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Anteroposterior limits of stability while standing on a foam pad in healthy young adults

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Abstract

To perform various daily activities while standing, a person should be able to move and maintain the center of mass within the base of support. This ability can be quantified by measuring the limit of stability (LoS), which refers to the maximum distance an individual can displace the center of pressure (CoP) by leaning the body within the base of support without having to take a step. Although balance training while standing on a foam pad, a thick rubber elastic pad, is often implemented in clinical physical therapy setting for individuals with balance problems, the effects of using the foam pad on the LoS remain unclear. Hence, this study aimed to examine such effects on anteroposterior LoS in healthy young adults. Ten healthy university students (mean age: 20.5 years) participated. The position and path length of the CoP in the anterior and posterior LoS were measured using a force platform under two surface conditions (with or without foam pad [form pad and control conditions, respectively]). Both the anterior and posterior LoS became significantly narrower under the foam pad condition than under the control condition. The CoP path length in the posterior LoS was significantly longer under the foam pad condition than under the control condition, but that in the anterior LoS did not differ significantly between the two conditions. These findings provide new insights into balance training protocols using foam pads.

Keywords: stability limit, foam pad, standing, kinetics, young adults

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I. Introduction

Humans can execute various daily activities while standing if they can move and maintain the center of mass within the base of support. A possible index of this ability is the limit of stability (LoS) (Melzer et al. 2009). The LoS refers to the maximum distance an individual can displace the center of pressure (CoP) by leaning the body within the base of support without the need to take a step; it can be quantified by measuring the CoP using a force platform (Melzer et al. 2009). The LoS decreases with age (Tomita et al. 2021) and in patients with neurological (Hugues et al. 2017; Tomita et al. 2024a) and orthopedic (Ucurum et al. 2024) diseases. If the ability to control CoP displacement decreases within the base of support, the possibility of a fall increases, particularly when performing daily activities that challenge the LoS (Tinetti et al. 1988). Therefore, increasing the LoS is an important target of physical therapy for individuals with balance problems (Roldán García et al. 2022).

Balance training is common in clinical physical therapy settings, and a thick rubber elastic pad (foam pad) is often used. Standing on the foam pad induces postural instability (Lin et al. 2015). Previous studies examining the effects of the foam pad on stance balance revealed that postural sway increases when standing on a foam pad compared with standing on a firm surface (Bieć et al. 2014; Lee et al. 2022; McCamley et al. 2022; Neville et al. 2015). In addition, balance training using a foam pad improves stance balance control in individuals with balance problems, such as older adults (Hirase et al. 2015), people with ankle sprains (McHugh et al. 2007), and patients with cancer (Saraboon and Siriphorn 2021). However, these foam pad studies have adopted quiet, tandem, and one-legged stance as a postural maintenance task. To our knowledge, no studies have examined the effects of a foam pad on the LoS. Given that using a foam pad increases postural instability, we hypothesized that the anteroposterior LoS reduces when standing on this pad. Examining such effects will provide new insights into balance training protocols using foam pads.

This study aimed to examine the effects of foam pads on the anteroposterior LoS in healthy young adults.

II. Methods

1. Participants

This study included 10 healthy university students (5 women and 5 men). The mean values (standard deviations) of the participant’ s age, height, weight, and foot length were 20.5 (0.5) years, 166.3 (10.1) cm, 63.8 (12.7) kg, and 24.6 (1.5) cm, respectively (Table 1). No participants had any history of neurological or orthopedic impairments. This study was conducted between October and December 2020.

All participants provided written informed consent before study participation. This study

Table 1. Demographic data of the participants.

	Age (years)	Height (cm)	Weight (kg)	Foot length (cm)
All participants (n = 10)	20.5 (0.5)	166.3 (10.1)	63.8 (12.7)	24.6 (1.5)
Women (n = 5)	20.4 (0.5)	157.8 (6.5)	54.5 (7.5)	23.7 (1.5)
Men (n = 5)	20.6 (0.5)	174.9 (2.6)	73.1 (9.5)	25.5 (0.8)

Mean (standard deviation).

conformed the principle of the Declaration of Helsinki and obtained approval from the Ethics Committee of the Toyohashi SOZO University (approval number: H2020003).

