

# The Postural Control Characteristics of Individuals with and without a History of Ankle Sprain during Single-leg Standing: Relationship between Center of Pressure and Acceleration of the Head and Foot Parameters

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**Abstract.** [Purpose] This study aimed to investigate the postural control characteristics of individuals with and without a history of ankle sprain during single-leg standing by examining the relationship between various parameters of center of pressure (COP) and head and foot acceleration. [Subjects] Twenty subjects with and 23 subjects without a history of ankle sprain (sprain and control groups, respectively) participated. [Methods] Mean and maximum COP velocity and maximum COP range in the anteroposterior and mediolateral components of movement were calculated using a gravicorder. The anteroposterior and mediolateral maximum accelerations of the head and foot, as well as the root mean square (RMS) of each acceleration parameter, were measured using accelerometers. [Results] In the mediolateral component, a significant positive correlation was found between maximum acceleration of the foot and all COP parameters in the sprain group. [Conclusion] Our findings suggest that mediolateral momentary motion of the foot in individuals with a history of ankle sprain has relevance to various parameters of COP.

**Key words:** Recurrent ankle sprain, Postural control assessment, Postural strategy

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## INTRODUCTION

An ankle sprain is the most common injury regardless of sex, age<sup>1)</sup>, and type of sport<sup>2)</sup>. If the normal recovery process does not occur after an ankle sprain, persistent symptoms such as feelings of “giving way” and “ankle joint instability” remain. These symptoms can lead to surgical management in severe cases and increase the risk of recurrent ankle sprains. In this regard, one of the main risk factors for recurrent ankle sprain is a deficit in static postural control, and a considerable number of studies have been conducted using instrumented force plate measures<sup>3–8)</sup>. However, no uniform consensus on the measurement of static postural control has been established<sup>9)</sup>, which may be due to the inadequacy of the sensitivity of traditional center of pressure (COP) postural control measurements<sup>7)</sup>. As highlighted by Tropp et al.<sup>4)</sup>, the force acting on a plate is the result of gravity and acceleration of body segments. Thus, the force plate measures gravity as well as the forces

generated by a person to maintain their center of gravity within the area of support. Therefore, even if the same COP is measured, the movements of each body segment may differ. We hypothesized that the absence of consensus on the measurement of static postural control may be the result of motion of body segments and used a gravicorder and head and foot accelerometry to assess the motion of various body segments with the aim of developing a new perspective on the relationship between ankle sprain and static postural control<sup>10)</sup>. Our results suggested that individuals with a history of ankle sprain have a lower foot-to-head acceleration ratio and different postural control characteristics than individuals without a history of ankle sprain, in spite of no significant differences between the groups with respect to path length of the COP. Thus, we believe that accelerometric measurement of the movements of each body segment affecting the COP will help enhance our understanding of postural control capacity and ankle sprain.

Several studies on ankle sprain and static postural control have reported various parameters of the COP, not only path length but also the velocity and range of the COP, in anteroposterior (AP) and mediolateral (ML) components. However, no uniform consensus on these parameters exists, because the parameters and directions of the COP that demonstrate significant differences between healthy and sprain groups have differed between studies<sup>3, 5, 7)</sup>. Further-

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more, even if a significant difference in COP velocity or COP range was found, studies considering the reasons for or factors underlying this significant difference are limited. Therefore, this study aimed to investigate the postural control characteristics of individuals with and without a history of ankle sprain during single-leg standing by examining the relationship between various parameters of the COP and head and foot acceleration.

