Iran Red Crescent Med J. 2017 March; 19(3):e44534. doi: 10.5812/ircmj.44534.

Research Article

The Alteration of Neuromuscular Control Strategies During Gait Initiation in Individuals with Chronic Ankle Instability

Zahra Ebrahimabadi,[1] Sedigheh Sadat Naimi,[2,*] Abbas Rahimi,[2] Heydar Sadeghi,[3] Seyed Majid Hosseini,[2] Alireza Akbarzadeh Baghban,[4] and Syed Asadullah Arsalan[5]

[1]PhD Student of Physiotherapy, Department of Physiotherapy, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[2]Physiotherapy Research Centre, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[3]Department of Kinesiology, School of Physical Education, Kharazmi University, Tehran, Iran
[4]Physiotherapy Research Centre, Department of Basic Sciences, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[5]PhD student of Physiotherapy, Department of Physiotherapy, School of Rehabilitation, TUMS, Tehran, Iran

[*]*Corresponding author*: Sedigheh Sadat Naimi, Physiotherapy Research Centre, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran, Iran. Tel: +98-2177561411, Fax: +98-2177561406, E-mail: naimi.se@gmail.com

Received 2016 December 08; **Revised** 2017 January 26; **Accepted** 2017 February 15.

Abstract

Background: Providing a clear picture of neuromuscular control mechanisms and deficits in patients with chronic ankle instability (CAI) requires further investigation. Gait initiation (GI) is a perfect task to evaluate concurrent open-loop (planned GI) and closed-loop (unplanned GI) neuromuscular control mechanisms in patients with CAI.
Objectives: The current study aimed at evaluating neuromuscular control mechanisms via assessment of the center of pressure (COP) displacements during planned and unplanned GI in patients with CAI and healthy individuals.
Methods: It was a case-control study. Twenty-two subjects with unilateral CAI and 22 healthy subjects stood on a force plate and initiated gait with maximal velocity under 2 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). The COP parameters were assessed during the preparatory and the execution phase of GI.
Results: The peak COP displacement toward swing leg decreased significantly, with P value = 0.003, in the preparatory phase of GI under planned and unplanned conditions in patients with CAI (0.028 ± 0.002) in comparison with the control group (0.038 ± 0.002). Forward velocity of the COP displacement increased in CAI patients (0.026 ± 0.003) compared with the control group (0.018 ± 0.002) in the execution phase of GI, with P value = 0.039.
Conclusions: According to the findings of the current study, both open-loop and closed-loop neuromuscular control mechanisms altered in patients with CAI.

Keywords: Ankle Injury, Postural Balance, Kinetic, Gait

1. Background

Chronic ankle instability (CAI) is characterized with lateral ankle sprain followed by residual symptoms such as pain, weakness, recurrent ankle sprain, feelings of instability, and episodes of giving way in ankle joint (1-4). Unfortunately, approximately 47% to 73% of patients experience recurrent sprains after initial injury (5). Due to the intervention of a large number of intrinsic (ie, posture) and extrinsic (ie, mechanism of sprain) parameters, an exact explanation of the neurophysiological mechanisms of ankle instability is not provided yet (6, 7). Therefore, the pathology of the CAI requires further investigation and research.

According to the theories and findings of former researches, patients with CAI probably have open-loop and/or closed-loop neuromuscular control mechanism alteration (8, 9). Former conducted studies showed that alteration during gait initiation (GI) and landing followed ankle instability, which further supported central alteration or open-loop neuromuscular control alteration in patients with CAI (10, 11). On the other hand, previous studies suggested proprioceptive deficits (12) and peroneal muscles reaction time delay in response to unexpected perturbation, which showed deficit in closed-loop neuromuscular control, in patients with CAI (13); however, some contradictory studies showed no difference in peroneal muscles reaction time between patients with ankle instability and healthy individuals (14, 15). Gutierrez et al., (9) suggested that closed-loop control may have no important role in maintaining the stability of ankle during perturbation (9). Although most studies assess closed-loop control in static situation, it seems that testing in static situation could not function as a valid proof to assess closed-loop control in patients with CAI; therefore, more dynamic tests are required to evaluate the deficit in closed-loop neuromuscular control in patients with CAI. Investigating the neuromuscular mechanisms during the same dynamic task can be beneficial to determine whether open-loop or closed-loop neuromuscular mechanisms alterations were attributed in ankle instability. Previous studies showed that ankle sprain happened during sport activities and daily activities (16). In this regard, recent literatures insist on the use of GI instead of high intrinsic variability tasks such as running and jumping to assess subjects (17-19).

