Relationship between Feet Position and Anterior-posterior Center of Pressure (COP) location – What are the Determining Factors in the Adjustment of Center of Gravity? –

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Abstract. [Purpose] The purpose of this study was to examine the locus of the center of pressure (COP) of standing postures with different feet positions. [Subjects] Sixty healthy young adults participated in the experiments as subjects. [Methods] The COP was measured using a force plate. Subjects stabilized themselves on the force plate, and the change of the COP trajectory was measured for 30 s. The COP was measured in three standing postures: wide-base, tandem, and one-foot standing. The relative center of anterior-posterior sway was examined as a proportion of the base of support length. [Results] Using one foot length, l , measured from the heel to the toe of the foot as a standard, the mean of the center of anterior-posterior sway was $44.5 \pm 5.5\%$ of l in the wide-base stance, $50.2 \pm 4.4\%$ of l in the one-foot dominant stance, and $50.4 \pm 4.3\%$ of l in the one-foot non-dominant stance. Since the length of the feet is $2l$ in the tandem posture, the mean of the center of anterior-posterior sway was $41.0 \pm 7.0\%$ of $2l$ with the dominant foot in front and $41.5 \pm 6.0\%$ of $2l$ with the non-dominant foot in front. [Conclusion] The mean of the center of anterior-posterior sway was inclined toward the anterior position in single leg standing compared to the wide base standing. In tandem standing, the COP was located on the rear foot. The results of this study might be useful in considering the mechanism of postural control of patients with hemiplegia.

Key words: COP location, Standing, Feet positions

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INTRODUCTION

Postural control is defined as the ability to maintain equilibrium in a gravitational field by keeping or returning the center of body mass over its base of support¹⁾. The center of body mass over its base of support is the center of pressure (COP) within the base of support (BOS). Maintaining the COP within the BOS prevents a subject from falling in a static situation. Moreover, an effective BOS adjustment during a COP deviation from the BOS can lead to dynamic fall prevention. Scientifically, the steadiest postural stability is achieved when the COP is located at the center of the BOS area. However, humans don't necessarily stand with COP located at the center of the BOS. In addition, if COP deviates from the BOS, the subject would make a step to position COP within the newly created BOS restoring stability. Postural sway has been measured in standing posture with various feet positions, and postural control strategies have been considered in various studies²⁻⁵⁾. However, the determining factor of the location of COP in one-foot standing and in tandem standing have not been adequately studied.

Many hemiplegic patients lose balance during standing

on a narrow BOS (e.g., tandem standing, semi-tandem standing and one-foot standing). Therefore, knowledge of how the sound foot is used in the tandem stance is important for avoiding falls. To understanding where the anterior-posterior position of the COP is located is also important for giving guidance on ADL to hemiplegic patients suffering from cerebrovascular accident. In the present study, we examined the position of COP healthy adult subjects. The purpose of this study was to examine the location of COP in wide base standing, single-leg standing, and two legged tandem standing. In addition, we also examined the determining factors of the anterior-posterior position of COP.

SUBJECTS AND METHODS

Subjects

The healthy subjects who participated in our experiments did not have any known motor impairments or movement-related disorders affecting their balance ability. The subjects were 30 men with a mean and standard deviation of age of 21.9 ± 3.1 years (age range of 19–32 years old) and 30

Table 1. Characteristics of the subjects

	age mean $\pm$ SD (years old)	height mean $\pm$ SD (cm)	weight mean $\pm$ SD (kg)	dominant foot right / left	dominant foot length mean $\pm$ SD (cm)	non-dominant foot length mean $\pm$ SD (cm)
total (N=60)	21.3 $\pm$ 2.4	164.5 $\pm$ 8.2	57.7 $\pm$ 9.3	57 / 3	23.8 $\pm$ 1.5	23.8 $\pm$ 1.5
male (N=30)	21.9 $\pm$ 3.1	170.7 $\pm$ 5.8	62.9 $\pm$ 8.9	29 / 1	24.9 $\pm$ 1.1	24.9 $\pm$ 1.1
female (N=30)	20.7 $\pm$ 1.2	158.4 $\pm$ 5.0	52.5 $\pm$ 6.5	28 / 2	22.7 $\pm$ 0.8	22.6 $\pm$ 0.8