## SUBJECTS AND METHODS

### Subjects

Twenty young adults with a history of ankle sprain (14 men, 6 women: age =  $22.7 \pm 3.4$  years, height =  $166.9 \pm 7.1$  cm, weight =  $58.8 \pm 8.9$  kg) and 23 young adults without a history of ankle sprain (18 men, 5 women: age =  $23.4 \pm 3.5$  years, height =  $167.3 \pm 6.3$  cm, weight =  $64.0 \pm 10.8$  kg) volunteered to participate. The inclusion criteria were similar to the criteria of Wikstrom et al.<sup>5)</sup> and were as follows: (a) score of 80 or less in the Karlsson scoring system<sup>6)</sup>, (b) history of at least one recurrent ankle sprain 3 to 6 months before study participation, and (c) a history of at least one unilateral ankle sprain that required non-weight-bearing exercises for at least 3 days. The Karlsson scoring system is based on eight different items (Pain, Swelling, Instability, Stiffness, Stair climbing, Running, Work activities, Support) according to the patient's own evaluation. The score correlates well with objective signs of ankle joint instability as measured by stress radiographs (anterior talar translation and talar tilt)<sup>6)</sup>. The subjects in the control group had a Karlsson score of 100 points, indicating no ankle joint instability, and the subjects in the sprain group had at least one item from (a) to (c). This study was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from each study participant, and the rights of all subjects were protected.

### Methods

The COP and acceleration of the head and foot during single-leg standing were measured. Subjects were instructed to stand as still as possible during testing, with the arms folded across their chests, while standing on one limb and holding the opposite limb with slight knee flexion<sup>11)</sup>. The supporting limb was the right and dominant limb (limb used to kick a ball) in all subjects in both groups. During single-leg standing, subjects were instructed to stand as still as possible while focusing on a visual target placed 2 m in front of them. The COP was measured using a gravicorder (Twin Gravicorder G-6100; Anima Corp., Tokyo, Japan) at a sampling frequency of 100 Hz. Accelerometers (triaxial accelerometer, MVP-RF8-AC; MicroStone Corp., Nagano, Japan; acceleration range,  $\pm 20$  m/s<sup>2</sup>; frequency range, 0–100 Hz; A/D resolution, 10 bit; size,  $45 \times 45 \times 18.5$  mm; wireless, real-time vision) were placed on the forehead and lateral malleolus of the involved (dominant) leg to measure acceleration of the head and foot, respectively. The AP and ML motion components were measured. The acceleration was measured using accelerometers at a sampling frequency of 100 Hz. Gravicorder and accelerometer data were col-

lected at the same time, and data collection was initiated after establishing stable single-leg standing. Each trial was 20 s in length and was repeated three times.

Acceleration data were stored in Excel through a Wireless Vibration Recorder (MVP-RF-S Ver. 1.0.8; MicroStone Corp., Nagano, Japan). Head and foot acceleration measurements were filtered by a high-pass filter with a cutoff frequency of 0.5 Hz to eliminate convergent gravity components around 0 Hz using vibration displacement analysis software (MVP-RF-S Ver. 1.0.8; MicroStone Corp., Nagano, Japan). The root mean square (RMS) values of the AP and ML components of acceleration were calculated, as were the maximum accelerations of the AP and ML components. The gravicorder data were calculated as the mean COP velocity, maximum COP velocity, and maximum COP range in the AP and ML directions.

A Mann-Whitney U test was used to compare each item between groups. Spearman's rank correlation coefficients were calculated between COP parameters and acceleration parameters in the AP and ML components, respectively. IBM SPSS Statistics Ver. 21 for Windows was used for statistical processing, and the significance level was set at  $p < 0.05$ .

## RESULTS

The results for the gravicorder and accelerometer data are shown in Tables 1–4. The gravicorder COP (Table 1) and acceleration (Table 2) values for the head and foot were similar between the two groups. A significant positive correlation was found between all COP parameters and AP acceleration in the control group (Table 3). Significant positive correlations were also observed between the RMS of head acceleration and mean COP velocity, RMS of head acceleration and maximum COP velocity, RMS of foot acceleration and maximum COP velocity, and maximum foot acceleration and mean COP velocity in the sprain group (Table 3). In examining the relationship between each COP parameter and ML acceleration, a significant positive correlation was found between all COP parameters and head acceleration in the control group (Table 4). RMS analysis also revealed a significant positive correlation between the maximum ML acceleration of the head and mean COP velocity in the control group (Table 4). No significant correlations were observed between COP parameters and ML acceleration of the head in the sprain group. However, the maximum ML acceleration of the foot was significantly positively correlated with all COP parameters (Table 4).