GI was explained as a transient process from stable static posture to continuous gait (20, 21), whereby a significant change occurs in the center of pressure (COP) and the center of mass (COM) move (22). GI cycle includes preparatory and execution phases (10, 23, 24). The COP moves posterolaterally toward the initial swing leg during the preparatory phase, which is defined as an anticipatory postural adjustment (APA) (21-25). Whole body COM moves toward the stance leg during the execution phase (10, 23, 24). Previous studies found a functional model to assess open-loop and closed-loop neuromuscular mechanism during planned and unplanned GI (24). Despite the huge number of researches and studies on neuromuscular mechanism of CAI, no study investigated open-loop and closed-loop neuromuscular control during the GI.

2. Objectives

The current case-control study aimed at evaluating open-loop and closed-loop neuromuscular control strategies in 2 phases (preparatory and execution) of GI via assessment of the COP displacements during planned and unplanned GI in patients with CAI and healthy subjects.

3. Methods

3.1. Participants

In the current case-control, analytical study, all participants signed a consent form before data collection and the study protocol was also approved by the research ethical and approval committee of Shahid Behesti University of Medical Sciences (code: 016/178, date: May 2014). Ethical requirements of the study were performed according to the world medical association (WMA) declaration of Helsinki (2008).

Necessary data were collected in biomechanics laboratory in rehabilitation faculty, Shahid Beheshti University of Medical Sciences, Tehran, Iran, from June 2014 to July 2016. Statistical population included physical education and sports sciences students of Tehran, Shariati, Shahid Beheshti and Payame Noor universities. Convenience sampling method was used to select patients with CAI and healthy individuals. Twenty-two female patients with unilateral CAI, who qualified according to the inclusion criteria, were selected. Inclusion criteria for the patients with CAI was delineated according to the selection criteria for patients with chronic ankle instability in controlled research (international ankle consortium 2010) (26) and included: (a) history of inflammation symptoms and, at least, 1 significant ankle sprain; (b) history of ankle sprain at least 3 months before the test; (c) History of recurrent ankle sprain and / or feeling giving way and /or feeling instability in ankle joint; and (d) acquiring a score < 90% in daily living activities and < 80% in sport activities from foot and ankle ability measure (FAAM) questionnaire (27). Patients with history of surgeries, acute musculoskeletal injuries and fractures in both lower limbs were excluded from the current study (19). Also, 22 healthy female students were randomly selected. Participants with neurological and lower extremity disorders were excluded from the current study (Figure 1) (26). According to Wikstrom (8), selecting patients with CAI did not need any physical exam or diagnostic imaging, because CAI is specified as repeated ankle sprain and/or feeling episodic giving way with or without laxity of ligament.

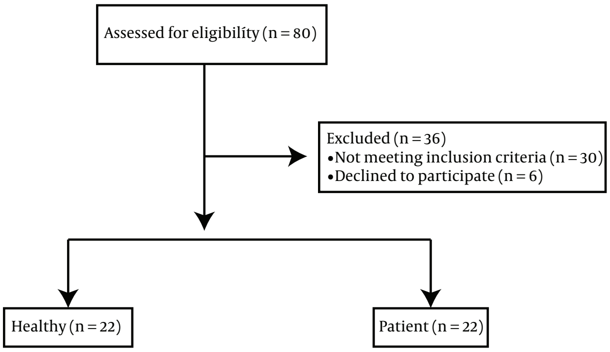

Figure 1. Flow Chart of the Study

Sample size was calculated based on the pilot study, 10 participants in each group, with the following formula (Equation 1). Assuming a type 1 error (α) = 0.005 ($Z_{1\text{-}\alpha/2}$ = 1.96) and type 2 error (β) = 0.2 ($Z_{1\text{-}\beta}$ = 0.84), and the power of test = 0.8; sample size turned out to be 22 participants in each group.

$$N = \frac{\left(S_1^2 + S_2^2\right)\left(Z_{\frac{1-\alpha}{2}}\right)^2}{\left(\overline{x}_1 - \overline{x}_2\right)^2} \tag{1}$$

3.2. Procedure

A force plate was used to collect all data. The force plate was calibrated before the initiation of each section. Also, between each trial, the system was calibrated to zero to show no weight. Ground reaction forces (GRFs) were calculated at a frequency of 1000 Hz by a force plate (Bertec Corporation, Columbus, and U.S.A).

