Stepping Over Obstacles: Dividing Attention Impairs Performance of Old More Than Young Adults

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Background. Tripping over an obstacle is a common cause of falls in the elderly. An earlier study of abilities to avoid stepping on suddenly appearing obstacles found that, although healthy old adults had a lower rate-of-success than young adults, the magnitude of that difference was not large. The present study inquired whether dividing attention during such a task would differentially affect young and old healthy adults.

Methods. Rates-of-success were observed in 16 young and 16 old healthy adults (mean ages 24 and 72 years) in avoiding stepping on a band of light that was suddenly projected across their gait path while they walked at their comfortable gait speed. This virtual obstacle was placed at predicted next-footfall locations to give 350 or 450 msec available response times before footfall. During most of the trials the subjects were asked, in addition to trying not to step on the obstacle, simultaneously to respond vocally as quickly as possible when red lights near the end of the walkway turned on. These attention-dividing reaction time tests were of two types: synchronized, when only red lights lit at intervals synchronized with the appearance of the obstacle, and unsynchronized, when green or yellow lights lit in addition to the red lights, with lighting intervals not synchronized with the appearance of the obstacle.

Results. When synchronized and unsynchronized reaction time tests were conducted concurrently with the obstacle avoidance tasks, mean rates-of-success in avoidance decreased significantly in both young and old adults. With available response times of 350 msec, mean success rates decreased from their no-division values in the young adults by 14.7% for synchronized reaction and by 19.9% for unsynchronized reaction, attention-dividing tests. Corresponding mean decreases for the old adults were 32.0 and 35.7%. This age difference in the effects of dividing attention was significant.

Conclusion. Both young and old adults had a significantly increased risk of obstacle contact while negotiating obstacles when their attention was divided, but dividing attention degraded obstacle avoidance abilities of the old significantly more than it did in the young. Diminished abilities to respond to physical hazards present in the environment when attention is directed elsewhere may partially account for high rates of falls among the elderly.

Although falls in the elderly are a major source of injury, morbidity, and mortality, the reason that fall rates are so high in this group is not yet known. Tripping over an object is one of the most frequently reported causes of falls in the elderly (1–5), but little is known about the factors that affect abilities to avoid tripping on obstacles. Cognitive impairments associate with increased rates of falling in the elderly (6–8). Moreover, old compared to young adults are thought to have more difficulty with performing several tasks simultaneously (9–11).

We earlier studied obstacle avoidance under time-critical conditions in young and old healthy adults (12). We found that decreases in available response time significantly reduced rates of success in avoidance, but age-group differences in those rates were small. We undertook the present study to examine whether dividing attention would affect old more than young healthy adults in their abilities to avoid gait path obstacles under time-critical conditions.

METHODS

Subjects. — Thirty-two volunteer subjects, divided into four groups of 8 subjects each — young adult females, young adult males, old females, and old males — participated in the study. The young adults were recruited among University of Michigan students. The old adults lived independently in the community and were recruited through the Human Subjects Core of the University’s Geriatric Research and Training Center. All old adults had completed high school. Eight of them had an associate’s or bachelor’s degree and five others had master’s or doctoral degrees. The old adults had Mini-Mental State Examination scores ranging from 26 to 30, with an overall mean score of 29.1. None of the subjects had participated in our earlier study (12) of time-critical obstacle avoidance. The mean ages of the young and old groups were 23.9 and 72.1 years (Table 1). In both age groups, the males were significantly taller than the females, and the young were significantly taller than the old.

Young and old adults were essentially healthy. Upon questioning, they denied any significant past head trauma, otologic or neurological disease, visual impairment not correctable with glasses, recent limb or spinal fracture, other musculoskeletal impairments, or persistent symptoms of vertigo, lightheadedness, or unsteadiness. Old adults also underwent a more detailed medical history and physical examination focusing on musculoskeletal and neurological...
OBSTACLE AVOIDANCE AND DIVIDED ATTENTION

Table I. Mean Ages (yr), Height (cm), and Reaction Times (msec) of Subject Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Age</th>
<th>Height*</th>
<th>Reaction Times While Standing†</th>
<th>Reaction Times While Walking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SRT*</td>
<td></td>
</tr>
<tr>
<td>YF</td>
<td>8</td>
<td>22.6</td>
<td>166.5</td>
<td>325.9 (45.8)</td>
<td>330.6 (35.4)</td>
</tr>
<tr>
<td>YM</td>
<td>8</td>
<td>25.1</td>
<td>177.0</td>
<td>336.0 (30.1)</td>
<td>369.8 (61.8)</td>
</tr>
<tr>
<td>OF</td>
<td>8</td>
<td>72.6</td>
<td>159.9</td>
<td>354.9 (34.7)</td>
<td>384.8 (29.5)</td>
</tr>
<tr>
<td>OM</td>
<td>8</td>
<td>71.6</td>
<td>169.9</td>
<td>331.3 (51.1)</td>
<td>361.9 (59.9)</td>
</tr>
</tbody>
</table>

Note: Standard deviations in parentheses. Y = young, O = old, F = female, M = male subjects. SRT = synchronized reaction time, URT = unsynchronized reaction time. The reaction times are for trials in which subjects knew that no obstacles would appear.