Fig. 1. Medial view of right foot bones
 * l : foot length. ** A: 44.5% point of l (from heel to tip of great toe). *** B: 50% point from heel to head of proximal phalangeal bone

women with a mean and standard deviation of age of 20.7 ± 1.2 years (age range of 19–23 years old) (Table 1). The subjects were asked to kick a ball, with the leg which they considered to be the dominant one. Two women and 1 man kicked the ball with the left foot and all others kicked the ball with the right foot. Written informed consent was obtained from all the subjects. The Medical Ethics Committee of Fujita Health University Nanakuri Sanatorium approved the design of this study.

Methods

COP was measured using a force plate (Twin-gravicoder G6100; ANIMA Corp.[®]). At first, the subjects were allowed practice trials so that they could become familiar with the measurements and the procedure of the experiment. After the subjects stabilized themselves on the force plates, the COP trajectory was recorded for 30 s at a sampling rate of 20 Hz in each trial. The subjects stood on the force plate with their eyes open and arms at their sides either barefoot or wearing thin stockings. No visual target or distracting noises were used in the experiments.

The subjects were asked to stand in three stances: wide-base, tandem and one-foot stances. The subjects stood with their feet 20 cm apart and parallel to each other in the wide-base stance. In the tandem stance, the feet were positioned with the heel of the front foot and toe of the rear one touching the longitudinal axis of the force-plate to ensure both feet were in a straight line. During the one-foot stance, subjects stood with one foot on the longitudinal axis of the force-plate with the other leg raised not touching the plate.

For each subject, COP was measured on the same day in the sequence of wide-base, tandem, and one-foot, as they are usually performed in the order of task difficulty. In the tandem and one-foot stances, the subjects performed the trials with dominant and non-dominant feet in a random order giving consideration to the effect of dominance.

Data analysis

The center of anterior-posterior sway was defined as the mean of the anterior-posterior sway given by:

$$\text{Mean of } Y = \frac{1}{n} \sum_{i=1}^n Y_i$$

where n is the number of sample points. The relative center of anterior-posterior sway was examined as a proportion of the base of support length. Repeated-measures analysis of variance (ANOVA) and the Tukey-Kramer multiple comparison test were used to evaluate differences in the relative center of anterior-posterior sway between each stance. All statistical procedures were performed using InStat 3 for Macintosh (GraphPad Software).

RESULTS

Using one foot length, l , measured from the heel to the toe of the foot as a standard, the mean of the center of anterior-posterior sway in the wide-base stance was $44.5 \pm 5.5\%$ of l , $50.2 \pm 4.4\%$ of l in the one-foot stance on the dominant foot, $50.4 \pm 4.3\%$ of l in the one-foot stance on the non-dominant foot, $41.0 \pm 7.0\%$ of $2l$ in the tandem stance with the dominant foot in front, and $41.5 \pm 6.0\%$ of $2l$ in the tandem stance with the non-dominant foot in front. Significant differences ($p < 0.001$) could be seen in all of the data categories other than between the dominant and non-dominant sides of both the tandem and one-foot stances.

DISCUSSION

The subjects tended to keep balance, and their mean of the center of anterior-posterior sway tended to be more anterior when standing in the one-foot stance than in the wide-base stance. In the tandem stance, COP was located on the rear foot.

