreviations: CAI, chronic ankle instability; COP, Center of pressure; EMG, Electromyography; GI, Gait initiation; S1, Phase 1 of gait initiation; S2, Phase 2 of gait initiation; S3, Phase3 of gait initiation.

TABLE 3 Summary of studies.

study	Type of study	Participants (control)	Inclusion criteria	Group	Procedure	Limb(s)	Outcome measures	Results in CAI versus healthy control(affected limb as an initial stance limb)	Results in CAI versus health control (affected limb as an initial swing limb)	Results in affected versus non-affected limb in CAI group	Status quality
Eebrahimabadi et al.[10]	-Cross-sectional	50(25) 25 CAI(20 women and five men, 22.01 ± 1.08 years old, 164.59 ± 7.34 cm, and 60.30 ± 6.65 kg) -25 healthy students (21 women and four men, 22.90 ± 1.61 years old, 167.34 ± 8.15 cm, and 61.54 ± 6.78 kg)	-History of 90 min of aerobic exercise -Having unilateral ankle sprain in dominant limb -History of at least one lateral ankle sprain that resulted in inflammatory symptoms associated with the interruption of ideal daily activities. -The most recent sprain must have occurred more than three months before testing (mean: 4 ± 8 months); - --Reporting at least two episodes of giving way within six months of enrollment (9 ± 1 episode) -FAAM SPORT<80% - FAAM daily<90%	-CAI -Control (healthy)	The participants were asked to initiate gait with maximum speed under two conditions; self-generated (when they felt ready after hearing an "all set" signal) and triggered (immediately upon hearing an acoustic signal) in three different directions: straight ahead (0◦), clockwise (30◦), and counter-clockwise (30◦).	Affected limb as an initial stance limb	-Postural phase time (S1and S2 phase time) -Peak of COP displacement in the medial-lateral and anterior posterior direction during S1and S2	-COP displacement during S1 and S2 was similar between the two groups -Rate of COP displacement during S1 and S2 was similar between the two groups -S1 and S2 phase duration was shorter in the CAI subjects than healthy controls	There was no data	There was no data	Poor
Yousefi et al.[9]	Cross-sectional	34(17) (n = 17, age: 24.31 ± 0.81 years old, height: 175.12 ± 4.28 cm, weight: 71.15 ± 7.21 kg, and BMI: 21.85 ± 1.78 kg/m2) --Healthy controls p (n = 17, age: 23.40 ± 1.70 years old, height: 176.32 ± 6.41 cm, weight: 72.25 ± 6.14 kg, and BMI: 22.33 ± 1.38 kg/m2)	-Having at least one unilateral ankle sprain that required protected weight-bearing or immobilization for at least three days between 12- and three months before testing -Having unilateral ankle sprain in dominant limb -Cumberland score <27 -FAAM in daily activity <90% -FAAM in sport <80%	-CAI -Control (healthy)	Participants were asked to stand barefoot on a force plate before initiating gait upon hearing an auditory cue	Affected leg as an initial swing limb	-Peak of COP displacement in the anterior-posterior and medial-lateral directions during S1and S2 -Soleus and Tibialis anterior muscles onset time during S1and S2	There was no data	-Peak of COP displacement was similar during S1and S2 between CAI subjects and healthy controls -APA phase time was shorter in the CAI subjects than healthy controls -Soleus onset activity was	There was no data	Fair

(Continues)

TABLE 3 (Continued)

