Effects of Age on Attentional Demands and Postural Control of Obstacle Crossing: Evidence from a Dual-task Approach

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Abstract

In order to determine whether cognitive demand disrupts balance and walking patterns for the elderly, a total of twelve healthy seniors and fifteen healthy young adults are recruited to complete three tasks: a single primary task (obstacle crossing), a single secondary task (pressing a button), and dual tasks (obstacle crossing and pressing a button). Two in-series force platforms and a three-dimensional six-camera motion analysis system are used to record the ground reaction forces and motion data, respectively. A stimulus tone is produced and the reaction time is recorded by STIM software. Our results show that aging might increase the stride time and reaction time, while decreasing the walking velocity, the peak center of mass velocity in the anterior/posterior and medial/lateral directions, the medial center of mass and center of pressure inclination angle, and accuracy in the tone discrimination task. In addition, elderly subjects demonstrated a significant increase in stride time, reaction time, and decrease in accuracy of tone detection under the dual-task condition compared to those demonstrated under single-task conditions. Data suggests that elderly subjects adopted a conservative gait strategy to maintain stability and that they were more likely to be distracted under dual-task conditions. Their performance in a cognitive task is thus influenced by locomotion.

Keywords: Dual-task condition, Balance, Elderly, Postural control

1. Introduction

Falls are among the most serious problems facing the elderly population. An injury from a fall can result in disability, loss of independence, and a reduced quality of life. The ability to quickly step over obstacles in a stable manner is required for people to adapt to a complex environment, and is especially important for avoiding falls in elderly people [1,2]. Previous studies showed that about 25% to 35% of people over 65 years old fall each year [3-6], a large proportion of whom trip over obstacles during gait [5].

A study has shown that slowed walking while talking can be used to predict a fall [7]. Previous studies also confirmed that balance decreases as the difficulty of a dual-task activity increases [8,9]. Thus, cognitive demand can disrupt balance [10] and walking patterns [11,12], increasing the risk of falling. Furthermore, research using the dual-task paradigm has shown that the use of an assistive device increases attentional demands during standing for healthy individuals [13]. The verbal reaction time (RT) for a secondary verbal task was found to be longer when healthy individuals walked with a standard walker or rolling walker compared to when they walked without a device [13]. It is thus reasonable to expect that it is more difficult to maintain dynamic balance of the whole body during obstacle crossing combined with verbal communication than it is during unobstructed level walking or simple obstacle crossing. However, few studies have documented this issue.

Aging leads to a decrease in dual-task performance, but the source of this effect is unclear. What is the difference between older adults and younger adults in strategy selection? Will older adults seek posture compensation for their poor balance during an obstacle crossing challenge or avoid responding to a verbal question in order to maintain balance? Answers to these questions will be a major part of designing fall rehabilitation programs for fall-prone elderly persons. The present study investigates the differences in obstacle crossing performances and the associated attentional demands between elderly and young adults under single- or dual-task conditions. The first hypothesis of this study is that elderly persons will exhibit poorer cognitive response and postural control than young adults. The second hypothesis is that elderly persons...
have more sensitivity to sound stimuli interference than young adults and that impairs their postural control ability while executing a cognitive task. The third hypothesis is that elderly persons have more sensitivity to motor task interference than young adults and that the decrease of information-processing ability when performing a cognitive task becomes more apparent during obstacle crossing. According to three hypotheses mentioned above, these functional reductions are marked by abnormal spatiotemporal gait data, RT, and accuracy ratio in the tone discrimination task.

2. Materials and methods

2.1 Participants

Twelve healthy elderly adults (4 males and 8 females) and fifteen healthy young adults (9 males and 6 females) were included in this study. The mean age of the elderly subjects was 70.75 ± 2.36 years and that of the young adults was 22.20 ± 1.92 years. The mean heights and body weights were 166.75 ± 10.84 cm and 63.75 ± 1.89 kg for elderly subjects and 170.20 ± 3.70 cm and 61.80 ± 2.86 kg for young adult subjects, respectively. To be included, participants had to be free of related musculoskeletal problems, hearing problems, and cognitive problems, and without a fall history. Informed consent, approved by the university ethical review committee, was obtained from all volunteers prior to involvement in the study.