The experiment of Nichols et al., with sixty-six subjects without any known impairment with an age range of 21 to 47 years, showed an association of the locus of the

balance of the y (anterior-posterior) coordinate with the foot position. The center of balance (COB) of y in the tandem stance was significantly more posterior than the COB of y in the other two stances (with the feet positioned apart, and with the feet positioned close together)³⁾. However, no study has determined the factors of the center of gravity in several feet positions. We think that the standing posture is the steadiest when the COP is controlled on the center of the BOS. It is interesting that the mean of the center of anterior-posterior sway of the tandem stance was on the rear foot. In the wide-base stance, the center of anterior-posterior sway was located at 44.5% of *l*. We think that an efficient BOS in the anterior-posterior direction of the foot is achieved in the first metatarsal bone, which extends from the heel up to the beginning of the proximal phalange of the foot. I in Figure 1, this length is shown as B. The center of the anterior-posterior sway falls in the 50% of B which is very close to the center of anterior posterior sway falling in the 44.5% of *l*. Meanwhile, the center of anterior-posterior sway in the one-foot stance was significantly more anterior than the center of anterior-posterior sway in the wide-base stance. We think that the subjects controlled their BOS using their toes in the one foot stance. Therefore, the center of anterior-posterior sway was more anteriorly located than in the wide-base stance. In addition, maximum ankle plantar flexor torque occurs in a slightly dorsiflexed ankle position⁶⁾. It also has biomechanical benefits as well.

Posture is adjusted while keeping COP on the rear foot in tandem standing in order to avoid the difficulty of postural adjustment caused by the narrowing of the base of support. That is because it is necessary to raise the heel if the knee of the front foot is kept fully extended. On the other hand, in order to move COP from the rear foot to the front foot without raising the heel of the rear foot, the knee must be bent and control has to be exercised on the knee joint in addition to the hip and ankle joints. It has been suggested that postural adjustment in the sagittal plane is performed mainly by the action of the hip and knee joints, and that the contribution of the knee joint is small⁴⁾. We assume that postural adjustment in tandem standing is performed by keeping COG within the rear foot, because it is not affected by the narrow the base of support, and also because it does not need the contribution

of the knee joint.

This finding is in agreement with findings in the clinical setting where hemiplegic patients can easily maintain their balance when they position their impaired foot in front of their sound one in tandem standing. Therefore, the position of the feet of the patients for ADL is important, and should be instructed accordingly. In other words, the patients should learn that they should position their impaired foot in front of their sound foot for tandem standing. This suggests that patients should position COP on the rear foot.

There are several limitations to the application of the findings of this study to hemiplegic patients. First, the age of the subjects was lower than that of the common onset age of stroke patients. Many studies have described an age-related change in the total path length of COP or the area of sway of COP^{2, 3, 5, 7)}. However, very few studies have noted changes in the COP location with aging. Imaoka et al. reported the COP location change in a narrow base standing by aging. They reported that the COP location moves slightly anteriorly with aging⁷⁾. We also need to confirm whether the postural increases when subjects raise the heel of the rear foot or bend both knees in tandem standing.

We plan to repeat the present study with hemiplegic patients as subjects.

REFERENCES

- 1) Horak FB: Clinical measurement of postural control of adults. *Phys Ther*, 1987, 67: 1881–1885. [[Medline](#)]
- 2) Era P, Sainio P, Koskinen S, et al.: Postural balance in a random sample of 7,979 subjects aged 30 years and over. *Gerontology*, 2006, 52: 204–213. [[Medline](#)] [[CrossRef](#)]
- 3) Nichols DS, Glenn TM, Hutchinson KJ: Changes in the mean center of balance during balance testing in young adults. *Phys Ther*, 1995, 75: 699–706. [[Medline](#)]
- 4) Winter DA, Prince F, Frank JS, et al.: Unified theory regarding A/P and M/L balance in quiet stance. *J Neurophysiol*, 1996, 75: 2334–2343. [[Medline](#)]
- 5) Goldie PA, Bach TM, Evans OM: Force platform measures for evaluating postural control: reliability and validity. *Arch Phys Med Rehabil*, 1989, 70: 510–517. [[Medline](#)]
- 6) Out L, Vrijkotte TG, van Soest AJ, et al.: Influence of the parameters of a human triceps surae muscle model on the isometric torque-angle relationship. *J Biomech Eng*, 1996, 118: 17–25. [[Medline](#)] [[CrossRef](#)]
- 7) Imaoka K, Murase H, Fukuhara M: Collection of data for healthy subjects in stabilometry. *Equilib Res Suppl*, 1997, 56: 1–84. [[CrossRef](#)]