## DISCUSSION

This study aimed to validate the postural control characteristics of individuals with and without a history of ankle sprain during single leg standing by examining the correlations between various parameters of COP with head and foot acceleration.

In the current study, we observed COP parameters to be similar (mean COP velocity, maximum COP velocity, and maximum COP range in AP and ML components of motion) in individuals with a previous ankle sprain and healthy

**Table 1.** Center of pressure (COP) outcome measures

	Mean COP velocity (cm/s)		Max COP velocity (cm/s)		Max COP range (cm)	
	AP	ML	AP	ML	AP	ML
Control	1.8 ± 0.5	2.1 ± 0.5	8.4±2.2	10.6 ± 2.5	3.4 ± 0.8	2.4 ± 0.4
Sprain	1.9 ± 0.4	2.2 ± 0.4	10.0±3.5	11.2 ± 2.2	3.6 ± 0.8	2.5 ± 0.3

Mean ± SD (SD=standard deviation)

Max, maximum; AP, anteroposterior, ML, mediolateral

**Table 2.** Acceleration (m/s<sup>2</sup>) outcome measures

	Head				Foot			
	Ac RMS		Max Ac		Ac RMS		Max Ac	
	AP	ML	AP	ML	AP	ML	AP	ML
Control	0.07 ± 0.02	0.11 ± 0.05	0.25 ± 0.09	0.43 ± 0.19	0.19 ± 0.09	0.15 ± 0.05	0.99 ± 0.41	0.95 ± 0.32
Sprain	0.07 ± 0.01	0.13 ± 0.03	0.25 ± 0.05	0.47 ± 0.15	0.16 ± 0.05	0.14 ± 0.05	1.04 ± 0.38	0.94 ± 0.36

Mean ± SD (SD=standard deviation)

Ac RMS, acceleration root mean square; Max Ac, maximum acceleration; AP, anteroposterior; ML, mediolateral

**Table 3.** Correlations between COP and acceleration parameters (in anteroposterior motion components)

		Head		Foot	
		Ac RMS	Max Ac	Ac RMS	Max Ac
		Control	Mean COP velocity	0.810**	0.806**
	Max COP velocity	0.840**	0.818**	0.756**	0.742**
	Max COP range	0.552**	0.551**	0.324**	0.305**
Sprain	Mean COP velocity	0.473*	0.222	0.434	0.362*
	Max COP velocity	0.462*	0.223	0.487*	0.395
	Max COP range	0.248	0.025	0.255	0.219

\*\*p < 0.5. \*p < 0.01

Ac RMS, acceleration root mean square; Max Ac, maximum acceleration

**Table 4.** Correlations between COP and acceleration parameters (in mediolateral motion components)

		Head		Foot	
		Ac RMS	Max Ac	Ac RMS	Max Ac
		Control	Mean COP velocity	0.734**	0.672**
	Max COP velocity	0.621**	0.564**	0.378	0.387
	Max COP range	0.619**	0.550**	0.106	0.214
Sprain	Mean COP velocity	0.338	0.307	0.365	0.572**
	Max COP velocity	0.354	0.329	0.310	0.491*
	Max COP range	0.158	0.151	0.289	0.464*

\*\*p < 0.5. \*p < 0.01

Ac RMS, acceleration root mean square; Max Ac, maximum acceleration

controls. Previous studies have not established a uniform consensus on the measurement of static postural control<sup>9</sup>). Wikstrom et al.<sup>5</sup>) reported a significantly greater COP velocity for the AP and ML components among people with chronic ankle instability. However, they did not observe a significant difference in COP range between the groups. Vries et al.<sup>3</sup>) reported no significant difference in COP velocity or COP range. Knapp et al.<sup>7</sup>) reported a significantly greater COP range for the ML components in the closed eyes condition in people with chronic ankle instability.