study	Type of study	Participants (control)	Inclusion criteria	Group	Procedure	Limb(s)	Outcome measures	Results in CAI versus healthy control(affected limb as an initial stance limb)	Results in CAI versus health control (affected limb as an initial swing limb)	Results in affected versus non-affected limb in CAI group	Status quality
			--Dominant limb was affected limb(right)						sooner in CAI subjects than healthy controls -Tibialis anterior onset activity was similar between CAI subjects and healthy controls		
Ebrahimabadi et al.[7]	Case-control	44(22) -CAI:(Age, y 22.4_1.5, Height, cm 164.9_8.5, Weight, kg 59.7_9.07) -Healthy controls (Age, y 22.7_1.8 Height, cm 166.4_5.2 Weight, kg 66.4_8.6.	History of inflammation symptoms and, at least one significant ankle sprain - A history of ankle sprain at least three months before the test - History of recurrent ankle sprain and feeling giving way -Having unilateral ankle sprain in dominant limb (Right limb) -FAAM in daily activity <90% -FAAM in sport <80% -Dominant limb was the right limb and the affected limb	-CAI -Control (healthy)	-Participants stood on a force plate and initiated gait with maximal velocity under two conditions: i) planned (initiated gait after hearing the "all set" signal when subjects felt ready to walk) and ii) unplanned (initiated gait "as soon as possible" after hearing acoustic signal).	Both	-Duration of S1 -Peak of COP displacement during S1 -Rate of COP displacement during S1	-Medial-lateral COP displacement was shorter in S1 in CAI subjects than healthy controls -Posterior COP displacement was similar between CAI subjects and healthy controls during S1 -Rate of COP displacement in anterior-posterior direction during S3 was similar between CAI subjects and healthy controls	-Medial-lateral COP displacement was shorter during S1 in CAI subjects than healthy controls -Posterior COP displacement during S1 was similar between CAI subjects and healthy controls rate of anterior-posterior COP displacement during S3 was higher in CAI subjects	Medial-Lateral COP shift was shorter during S1 when GI was with the non-affected leg as an initial swing limb -Posterior COP displacement in APA phase was similar between two legs in CAI subjects -Rate of anterior-posterior COP displacement during S3 was higher in CAI subjects when GI was with the affected	High

TABLE 3 (Continued)

study	Type of study	Participants (control)	Inclusion criteria	Group	Procedure	Limb(s)	Outcome measures	Results in CAI versus healthy control(affected limb as an initial stance limb)	Results in CAI versus health control (affected limb as an initial swing limb)	Results in affected versus non-affected limb in CAI group	Status quality
									than healthy controls	leg as an initial swing limb	
Ebrahimabadi et al.[8]	Cross-sectional	40(20)--CAI(aged 21.4 ± 1.3 years, with the average height of 164.5 ± 6.2 cm and weight of 61.8 ± 9.57 kg) -Healthy controls (aged between 21.7 ± 1.5 years, with the average height of 166.5 ± 5.5 cm and weight of 64.2 ± 8.6 kg)	-Doing aerobic exercises in at least three sessions per week for 90 min -All participants were dominant side injured limb (right side); -having unilateral ankle sprain at least 1 year before the test, a minimum of 1 day break from activities after the first ankle sprain, recurrent sprain at least 3 months before the test -A minimum of two episodes of giving way within the 6 months before the test -FAAM daily activity<90% -FAAM sport activity <80%	-CAI -Control (healthy)	Participants stood barefoot on the force plate and initiated gait in forward, 30_ lateral, and 30_ medial directions.	Both	-Peak posterior-lateral displacement of COP during S 1 -Rate of Posterior-lateral COP displacement during S 1	-Lateral COP displacement during S1 was shorter in CAI subjects than healthy controls -Rate of Lateral COP displacement in S1 was similar between CAI subjects and healthy controls	-Lateral COP displacement during S1 was shorter in CAI subjects than healthy controls -Rate of Lateral COP displacement during S1 was similar between CAI subjects and healthy controls	-Lateral COP displacement during S1was shorter in individuals with CAI when GI was with the affected leg as an initial swing limb -Rate of lateral COP displacement during S1 was similar in individuals with CAI whether the gait was initiated with the affected leg or non-affected leg.	Poor
Hass et al.[6]	single-session, mixed-model design	40(20) -CAI ((5 males, 15 females; age, 20.5 6 1.0 years; height, 169.8 6 9.8 cm; weight, 74.2 6 20.2 kg) - Healthy ((4 males, 16 females; age, 20.85 6 1.6 years; height, 164.3 6 7.9 cm;	-Operationally defined as performing three aerobic exercise sessions per week for a total of 90 min. -History of at least one unilateral lateral ankle sprain that required immobilization for at least three days (11.5 ± 6 9.2 days)	-CAI -Control (healthy)	Participants began each trial by standing quietly with a foot on each of the two adjacent force platforms in a relaxed position and completed five gait initiation trials for each leg at a self-selected pace	both	-Peak of normalized COP displacement in the Medial-lateral and anterior-Posterior and resultant direction	- Displacement of COP in the posterior-lateral direction and the resultant plane during S1 was shorter in CAI subjects than healthy controls -Medial-lateral displacement of COP during S1 was similar between CAI subjects and healthy controls	There was no significant difference between CAI and healthy controls subjects in all variables -	-Displacement of COP in the resultant plane during S1 was shorter in CAI subjects when GI was with an non-affected limb as an initial swing limb -Medial-Lateral	Fair