In each trial, the subjects stood barefoot in a relaxed position on a force plate and initiated gait, while looking at a sign in front of them until they reached the end of track. Subjects were asked to distribute their weight equally on both feet. The placement of feet was marked for other trials.

During planned GI, the subjects initiated gait with maximal velocity after hearing the “all set” signal and had enough time to prepare for movement. However, the subjects initiated gait with maximal velocity, immediately after hearing an acoustic signal during unplanned GI (24).

One observer collected all data. The test sequences were randomly selected and a 10-minute break was given between the 2 conditions. Since patients with CAI had unilateral injury, each subject performed 5 trials with right leg and 5 trials with left leg.

3.3. Data Processing

At first, a 2nd-order, zero-lag Butterworth low-pass filter was used to decrease the effect of noise, by cutting off frequency to 25 Hz, in the force plate data. The peak displacement (Equation 2) and velocity (Equation 3) of COP during the 2 phases of GI were calculated (28). The GI was divided into 2 phases: Preparatory phase and execution phase. Preparatory phase was the time between t0 and the swing heel-off, and execution phase was the time between the swing heel-off and the stance toe-off. All calculations were done with the customized program written in MATLAB (MathWorks Inc., R2013a) (Figure 2).

The following instants were calculated to separate the 2 phases of GI:

t0: calculated by “threshold” method when anteroposterior force exceeded the baseline (mean ± 3SD) during the first 200 meters of each trial (24, 29). Visual revision with computer-based algorithm was used to find t0 from changes in COP signal (16).

Heel-off: calculated by integrating vertical GRF (Iz), after weight correction, when Iz peaked downwards before the last downward peak (Equation 2) (29).

Toa-off: precisely detected when the stance foot leaves the force plate; ie, when the vertical force drops below 5 Newtons (30, 31).

3.4. Statistical aAnalysis

Independent t test was employed to check group demographics between the patients with CAI and the control group (Table 1). Multifactorial 2 (CAI and healthy groups) × 2 (planned and unplanned conditions) × 2 (right and left legs) repeated measure ANOVA were used. Each test comprised of 2 within-subject (conditions and leg) and 1 between-subject (group) factors. Repeated measurement assumption was checked. When the sphericity assumption was rejected, the Greenhouse-Geisser test was applied. Pair wise comparisons were performed between the dominant leg of the control group or the unstable ankle leg (right leg) of the CAI group and the non-dominant leg of the control group or the healthy leg of the CAI group (left leg) (10). The Kolmogorov-Smirnov test showed normality of data exception for mediolateral COP velocity during preparatory phase of planned gait initiation and anteroposterior COP velocity during execution phase of planned gait initiation. The Mann-Whitney test was used to compare nonparametric variables between the groups. P-values less than 0.05 were used on all statistical tests.

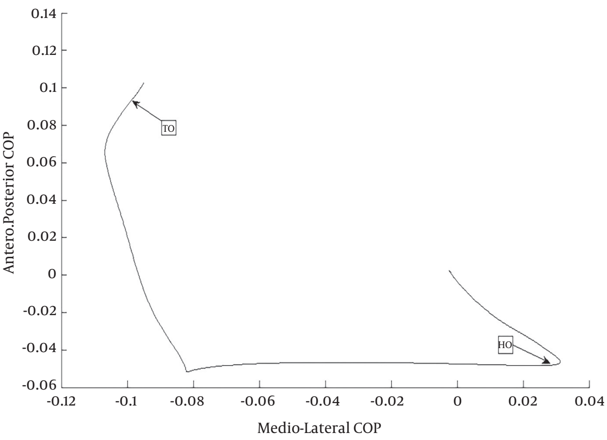

Figure 2. Center of Pressure Trajectories (m) During Gait Initiation Cycle; HO: Swing Heel-Off Time; TO: Stance Toe-Off Time

4. Results

There were no significant differences between the 2 groups in demographic data ($P > 0.05$) (Table 1). During the preparatory phase, the COP moved posterolaterally toward the initial swing leg. Then, during the execution phase, the COP moved toward the stance leg and, finally, the COP shifted forward in both groups of the study (Figure 2). As expected, duration of GI was longer in planned GI in comparison with unplanned GI ($P < 0.001$).