2.2 Materials

A sound operating system (STIM Acquisition Software, Compumedics Neuroscan, USA) was used to provide a stimulus tone to the subjects. Two in-series force platforms (Kistler Instruments, Inc, Winterthur, Switzerland) embedded in the center of a 12-m walkway were used to record ground reaction forces with a sampling frequency of 1000 Hz. Obstacles (11 in total) were made of polyvinyl chloride plates. Each obstacle contained two upright standards (length: 19 cm; width: 2 cm; height: 8 cm) and one crossbar (length: 90 cm; width: 19 cm; height: 2 cm). One of the eleven obstacles was centered between two force plates. Five obstacles were placed in front of the first force platform and the other five were placed behind it. The spacing between obstacles was adjusted for each subject to ensure comfortable foot placements and to be equal distance for each step. A three-dimensional six-camera motion analysis system (Qualisys Motion Capture Systems, Qualisys AB, Sweden) was used to collect the motion data of the whole body with a sampling frequency of 100 Hz. During the RT test, a self-assembled radio telemetry handheld trigger was used to signal a response. The ground reaction force and motion data were recorded on a desktop computer. The stimulus tone and reaction signals were recorded on a notebook computer.

2.3 Procedure

For kinematic analysis, twenty-one reflective landmarks (Helen Hayes) were attached to the trunk, upper limbs, and lower limbs to register the positions of eleven body segments, namely feet, lower legs, upper legs, lower arms, upper arms, and head-trunk, in three-dimensional coordinates. Markers were placed on the sacrum, bilaterally on the acromion, lateral humeral epicondyle, midpoint of the radius and ulnar styloid process, anterior superior iliac spines (ASIS), lateral femoral condyles, lateral malleoli, the space between the first and second metatarsal heads, the heels, and on 10-cm wands placed at mid-thigh and mid-shank.

Prior to the RT test, the participants were familiarized with two tones (2 kHz target tone and 1 kHz nontarget tone) and were instructed to walk at their self-selected comfortable speed and press the button with the dominant hand upon hearing a high-frequency tone signal. A large number of practice runs were carried out in order to minimize the effects of learning.

In order to determine the differences in obstacle crossing performances and the associated attentional demands between elderly and young adults, three conditions, namely a single primary task (obstacle crossing), a single secondary task (pressing a button), and dual tasks (obstacle crossing and pressing a button), were tested for each participant.

For the single primary task, each subject was first asked to stand in front of the first obstacle as a starting point with a symmetric stance. Subjects were then asked to perform barefooted obstacle crossing for a total of eleven obstacles at a comfortable self-selected pace for each trial. Each subject performed a total of three trials of obstacle crossing upon hearing “go” from an examiner.

For the single secondary task, each subject performed quick button presses while quietly standing upon hearing a high-frequency (2 kHz) tone signal. The stimulus signal was programmed to trigger every 1.5 seconds with a duration of 200 ms. Of all auditory stimuli, 20% were high-frequency tone target stimuli, and the rest were randomly occurring low-frequency (1 kHz) tone nontarget stimuli. The sound operating system generated a total of 150 test signals (30 high-frequency and 120 low-frequency signals) in random order, with the only constraint being that two target signals could not appear consecutively. A thirty-second rest was arranged between every fifty test signals.

