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Original Article

Frequency analysis of the center of pressure in tandem stance in community-dwelling elderly

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Abstract. [Purpose] The present study aimed to clarify the effects of balance control on the pronation and supination movements of the talocrural joint in community-dwelling elderly women by conducting a frequency analysis of the center of pressure during tandem stance. [Subjects and Methods] The study participants were 18 subjects who maintained tandem stance for 20 s and 11 who had difficulty maintaining tandem stance for 20 s. The frequency-power spectra were computed and classified into three frequency bands. Each power spectral value was divided by the sum of the power spectral values to obtain the %power. [Results] Significant differences in high-frequency band %power value for the center of pressure in both the mediolateral and anteroposterior components were evident between the groups. [Conclusion] A markedly significant difference was observed, particularly in high frequency band %power, depending on balance control. The present findings indicated that elderly participants with diminished balance control had difficulty with rapid adjustment centered on the ankles, suggesting that rapid joint movement involving interlimb coordination centered on the ankles is required to maintain tandem stance.
Key words: Tandem stance, Center of pressure, Community-dwelling elderly

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INTRODUCTION

Smoothness and efficiency of human movements are achieved through the strength and appropriate combination of relevant muscles and delicate adjustments of aspects such as timing of the start and finish of muscle contractions[1–3)]. This process is widely known by the term *coordination*[4, 5)] and represents an important analytical perspective from which physical therapists can assess patients' movements and motions. Winter et al.[6)] and Wang et al.[7)] reported details of the inter-leg coordination involved in postural control during standing. Among standing postures, tandem stance is distinctive in that it involves the placement of one foot behind the other, which requires complex control centered on the talocrural joint[8)]. Thus, maintaining this posture represents a high level of task difficulty. Suzuki et al.[9, 10)] assessed the inter-leg motor coordination necessary for postural control during tandem stance from the perspectives of both spatial and temporal control, and reported the effects of aging and static balance ability. However, further clarification is required regarding the details of inter-leg motor coordination that are important for postural control during tandem stance. The present study aimed to clarify the effects of balance control on pronation and supination movements of the talocrural joint in community-dwelling elderly women by conducting a frequency analysis of the overall center of pressure (COP) during tandem stance.

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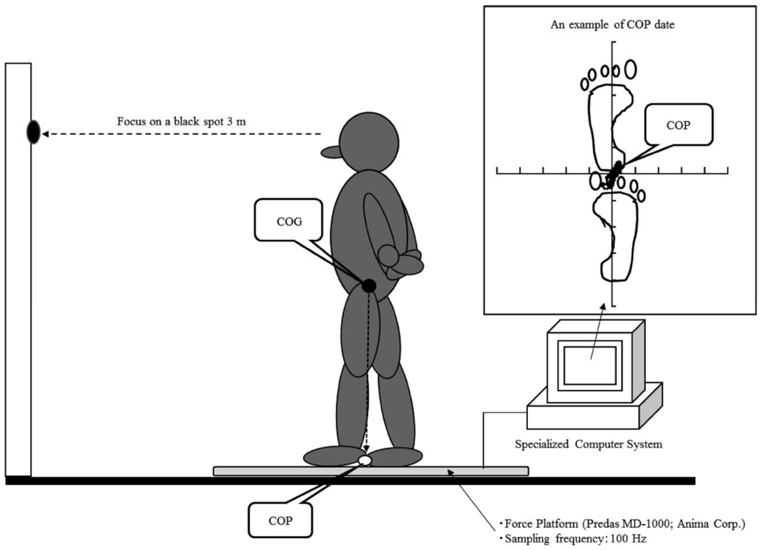

Fig. 1. Schematic diagram of the experimental condition
The projected COG was to be maintained at the point of contact between the left heel and the right second toe.
COG: center of gravity; COP: center of pressure

