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Importance of the Rear and Non-dominant Leg in Supporting the Body in Tandem Stance

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Abstract

Objective: Some studies have reported that postural assessment of a narrow base of support such as the tandem stance is useful in evaluating the risk of falls. The purpose of the present study was to obtain maximum inter-foot distance (IFD) during crossover movement of the rear foot from tandem stance, and to compare these data with those of our previous study of the front leg moving across the front of the body.

Methods: Forty healthy young people were recruited as subjects (aged 29 ± 6 years, 19 men). The subjects moved their rear leg across the rear of their body according to split treadmill belt movement. Maximum IFD was measured by a three-dimensional motion analysis system and defined as the largest IFD such that either foot could be removed from the treadmill belt while maintaining a standing posture. Four conditions were set for the measurements: the rear leg was dominant and non-dominant under two treadmill belt velocities (0.5 km/h and 1.0 km/h). Two-way analysis of variance was used for the analysis.

Results: Normalized maximum IFD (NMIFD) was 8-9% of subject height. Interaction between the rear leg and treadmill belt velocity was not significant. There was no significant main effect of treadmill belt velocity and the dominant foot on NMIFD. Comparing the results of our previous study, under the condition of the dominant foot moving, the NMIFD of the front leg moving across the front of the body was significantly larger than that of the rear leg moving across the rear of the body.

Conclusion: The function of the rear leg is important as a support under the condition of crossing the legs from a standing posture such as tandem stance.

Keywords: Tandem stance; Fall; Lateral balance; Three-dimensional motion analysis; Inter-foot distance; Rear leg

Introduction

Falls are a serious problem among elderly people. 20-40% of community-dwelling elderly fall at least once per year [1-3]. 24% of those who fall have serious injuries and 6% have fractures [1]. Falling is an important issue for elderly people with poor balance and frailty. Therefore, determining whether a person has a high risk of falling or not using balance assessments is essential.

Robinovitch et al. found that the most common cause of falls was not tripping or stumbling, but incorrect transfer or shifting of body weight, which they defined as a seemingly self-induced shifting of body weight that causes the center of gravity (COG) to move to the outside [4]. Controlling the center of mass (COM) and center of pressure (COP) inside the base of support (BOS) is important in order to prevent incorrect transfer or shifting of body weight. Therefore, among a variety of assessments to evaluate balance, we focused on narrowing the BOS. The Short Physical Performance Battery uses both tandem stance and standing balance items to assess balance using the size of the BOS [5]. These assessments are related to lateral BOS, and we think that falls in patients with frailty are related to the movement of the COG in the lateral direction. Recently, the Standing Test for Imbalance and Disequilibrium (SIDE) was developed as a balance assessment that evaluates the BOS [6]. SIDE consists of six levels to assess balance ability. The postures are wide base, narrow base, tandem stance, and one-foot stance, with the BOS becoming respectively narrower with each posture. Using SIDE levels, complete separation of subjects who had not experienced a fall within 14 days of hospital admission was seen at level 2b, which can maintain tandem stance and higher [7]. It is important to evaluate the BOS to detect the probability of whether patients may fall or not. However, SIDE evaluation is an ordinal scale and lacks consecutive changes in the BOS. In addition, SIDE does not evaluate crossover steps in relation to falls [8].

We previously developed a test to evaluate the maintenance of posture based on inter-foot distance (IFD) [9]. In this test, subjects were instructed to stand on a treadmill and move their front leg across the front of their body according to the treadmill belt movement. Maximum IFD was defined as the IFD when either foot was removed from the treadmill belt while the subject maintained a standing posture. The maximum IFD was 10-12% of subject height. In addition, there were significant differences based on the dominant foot. These results suggested that the dominant foot influences the maintenance of standing posture. On the other hand, the vertical ground reaction force for the rear leg was larger than that for the front leg during tandem stance [10]. Therefore, the IFD of the rear leg moving across the rear of the body might be smaller than that of the front leg moving across the front of the body.

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The purposes of this present study were: 1) to quantify the maximum IFD and the ability of young healthy adults to maintain a standing posture when the rear leg moves across the rear of the body; and 2) to compare the results of the present study with our preliminary study [9] of the front leg moving across the front of the body.

Methods

Participants

Forty healthy subjects (19 men and 21 women; mean ± standard deviation age 29 ± 6 years, height 164.4 ± 8.9 cm) volunteered to participate in this study. Subjects with severe orthopedic disorder were excluded. The present study was approved by the Ethics Committee of the author's institution (No. 829). All subjects received an explanation of this research and provided written informed consent to participate.