For the dual-task condition, the subjects were required to perform two tasks simultaneously: pressing a button and obstacle crossing. Initially, each subject stood in front of the first obstacle as a starting point with a symmetric stance and was instructed to cross the other ten obstacles at a comfortable speed. Subjects heard an audible stimulus signal every 1.5 seconds and were asked to respond upon hearing a high-frequency (2 kHz) tone signal by pressing a button with the dominant hand on the handheld trigger. Subjects were given instructions to react as soon as possible. Low-frequency tone stimuli were randomly dispersed throughout the testing session. Approximately 80% of the audible stimulus signals were the low-frequency tone so that subjects were unaware of when a high-frequency tone signal would occur. After each obstacle crossing trial, the subject returned to the starting position and waited several seconds for the next trial to begin.
A three-minute rest was arranged between every five obstacle crossing trials (1 session). In total, each subject performed approximately 30 trials (6 sessions) for this experimental condition.

Overall, subjects were allowed a rest period of ten minutes between each testing conditions (single primary task, single secondary task, and dual-task activity). All subjects were tested under three conditions in random order.

2.4 Data analysis

The signals from the stimulus tone and the radio telemetry receiver were collected at 1000 Hz for 10 s. The RT was calculated from the time difference between the stimulus tone signal onset and the trigger signal onset. The accuracy of responses was defined as the ratio of correct responses to the total target tones.

Qualisys Track Manager software (Qualisys Motion Capture Systems, Qualisys AB, Sweden) was used to track the markers in space for 10 s at 100 Hz. The position data of all markers were smoothed using a fourth-order Butterworth low-pass filter with the cutoff frequency set to 6 Hz. The walking velocity, stride time, and step width were calculated using Visual3D software (Qualisys Motion Capture Systems, Qualisys AB, Sweden) and analyzed only for the middle of the 6-walking step values. An 11-segment, full-body model (forearms, upper arms, head + trunk, thighs, shanks, feet) was implemented in Visual3D, and the instantaneous location of the full-body center-of-mass (COM) and the first time derivative of the position data of COM (COM velocity) were calculated within Visual3D. The position of the whole body COM was computed from the positions of the segmental COMs. The COM velocity values were calculated from position and time measurements. COM data was truncated to one obstacle crossing stride from the leading limb toe-off (LTO) to the trailing limb heel-strike (THS), and individual gait events were identified for further processing [14]. Finally, the COM peak velocities in the A/P (AP V) and M/L directions (ML V) were analyzed.

Ground reaction force (GRF) data were filtered with a fourth-order Butterworth low-pass filter with the cutoff frequency set to 20 Hz. The filtered data was used in the subsequent center of pressure (COP) analysis. COP data were calculated during one obstacle crossing stride from the signals from the first and second force plats. Self-developed MatLab (MathWorks) programs were used to complete the processing of the data. Finally, the COP data were synchronized with the COM data to find the peak anterior (A angle), posterior (P angle), and medial COM-COP inclination (M angle) angles. The sagittal and frontal COM-COP inclination angles were defined as the angles formed by the interaction of the line connecting the COM and COP with a vertical line through the COP [14,15] on these planes, respectively. The peak angles in the sagittal and frontal planes were calculated using the maximum horizontal COM-COP separation distance in the anterior-posterior and medio-lateral direction, respectively, and the corresponding vertical COM height. A previous study showed that the COM-COP inclination angle can be used to identify fallers from non-fallers [14]. This parameter could serve as a sensitive measure of gait stability in the elderly.

2.5 Statistical analyses

Spatio-temporal parameters (walking velocity, stride time, and step width), COM parameters (AP V and ML V), and COM-COP parameters (A angle, P angle, and M angle) were compared between two experimental conditions, namely single primary task (obstacle crossing) and dual tasks (obstacle crossing and pressing a button), and between two age groups with a one-way repeated measures analysis of variance (ANOVA). The RT and accuracy ratio in the tone discrimination task were also compared between two experimental conditions, namely single secondary task (pressing a button) and dual tasks (obstacle crossing and pressing a button), and between two age groups with a one-way repeated measures ANOVA.

