Older Adults At High Risk of Falling Need More Time for Anticipatory Postural Adjustment in the Precrossing Phase of Obstacle Negotiation

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Background. Obstacles are a common cause of falls among older adults. Anticipatory motor planning for obstacle negotiation must be completed during the precrossing phase in order to step over the obstacle safely. This cognitive load may affect anticipatory postural adjustments (APAs) in older adults at high risk of falling. This study explored the effect of obstacle negotiation on APA during gait initiation in older adults at high risk of falling.

Methods. Seventy-six elderly volunteers (mean age: 80.5 [7.6 years]) from the community participated in this study. Participants performed gait initiation tasks from a starting position on a force platform under the following two conditions: (1) unobstructed (smooth walkway) and (2) obstructed (walkway with an obstacle placed at 1 m from the initial position). The reaction and APA phases were measured from the data of center of pressure. Each participant was categorized as a high-risk or a low-risk individual according to the presence or absence of a fall experience within the past year.

Results. High-risk participants had significantly longer APA phases than low-risk participants under the obstructed condition even though there was no significant difference between groups under the unobstructed condition. Reaction phase was not significantly different between groups in either the unobstructed or the obstructed condition.

Conclusion. Motor performance deterioration occurred in high-risk participants in the beginning of the precrossing phase of obstacle negotiation. A slow and inefficient APA at the precrossing phase of obstacle negotiation might be one of the causes of accidental falls.

Key Words: Accidental fall—Rehabilitation—Postural control.

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In the elderly population, trip is a common cause of falls and contributes to approximately 35%–53% of all falls (1–3); a large number of falls are reportedly caused by stepping on or tripping over obstacles (4,5). Trip-related falls are specifically responsible for 12%–22% of hip fractures suffered by older adults. There is, therefore, a need for effective interventions to reduce the incidence of trip-related falls in older adults.

Obstacle negotiation appears to stress the availability of cognitive resources, particularly among older adults. This finding is based on previous work demonstrating that successful obstacle crossing was compromised when participants were required to concurrently perform a cognitively demanding task (4,5). Obstacle negotiation, from the precrossing phase, is attentionally demanding due to the need for motor planning and visually dependent gait regulation (6,7). From these reports, the possibility of motor performance deterioration may precede the obstacle crossing event. However, other reports on obstacle negotiation examined only the crossing phase (ie, obstacle clearance, foot placement) (8–10), and no reports have focused on anticipatory postural adjustment (APA) during the precrossing phase of obstacle negotiation. In addition, few studies have examined the pattern of postural activity during obstacle negotiation in the older adults who are at a high risk of falling.

Many older adults fall while walking only short distances (11), suggesting that they have difficulty in balance control during the transition phase, including gait initiation and termination, which are frequently repeated during daily activities. It is considered that gait initiation requires more attentional resources than does steady-state walking (12,13). It is therefore necessary to clarify the postural control strategies employed by older adults at a high risk of falling in order to examine the gait initiation task. Gait initiation with motor planning for obstacle negotiation may demand high levels of attention and cause dual-task interference for older adults with attention allocation deficits.

Anticipatory motor planning for obstacle negotiation (eg, change of foot placement and obstacle clearance) may be the key component of successful obstacle crossing. The
goal of this study was to clarify motor performance deterioration specific to the older adults at a high risk of falling during obstacle negotiation, particularly in the precrossing phase. The present study compared APA during gait initiation under unobstructed and obstructed (with an obstacle placed anteriorly) conditions in older adults who were or were not at high risk of falling. We hypothesized that APA will be affected by motor planning for obstacle negotiation in older adults with a high risk of falling.

**METHODS**

**Participants**

Seventy-six older adults (mean age [SD], 80.4 [7.0 years]; height, 155.1 [9.9 cm]; weight, 54.7 [10.9 kg]) participated in this study. Volunteer participants were recruited from the community through advertisements in various local papers. Because approximately three of people more than 65 years of age in the community experience a fall each year (14), we selected this convenient sample for investigation. Inclusion criteria consisted of age ≥65 years, minimal hearing and visual impairments, and the ability to ambulate at least 10 m without the assistance of another person (cane permitted but not a walker).