(Continues)

TABLE 3 (Continued)

study	Type of study	Participants (control)	Inclusion criteria	Group	Procedure	Limb(s)	Outcome measures	Results in CAI versus healthy control(affected limb as an initial stance limb)	Results in CAI versus health control (affected limb as an initial swing limb)	Results in affected versus non-affected limb in CAI group	Status quality
		weight, 64.2 6 10.62 kg)	-At least 1 episode of giving way within the past year (8.5 6± 6.7 episodes) -At least one recurrent ankle sprain between 3 and 6 months before study participation (2.9 6 ± 1.8 recurrent sprains) -Report of pain, instability, and weakness in the affected ankle -Attribution of these signs to the initial ankle injury -Failure to resume all pre-injury levels of Activities -No previous ankle fracture -No previous head and acute lower extremity injury within the past 3 months -No formal rehabilitation of the affected ankle -It is not clear whether the dominant limb is an affected limb or not				-Mean of normalized rate of anterior-posterior and medial-lateral COP displacement	-Medial-lateral-displacement of COP during S2 was shorter in CAI subjects than healthy controls -Medial-lateral displacement of COP during S3 was shorter in the CAI subjects when GI was with the affected leg as the initial swing limb -Rate of medial-lateral COP displacement during S3 was slower in CAI subjects than healthy controls when GI was with the non-affected leg as an initial swing limb		displacement of COP during S1 was similar between affected and non-affected limbs of CAI subjects -Medial-Lateral displacement of COP during S2 was shorter in CAI subjects when GI was with the non-affected limb as an initial swing limb -Medial-lateral displacement of COP during S3 was greater when GI was with the non-affected leg as an initial swing limb -	

Abbreviations: CAI, chronic ankle instability; COP, Center of pressure; FAAM, Foot And Ankle Ability Measure; GI, gait initiation; S1, Phase 1 of gait initiation; S2, Phase 2 of gait initiation; S3, Phase 3 of gait initiation.

non-affected leg.[10] Additionally, the findings of three included studies (Quality: poor, fair, and high) indicated that the peak of COP displacement in the lateral direction during phase 1 of GI in individuals with CAI was shorter than in healthy controls, when the GI was with the affected leg,[7,8] or non-affected leg.[6–8] However, two studies by Yousefi et al. and Ebrahimabadi et al. (Quality: poor and fair) reported that there was no significant difference in the peak of COP displacement during the combination of phases 1 and 2 of GI among individuals with CAI and healthy controls.[9,10] Finally, due to the lack of homogeneity in the results of included studies, the present review was unable to conduct a meta-analysis. Therefore, the conclusion regarding the necessary studies is based on the quality of the studies. As there is only one study of high quality, reaching a conclusion is challenging.

