The Influence of Aging on the Center of Pressure Trajectory: a Comparison of Crossing an Obstacle and Stepping onto a Curb from a Position of Quiet Stance

HYEONG-DONG KIM

Catholic University of Daegu, College of Health Science, Department of Physical Therapy: 330 Geumnak 1-ri, Hayang-eup, Gyeongsan-si, Gyeongbuk, Republic of Korea 712-702.
TEL: +82 53-850-3274, FAX: +82 53-850-3292

Abstract. [Purpose] The purpose of this study was to investigate how young and older adults modulate the center of pressure (COP) trajectory and stance time during obstacle negotiation. [Subjects] Fifteen healthy young adults and fifteen healthy older adults participated in the study. [Methods] The subjects stepped over an obstacle (18 cm in height, 10 cm in breadth and 140 cm in width) and a curb (18 cm in height, 140 cm in breadth and 140 cm in width) at a self-paced speed from a position of quiet stance. Performance was assessed by recording changes in the displacement of COP in the anteroposterior (A-P) and mediolateral (M-L) directions, and by measuring the average velocity of the COP and stance time using a force platform. [Results] The A-P and M-L displacement of COP and the average velocity of COP of the older adults were significantly less than those of the young adults (p <0.01). The stance time of the older adults was significantly greater than that of the young adults (p<0.01). However, the COP variables between the stepping tasks were not significantly different. [Conclusion] The COP shift and velocity and stance time during obstacle negotiation might be appropriate parameters for evaluating the dynamic balance and motor control strategies of older adults.

Key words: Balance, Falls, Obstacle negotiation

INTRODUCTION

Falls among older adults are common and can lead to serious morbidity. Approximately 33% of persons aged 65 years and over fall at least once a year\(^1,2\). Twenty percent of these older subjects require medical care after a fall and about ten percent of the subjects sustain a fracture; of the subjects who sustain a fracture, half require hospitalization to treat fall related injuries\(^3\). Furthermore, falls by the elderly result in disabilities, increased fear of falling, social isolation and even increased mortality\(^4\). Falls also present an enormous economic burden on the health care system and on society\(^5,6\). Thus, identification and understanding of the risk factors, in order to prevent or decrease falls, is of primary importance for the health and well being of the elderly.

Although the causes of falls of older subjects are multifaceted and heterogeneous, many falls by the elderly occur during stepping over obstacles or transitional movements, such as initiating, terminating or changing direction\(^7-9\). Some studies have investigated age-related differences in obstacle crossing. Compared to young adults, older adults show a slower approach speed, a...
significantly slower crossing speed and a shorter step length before crossing\textsuperscript{10,11}). The older adults also show positioning of both the leading and trailing feet relatively farther from the step edge in crossing\textsuperscript{10,11}). The older adults also appear to have less lead-foot clearance, little correction time in the event of a foot contacting an obstacle\textsuperscript{11}) and require increased warning times to avoid contact with an obstacle\textsuperscript{12}). These previous studies indicate that older adults use less efficient strategies than young adults to modify and adapt gait patterns when confronted with obstacles.

However, previous reports have only discussed the temporal and spatial parameters of obstacle avoidance and not the potential mechanisms underlying the diminished abilities of obstacle crossing of older adults. Since the center of pressure (COP) represents the response of the central nervous system (CNS) to movement of the whole body center of mass (COM)\textsuperscript{13}), an examination of changes in COP would provide valuable information about how older adults modulate gait patterns when encountering obstacles\textsuperscript{14,15}). Previous studies\textsuperscript{13,16,17}) suggest that with aging and in subjects with disabilities, the COP trajectory is destabilized, leading to diminished postural control and gait. For example, older adults show a reduced capability to generate COP shift and the magnitude of the peak COM-COP moment arm (measurement of the COM-COP distance) is lowered during gait initiation (GI)\textsuperscript{13,16,17}). However, no reports have examined age-related changes of the COP trajectory while actually crossing obstacles, including stepping over an obstacle and stepping onto a curb from the position of quiet stance, a task that would increase the risk of a fall. A comparison of young and older adults in negotiating obstacles may reveal different obstacle-avoidance strategies that may help to identify risk factors related to falls. The purpose of this study was to investigate how young and older adults modulate the center of pressure (COP) trajectory and stance time during obstacle negotiation.

### SUBJECTS AND METHODS

Fifteen community dwelling healthy older adults (mean age = 77.8 ± 5.6 years; age range, 65–83 years) and 15 healthy young adults (mean age = 24.3 ± 3.6 years; age range, 21–26 years) volunteered to participate in this study. Inclusion criteria for the older participants were: a Berg Functional Balance Scale score\textsuperscript{18,19}) > 50, a Frenchay Instrumental Activities of Daily Living Score\textsuperscript{20}) > 50 and a Physical Function Score\textsuperscript{21}) > 20. All participants scored more than 25 on the Mini Mental Status Examination (MMSE)\textsuperscript{22}). The reliability and validity of these tests have previously been reported as satisfactory\textsuperscript{23–25}). The subjects had no history of neurological, orthopedic or cardiac problems. All of the elderly participants reported no falls in the previous 12 months. All participants signed an informed written consent form approved by the University Institutional Review Board prior to participation. The subject characteristics are summarized in Table 1.