Exclusion criteria were as follows: inability to see an obstacle or visual cue used during the experiment due to a visual impairment not correctable with glasses; severe cardiac, pulmonary, or musculoskeletal disorders; pathologies associated with an increased risk of falling (ie, Parkinson’s disease); use of psychotropic drugs; and the inability to follow multiple commands given by a physical therapist (eg, inability to perceive light-emitting diode [LED] illumination as a cue). Written informed consent was obtained from all 76 older adults included in the trial in accordance with the guidelines approved by the Kyoto University Graduate School of Medicine (approval number: E-809) and the Declaration of Human Rights, Helsinki, 1975.

Our sample size estimation was based on work by Melzer and colleagues (15) who showed that step execution (foot contact times) during the execution of a cognitive task was 1,414 ± 417 ms for elderly fallers. In their study, the foot contact time of all 11 elderly fallers was 1,050 ms or higher. Using the earlier values for a two-sided estimate at a significance level of 0.05 and 80% power, at least 22 participants are required to detect a significant change in foot contact from 1,414 to 1,050 ms.

Falls were assessed using the item “Have you fallen in the last year?” with two response categories (yes/no) (3). Each participant was categorized as being a high-risk (HR) or a low-risk (LR) elderly individual according to the presence or absence of a fall experience within the past year. (16). A fall was defined as an event that results in a person unintentionally coming to rest on the ground or any other lower level with or without injury or loss of consciousness.

(17). We specifically explained the definition of “fall” to the participants so that they could report falls correctly. If they were unclear as to whether they had experienced a fall, we consulted their families to verify the occurrence of a fall. The number, characteristics, and consequences of falls were recorded using a standardized questionnaire. Falls resulting from extraordinary environmental factors (eg, traffic accidents and falls while riding a bicycle) were excluded.

We recorded the following demographic and medical variables: the number of drugs used, mental status (Rapid Dementia Screening Test (18)), and fear of falling (modified Fall Efficacy Scale [FES] (19)). The total score for the modified FES can range from 10 to 40, with low scores indicating greater confidence.

**Experimental Protocol**

Participants initially stood upright on a force platform and loaded their weight evenly on both legs with their feet abducted 10° and their heels separated mediolaterally by 6 cm. In the gait initiation task (Figure 1), participants were instructed to execute a first step using the self-selected leg as quickly as possible after a visual cue. The obstacle was placed at 1 m from the initial position.

Figure 1. Schematic representation of the gait initiation test under the obstructed condition. Each participant initially stood upright on a force platform. Participants were instructed to execute the first step as quickly as possible after a visual cue. The obstacle was placed at 1 m from the initial position.

Participants were instructed to execute a first step using the self-selected leg as quickly as possible after a visual cue. The obstacle was placed at 1 m from the initial position. An LED was set 2.5 m in front of the participants at eye level. The test was performed under two different conditions: (1) unobstructed (normal gait initiation on the smooth walkway) and (2) obstructed (gait initiation on walkway with an obstacle placed 1 m from the initial position). Under both conditions, participants were made to gaze at the LED in the initial position and were allowed to see the floor and an obstacle after the visual cue of the LED. The obstacle was wooden and white (91.0 cm wide × 2.4 cm high × 1.0 cm deep). The walkway floor was dark brown. The obstacle location in the present study was defined as
being 1 m from the initial position because it is a length the older adults could not step over in the first step and would instead initiate anticipatory motor planning, which demands attention during gait initiation on the force platform. It is reported that the average first-step length during gait initiation is 52.5 cm in healthy older adults (mean age: 73 years) (16). If an obstacle were placed directly ahead, anticipatory motor planning during gait initiation would demand little attention because participants would know that they could cross the obstacle by the first step. Researchers made the participants check the location of the obstacle before the trial and instructed them to step over the obstacle. The number of steps to the obstacle crossing was arbitrarily prescribed. The obstacle would tip with a small external force, so it was expected that the risk of accidental falling by tripping was minimal. The order of the tasks was randomized. Before the experimental data were collected, the participants performed at least three trials to familiarize themselves with equipment, gait initiation task (except for the obstacle), and conditions.

