Abstract
This study aimed to investigate the relationship between the muscular strength of the lower extremity in a load side and the characteristics of center of foot pressure (COP) during landing after crossover stepping in the elderly. The study population comprised 8 elderly subjects (average age, 75.8±8.0 years) and 9 young individuals (average age, 21.6±2.5 years). Using a separation-type force plate, we measured the deflection characteristics of the COP; these were defined by the root mean square of positional change (COP-RMS) and the deflection velocity of the COP (COP-Vel) during landing after crossover stepping. Furthermore, we measured the muscular strength of the lower extremity by using a hand-held dynamometer. By using multiple regression analysis, we detected the calculated muscular strength as the independent variable of the deflection characteristics of the COP. Compared to the young group, the elderly group showed significantly higher anterior-posterior COP-RMS values (p<0.05) and lower lateral COP-Vel values (p<0.001). In the elderly, the muscular strengths of the tibialis anterior and adductor magnus were detected as a significant independent variable of the anterior-posterior COP-RMS (R²=0.85, R²^* = 0.76, p<0.01) and lateral COP-Vel (R²=0.75, R²^* = 0.65, p<0.05), respectively. With regard to the COP deflection characteristics during landing after crossover stepping in the elderly, we recognized the diagnostic character of the anterior-posterior COP-RMS and lateral COP-Vel. Further, it was suggested that the muscular strengths of the tibialis anterior and adductor magnus played a role in regulating the COP deflection characteristics. J Physiol Anthropol 28(1): 1–5, 2009 http://www.jstage.jst.go.jp/browse/jpa2 [DOI: 10.2114/jpa2.28.1]

Keywords: the elderly, landing after crossover stepping, center of foot pressure, muscular strength
With regard to the stepping reaction and the muscle strength of the lower extremity, there is a report on the relationship of step length (Wu et al., 2007) and stepping performance, including reaction time, movement time, and extent of obstacle clearance (Berg and Blasi, 2000). However, there has been no study investigating the relationship between the COP deflection characteristics during landing after a stepping reaction and muscle strength of the lower extremity.

This study aimed to investigate the relationship between the muscular strength of the lower extremity, which is associated with postural stability, and the deflection characteristics of COP during landing after crossover stepping in the elderly.

**Methods**

**Subjects**

The study population comprised 8 elderly subjects (3 males and 5 females; average age, 75.8 ± 8.0 years [range, 64–89 years]; height, 153.3 ± 9.6 cm; weight, 59.3 ± 10.5 kg) and 9 young individuals (7 males and 2 females; average age, 21.6 ± 2.5 years [range, 19–26 years]; height, 174.2 ± 5.6 cm; weight, 61.7 ± 7.0 kg). None of the subjects had a history of orthopedic disorders or disorders of the nervous or vestibular systems. Both verbal and written informed consent was obtained from all the subjects after explaining the experimental purpose and procedures in detail.

**Experimental procedures and data analysis**

The subjects were instructed to stand barefoot and upright on a separation-type force plate (G6100; Anima, Tokyo, Japan) in a quiet stance with their feet separated mediolaterally by 10 cm. They maintained the quiet stance for 20 s, with both the upper extremities crossed in front of their chest. After 20 s, when signaled by the examiner, they shifted their center of gravity (COG) as laterally as possible and then took a “crossover” step with the unloaded leg from the maximum lateral shift position (Fig. 1). In order to examine the natural stepping reaction, the landing place of the foot and the speed of stepping were performed at the discretion of the subject.

We confirmed the landing of the crossed unloaded foot on the contralateral force plate.

The COP signal was acquired at a frequency of 200 Hz and recorded on the force plate with piezoelectric transducers. Using the waveform of the vertical ground reaction force recorded with the force plate, we divided the crossover step of each subject into 4 phases (Fig. 2; A–D). Among the 4 phases, we focused our attention on the initial 1-s landing phase just after the crossover step (Fig. 2D; gray area).

The deflection characteristics of COP were defined by the root mean square of positional change (COP-RMS) and deflection velocity of the COP (COP-Vel) in the landing phase. The deflection characteristics of COP were calculated separately for the anterior-posterior and lateral directions.

A hand-held dynamometer (MICROFET; Hoggan Health Industry, West Jordan, USA) was used to measure the strength of the following antigravity muscles of the lower extremity: iliopsoas, gluteus maximus, gluteus medius, adductor magnus, quadriceps femoris, hamstrings, tibialis anterior, triceps surae, peroneus longus, and tibialis posterior. A physical therapist measured the muscular strength and used the mean value of 3 measurements. Furthermore, since the subject would experience fatigue during the exercises, we allowed a break of 3 minutes after every measurement of muscular strength. The procedure used for measuring the muscular strength and the position of the subject was that described in the book titled “Daniels and Worthingham’s Muscle Testing” (Helen and Jacqueline, 2002). The muscular strength was measured for the loaded limb and was expressed as a ratio to the body weight (%BW).