4.1. Preparatory Phase

Main significant effects in group ($F_{1, 42} = 4.52$, $P = 0.003$), conditions ($F_{1, 42} = 78.49$, $P < 0.001$), and leg ($F_{1, 42} = 13.51$, $P = 0.001$) were detected for the peak lateral COP displacement

$$PeakCOPx = max\left(COPx\right), PeackCOPy = max\left(COPy\right) \tag{2}$$

$$V_{COP_x} = \frac{\left(COP_{x_{i+1}} - COP_{x_i}\right)}{t_{i+1} - t_i}, PeakV_{COP_x} = Max\left(V_{Cop_x}\right), V_{COP_y} = \frac{\left(COP_{y_{i+1}} - COP_{y_i}\right)}{t_{i+1} - t_i}, PeakV_{COP_y} = Max\left(V_{COP_y}\right) \tag{3}$$

Table 1. Demographic Variables in the Study Groups

Demographic Variables	Case	Control	P Value
University			0.572[a]
Tehran	4	5	
Shariati	7	8	
Shahid Beheshti	6	4	
Payame Noor	5	5	
Age, y	22.4 ± 1.5	22.7 ± 1.8	0.592[b]
Height, cm	164.9 ± 8.5	166.4 ± 5.2	0.488[b]
Weight, kg	59.7 ± 9.07	66.4 ± 8.6	0.180[b]

[a] Chi-square test.
[b] Independent t test.

toward the swing foot. As illustrated in Figure 3, the peak lateral COP displacement was shorter in patients with CAI, compared to the healthy individuals, under both planned (P = 0.046) and unplanned (P = 0.035) conditions. Peak lateral displacements of the COP were longer in unplanned GI than in planned GI in CAI (P < 0.001) and control (P = 0.022) groups. Also, peak lateral displacements of the COP were longer when subjects initiated gait with left leg under unplanned condition in CAI (P < 0.001) and control (P = 0.012) groups (Table 2).

ML DIS (P = 0.001) in CAI group, ML DIS (P = 0.012) in healthy group, AP Dis (P = 0.03) in healthy group.

Although there was no significant difference ($F_{1, 41}$ = 0.14, P = 0.719) regarding the peak posterior COP displacement toward the swing foot, a significant difference effect in conditions ($F_{1, 41}$ = 60.35, P < 0.001) was detected for the peak posterior COP displacement. Peak posterior displacements of the COP were longer in unplanned GI than in planned GI in both groups (Table 2).

Repeated measure ANOVA exhibited significant interactions only between the conditions and leg for posterior (P = 0.01) and lateral (P < 0.001) peak displacement and velocity (P = 0.031) of the COP. As illustrated in Table 1, the peak lateral COP displacement decreased during unplanned GI (P < 0.001) and increased during planned GI (P = 0.155), when the subjects initiated gait with right leg.

According to the Mann-Whitney test, there was no significant difference in mediolateral COP velocity during preparatory phase of planned GI with right leg (P = 0.228) and left leg (P = 0.564) between the 2 groups of control and patients with CAI (P = 0.228) (Table 2).

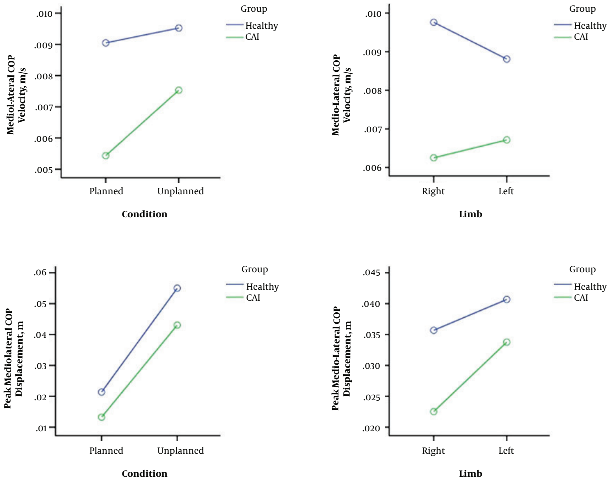

Figure 3. Center of Pressure Parameters in Mediolateral Direction During Preparatory Phase of Gait Initiation; Right Indicates Initiated Gait with Right Limb; Left Indicates Initiated Gait with Left Limb

4.2. Execution Phase

No significant difference was observed in peak displacements of the COP during planned or unplanned GI in any of the groups. ANOVA repeated measures showed significant increase of the peak COP displacement toward the stance leg (P < 0.001), and forward direction (P < 0.001) in unplanned GI in comparison to planned GI in both groups (Table 3).