3. Results

The data show that no significant interaction effects on the outcome measures (such as walking velocity, stride time, and step width, A angle, P angle, and M angle, RT, and accuracy ratio) were observed when using the repeated measures ANOVA. Therefore, the following subsections mainly discuss the between-group effects and within-group effects on the outcome measures.

3.1 Spatio-temporal parameters

The gait temporal-distance measurements from LTO to THS during an obstructed crossing for young adult and elderly subjects are shown in Table 1. In total, there were significant group differences in stride time (p < 0.05) and walking velocity (p < 0.05). Compared to the young adult group, walking velocity in the elderly group was significantly lower and the stride time was longer. In addition, compared to the single primary task, the stride time increased for the dual-task activity for the young adult (p < 0.05) and elderly (p < 0.05) groups.

Table 1. Gait temporal-distance measurements for the two age groups during single primary task and dual-task activity (mean value with standard deviation in parentheses).

<table>
<thead>
<tr>
<th></th>
<th>Young adults (n=15)</th>
<th>Elderly (n=12)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single primary task</td>
<td>Dual-task activity</td>
</tr>
<tr>
<td>Stride time (s)</td>
<td>1.37 (0.15)*†</td>
<td>1.50 (0.20)*†</td>
</tr>
<tr>
<td>Walking velocity (m/s)</td>
<td>0.76 (0.11)†</td>
<td>0.78 (0.10)†</td>
</tr>
<tr>
<td>Step width (m)</td>
<td>0.11 (0.04)</td>
<td>0.12 (0.05)</td>
</tr>
</tbody>
</table>

* denotes p < 0.05 compared to the dual-task activity in the given group.
† denotes p < 0.05 compared to elderly group.

3.2 COM parameters

Significant decreases in peak AP V and ML V were detected in the elderly group when compared to those of the young adult group (Table 2, p < 0.05) during all tasks. However, no task effects were detected for this parameter in
either the young adult (p > 0.05) or elderly (p > 0.05) groups. This means that the differences in this parameter between the single primary task and dual-task activity were not statistically significant for both the young adult and elderly groups.

Table 2. Mean and standard deviations of the peak velocities in the A/P (AP V) and M/L directions (ML V) for the two age groups during single primary task and dual-task activity (mean value with standard deviation in parentheses).

<table>
<thead>
<tr>
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<th>Elderly (n=12)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single primary task</td>
<td>Dual-task activity</td>
</tr>
<tr>
<td>AP V (m/s)</td>
<td>1.00 (0.11)†</td>
<td>0.91 (0.12)†</td>
</tr>
<tr>
<td>ML V (m/s)</td>
<td>0.25 (0.05)†</td>
<td>0.28 (0.04)†</td>
</tr>
</tbody>
</table>

† denotes p < 0.05 compared to elderly group. No task effects were detected for these parameters.

3.3 COM-COP parameters

The instantaneous COM-COP inclination angles are illustrated in Fig. 1. The overall pattern of angular changes in elderly subjects is similar to that observed in young adult subjects. However, a narrower medio-lateral angular excursion than youngers is shown in Fig. 1. Table 3 shows that the M angles are significantly smaller in elderly subjects than in young adult subjects (p < 0.05). However, no group differences were detected for the A and P angles. In addition, no significant task effects were detected for the A angles, P angles, and M angles during a stride cycle in either group.

![Figure 1](image1.png)

Figure 1. (a) Mean anterior-posterior and (b) medial COM-COP inclination angles for younger and elderly adults during performing single-primary task and dual-task.

Table 3. Mean and standard deviations of the A angle, P angle, and M angle during single primary task and dual-task activity (mean value with standard deviation in parentheses).

<table>
<thead>
<tr>
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<th>Elderly (n = 12)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single primary task</td>
<td>Dual-task activity</td>
</tr>
<tr>
<td>A angle (°)</td>
<td>10.14 (4.58)</td>
<td>9.57 (3.99)</td>
</tr>
<tr>
<td>P angle (°)</td>
<td>10.31 (6.74)</td>
<td>9.04 (6.77)</td>
</tr>
<tr>
<td>M angle (°)</td>
<td>6.41 (0.34)†</td>
<td>5.74 (0.75)†</td>
</tr>
</tbody>
</table>

† denotes p < 0.05 compared to elderly group. No task effects were detected for these parameters.