Instruments

Eight cameras analyzed three-dimensional motion (VICON MX, Vicon Motion Systems Ltd., Oxford, UK) and a split-belt treadmill with two separately controlled belts (Tech Gihan Co. Ltd., Uji, Japan) was used to collect data. The split-belt was equipped with force plates (size: 320 mm × 1200 mm) under each belt to check the amount of load during movement.

Procedure

The conditions under which the present study was performed are the same as our previous study [9]. Briefly, the subjects wore socks with a reflective marker (14-mm diameter) attached over the head of the first metatarsal on each foot. They were instructed to stand on the rear belt of the treadmill perpendicular to the flow of the belt with their feet shoulder-width apart and their arms crossed over their chest to avoid using them to maintain balance.

As the subjects took one side step onto the front belt, we asked them to stare at an eye-level marker directly in front of them and not to turn their head or torso while stepping. The subjects were also asked to stand with their weight distributed equally across both legs; we confirmed the load distributed to each lower extremity using data from the force plate. As the treadmill belt started to move, the subjects were instructed to move their rear leg across the rear of their body. The IFD was measured when either of the feet was removed from the treadmill belt, which was defined as force plate data <20 N. When both feet were aligned perpendicular to the flow of the treadmill belts, the IFD was 0.

The IFD was positive when the rear foot crossed behind the front foot, and negative when the rear foot had not crossed behind the front foot (Figure 1). All IFD values were calculated using raw data. All subjects wore a safety harness (Morito Co. Ltd., Ichinomiya, Japan) to prevent falls.

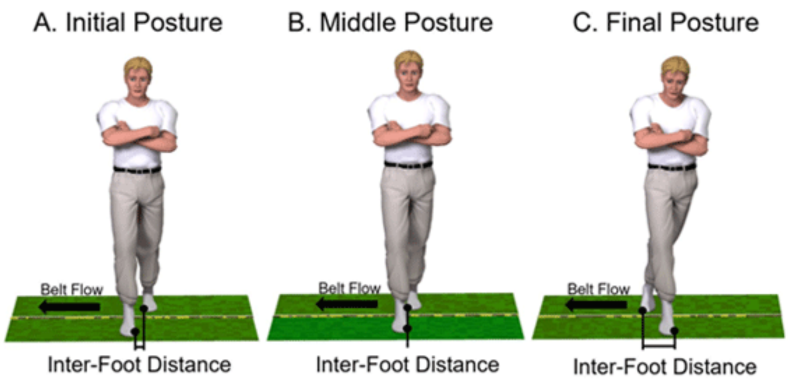

Figure 1: Initial, middle, and final posture during one trial. (A) Inter-foot distance (IFD)<0, (B) IFD=0, (C) IFD>0.

The following four measurement conditions were tested in random order: the dominant and non-dominant foot each moved to the rear of the body with treadmill belt velocities of 0.5 km/h and 1.0 km/h. The subject's dominant foot was defined as the foot they would normally use to kick a ball. The velocity of the treadmill belt was set just after the belt began to move using LabView (National Instrument Japan Co., Tokyo, Japan). Each subject performed one practice trial to become familiar with the movements for the test conditions. After that, five test trials were performed.

Data analysis

The maximum IFD was divided by subject height and multiplied by 100 to normalize the data. The value was defined as Normalized Maximum IFD (NMIFD). The mean value of the five trials for each condition was used. Two-way analysis of variance was used for the analysis (rear leg × belt velocity).

Furthermore, the NMIFD of the rear leg moving across the rear of the body was compared with the results for the NMIFD of the front leg moving across the front of the body in the previous study using an unpaired t-test under the same conditions of the dominant foot and non-dominant foot moving, respectively.

The participants of this study were different from those of our previous study. SPSS ver. 23.0 (IBM Japan, Tokyo, Japan) was used for all statistical analyses. The level of significance was set at 5%.

Results

The NMIFD results are shown in Table 1 and Figure 2. There was no significant interaction between the rear leg and belt velocity. There was no significant main effect of the rear leg and the belt velocity on NMIFD.

Moving foot	Belt velocity	
	0.5 km/h	1.0 km/h
Rear leg	-	-
Dominant	8.5 (5.6)	8.4 (5.9)
Non-dominant	9.0 (7.4)	8.6 (7.4)
Data are mean (standard deviation); NMIFD: Normalized Maximum Inter-Foot Distance		

Table 1: NMIFD with the rear leg moving across the rear of the body (%height).