SUBJECTS AND METHODS

The participants included 18 subjects who maintained tandem stance for 20 s (AMTS; mean age, 72.9 ± 6.3 years; mean height, 150.0 ± 4.7 cm; mean weight, 54.3 ± 9.3 kgw) and 11 who had difficulty maintaining tandem stance for 20 s (DMTS; mean age, 75.3 ± 5.9 years; mean height, 150.2 ± 6.0 cm; mean weight, 56.6 ± 7.5 kgw). The participants comprised community-dwelling elderly women without central nervous system and orthopedic disorders that could affect the ability to maintain a standing posture. Participants provided consent for participation after receiving verbal and written explanations of the study, which was approved by the Tohoku Bunka Gakuen University Research Ethics Committee (approval Nos. 13-05 and 14-18). The posture protocol for tandem stance with equal weight bearing required the participants to stand with their arms folded behind their back, their left foot positioned forward along the midsagittal plane (front foot), and their right foot positioned behind (back foot) with the second toe touching the heel of the front foot. The projected center of gravity (COG) was to be maintained at the point of contact between the left heel and the right second toe. In this position, the participants were instructed to extend both knees, avoid raising either heel from the floor, and focus on a black spot 3 m in front of them to maintain a static posture. For the measurement of COP, Predas MD-1000 (Anima Corp., Japan) was used (Fig. 1). The participants stood barefoot on a force platform while maintaining the designated tandem stance, and measurements were taken at a sampling frequency of 100 Hz. Data were analyzed by using a specialized computer system and presented as a two-dimensional (2-D) pressure distribution and COP, representing the projected COG. The author who performed the measurements examined the 2-D pressure distribution of both feet depicted on the monitor and confirmed that all the participants maintained the posture for at least 3 s without the COP deviating from the designated zone, including the heel of the front foot and front of the back foot. Measurements were then conducted once per participant while the participant maintained the designated tandem stance up to a maximum of 20 s[9]. If the participants lost their balance and had to step with either foot to avoid falling during the measurement period, the measurements were immediately stopped. The tester spoke to the participants during measurements to help them maintain the COP within the designated zone and asked them to correct their COG if the COP seemed to deviate. Participants who could maintain the posture for 20 s but whose COP deviated from the designated zone with posterior or anterior movement of the COG were excluded from the present analysis. COP data were processed on a MATLAB (MathWorks)-based program designed by the authors and analyzed. After applying a 5-Hz low-pass filter to the COP data, fast Fourier transform (FFT) was conducted to find the mean trajectory per nine data, and the frequency power spectra were computed and divided into the following three frequency bands according to Kapteyn et al.[11]: 0 to <0.02 Hz (low-frequency band [LFB]), 0.02 to <2 Hz (mid-frequency band [MFB]), and 2 to <5 Hz (high-frequency band [HFB]). Each power spectral value was divided by the total sum of the power spectral values to obtain the %power. Statistical analysis was performed by using SPSS 13.0 J for Windows. The mediolateral (COP_{ML}) and anteroposterior (COP_{AP}) components of COP were analyzed with respect to the frequency bands by using the two-sample t-test and Mann-Whitney *U* test. The significance level was set at $p<0.05$.

Table 1. The proportions of COP_{ML} %power in each band

	LFB (%)		MFB (%)		HFB (%)	
	AMTS	DMTS	AMTS	DMTS	AMTS	DMTS
Mean	52.5	56.8	45.8	42.8	1.7	0.4 **
SD	20.9	18.0	19.8	17.9	1.4	0.3

COP_{ML}: mediolateral components of COP; LFB: low-frequency band; MFB: mid-frequency band; HFB: high-frequency band; AMTS: participants who had the ability to maintain the tandem stance for 20s; DMTS: participants who had the difficulty maintaining the tandem stance for 20s; SD: standard deviation; **p<0.01

Table 2. The proportions of COP_{AP} %power in each band

	LFB (%)		MFB (%)		HFB (%)	
	AMTS	DMTS	AMTS	DMTS	AMTS	DMT
Mean	59.7	58.3	38.0	40.6	2.1	1.1 *
SD	19.6	14.7	18.9	14.0	1.4	1.1

COP_{AP}: anteroposterior components of COP; LFB: low-frequency band; MFB: mid-frequency band; HFB: high-frequency band; AMTS: participants who had the ability to maintain the tandem stance for 20 s; DMTS: participants who had difficulty maintaining the tandem stance for 20 s; SD: standard deviation; *p<0.05

RESULTS

Based on the FFT results, significant differences were observed between the groups regarding the HFB %power values for both the COP_{ML} ($p<0.01$) and COP_{AP} components ($p<0.05$). Specifically, the overall HFB %power values were significantly smaller with regard to COP_{ML} and COP_{AP} in the DMTS group than in the AMTS group (Tables 1 and 2).