The main significant group effect was observed in forward velocity of the COP displacement ($F_{1, 39}$ = 4.55, P = 0.039). Forward velocity of the COP displacement was higher in CAI group only in planned GI ($F_{1, 39}$ = 5.91, P = 0.02) (Table 3).

According to the Mann-Whitney test, there was significant difference in anteroposterior COP velocity during execution phase of planned GI with left leg (P = 0.037) between the 2 groups (Table 3).

Table 2. The Center of Pressure Parameters During the Preparatory Phase of Gait Initiation[a]

Groups	Planned GI		Unplanned GI	
	R. Leg	**L. Leg**	**R. Leg**	**L. Leg**
Chronic ankle instability				
ML Dis[b,c]	0.015 ± 0.004	0.012 ± 0.003	0.030 ± 0.005[d]	0.056 ± 0.006[d]
AP Dis[b]	0.032 ± 0.007	0.021 ± 0.003	0.053 ± 0.007	0.058 ± 0.006
ML V	0.006 ± 0.003[e]	0.005 ± 0.002[e]	0.007 ± 0.001	0.008 ± 0.001
AP V	0.015 ± 0.003	0.012 ± 0.002	0.011 ± 0.002	0.014 ± 0.002
Healthy				
ML Dis[b,c]	0.028 ± 0.004	0.015 ± 0.003	0.044 ± 0.005[d]	0.066 ± 0.006[d]
AP Dis[b]	0.025 ± 0.006	0.020 ± 0.003	0.055 ± 0.007[d]	0.071 ± 0.005[d]
ML V	0.012 ± 0.003[e]	0.006 ± 0.002[e]	0.008 ± 0.001	0.011 ± .002
AP V	0.013 ± 0.004	0.008 ± 0.002	0.010 ± 0.002[d]	0.019 ± 0.004[d]

Abbreviations: AP, Anteroposterior; Dis, Displacement (m); GI, Gait Initiation; L. Leg, Healthy or Non-Dominant Leg; ML, Mediolateral; R. Leg, Unstable Ankle or Dominant Leg; V: Velocity (m/s).

[a] Data were expressed as mean ± SD.

[b] Indicates differences between conditions (ML: 95%CI: 0.024 - 0.04, and AP: CI 95%: 0.026 - 0.044 ($P < 0.001$).

[c] Indicates differences between groups (95%CI: 0.004 - 0.016)) ($P = 0.003$).

[d] Indicates Differences between Legs (95%CI: 0.001 - 0.015) ($P < 0.05$).

[e] Median (interquartile range) was 0.01 (0.01) in right leg and 0.005 (0.1) in left leg in healthy group and median (interquartile range) was 0.01 (0.02) in right leg and 0.01 (0.01) in left leg in CAI group ($P = 0.564$).

Table 3. The Center of Pressure Parameters during the Execution Phase of Gait Initiation[a]

Groups	Planned GI		Unplanned GI	
	R. Leg	**L. Leg**	**R. Leg**	**L. Leg**
Chronic ankle instability				
ML Dis	0.029 ± 0.004[b]	0.024 ± 0.005[b]	0.055 ± 0.006[b]	0.051 ± 0.008[b]
AP Dis	0.035 ± 0.006[b]	0.026 ± 0.004[b]	0.062 ± 0.007[b]	0.053 ± 0.006[b]
ML V	0.034 ± 0.008[b]	0.010 ± 0.003	0.010 ± 0.002[b]	0.007 ± 0.001
AP V	0.060 ± 0.010[c,d]	0.017 ± 0.004[c,d,e]	0.017 ± 0.003	0.010 ± 0.002
Healthy				
ML Dis	0.013 ± 0.004[b]	0.016 ± 0.004[b]	0.055 ± 0.006[b]	0.042 ± 0.004[b]
AP Dis	0.027 ± 0.005[b]	0.022 ± 0.003[b]	0.070 ± 0.006[b]	0.064 ± 0.005[b]
ML V	0.017 ± 0.007	0.010 ± 0.003	0.012 ± 0.002	0.007 ± 0.001
AP V	0.031 ± 0.009[c,d]	0.013 ± 0.003[c,d,e]	0.017 ± 0.003	0.012 ± 0.002