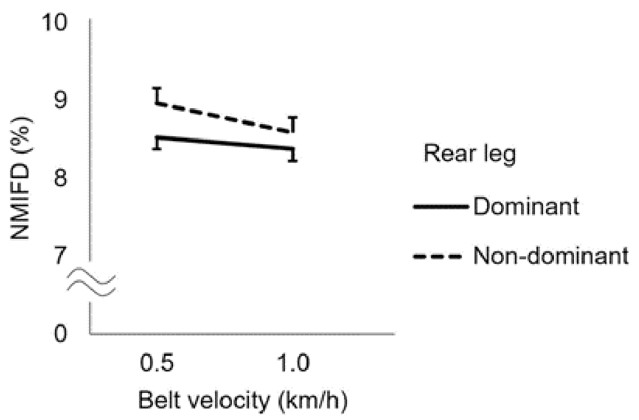

Figure 2: The normalized maximum inter-foot distance (NMIFD) (%height) with the rear leg moving across the rear of the body.

Table 2 and Figure 3A show a comparison of NMIFD results between the previous and present studies under the conditions of the dominant and non-dominant foot moving. Under the condition of the dominant foot moving, the NMIFD of the front foot moving across the front of the body was significantly larger that of the rear foot moving across the rear of the body (belt velocity 0.5 km/h: p=0.02; 1.0 km/h: p=0.009). On the other hand, NMIFD was not significantly different when the non-dominant foot was moving (Figure 3B). There was no significant interaction between the rear leg and belt velocity (P=0.84). There was no significant main effect of the rear leg and belt velocity (P=0.60, 0.70). Error bars are standard errors.

Moving foot		Belt velocity	
		0.5 km/h	1.0 km/h
Dominant	Front	11.9 (7.1)	12.4 (7.0)
	Rear	9.0 (7.4)	8.6 (7.4)
Non-dominant	Front	10.5 (6.2)	10.1 (6.0)
	Rear	9.2 (7.6)	8.8 (7.4)
Data are mean (standard deviation); NMIFD: Normalized Maximum Inter-Foot Distance.			

Table 2: NMIFD under the conditions of the dominant and non-dominant foot moving (%height).

Discussion

Evaluating balance in tandem stance is important for preventing falls. However, the use of dynamic tandem stance has seldom been reported. Our previous study of the front leg moving across the front of the body found that NMIFD was 10-12% of subject height and that there was a significant main effect of the front leg on NMIFD [9].

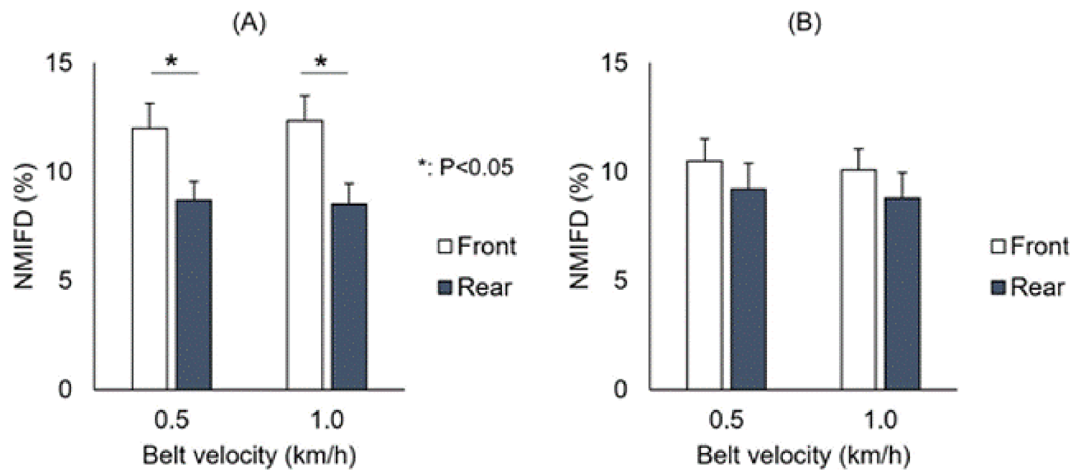

Figure 3: The normalized maximum inter-foot distance (NMIFD) (%height) between the previous and present studies. (A) Under the condition of the dominant foot moving, the normalized maximum inter-foot distance (NMIFD) of the front leg moving across the front of the body was significant larger than that of the rear leg moving across the rear of the body. (B) Under the condition of the non-dominant foot moving, there was no significant difference between the NMIFD of the rear and front legs.