However, this study did not assess factors underlying the relationship between ankle sprain and postural control, and the authors suggested that the lack of significant results may reflect the possibility that people with chronic ankle instability use a variety of compensatory mechanisms to maintain balance. They further suggested that the sensitivity of traditional COP postural control measurement is limited. We hypothesized that assessment of movement of each body segment can reveal this variety of compensatory mechanisms. Therefore, we further considered the relation-

ship between each COP parameter and the acceleration of the head and foot to seek novel factors related to COP.

The results of the current study regarding relationships between each COP parameter and acceleration of the head and foot were as follows: 1) a significant positive correlation was found between all COP parameters and head acceleration in the control group, 2) most AP COP parameters were significantly correlated with AP foot acceleration in the control group, and 3) most ML COP parameters were significantly correlated with ML foot acceleration in the sprain group. Significant positive correlations between COP parameters and head acceleration among controls were observed in both the AP and ML components. Instantaneous and average acceleration of the head may affect both AP and ML COP velocity and COP range. These findings suggest that movement of the head during the single-leg stance in the control group affected various COP parameters. By contrast, no significant correlation was found between many combinations of COP parameters and AP/ML head acceleration in the sprain group. These findings suggest that movement of the head during the single-leg stance in the sprain group had little direct effect on various COP parameters and that other segments affected COP parameters instead.

Foot acceleration was measured using an accelerometer placed on the lateral malleolus of the involved (dominant) leg. Therefore, movement of the lateral malleolus with subtalar joint motion reflected acceleration of the foot. During weight bearing, supination and pronation of the subtalar joint are reflected by internal/external rotation and forward/backward tilt of the lower thigh through the talocrural joint. The internal/external rotation and forward/backward tilt of the lower thigh are perceived as AP acceleration<sup>10</sup>. Therefore, the postural control characteristics of the healthy control group mainly involve internal/external rotation and forward/backward tilt of the lower thigh, and this involvement may underlie the significant positive correlation observed between COP parameters and AP foot acceleration in the control group.

Finally, a significant positive correlation was found between the maximum ML acceleration of the foot and all COP parameters in the sprain group. Instantaneous acceleration of the foot may affect COP velocity and COP range in the ML component. The large-amplitude motion of the lateral malleolus, with supination and pronation of the subtalar joint, is perceived as ML acceleration. This motion reflects joint movement in ankle sprain. Therefore, postural control with supination and pronation of the subtalar joint might be poor, and this motion might affect various COP parameters in the sprain group. We previously reported that individuals with a history of ankle sprain have a lower foot-to-head acceleration ratio and different postural control characteristics than control subjects<sup>10</sup>. In fact, while individuals with a history of ankle sprain had limited ML foot motion during a single-leg stance, if instantaneous foot

motion was needed in the ML component during postural control, it affected various COP parameters. However, the timing of maximum acceleration with respect to joint motion is unclear in the design of the current study, which used root mean square analysis with a trial time of 20s. Nonetheless, these findings suggest that instantaneous foot motion in the ML component is a factor affecting mean COP velocity, maximum COP velocity, and maximum COP range in the sprain group.

Our findings indicate that the following factors affected various COP parameters: in the control group, head acceleration in all directions and the AP component of foot acceleration, and in the sprain group, the ML component of foot acceleration. By examining the relationships between various parameters of the COP with head and foot acceleration, the postural control characteristics of individuals with and without a history of ankle sprain during single-leg standing were validated. These findings may be the result of the motion of each segment. As limitations of this study, accelerometers were only placed on the forehead and lateral malleolus of the involved (dominant) leg. Additionally, the relationship between acceleration and three-dimensional motion analyses is unclear. Therefore, a future challenge is to better define postural control characteristics in individuals with a history of ankle sprain using the accelerations of the lumbar and hip regions, along with kinematic analysis of the trunk and supporting limb.

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