Abbreviations: AP, Anteroposterior; Dis, Displacement (m); GI, Gait Initiation; L. Leg, Healthy or Non-Dominant Leg; ML, Mediolateral, R. Leg, Unstable Ankle or Dominant Leg; V, Velocity (m/s).

[a] Data were expressed as mean ± SD.

[b] Indicates differences between conditions (ML: 95%CI: 0.023-0.037 and AP: 95%CI: 0.027 - 0.043) ($P < 0.001$).

[c] Indicates differences between groups (95%CI: 0.015 - 0.001) ($P = 0.039$).

[d] Indicates differences between legs in planned condition (95%CI : 0.003 - 0.030) ($P = 0.02$).

[e] Median (interquartile range) = 0.01 (P-value =0.037).

Significant main effects ($P = 0.002$) of condition and leg in anteroposterior velocity of the COP are shown in Table 3.

5. Discussion

5.1. Preparatory Phase

The current study was conducted to focus on the COP displacements during planned and unplanned GI in patients with CAI. The findings of the study verified that the peak lateral shift of the COP during the preparatory phase of GI decreased in patients with CIA. The results of the peak lateral COP displacement in the current study were consistent with those of Hass et al. (10). The values of the studies could not be compared, because they normalized raw values to stance width. Similar to the previous studies, peak mediolateral displacement of the COP during the preparatory phase of GI predicted postural stability at the end of the 1st step (24). It seemed that the supra spinal control strategy aimed at decreasing the APA to maintain postural stability during forward locomotion (10). Therefore, it was concluded that APAs decreased in patients with CAI to maintain optimal forward locomotion through reducing internal perturbation.

Also, the results of the current study showed decreased APA in both planned and unplanned GI in patients with CAI in comparison to the control group. As stated by formerly conducted studies, planned and unplanned conditions were modulated by open-loop and closed-loop neuromuscular control (8). Results of previous researches showed sensorimotor dysfunction in patients with CAI (32), and this theory was the major caution of ankle instability, a theory recently challenged widely (20). Decreased peak mediolateral displacement of COP in patients with CAI during unplanned GI was controlled by closed-loop neuromuscular mechanism in the current study, because participants responded to the external cue (auditory cue) as soon as possible; it was consistent with the results of studies by Wikstrom et al. (8) and Yen et al. (16), which showed closed-loop neuromuscular deficits in patients with CAI during gait termination and gait. Therefore, closed-loop neuromuscular deficits may appear in patients with CAI.

The findings of the current study showed significant difference in the peak displacement of COP between the patients with CAI and control groups during planned GI. It seems that supra spinal motor control decreased anticipatory force in patients with CAI (10) to compensate movement organization. Results of the current study were consistent with those of Wikstrom that showed gait termination strategies differed during planned gait termination, and suggested open-loop neuromuscular control alteration in patients with CAI (8). Alteration in movement pattern during gait (16) showed supra spinal alteration in patients with CAI; therefore, it seems that open-loop neuromuscular alterations happen in patients with CAI during GI.

The results of the current study showed that peak posterior displacement of the COP had no specific alteration between the 2 groups, which was consistent with those of Hass et al. (10) that showed significant difference in peak COP displacement toward the swing leg in patients with CAI. Also, Hartley et al. (33) found some data (3.9 cm in CAI patients) similar to those of Hass et al. (3.8 cm) (10); however, there was a difference between the raw values in peak posterior displacement of the COP (3.2 cm with involved leg and 2.1 cm with uninvolved leg). Hertley showed that peak mediolateral COP displacement had good reliability and peak anteroposterior COP displacement had poor reliability in the preparatory phase (33); this difference of values in the current study might be due to poor reliability of the peak anteroposterior displacement of COP. Earlier researches showed that in older adults (34) and patients with neurological disorders (35), central nervous system (CNS) decreased posterior shift of the COP in the preparatory phase; the risk of falling was low in such people. Patients with CAI do not frequently experience falling; thus, changing the peak posterior COP displacement could not be observed in such patients.