3.4 Reaction time and accuracy ratio in tone discrimination task

The RT was significantly faster for all participants in the single secondary task condition than for the dual-task condition (p < 0.05). RT values for the two conditions in each group show a difference of almost 100 ms (Table 4). Analysis results show a significant group effect on RT values in the single secondary task (pressing a button, p < 0.05) and dual-task (obstacle crossing and pressing a button) conditions (p < 0.05).

The accuracy ratios were 99.77 ± 1.29 for the young adult group and 98.97 ± 4.12 for the elderly group for the single secondary task. During the dual-task activity, the accuracies decreased to 99.50 ± 1.33 and 92.26 ± 24.01 for the young adult and elderly groups, respectively. The accuracy ratio in the tone discrimination task was significantly higher for elderly participants in the single secondary task condition than for the dual-task condition (p < 0.05, Table 4). However, no significant differences were detected for young adults between the single secondary task condition and the dual-task condition (p > 0.05). Overall, no significant group differences were found in the accuracy ratio for the single secondary task (p > 0.05) condition. However, analysis results show a significant group effect on the accuracy ratio for the dual-task condition (p < 0.05).

Table 4. Reaction time and accuracy measurements for the two age groups during single primary task and dual-task activity.

<table>
<thead>
<tr>
<th></th>
<th>Younger (n=15)</th>
<th>Elderly (n=12)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single primary task</td>
<td>Dual-task activity</td>
</tr>
<tr>
<td>Reaction time (ms)</td>
<td>(61.81)*†</td>
<td>(56.98)*†</td>
</tr>
<tr>
<td>Accuracy</td>
<td>99.77 (1.29)‡</td>
<td>98.97 (4.12)‡</td>
</tr>
</tbody>
</table>

* denotes p < 0.05 compared to the dual-task activity in the given group.
† denotes p < 0.05 compared to elderly group.
A mean value with standard deviation in parentheses.

4. Discussion

Differences in abilities to respond appropriately in the cognitive-challenging dual-task condition may help explain the differences in rates of falls and fall-related injuries between age groups. However, the biomechanical factors that underlie mobility problems among older adults in the cognitive-challenging dual-task condition are not well understood. This study thus discusses the gait changes that occur in spatio-temporal parameters, COM parameters, COM-COP parameters, RT, and accuracy ratio in the tone discrimination task.
Firstly, it was found that walking velocities in the elderly group are significantly lower compared to those for the young adult group (Table 1). The stride time was longer in the elderly group. These results agree with those in previous studies [1,16]. Previous studies showed that older adults exhibit a conservative strategy when crossing obstacles, with slower crossing speed [1] and shorter step length [1,16]. For the dual-task condition, previous studies showed that older adults decrease their gait speed [17-21], stride length [22], and swing time [18]. During the dual-task challenge, the elderly also displayed a gait pattern with a longer stride time than that during the single task condition [17,22]. In this study, the only difference compared to single-task activity is that the stride time increased for the dual-task activity for both the young adult and elderly groups. There were no other significant task differences in gait speed and step width for either the young adult or elderly groups. This might be explained by the low impact level of the auditory stimulation. In this study, the dual-task design was possibly not difficult enough to affect gait measurements. As a result, no significant task differences were found.

Significant decreases in peak AP V and ML V were detected in the elderly group when compared to the young adult group during all tasks in this study (Table 2). This means that the elderly change their gait strategy to maintain stability during obstacle crossing. These results are similar with those in a previous study [23]. This study and that by Michael and Chou (2004) [23] show that anterior COM velocities were significantly lower in the elderly group. This study also shows that the peak ML V values are significantly decreased in the elderly subjects compared to those of young adult subjects. The result differs from Michael and Chou’s study [23]. The results in their study suggested that healthy elderly adults can maintain dynamic balance control in the frontal plane (M/L directions) during locomotion. It means the elderly subjects in this study adopted a slower and more conservative gait strategy to maintain stability.