From five studies, two studies by Ebrahimabadi et al.[7,8] reported findings that contradicted those of Yousefi et al. and Ebrahimabadi et al.[9,10] The discrepancy in these results may be due to differences in the methods of COP data processing and normalization. In their studies, Ebrahimabadi et al. defined phase 1 as the end of the preparatory phase [12,13] and separated it from other phases.[7,8] However, Yousefi et al. and Ebrahimabadi et al. (2023) considered phases 1 and 2 as the preparatory phase (10, 25–28) and evaluated them in combination.[9,10] Additionally, participants in the studies of Ebrahimabadi et al. adopted a self-selected stance in the first trial of GI and then fixed it by trial-to-trial without normalizing COP data to stance width and foot length.[7,8] In contrast, participants in studies by Yousefi et al. and Ebrahimabadi et al. maintained a self-selected stance in all trials and normalized COP data to stance width and foot length.[9,10] Honeine et al. suggested that a fixed stance width for all individuals could lead to different COP displacements during GI due to biomechanical differences between individuals.[24] Hass et al. reported differences in COP displacement patterns between individuals with CAI and healthy controls during different phases of GI.[6] The findings of the study by Hass et al. align with those of studies conducted by Ebrahimabadi et al. when GI was with the non-affected leg but not when GI was with the affected leg.[7,8] The discrepancy in these results can be attributed to the use of two force plates by Hass et al., resulting in a wider stance width and normalized COP data. It was noted that a larger stance width before GI could impact COP displacement, with different stance widths affecting lateral COP displacement.[25] The findings of Hass et al. contrast with those of Ebrahimabadi et al.[10] due to differences in the injured limb dominance among participants.[6] The participants in the study by Ebrahimabadi et al. had a right dominant limb and a right injured limb. In contrast, the affected and dominant legs were not the same in the study by Hass et al. It was reported that when assessing the lower limbs, leg dominance should be taken into consideration.[26] All participants in the reviewed studies had a history of at least one unilateral ankle sprain, with recent giving way occurring three to twelve months before testing. The presence of residual pain and instability post-injury could impact GI performance.[27] Therefore, there was consistency in the participation of the study participants, which may not have influenced the outcome.

The findings of the included studies indicated that individuals with CAI modulate the phase 1 of GI, which is observed regardless of whether GI is performed with the affected[7,8] or non-affected leg.[6–8] In agreement with our results, previous studies have shown that individuals with posttraumatic ankle osteoarthritis exhibit a reduced peak COP displacement in a posterior-lateral direction during phase 1, irrespective of the involved stepping leg.[28] Additionally, individuals with CAI reduce postural sway in the preparatory phase when transitioning to a single-leg position.[29] It appears that individuals with CAI alter phase 1 in response to internal perturbations caused by leg raising.[29,30]

The included studies revealed that the alteration during phase 1 is bilateral.[7,8] Consistent with these findings, it has been reported that individuals with CAI demonstrate altered muscular patterns not only around the affected ankle but also around other joints.[5] On the other hand, unilateral constraint in the ankle of the affected side forces the central nervous system (CNS) to issue specific commands to stabilize the non-affected side.[31] This problem is thought to be due to changes in the brain of individuals with CAI[6]; the postural demands of individuals with CAI compel the CNS to send postural commands to both sides to maintain optimal dynamic stability.[32]

One of the included studies reported that soleus muscle inhibition was reduced before phase 1 of GI in individuals with CAI when GI was with the affected leg.[9] The soleus muscle must be inhibited before phase 1 to allow for the posterior displacement of the COP to control posture.[11] It was reported that there is a time relationship between soleus inhibition and tibialis anterior activation, represented as a motor program that the supra-spinal aspect uses to control GI.[33] Therefore, it seems that the absence or reduced soleus muscle inhibition could be a consequence of supra-spinal motor program alterations.

Based on the results of the included studies, individuals with CAI spent less time during phases 1 and 2, whether GI was with the affected or non-affected leg.[9,10] It was shown that after the first ankle sprain, supra-spinal neuromuscular control changed in such a way that the patients used compensatory motor patterns such as alterations of COP velocity and time to stability[34] to decrease their postural demands and reduce internal disturbance.[29,30]

The findings of the three included studies did not lead to a comprehensive conclusion about the difference in the peak of COP displacement between the two legs in individuals with CAI. The results of two studies by Ebrahimabadi et al.[7,8] (Quality: poor and high) confirmed that GI with the affected leg resulted in a shorter peak of COP displacement in the ML direction,[7,8] while one study (Quality: fair) reported that GI only with the non-affected leg resulted in a shorter COP displacement in the resultant plane and ML direction during phases 1 and 2, respectively.[6] It is worth noting that, because there are two studies (Quality: high and poor) that oppose the one study (Quality: fair), and due to the small number of articles in this field, it is impossible to reach a general conclusion about the peak of COP displacement during GI, between the affected and non-affected legs in individuals with CAI.