A force platform (AMTI, Newton, MA, USA), embedded in a level walkway (5 m in length and 1.22 m in width), was used to measure ground reaction forces during obstacle negotiation. The amplified force platform signals were sampled online at a rate of 1,000 Hz for 5 seconds (AMTI, Watertown, MA, USA). COP data were analyzed using BioAnalysis v2.0 software (AMTI, Watertown, MA, USA). An obstacle (18 cm in height, 10 cm in breadth and 140 cm in width) and a curb (18 cm in height, 140 cm in breadth and 140 cm in width) were used as obstacles. For each trial, subjects stood in a predetermined position on the force platform. Subsequently, the subjects then stepped over the obstacle or onto the curb at a self-paced speed with the right limb in response to an auditory cue. Subjects completed two practice trials and approximately five successful experimental
trials of stepping over the obstacle, and stepping onto the curb. All tasks were presented in a random order.

Two-way repeated analysis of variance (ANOVA) was used to determine the main effects. Single degree of freedom mean contrasts were used to determine the source of any significant effects. Statistical significance was accepted at p<0.05 and p<0.01. The independent variables were groups (young adults, older adults) and initiation condition (step over an obstacle, step onto a curb). The dependent variables included A-P and M-L displacement of COP, the average velocity of COP and stance time. The A-P (or M-L) displacement of COP was defined as the total distance (or difference) between the minimum and maximum A-P (or M-L) of the COP locus for the length of time that either the left or the right foot was in contact with the force platform. The average velocity of COP was defined as the average velocity traveled by the COP for the length of time that either the right foot or the left foot was in contact with the force platform. The stance time was measured from the onset of movement to toe-off of the stance limb (left foot) on the force platform. Time was measured from the first detectable onset of force platform activity. Statistical software SPSS 14.0 KO (SPSS, Chicago, IL, USA) was used for the statistical analyses.

RESULTS

Comparisons of changes in the COP responses and stance time for stepping over the obstacle and stepping onto the curb were analyzed for the young adults and the older adults. Generally, there were significant group differences in the A-P and M-L displacement of the COP, the average velocity of COP and the stance time. With the data for both tasks combined, the A-P and M-L displacement of COP of the young adults were significantly greater than those of the older adults (p<0.01) (Table 2). Furthermore, the average velocity of COP of the young adults was also significantly greater than that of the older adults (p<0.01). However, there were no significant differences between the stepping tasks for the A-P and M-L displacement of COP and the average velocity of COP. The mean of the A-P and M-L displacement of COP and the mean of the average velocity of COP between the stepping tasks were also similar. The stance time of the older adults was significantly longer than that of the young adults (p<0.01). In addition, the stance time showed a significant task effect (p<0.01). The obstacle crossing task has a significantly longer stance time than the stepping onto the curb task (p<0.01). The mean values for COP and stance time data for both groups (young adults and older adults) are summarized in Table 2.

DISCUSSION

The primary goal of this study was to investigate how young adults and older adults modulate COP trajectory and stance time during obstacle negotiation. The A-P and M-L displacement of COP and the average velocity of COP of older adults were significantly less than those of young adults. Furthermore, the stance time of older adults was significantly longer than that of young adults. With the data for both tasks combined, the mean A-P displacement of the COP of young adults was approximately 153% greater than that of the older adults. This finding is in accord with a previous study16, which demonstrated a decreased backward displacement of COP of older adults, indicating a diminishment in the forward momentum necessary to initiate gait. Such a reduction in forward momentum would result in decreased forward COM in the older adults during the early stage of GI. During GI, inhibition of the tonic soleus and the

| Table 2. Means (± SD) for the COP parameters and stance times of young and older adults during stepping over the obstacle and stepping onto the curb |
|---------------------------------|-----------------|-----------------|
|                                | Obstacle        | Curb            |
| A-P displacement (cm)*         |                 |                 |
| Young adults                   | 23.50 (2.40)    | 21.49 (2.17)    |
| Older adults                   | 13.62 (2.88)    | 15.80 (1.96)    |
| M-L displacement (cm)*         |                 |                 |
| Young adults                   | 22.18 (3.89)    | 20.12 (3.27)    |
| Older adults                   | 18.50 (5.03)    | 16.37 (4.29)    |
| COP average velocity (cm/sec)* |                 |                 |
| Young adults                   | 41.35 (5.16)    | 44.42 (7.14)    |
| Older adults                   | 31.68 (4.09)    | 34.36 (3.63)    |
| Stance time (ms)*†             |                 |                 |
| Young adults                   | 2157 (479)      | 1863 (408)      |
| Older adults                   | 2661 (244)      | 2331 (368)      |

*Significant difference (p<0.01) between groups.  †Significant main effect by task (p<0.01).