All participants underwent three clinical measurements—a 10-m walking test (WT) (20), a timed up and go test (TUG) (21), and a functional reach (FR) test (22)—in the presence of an experienced physiotherapist.

In the WT, steady-state walking time (seconds) at a self-selected pace on a 10 m—long straight walkway was measured. Walking time was calculated using a stopwatch to measure the time taken to cover the central 10 m of the walkway (2 m at the start and finish were used for acceleration and deceleration). A WT score was calculated as the average time in seconds for completion of two trials.

In the TUG test, participants were asked to stand up from a standard chair with a seat height of 40 cm, walk a distance of 3 m at a normal pace, turn, walk back to the chair, and sit down. Time measured in seconds was counted from the moment the word “go” was said and was stopped when the participant’s back touched the chair backrest. The data of the second TUG trial were used for analyses.

In the FR test, each participant was positioned next to a wall with one arm raised at 90° and fingers extended. A yardstick was mounted on the wall at shoulder height. The distance that a participant could reach while extending forward from an initial upright posture to the maximal anterior leaning posture without moving or lifting the feet was visually measured in centimeters as the position of the third fingertip against the mounted yardstick. In this trial, participants used both arms. An FR score was calculated as the average distance (centimeters) between the initial and final fingertip positions of the middle finger obtained from each of two trials.

Data Collection and Analysis

Center of pressure (COP) data during gait initiation tests were collected with a portable Kistler 9286 Force Platform (Kistler Instrument Corp., Winterthur, Switzerland). The force platform data were sampled at a frequency of 1 kHz and low-pass filtered at 6 Hz. The analysis of gait initiation data extracted specific temporal events using a program written in MATLAB (MathWorks, Inc., Cambridge, MA). The following events were extracted from the COP data: (i) Step initiation was defined as the first mediolateral deviation of the COP toward the swing leg (COP excursion >3 SD away from the initial COP position defined as the mean amplitude in the 1,500-ms period prior to the onset of the visual cue) (23) and (ii) foot-off was defined as the end of the mediolateral shift of the COP toward the stance leg (absolute COP slope <100 mm/s, two samples in a row) (15). The reaction phase was calculated as the time from cue to step initiation. The APA phase was calculated as the time from step initiation to foot-off (Figure 2). The means and standard deviations were determined using data from three trials.

Statistical Analysis

For each parameter, the mean dependent variables were calculated by SPSS II (SPSS, Inc., Chicago, IL) using a two-way analysis of variance that included groups (HR and LR) as the between-subjects factor with repeated measures on the within-subjects factors of tasks (unobstructed and obstructed). A probability of $p < .05$ was considered statistically significant. When interaction effects were detected, Bonferroni post hoc comparisons were performed to assess group and task differences. The significance level of the multiple comparisons was adjusted by the Bonferroni correction ($p < .0125$). Student’s $t$ test for independent measures was used to evaluate the differences between fallers and nonfallers in the WT, TUG, and FR tests. Partial $\eta^2$ and Cohen’s $d$ values were calculated as measures of effect size.

To assess the predictive abilities of the gait initiation measures and whether the relationship between these measures and fall risk persisted in multivariate analyses after adjusting for confounding effects, logistic regression analysis, performed as an enter analysis, was carried out. In this analysis, HR and LR were used as the dependent variables,
and gait initiation measures (the reaction and APA phase, under the obstructed and unobstructed conditions), WT, TUG, FR, FES, and the number of drugs used were employed as independent variables.

**RESULTS**

**Participant Characteristics**

Of the 76 participants aged 65–96 years who participated in the study, 26 (34%) were classified as HR (one or more falls) and 50 (66%) were classified as LR in terms of events over the past year. Table 1 shows the demographic and medical variables and performance characteristics of the 76 participants and the differences in performance test scores between HR and LR. There were no significant differences in age, height, weight, gender, number of medications, or Rapid Dementia Screening Test score between the groups. HR, however, showed a higher score in the FES than LR (p = .01). In clinical measurements, no significant differences were detected in the WT (p = .14, d = .37) or FR (p = .13, d = .40) tests. In the TUG test, HR participants had significantly slower times than LR participants (p = .013, d = .67).