In the present study, there was no significant difference in NMIFD regardless of whether the rear leg was dominant or non-dominant. There are a few previous reports about crossover steps in front of the supporting leg. Maki et al. investigated postural reactions evoked by sudden horizontal translation of a movable platform [8]. The results suggested that the demands of controlling lateral stepping reactions may create difficulties for active and healthy older adults above and beyond previously reported problems in controlling forward and backward stepping. In another study, subjects were instructed to walk straight ahead for about 4 m, and then turn onto a designated path that was at an angle of 45° or 90° and keep walking [11]. Spin turns (turning towards the stance limb) are less stable and have a greater biomechanical cost than step turns (turning to the opposite side of the stance limb).

The present study is one of the few reports about crossover steps to the rear of the supporting leg. In our results, there was no significant main effect of the rear leg on NMIFD and we found that there were no significant differences between the conditions regardless of whether the dominant or non-dominant foot was moved. The movements in this research may be similar to the movements of turning backward from a standing posture, but the rear leg crossing the rear of the body to the extent studied here is rare in activities of daily living.

We did not find any significant differences in NMIFD under either of the two velocity conditions. This result was the same as our previous study. Therefore, NMIFD might not be related to velocity. In this study, belt velocity was set at 0.5 km/h and 1.0 km/h. In a pilot study, we observed that the subjects often removed their foot from the treadmill belt just after the treadmill belt started to move at 1.5 km/h. We should investigate the protocol used in this study under belt velocities over 1.0 km/h in the future.

Under the condition of the dominant foot moving, the NMIFD of the front leg moving across the front of the body was significantly larger than that of the rear foot moving across the rear of the body. There are a few studies on the amount of load on the legs in tandem stance. Teranishi et al. reported that COP in the tandem stance was located on the rear foot regardless of whether the front foot is dominant or non-dominant [12]. Jonsson et al. measured tandem stance for 30 seconds using ground reaction forces [10]. During tandem stance, the vertical ground reaction force was twice as large for the rear leg as for the front leg. Moving the rear leg, which is weighted more heavily in the tandem stance, is difficult. Therefore, IFD might be shorter under that condition. On the other hand, NMIFD was not significantly different under the condition of the non-dominant foot moving. Moving the non-dominant foot means that the body is supported by the dominant foot. In a previous review of the dominant leg, the author indicated that the dominant and non-dominant leg play a role in mobilization and stabilization, respectively [13]. We think that this result is affected by supporting with legs characterized as mobilization. To summarize the above, the role of the non-dominant foot is more important in maintaining balance than that of dominant foot in tandem stance.

Crossover steps evoked by lateral perturbation from the tandem stance might allow better balance when the front foot is the dominant foot and also when the stepping foot is the dominant foot. Patients with poor balance and participants in fall prevention classes should probably be instructed to first move the dominant foot when cross stepping, such as when transferring.

There were some limitations in this present study. First, we used healthy young people as subjects to collect fundamental data. In order to use this procedure in balance assessment, we have to investigate the assessment in elderly subjects. In addition, a future study should investigate subjects with fall risk, such as those with poor standing balance. Second, we assumed that NMIFD is related to COG and COP; however, COG and COP were not actually investigated. In a pilot study, we tried to measure COG; however, some markers attached on hip and knee joint were not visible while the leg was crossing over and our cameras could not collect information from these markers. We were only able to capture information from the marker over the head of the first metatarsal. We plan to investigate COG and COP in a future study since these outcomes were not measured with the current system. Third, in the present study, the number of subjects was insufficient to determine the reliability and validity of this research protocol. Moving the rear foot from a posture such as tandem stance is a rare movement in daily life. Accordingly, the reliability may be low after practicing only once. We should have provided the subjects with more opportunity to practice the movement. In addition, it is thought that IFD is affected not only by balance ability, but also by the flexibility of the muscle and joints. However, assessment of flexibility was not conducted in the present study. We should have investigated the relationship between NMIFD and other assessment as well as the flexibility of the subjects to improve the validity of the present results.

Conclusion

We quantified the NMIFD when the BOS in standing posture was changed by moving the rear leg across the rear of the body in healthy young subjects. The results provide the new finding that posture can be maintained when the legs cross by up to 8-9% of the height. The NMIFD was not significantly affected by the dominant foot or by the treadmill belt velocity. Under the condition of the dominant foot moving, the NMIFD of the front leg moving across the front of the body was significantly larger than that of the rear leg moving across the rear of the body. Our results suggested that patients with poor balance should move the dominant foot first when cross stepping, such as when transferring. In future studies aimed at preventing falls, we would like to evaluate NMIFD relationships in persons with poor standing balance.

Acknowledgment

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Conflicts of Interest

All authors declare that there are no conflicts of interest.

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