SD: Standard deviation; COP: center of pressure; A-P: anteroposterior; M-L: mediolateral.
activity of the tibialis anterior of both the swing and stance limbs are responsible for the backward movement of COP\(^{26-28}\). Swing limb hip abductors also create movement of COP toward the swing limb\(^{29}\). Thus, muscle activity at the ankle and hip tend to propel COM forward and toward the intended stance limb. The reduction in the magnitude of the displacement of the A-P COP and in forward momentum observed in the older adults would have been caused by reduced inhibition of soleus and gastrocnemius activity and increased ankle joint stiffness\(^{30}\). It has been suggested that a reduced ability to generate sufficient momentum may increase the risk of falls for the elderly\(^{31}\).

With the data for both tasks combined, the mean M-L displacement of COP of older adults was significantly lower than that of young adults. The current finding is consistent with the results of a previous study\(^{13}\) that demonstrated that older adults had a significantly decreased M-L displacement of COP as compared to young adults. During stepping trials, M-L shift of COP created by swing limb hip abductors toward the swing limb generated momentum toward the stance limb, thus moving COM anterolaterally toward the stance limb\(^{29}\). Decoupling of COM from COP is an important feature of GI since a more active postural control is needed as the separation of COM-COP increases. The mechanism maintaining M-L stability during GI is controlled by coordinated action of the hip abductor and adductor muscles\(^{32}\). Previous studies\(^{33-35}\) have reported that control of the whole body COM in the M-L direction through manipulation of COP during walking is responsible for maintaining lateral balance, which is highly related to the risk of lateral falls for the elderly. Chou et al.\(^{36}\) have suggested that M-L COM motion during obstacle crossing is an important functional indicator which can identify persons who are at risk of lateral falls or imbalance.

The velocity of COP provides valuable information about how individuals modulate gait when encountering various obstacles. With the data for both tasks combined, the mean velocity of COP of the older adults was significantly lower than that of the young adults. These observations suggest that the older adults perceived both stepping over the obstacle and onto the curb as challenging, and therefore changed their stepping strategy. However, there were no significant differences in the COP velocities between the stepping tasks. This finding suggests that the strategy for stepping over the obstacle adopted by both groups of subjects was not different from the strategy for stepping onto the curb.

Temporal variables for obstacle negotiation also provide information about the time that is required to modify limb trajectories. The stance time, from movement onset to toe-off of the stance limb (left foot), provides insight into the total time required for obstacle negotiation. Older adults showed significantly increased stance times as compared to young adults. During obstacle clearance, the stance limb must provide a stable base from which to cross an obstacle or step onto a curb. The obstacle or curb (18 cm) used in the present study clearly placed a higher demand on the hip abductor muscles of the older adults, to maintain pelvic obliquity, than was seen for the young adults\(^{37}\). There was also a significant difference in the stance times of the different stepping tasks. Stepping over the obstacle required a longer stance time than that required for stepping onto the curb. This finding indicates that even though the height of the obstacle and the curb were the same, the swing limb trajectories may be different, possibly requiring a greater toe clearance for stepping over the obstacle. A previous study\(^{37}\) reported that the toe clearance required for stepping over an obstacle was significantly greater than that for stepping onto a curb. The gluteus medius activity was also significantly increased for stepping over an obstacle as compared to stepping onto a curb or for GI\(^{37}\). These factors may influence the stance time required for stepping over an obstacle which was longer than that of stepping onto a curb.

In conclusion, there were age-related differences in the A-P and M-L displacement of COP, COP velocity and stance time during obstacle negotiation. The older adults had significantly lower COP shift and velocity than those of the young adults. Furthermore, the stance time was significantly longer for the older adults than for the young adults. The decreased magnitude of the COP shift and the reduced COP velocity diminished the abilities of the older adults to generate forward momentum and to maintain lateral stability. This reduction in the generation of forward momentum resulted in the increased stance time of the older adults as compared to the young adults. Moreover, the reduction of the COP shift and velocity and the increased stance time may indicate a control
strategy that was adopted by the older adults to maintain a slower progression of the body over the stance foot, as compared to the young adults, when stepping over the obstacle or stepping onto the curb. Given these circumstances, the COP shift and velocity and stance time during obstacle negotiation might be appropriate parameters for evaluating dynamic balance and motor control strategies of older adults. Finally, it will be necessary to explore the COP shift and velocity behavior in older adults who are at risk of falls and populations with CNS diseases associated with aging such as Parkinson’s disease and other degenerative disorders including Alzheimer’s disease.

REFERENCES