2. Experimental procedures

The CoP in the anteroposterior LoS was measured using the protocol used in previous studies (Tomita et al. 2021, 2024a). In all measurements, the participants stood barefoot on a force platform (G-6100, Anima, Japan) while crossing their arms in front of the torso. Using the G-6100 software, we recorded participants' CoP position in the mediolateral and anteroposterior directions (CoPx and CoPy, respectively) with a sampling frequency of 100 Hz on a computer (NJ3900E, Epson, Japan). We instructed the participants to gaze at a fixation point placed 1.5 m straight ahead on their horizontal line (Figure 1A). The heels were aligned, the insides of both feet were in parallel, and both feet were positioned 10 cm apart.

During the LoS measurements, the participants leaned their body forward or backward (Figure 1B). We instructed them to lean and place their weight on the forefoot (anterior LoS) or the rearfoot (posterior LoS) as much as possible without having to take a step, and to verbally report when they reached LoS and felt stable. Then, they maintained the leaning posture for 3 s. Such measurements were repeated thrice after five practice trials. The CoP positions in the anterior and posterior LoS were measured under two surface conditions (with and without a foam pad with a thickness of 6 cm [EBP-20, OG Wellness, Japan] [foam pad and control conditions, respectively]) (Figure 1C). The fixation point in the foam pad condition was raised by 6 cm so that the height of fixation point was the same between the foam pad and control conditions. We randomized the order of measurements in the two standing positions (anterior LoS and posterior LoS) and under the two surface conditions (control and foam pad) between the participants.

3. Data analyses

In each trial, we calculated the mean CoP position and the CoP path length per second. To minimize interparticipant differences in the foot length, we normalized the CoPy data by calculating the percentages of the foot length (% of foot length). CoPy values of 0% and 100% of foot length indicated that the CoPy position was at the heel and tip of the toe, respectively (Figure 2).