The findings in this study also reveal that the elderly subjects had a smaller inclination COM-COP angle in the frontal plane (Table 3). This means that elderly subjects adopted a more conservative gait strategy to maintain stability during obstacle crossing task. They keep their line of gravity as close as possible to the base of the supporting foot to maintain stability.

Many previous studies [24-26] have reported statistically significant age differences among healthy adults in myoelectric latencies and time of muscle force development. Similar observations were made in this study. The RT is defined as the delay between stimulus onset and the first measurable change in the button-pressing forces exerted by the dominant finger on the trigger. It includes both the myoelectric latency and the finite time required for a muscle to develop or change its force magnitude after myoelectric activity begins. This study verified that the overall RT increases with age (Table 4). In addition, this study also found that the RT was significantly faster for all participants in the single secondary task than for the dual-task condition. It is known that the latency period, before myoelectric activity begins, is affected by the difficult of a task. This implies that the difficulty of the dual-task activity delays the electrical signals sent through the brain's motor cortex to initiate or modify the muscle contraction process.

It was also found that there were variations in the tone discrimination accuracy ratio for elderly people for the dual-task condition. The ratio varied by a standard deviation of 24.01 (Table 4). This implies that differences in physical or mental health, such as fitness levels or cognitive functions, may be related to poor discrimination ability. It is suggested that future studies group elderly subjects according to their fitness levels or cognitive functions in order to discriminate whether these factors affect dynamic balance and attentional demands during obstacle crossing.

In summary, the findings of this study reveal significant age-related differences in stride time, walking velocity, AP V, ML V, M angle, RT, and accuracy ratio in the tone discrimination task, but no differences in A and P angles. Walking with a concurrent cognitive task resulted in insignificant changes in most gait measurements for both groups, with only some differences in stride time, RT, and accuracy ratio measurements. This means that the subjects in this study adopted similar gait strategies to maintain stability for the dual-task and single primary task conditions. There were minor differences exhibited in information processing speed. The subjects in this study processed all information more slowly during dual-task work and gave most of their attention to the obstacle crossing task. A person has a fixed capacity for attention [27], such that when attention is divided between two tasks, performance decreased compared to performing each task individually [28]. Therefore, if failure in the secondary task presents no danger, locomotion naturally receives first priority [29]. The dual-task design used in this study was not difficult enough to affect both gait and RT measurements. More challenging tests are recommended for future design of the testing protocol.

A limitation of the present study is that some factors were not taken into consideration, such as the different degrees or types of cognitive load, which will also influence the task effect. As a result, the task effect on gait parameters cannot be clearly distinguished in the present study. In future studies, a dual-task activity with different degrees or types of cognitive load should be designed to allow the monitoring of their effects.

5. Conclusions

This study has verified that there are age-related differences in the ability of individuals to perform obstacle crossing tasks and that the associated attentional demands increase with aging. Aging might delay early sensory processing and cognitive functioning. Elderly subjects changed their gait strategy to maintain stability during obstacle crossing. They adopted a slower, more conservative gait strategy to maintain stability. All subjects were found to be able to adjust their whole body center of mass motion to maintain dynamic
stability while crossing obstacles with divided attention. However, they demonstrated a significantly poor response time, especially the elderly. Results suggest that the attention of elderly subjects is more likely to be distracted under motor interference during a dual-task activity. Their performance of a cognitive task is thus influenced by locomotion. The findings prove that maintaining dynamic balance of the whole body during cognitive combined task is not more challenging than that during simple locomotion task. However, the elderly's cognitive performance is significantly changed under cognitive combined task.

Acknowledgements

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