The current study confirmed the results of previous researches (24, 36) and showed that peak posterolateral displacement of the COP was greater in unplanned GI as compared to planned GI in both groups. According to formerly conducted researches, the APA duration decreased under unplanned conditions in healthy people (24, 34). The current study results showed that the duration of GI decreased under unplanned condition. Therefore, it was suggested that unplanned GI increased peak displacement of the COP to produce higher propulsive force in less time to maintain postural stability and velocity of the COM at the end of GI (17, 24, 37). It seems that CNS could use different APAs to reduce postural disturbance (36) to adapt to different conditions, such as unplanned condition.

GI dynamic, as well, was affected by unilateral lower extremity pathologies (38). When the patients initiated gait with the unstable ankle leg, the peak lateral COP displacement decreased in the current study. Hass et al. (10) showed that the COP excursion decreased when the patients with CAI initiated gait with the healthy leg in self-selected position. In the study by Hass et al., participants initiated gait only under planned conditions; however, participants of the current study initiated gait under planned and unplanned conditions. Unplanned GI of the current study was compared to that of planned GI mode in the study by Hass et al., the reason for which could be challenged pre-programming motor control during GI. During unplanned GI, subjects generated specific tasks in less time; therefore, they did not have sufficient time to decrease postural demands of the unstable ankle leg.

5.2. Execution Phase

The findings of the current study were consistent with those of the previous studies which focused on COP shifts;

1st, toward the stance leg, and then forward, in the execution phase of GI (10, 24, 30). In the current study, forward velocity of the COP displacement increased in patients with CAI during planned GI. It seems that patients with CAI needed less time to reach the end of GI under planned conditions. In previous studies, patients with CAI showed postural instability (39, 40) and former literatures confirmed that after the 1st ankle sprain, closed-loop neuromuscular control changed in such a way that the patients used reparative motor pattern (8). Therefore, it is proposed that preprogramming motor control alterations in patients with CAI patients cause different motor performance during the execution phase of GI.

The peak COP displacement increased in unplanned GI compared to the planned GI in both groups during the execution phase, as was the case with preparatory phase. Although Yiou et al. (24) stated that duration of the execution phase did not change during unplanned GI; it seemed that increase in peak displacement of the COP during the execution phase was a strategy to adapt to APAs alteration during the preparatory phase to improve postural control during unplanned GI.

Further studies may investigate hip and ankle muscles activities to conduct more exploration on compensatory strategies after initial ankle injury during planned and unplanned GI.

The main limitation of the current study was the initial stance width marked on a force plate in the 1st trial, and then fixed it from trial to trial. Fixed stance width could cause biomechanical constraints on the COP displacements during other trials. Also, Honeine et al. (41) suggested that the fixed stance width in all participants could cause different COP displacements during GI because of biomechanical differences between the subjects. The stance width should be self-selected, and finally, data should be normalized to stance width in future studies.

The strengths of the current study were that patients acquired a score $< 90\%$ in daily living activities and $< 80\%$ in sport activities based on FAAM questionnaire. Also, all participants in the case and control groups were students of Physical Education and Sports Sciences. There was minor difference between the number of subjects in the universities (Table 1). All subjects were female and lived in the university dormitories. These criteria could provide minor variations in the current study. Based on the results of the current study, alteration in open-loop and closed-loop neuromuscular control emerged in patients with CAI during GI. Results of the current study can open new insight into rehabilitation programs to prevent recurrent ankle instability. It seems that neuromuscular control training can produce desirable APAs in patients with CAI.

Acknowledgments

Authors wish to offer their special thanks to Mr. Mohammad Yousefi, PhD student in Sports Biomechanics at the University of Kharazmi, for his collaboration in data analysis.

Footnotes

Authors' Contribution: Data collection, Zahra Ebrahimabadi and Seyed Majid Hosseini; data analysis, Abbas Rahimi and Alireza Akbarzadeh Baghban; study design, Heydar Sadeghi and Sedighe Sadate Naimi; writing the manuscript, Sedighe Sadate Naimi and Zahra Ebrahimabadi; editing the manuscript, Syed Asadullah Arsalan.

Funding/Support: There was no financial support for the current study.

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