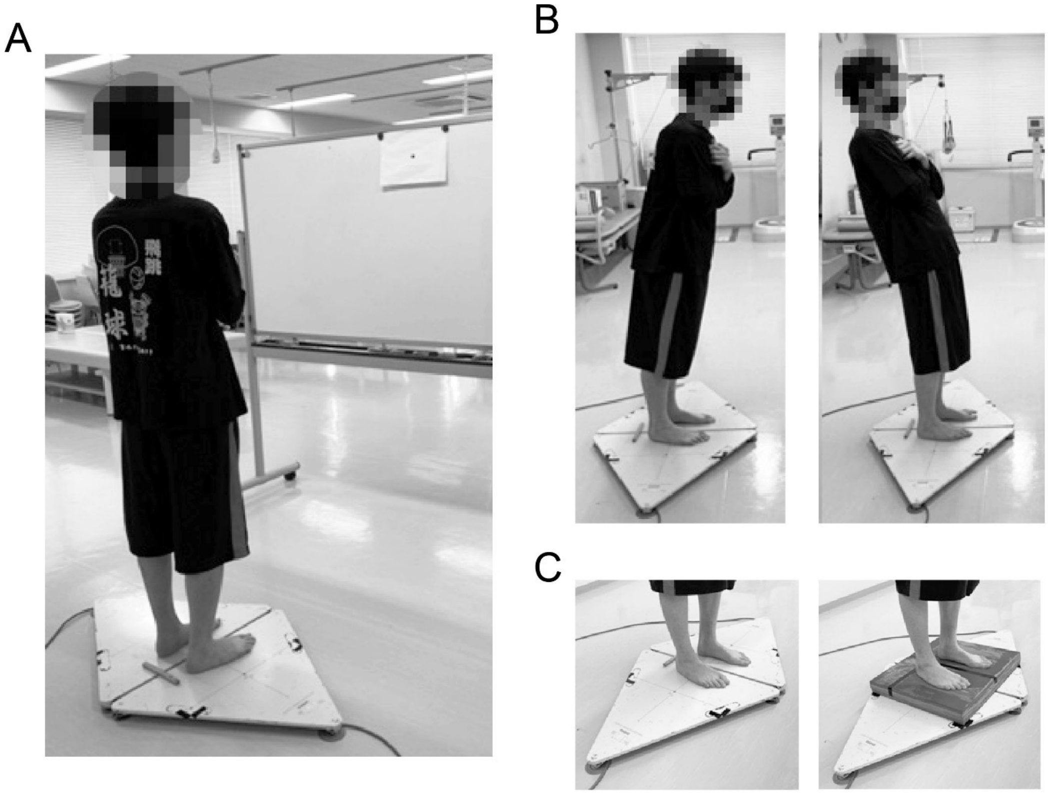

Figure 1. (A) Experimental setup. During measurement, participants stood barefoot on a force platform while crossing their arms in front of the torso and gazing at a fixation point placed 1.5 m straight ahead on their horizontal line. (B) Anterior LoS (left panel) and posterior LoS (right panel) measurements. (C) Surface conditions: control condition (participants stood directly on a force platform [left panel]) and foam pad condition (participants stood on a foam pad placed on the force platform [right panel]).

The Shapiro–Wilk test confirmed the normal distribution of all CoP position data. Differences in the CoP positions and CoP path lengths between the control and foam pad conditions were assessed using paired *t*-test. A *p*-value less than 0.05 was considered statistically significant. All statistical data were analyzed using IBM SPSS Statistics version 25 (IBM, USA).

III. Results

Figure 2 shows the means and standard deviations of the CoPy positions in the anterior and posterior LoS under the control and foam pad conditions. Both the anterior and posterior LoS became significantly narrower under the foam pad condition than under the control condition (anterior LoS: $t_9 = 6.86$, $p < 0.001$, d = 2.17; posterior LoS: $t_9 = 5.86$, $p < 0.001$, d = 1.85). Conversely, the CoPx positions in the anterior and posterior LoS did not differ significantly