DISCUSSION

Tandem stance involves placing the feet in a toe-to-heel position along the midsagittal plane, with the toe of one foot touching the heel of the other, and is laterally unstable. Tandem stance is distinctive in that it involves the placement of one foot behind the other, which requires complex control centered on the talocrural joint[6, 7]. In a physiotherapy setting, the degree of difficulty involved in maintaining this posture makes it ideal for balance training tasks and for measuring static balance ability[4, 5, 12]. The present study used frequency analysis to investigate COP trajectories during tandem stance and found that most COP_{ML} and COP_{AP} components were either very slow (LFB) or fast (MFB). However, although the proportions were low overall, very fast COP_{ML} and COP_{AP} components (HFB) were also present and showed marked differences between the AMTS and DMTS participants. Therefore, the occurrence rate of HFB wave components in the COP trajectory during postural control in tandem stance is an important parameter that is likely to be closely related to differences in balance ability. During static standing, mechanical stability is usually maintained by controlled adjustments of COP within the base of support in response to slight shifts in the COG[6]. Under the present tandem stance conditions, mechanical stability is similarly maintained but within a distinctively narrow base of support[9, 10, 13]. The inability of DMTS participants to maintain the tandem standing posture for 20 s is thought to be due to poor talocrural joint coordination between the feet and the inability to perform early-stage COP correction of the increasing gravitational moment. One cause of this may be the decreased ability of the muscles around the bilateral talocrural joint to exert coordinated tensile force, which generates the very fast components found in the HFB, in the DMTS group. Suzuki et al.[9] reported that a characteristic of tandem stance in elderly people able to maintain the posture for 20 s was that the COP for each leg (COP_L and COP_R) moved in the same direction and was controlled by ensuring that the timings of the movements matched almost exactly. In elderly people unable to maintain the posture for 20 s, time lags were found in the movements of COP_L and COP_R, and could not be corrected, making it difficult for them to maintain the tandem stance. Thus, the significant decrease in the proportion of HFB components in the DMTS participants may represent a major characteristic when breaking down inter-leg motor coordination during tandem stance in elderly people.

The equal weight-bearing protocol used for the tandem stance was determined based on the designated COP position rather than on the actual weight distribution. Therefore, the results may not be suitable for interpretation as a phenomenon of tandem stance in comparison with studies that used an equal weight-bearing protocol, where weight distribution was strictly stipulated or involved posterior weight distribution. Further investigation is required.

The present findings regarding COP during tandem stance in community-dwelling elderly women were of considerable interest with regard to the significant differences observed in HFB %power depending on balance ability. Decreased ability of the skeletal muscles to exert tensile force and rapidly coordinate movements centered on the pronation and supination movements of the talocrural joint was suggested as a potential cause of difficulty maintaining a tandem stance. The present findings further clarified the inter-leg coordination involved in the control of tandem stance and may enable development of a practical training program to predict balance ability and improve motor function in both healthy elderly individuals and elderly individuals with disabilities.

REFERENCES

1) Tseng SC, Morton SM: Impaired interlimb coordination of voluntary leg movements in poststroke hemiparesis. J Neurophysiol, 2010, 104: 248–257. [Medline] [CrossRef]
2) Krasovsky T, Baniña MC, Hacmon R, et al.: Stability of gait and interlimb coordination in older adults. J Neurophysiol, 2012, 107: 2560–2569. [Medline] [CrossRef]
3) Damiano DL, Norman T, Stanley CJ, et al.: Comparison of elliptical training, stationary cycling, treadmill walking and overground walking. Gait Posture, 2011, 34: 260–264. [Medline] [CrossRef]
4) Shumway-cook A, Woollacott MH: Motor control translating research into clinical practice, 3rd ed. Philadelphia: Lippincott Williams & Wilkins, 2007, pp 100–135.
5) Montgomery PC, Connolly BH: Clinical applications for motor control. Thorofare: SLACK Incorporated, 2003, pp 175–204.
6) 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]
7) Wang Z, Newell KM: Asymmetry of foot position and weight distribution channels the inter-leg coordination dynamics of standing. Exp Brain Res, 2012, 222: 333–344. [Medline] [CrossRef]
8) Oatis CA: Kinesiology: the mechanics and pathomechanics of human movement. Philadelphia: Lippincott Williams & Wilkins, 2004, pp 775–802.
9) Suzuki M, Miki C, Suzuki H, et al.: Postural control in tandem stance by young females and community-dwelling elderly females: examination of interlimb coordination of center of pressure (COP). Annu Rep Tohoku Sect Jpn Phys Ther Assoc, 2015, 27: 45–50 (in Japanese).
10) Suzuki M, Suzuki H, Kawakami S, et al.: Posture control in tandem stance and step stance: medial-lateral balance control at the center of pressure. Memoirs of the Tohoku Bunka Gakuen University Faculty of Medical Science & Welfare. Dep Rehabilitation-Rehabilitation Sci, 2016, 12: 23–27 (in Japanese).
11) Kapteyn TS, Bles W, Njiokiktjien CJ, et al.: Standardization in platform stabilometry being a part of posturography. Agressologie, 1983, 24: 321–326. [Medline]
12) Scott R: Foundations of physical therapy: a 21st century-focused view of the profession. Columbus: McGraw-Hill, 2002, pp 109–140.
13) Arisue I, Fujisawa H: The difference between the anterior and posterior center of foot pressure and the combined center of foot pressure in tandem standing: the influence of visual information. Rigakuryoho Kagaku, 2015, 30: 713–717 (in Japanese). [CrossRef]