By using multiple regression analysis, we detected the muscular strength as the independent variable of the deflection characteristics of COP.
Statistical analysis

Welch's t test was used to compare the difference between the elderly group and the young group with regard to the COP-RMS, COP-Vel, and muscular strength. Multiple regression analysis was performed by the stepwise method (Fin=2.5, Fout=2.0) (Draper and Smith, 1981) with COP-RMS and COP-Vel as dependent variables and the strength of each muscle as the independent variable. In addition, considering multicollinearity, when we found an extensive correlation between measurements of muscle strength, we selected muscular strength as an independent variable to determine its extensive correlation with the dependent variables. All statistical analyses were performed using the statistical program SPSS 11.0J for Windows and statistical significance was set at \( p<0.05 \).

Results

Table 1 shows the results of the comparison between the elderly group and the young group with regard to the COP-RMS and the COP-Vel. The elderly group showed significantly higher COP-RMS values \( (p<0.05) \) and lower COP-Vel values \( (p<0.001) \) than the young group. No significant difference was observed between the elderly group and the young group with regard to the lateral COP-RMS and the anterior-posterior COP-Vel.

Table 2 shows the muscular strength of each muscle studied in the elderly and young groups, and the differences between the two groups. The results revealed that the elderly group had significantly lower values than the young group with regard to muscular strength of all the muscles investigated.

In the elderly group, the muscular strength of the tibialis anterior was detected as a significantly independent variable of the anterior-posterior COP-RMS (Table 3), and the muscular strength of the adductor magnus was detected as a significantly independent variable of the lateral COP-Vel (Table 3).

Discussion

McIlroy et al. (1996) reported that the frequency of forward or backward stepping reactions followed by direct steps taken in order to recover lateral stability was 30% greater in the elderly subjects than in the young subjects. Furthermore, as compared to the young, the elderly were more likely to take multiple steps or use arm reactions to regain equilibrium, particularly when attempting crossover steps, in response to lateral perturbation of stance (Maki et al., 2000). These previous studies suggest that elderly subjects have difficulty in controlling their center of gravity (COG) in the lateral direction immediately after the stepping reaction (landing phase). In the present study, the elderly subjects exhibited significantly higher values of anterior-posterior COP-RMS and lower values of lateral COP-Vel than the young. The COP position was reported to vary around the COG and have a higher frequency than the COG motion (Benda et al., 1994). In other words, there is a positional change in the COP functions to control the drifting of the COG. The results of COP-RMS in this study indicated anterior-posterior instability during landing and the need to use multiple steps in the elderly subjects. Furthermore, they suggested the need to control the COG depending on the displacement of the anterior-posterior
COP during landing.

With regard to the relationship between the muscular strength and COP-RMS, the muscular strength of the tibialis anterior was detected as a significant independent variable of the anterior-posterior COP-RMS. Hurley et al. (1998) reported that many elderly subjects have relatively weaker tibialis anterior and vastus lateralis muscles as compared to the healthy younger individuals. Moreover, weakness in the tibialis anterior and vastus lateralis muscles could potentially impair an individual’s ability to correct a shift in COG and effectively prevent a fall (Laughton et al., 2003). The kinematic function of the tibialis anterior involved in maintaining standing stability cooperates with the triceps surae to coordinate the torque of dorsiplantar flexion of the ankle, and control the anterior-posterior COP. Considering the results of these previous studies and the present study, we suggest that the muscular strength of the tibialis anterior participates in the anterior-posterior stability of COP during landing.

This study revealed significantly lower values of lateral COP-Vel in the elderly than in the young. Shumway-Cook and Woollacott (1995) have reported that in conditions of unstable balance, the young can more rapidly shift the position of their COP and assimilate more information from the sensory system when compared with the ability of the elderly. The differences in COP-Vel between the groups revealed in this study indicated that the young may respond to lateral instability of posture occurring during a crossover step, depending on their control of the COG position in the lateral direction; may benefit from the feedback information from plantar sensibility; and may produce a rapid lateral shift in the COP position. In the elderly, the function of these posture regulations is probably decreased.

The muscular strength of the adductor magnus was detected as a significant independent variable of lateral COP-Vel. A previous study has reported that age-related strength loss in certain muscles may contribute to difficulty in controlling stability during the single stance phase and landing (Luchies et al., 1994; Maki and McIlroy, 1999). Furthermore, Maki and McIlroy (2006) reported that the profound weakening of the hip abductors and adductors that has been observed in the previous studies and the present study, we suggest that the muscular strength of the tibialis anterior involved in maintaining standing stability cooperates with the triceps surae to coordinate the torque of dorsiplantar flexion of the ankle, and control the anterior-posterior COP. Considering the results of these previous studies and the present study, we suggest that the muscular strength of the tibialis anterior participates in the anterior-posterior stability of COP during landing.

In conclusion, with regard to the COP deflection characteristics during landing after the stepping, the elderly subjects exhibited higher values of anterior-posterior COP-RMS and lower values of lateral COP-Vel than the young individuals. Furthermore, it was suggested that the muscular strengths of the tibialis anterior and adductor magnus participated in the control of these COP deflection characteristics.

References


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