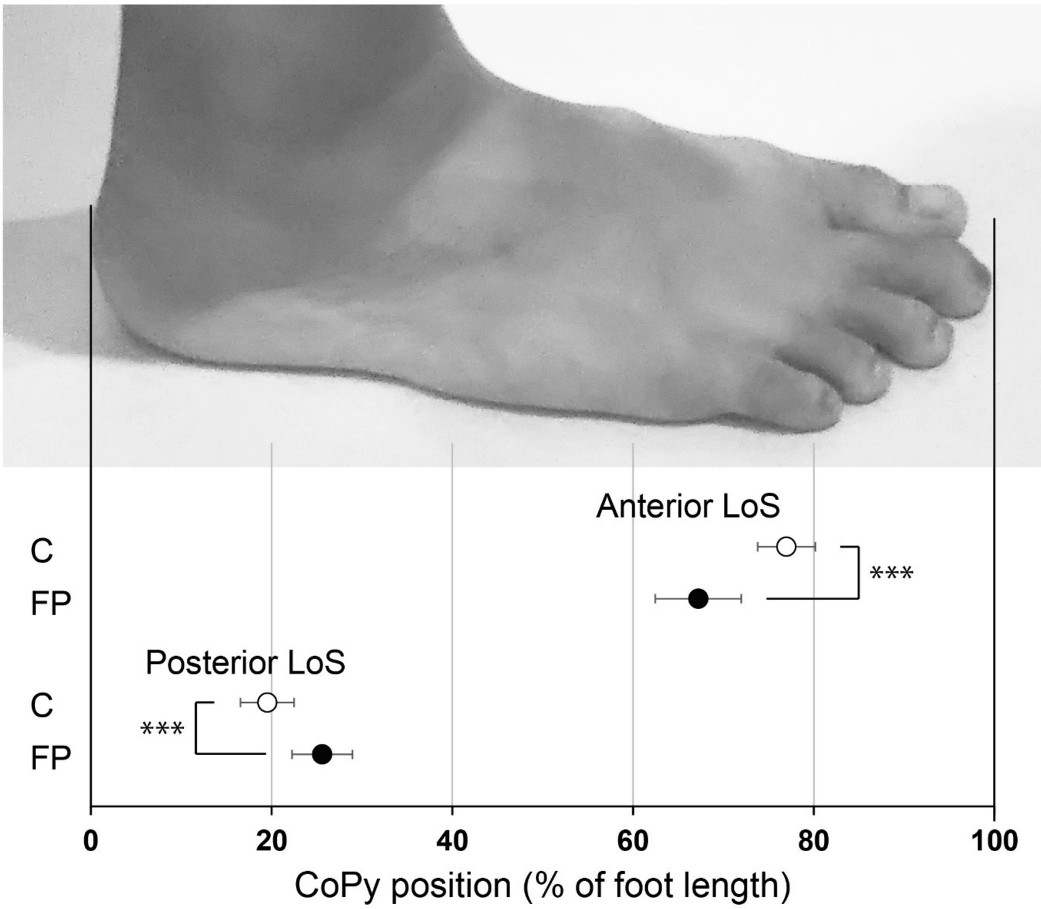

Figure 2. Means and standard deviations of the positions of the center of pressure in the anteroposterior direction (CoPy position) in the anterior and posterior limits of stability (LoS). A photograph of a participant's foot is shown to enhance visibility. Open and black circles denote the CoPy positions under the control and foam pad conditions, respectively. C: control condition; FP: foam pad condition. *** $p < 0.001$.

between the two surface conditions ($t_9 < 0.56$, $p > 0.595$, d < 0.17).

Figure 3 shows the means and standard deviations of the CoP path length in the anterior and posterior LoS under the control and foam pad conditions. The CoP path length in the posterior LoS was significantly longer under the foam pad condition than under the control condition ($t_9 = 3.55$, $p = 0.006$, d = 1.12). In the anterior LoS, it did not differ significantly between the two surface conditions ($t_9 = 0.50$, $p = 0.628$, d = 0.16).

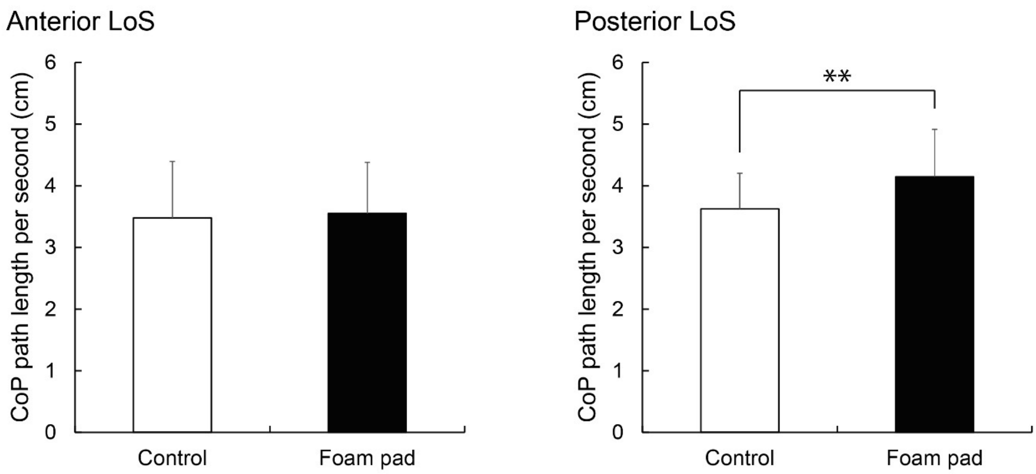

Figure 3. Means and standard deviations of the center-of-pressure (CoP) path length per second in the anterior and posterior limits of stability (LoS). Open and filled bars denote the CoP path length under the control and foam pad conditions, respectively. ** $p < 0.01$.

IV. Discussion

The human postural control system mainly utilizes three types of sensory inputs (i.e., vision, vestibular sensation, and somatosensory) to control stance balance (Horak 2006). Reliance on somatosensory information from the foot and ankle decreases when standing on the foam pad, because the foam pad deforms as the CoP fluctuates (Azbell et al. 2021; Lee et al. 2022; Young 2015). Therefore, standing on the foam pad induces postural instability because of the disturbed somatosensory information from the foot and ankle (Azbell et al. 2021; Young 2015).

Under the foam pad condition, the anterior and posterior LoS decreased. Standing position is more precisely perceived in the LoS with high fall risks than in the relatively stable quiet standing (Fujiwara et al. 2010). Pressure on the forefeet and heels increases in the anterior and posterior LoS, respectively (Asai and Fujiwara 2003). Pressure sensation from the plantar soles with weight-bearing distribution change plays an important role in precisely perceiving the LoS (Asai and Fujiwara 2003). In fact, impairments in plantar touch–pressure sensation are related to LoS limitations in individuals with neurological diseases (Tomita et al. 2024b). However, when standing on the foam pad, pressure sensation from the plantar soles becomes unreliable (Azbell et al. 2021; Lee et al. 2022) because the foam pad deforms as the CoP displaces during LoS maintenance. The participants may not have precisely perceived anteroposterior LoS positions on the foam pad, resulting in LoS reduction.