Due to inadequate investigations, the current review didn't make conclusions regarding the other parameters, such as the rate of COP displacement in ML and AP directions during phases 1, 2, and 3 of GI. In general, the present review's findings represented that the rate of COP displacement during phase 3 was slower in the ML direction when GI was with the non-affected leg as the initial swing limb[6] and higher in the AP direction when GI was with the affected leg as the initial swing limb in individuals with CAI compared to healthy controls.[7] These studies[6–8] reported that there was no heterogeneity in gait velocity among the participants, which had no impact on the velocity of COP displacement. It was also revealed that individuals with CAI adopt a higher COP velocity in the ML and AP directions,[35] and it takes a longer time for COP to be stabilized in the ML direction during single-leg standing than healthy controls.[34] Additionally, it was found that individuals with CAI cannot control the ML direction of COP displacement and spend more time implementing it while standing on the affected limb.

Finally, it was previously reported that phase 1 is controlled by the secondary motor area in the cerebral cortex.[32] The CNS is responsible for coordinating activities such as lateral weight shift and walking during phase 1 to achieve the desired movement while maintaining stability.[32,36–40] This review suggests that future studies should investigate how changes in the CNS correspond to GI changes in individuals with CAI. CNS probably changes due to CAI may impact COP differences during GI in individuals with CAI compared to healthy controls, regardless of whether gait is with the affected or unaffected leg. This review proposes that healthcare professionals focus on both the affected and non-affected legs when treating individuals with CAI. Perhaps individuals with CAI eventually apply force to the non-affected leg to lessen the postural stress on the affected leg.

5 | LIMITATIONS

Due to the limited number of studies in this area and conflicting results, more research is needed to explore GI alterations in individuals with CAI. Individuals with CAI in the studies did not meet the International Ankle Consortium's minimum selection criteria for diagnosing CAI, although all studies used similar criteria for individuals with CAI. Another limitation was the variation in processing methods; in other words, two studies identified the heel off time (end of phase 1) as the end of the preparatory phase, while three studies considered the foot off (end of phase 2) as the end of the preparatory phase of GI. Another limitation was the lack of full text records identified from the scientific databases.

6 | CONCLUSION

The results of the present review revealed that individuals with CAI had a shorter peak of COP displacement in the ML direction during phase 1, spending less time during phases 1 and 2, whether the GI was with the affected or non-affected leg. It seems that people with CAI adopted an alternative postural control strategy, such as altering COP displacement to control internal sway during the single leg position.[29,30] Additionally, since phase 1 is controlled by the secondary motor area in the brain,[32] individuals with CAI may have difficulty in GI phases that require movement planning. Future studies examining brain activity can help confirm or reject this finding.

AUTHOR CONTRIBUTIONS

Marzieh Mortezanejad: Conceptualization; investigation; writing—original draft. **Aliyeh Daryabor**: Investigation; writing—original draft; writing—review and editing. **Zahra Ebrahimabadi**: Conceptualization; writing—review and editing; writing—original draft. **Abbas Rahimi**: Writing—review and editing. **Mohammad Yousefi**: Writing—review and editing. **Fatemeh Ehsani**: Writing—review and editing. **Ali Maleki**: Writing—review and editing.

ACKNOWLEDGMENTS

We appreciate from all participants of the mentioned studies.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data is not publicly available due to privacy or ethical restrictions. The authors confirm that the data supporting the findings of this study are available from the corresponding author and research data will be sent if required Datasets generated and analyzed during the current study. Zahra Ebrahimabadi had full access to all of the data in this study and takes complete responsibility for the integrity of the data and the accuracy of the data analysis. All authors have read and approved the final version of the manuscript. Zahra Ebrahimabadi has full access to all of the data in this study and takes complete responsibility for the integrity of the data and the accuracy of the data analysis.

TRANSPARENCY STATEMENT

The lead author Zahra Ebrahimabadi affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Mortezanejad M, Daryabor A, Ebrahimabadi Z, et al. Kinetic changes of gait initiation in individuals with chronic ankle instability: a systematic review. *Health Sci Rep*. 2024;7:e70143. doi:10.1002/hsr2.70143