**Performance of Gait Initiation Test**

There were no unsuccessful crossings or obstacle contacts recorded in this study. Table 2 depicts all variables for HR and LR participants in the individual task condition.

![Figure 3. Average measurement parameters for both groups of participants in unobstructed and obstructed conditions.](image)

No interaction effects between group and task conditions were detected in the reaction phase; p = .65, F(1,74) = 0.21, η² = 0.003; Figure 3. There was a significant main effect of the task condition; p = .031, F(1,74) = 4.82, η² = 0.061; whereas there was no significant group effect; p = .51, F(1,74) = 1.95, η² = 0.027.

Interaction effects between group and task condition were detected in the APA phase; p = .025, F(1,74) = 5.25, η² = 0.066; Figure 3. There were significant main effects of task condition; p < .001, F(1,74) = 24.7, η² = 0.25; and group; p = .04, F(1,74) = 4.35, η² = 0.056. The main effect was qualified by the interaction. Post hoc comparison showed that the APA phases of the HR participants were significantly longer than those of the LR participants under the obstructed condition (HR: 0.45 [0.12] seconds; LR: 0.42 [0.13] seconds; p = .008, d = 0.84) and that there was no statistical difference between groups under the unobstructed condition (HR: 0.58 [0.17] seconds; LR: 0.46 [0.13] seconds; p = .36, d = 0.25). HR participants had significant delays in the APA phase under the obstructed condition compared with the unobstructed condition (p < .0025, d = 0.88), whereas there was no statistical difference between task conditions in LR participants (p = .025, d = 0.31).

The data of the gait initiation measures (the reaction and APA phase, under the obstructed and unobstructed conditions), WT, TUG, FR, FES, and the number of drugs used were entered in the logistic regression models by using enter analysis. The APA phase under the obstructed condition was the only independent variable that persisted in the final

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**Table 1. Participant Characteristics**

<table>
<thead>
<tr>
<th>Value</th>
<th>HR (n = 26)</th>
<th>LR (n = 50)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>81.6 [7.3] (65–95 y)</td>
<td>79.7 [6.9] (65–93 y)</td>
<td>.32</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>156.7 [11.0]</td>
<td>155.6 [9.0]</td>
<td>.41</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>57.9 [11.8]</td>
<td>54.2 [10.3]</td>
<td>.29</td>
</tr>
<tr>
<td>Gender (% males)</td>
<td>34.6%</td>
<td>34%</td>
<td>.96 †</td>
</tr>
<tr>
<td>No. of medications</td>
<td>7.0 [4.7]</td>
<td>4.7 [4.7]</td>
<td>.09</td>
</tr>
<tr>
<td>RDST</td>
<td>5.3 [3.2]</td>
<td>5.4 [3.1]</td>
<td>.95</td>
</tr>
<tr>
<td>FES</td>
<td>17.7 [6.0]</td>
<td>13.9 [5.8]</td>
<td>.01</td>
</tr>
<tr>
<td>WT (s)</td>
<td>13.8 [5.9]</td>
<td>11.9 [4.7]</td>
<td>.14</td>
</tr>
<tr>
<td>TUG (s)</td>
<td>15.2 [6.3]</td>
<td>11.2 [4.6]</td>
<td>.013</td>
</tr>
</tbody>
</table>

Notes: FES = Fall Efficacy Scale; FR = functional reach test; HR = high-risk elderly individual; LR = low-risk elderly individual; RDST = Rapid Dementia Screening Test; TUG = timed up and go test; WT = walking test. Values are shown as mean [SD]. 

*p values are based on t test or chi-square.