Postural sway during quiet, tandem, and one-legged stance increases when a person stands on the foam pad (Bieć et al. 2014; Lee et al. 2022; McCamley et al. 2022; Neville et al. 2015). However, in this study, the foam pad did not influence the CoP path length in the anterior

LoS. When individuals displace the CoP toward the anterior direction with their body leaning forward, the postural sway increases in the forward-leaning posture compared with quiet standing (Fujiwara and Ikegami 1981). We noted that foam pad use induced posterior shift in the anterior LoS. Therefore, the cause of no significant differences in the CoP path length in the anterior LoS between the two surface conditions may not be the lack of impact of the foam pad on postural stability in the anterior LoS but the shift of the anterior LoS posteriorly to constrict larger postural sway on the foam pad.

In the posterior LoS, postural sway, which is quantified by the CoP path length, increased when the participant stood on the foam pad. The reason might be the CoP position in the posterior LoS under the foam pad condition. The CoPy positions in the posterior LoS under the control and foam pad conditions were approximately 20% and 25% of foot length, respectively. The ankle joint is located at roughly 25% of foot length (Fujiwara et al. 1985); therefore, posterior LoS under the foam pad condition was maintained at a position quite close to the ankle joint. In the lower legs, postural muscles that activate for stance maintenance change with standing positions; in particular, posterior lower leg muscles (e.g., ankle plantar flexors and toe flexors) activate when the CoP moves anteriorly from the ankle joint position, whereas anterior lower leg muscles (e.g., ankle dorsiflexors and toe extensors) activate when the CoP moves posteriorly from the ankle joint position (Asai and Fujiwara 2003; Fujiwara et al. 1984; Tomita et al. 2010). However, stance maintenance over the ankle joint position requires a switch of anterior and posterior lower leg muscle activations with CoP fluctuations. Such complex control of postural muscle activities may cause the postural sway to increase in the LoS on the foam pad.

The human visual field' s characteristics might be another reason. Standing on the foam pad relies more on visual and vestibular information because somatosensory information from the foot and ankle is disrupted (Young 2015). Visual information could not be effectively used to control the posterior LoS as compared with that for the anterior LoS because the human visual field is not covered in the posterior direction. Useful sensory information to control the LoS position may be limited; consequently, postural sway increases in the posterior LoS on the foam pad.

Balance training with a foam pad can decrease postural sway in individuals with balance problems (Hirase et al. 2015; McHugh et al. 2007; Saraboon and Siriphorn 2021), suggesting that postural stability enhances with foam pad training. A decreased ability to control postural sway is reportedly related to LoS reduction (Tomita et al. 2024a). Therefore, although no studies have examined whether LoS maintenance training on the foam pad results in LoS increase, such training protocol may stabilize stance balance in the LoS, leading to the increase of LoS in individuals with balance problems.

Although this study is the first to examine the effects of foam pad on anteroposterior LoS, it has several limitations. First, the participants were limited to healthy young adults without disability. Second, the CoPy position in this study was normalized by participant' s foot length. Although sex-difference in the foot length might influence the effects of using the foam pad on the LoS, we could not examine such effects due to the small number of participants. Third, we did not employ electromyographic recording, thereby preventing detailed analyses on postural muscle activities in the LoS on foam pad. Last, the insight into whether LoS maintenance training on the foam pad increases the LoS remains unclear. Further research to address these issues is needed to develop a more effective therapeutic intervention using the foam pad for individuals with balance problems.

V. Conclusions

When an individual stands on a foam pad, the anteroposterior LoS may decrease and postural sway in the posterior LoS may increase.

CRediT authorship contribution statement

Hidehito Tomita: Conceptualization, methodology, formal analysis, investigation, writing – original draft, and visualization. **Naoki Hikosaka**: Formal analysis, investigation, and writing – review & editing. **Shunya Ban**: Formal analysis, investigation, and writing – review & editing. **Manami Omori**: Formal analysis, investigation, and writing – review & editing. **Natsuki Inoue**: Formal analysis, investigation, and writing – review & editing.

Conflict of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

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