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**Table 2. Two-Way Repeated Measures Analysis of Variance Findings on Measurement Parameters**

<table>
<thead>
<tr>
<th>Value</th>
<th>Unobstructed</th>
<th>Obstructed</th>
<th>Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR</td>
<td>LR</td>
<td>HR</td>
<td>LR</td>
</tr>
<tr>
<td>Reaction phase, s</td>
<td>0.30 (0.09)</td>
<td>0.28 (0.09)</td>
<td>0.32 (0.10)</td>
</tr>
<tr>
<td>APA phase, s</td>
<td>0.45 (0.12)</td>
<td>0.42 (0.13)</td>
<td>0.58 (0.17) †</td>
</tr>
</tbody>
</table>

Notes: Values are shown as mean (SD). HR = high risk; LR = low risk.

* Significant difference between unobstructed and obstructed condition in individual groups (Bonferroni, p < .0025).

† Significant difference between HR and LR participants in individual task condition (Bonferroni, p < .0125).
Discussion

No significant differences were observed between HR and LR participants in the reaction or APA phases under the unobstructed condition. This indicates that HR and LR individuals use the same motor program in normal gait initiation on the smooth walkway. In the present study, even HR participants might have sufficient ability to perform a gait initiation task on a smooth walkway as successfully as LR participants because it requires little anticipatory motor planning.

On the other hand, HR participants had significantly longer APA phases than LR participants under the obstructed condition. During the precrossing phase, specific deterioration of motor performance in HR participants arose from the anteriorly placed obstacle. The precrossing phase of obstacle negotiation is a visually guided process (24), and it is thought that visually dependent regulation of gait incurs an additional attention cost (6,7). Greany and colleagues (25) reported that elderly community dwellers at high risk of falling demonstrate longer saccade-footlift latency during the crossing phase than those at low risk of falling and that the delay may be attributed to the greater central nervous system processing time necessary to plan precise foot placement. It is also likely that delayed central cognitive processing can cause an increase in preparation (i.e., APA) phase duration for which older adults may need more time to plan an anticipatory control strategy (26,27). We focused on the beginning of the precrossing phase and suggest that prolonged APA phases (i.e., weight transfer to the stance limb for safe stepping) under the obstructed condition in HR participants may be associated with the delay in central processing time for developing a motor plan from visual anchors in the working memory.

In the reaction phase, no interaction effects between group and task conditions were detected. The reaction phase was defined as the time required for perception of the cue and recollection of the motor plan (28). Secondary cognitive tasks prolong the reaction phase of step initiation, particularly in HR individuals (15). In the present study, even HR participants could focus all their attention on a visual cue because participants were not instructed to perform a secondary task while awaiting a cue.

Logistic regression analysis revealed that the prolonged APA phase observed under the obstructed condition was associated with a fall risk after adjusting for confounding effects. In addition, effect size (Cohen’s $d$) for the difference in the duration of the APA phase under the obstructed condition between HR and LR was the largest among the variables measured in the present study. Therefore, the prolonged APA phase observed under the obstructed condition in HR participants may be one of the reasons why some older adults fall or trip more frequently than others when walking in situations in which precise foot placement is required, such as obstacle negotiation. The movement of the stepping leg during gait initiation is preceded by APA serving to shift the center of mass toward the supporting side so that the leg can be raised (23). Cognitive load, such as motor planning for obstacle negotiation, might cause the affected postural synergy (i.e., weak response of the gluteus medius on the stepping side, cocontraction of antagonistic muscles) that makes center of mass movement nonsmooth in HR participants.

Obstacle negotiation necessitates modifications to the gait pattern that occur at least two steps prior to stepping over (29). Impairment of motor planning and gait regulation for obstacle negotiation may be one of the causes for trips or falls. Rehabilitation strategies that correct not only the obstacle crossing but also the cognitive process and the APA phase during the precrossing phase would be potentially beneficial for fall prevention in older adults.

In conclusion, we demonstrated a significantly longer APA phase in HR participants during gait initiation under the obstructed condition. The present study is the first to investigate postural activity during the precrossing phase of obstacle negotiation. The major implication of our findings is that specific deterioration of motor performance occurs in HR individuals in the beginning of the precrossing phase of obstacle negotiation. Insufficient central processing capacity for motor planning and gait regulation may be one of the causes of trip-related falls in older adults.

Acknowledgments

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References