* p < .001 by ANOVA for significant gender difference.
† p < .008 by ANOVA for significant age difference.
‡ p < .001 by repeated measures ANOVA for significant SRT/URT difference.
§ p < .015 by repeated measures ANOVA for significant standing/walking difference.
¶ p < .001 by repeated measures ANOVA for significant (SRT/URT) x (standing/walking) interaction.

items, similar to the history/examination described by Alexander et al. (13). Corrected binocular visual acuity was 20/50 or better, with two of the old subjects having acuity of 20/200 or worse in the left eye only. Other subtle abnormal findings in the old adults included occasional exertional low back pain (25% of group); a distant history of knee pain (19%); mild hearing loss, apparently bilateral and age-related (38%); and decreased lower extremity reflex, primarily at the Achilles tendon (44%). Despite these subtle abnormalities, all of the old adults were active in regular, often daily, walking, calisthenics, and/or in sports such as biking or swimming.

Equipment. — Walks were along an 8 m long walkway that incorporated a 5.76 m long and 1.20 m wide main conducting surface (Figure 1) and two conductive start- trigger foot pads located at the beginning of the walkway, 1 m from the main conductive surface. The conductive surface was instrumented with parallel aluminum tape strips 8 mm wide, separated by 2 mm. Subjects wore a pair of shoes with two conducting strips attached transversely across each sole, one under the heel and one under the metatarsal head. A computer scanned these strips and detected the location and timing of contacts between the walkway and the heel and between the walkway and the mid-foot position under the metatarsal head.

After the first few steps were taken on the main conducting surface, the computer calculated walking speed and continually predicted future mid-foot locations. These predictions were used to place and time the appearance of a virtual obstacle. This obstacle was a band of light projected across the subject's path using a projector and a rotating mirror driven by a computer-controlled servo motor. Additional descriptions of this equipment are given by Chen et al. (12). In the present study, the virtual obstacle display was synchronized with the subject's stride pattern to appear at the predicted mid-foot position with an available response time (ART) of either 350 or 450 msec. The ART was the time from the appearance of the virtual obstacle to the predicted next footfall.

To divide their attention from where and when the obstacle might appear, vocal reaction time tests were conducted while subjects were walking. These tests employed a panel on which 57 randomly dispersed red, yellow, and green-light-emitting diodes were mounted within a 12 cm diameter circle. This panel was placed just above the floor at 0.5 m beyond the end of the walkway (Figure 1). Diode illumination was controlled by the computer in predetermined timing and color sequences that could be coordinated with the subjects' stepping patterns. For synchronized reaction time (SRT) tests, only red diodes were lit and the subjects were asked to say “ah” as quickly as possible upon seeing the red lights. For unsynchronized reaction time (URT) tests, red, green, and yellow diodes were lit and the subjects were asked to respond only when the red diodes lit. Subjects'
vocal responses were detected by a microphone, amplified and relayed to the computer. The microphone was attached to a harness shoulder strap and connected to an amplifier attached to a waist strap. A thin cable connected the amplifier and the strips under the shoes to the computer.

For safety, each subject wore a lightweight harness attached to a low-friction overhead track. The attachment cable was adjusted so that, when hanging fully supported by the harness, the subject's head was always above his hips, and his hands and knees could not touch the floor. A staff member walked slightly behind and to the side of the subject to assist in the event of a stumble.

**Vision tests.** — All subjects underwent three vision tests prior to the walking trials. First, visual acuity was tested using an eye chart. Subjects were not entered into the study unless this acuity with correction was 20/50 or better. Second, and more directly relevant to the walking trials, subjects were required for entry into the study to identify correctly the number of 32 mm deep, 60 mm wide light rectangles, separated transversely by 30 mm, projected onto the walkway 4 m ahead of them. Third, subjects were required to correctly identify the colors of lights appearing on the diode panel while standing at rest on the starting foot pads.

**Vocal reaction tests when standing and walking.** — Before obstacle avoidance trials were conducted, subjects' equivalent-SRT and equivalent-URT were measured during both standing and walking. The modifier, “equivalent,” is used here because no obstacles appeared during these tests, so the issue of synchronization was moot. In the standing tests, subjects stood halfway along the walkway. In the walking tests, subjects were asked to walk at a comfortable speed from the beginning to the end of the walkway. During both tests, subjects looked at the diode panel and were asked to say “ah” as quickly as possible as soon as they saw the red lights. In these SRT tests, red lights were lit two or three times at fixed, initially randomized sequences. Twelve initial SRT and 12 initial URT, no-obstacle trials were conducted with a minimum of 20 SRT and 20 URT responses measured during those trials.

**Walking trials.** — Subjects first stood on the starting pads. They were asked to walk along the walkway at a self-selected comfortable speed, to say “ah” as quickly as possible whenever they saw red lights go on, to avoid stepping on the virtual obstacle if it appeared, and to continue walking until they reached the end of the walkway. Nothing was said or suggested to the subjects as to priorities of goals. Even if they asked whether it was more important to avoid the obstacles or to correctly identify the light flashes, subjects were instructed to do both as well as they could. Data collection began when the subjects left the foot pads, continued while they approached and stepped over the virtual obstacle, and ended when they reached the end of the walkway.

Seven control trials, in which the subjects knew that neither obstacles nor lights would appear, were first conducted to measure self-selected comfortable gait speed. These were followed by 12 trials for which the subjects knew that virtual obstacles would appear suddenly, without warning and at varying locations, but in which no lights would appear. The subjects were asked not to step on the obstacle while walking to the other end of the walkway. During these trials, subjects were occasionally reminded to maintain their usual speed. If any subject slowed to 90% or less of his comfortable walking speed that had been measured in the control trials, the trial data were discarded, the subject was asked to speed up, and the trial was repeated. After the first few trials, no young subjects needed to be prompted to speed up. A few old subjects needed to be prompted, but only once.

These trials were followed by 69 trials in which both virtual obstacles and reaction time (RT) stimulus lights appeared. These trials were presented in four blocks: three blocks each of 19 trials in which SRT were measured and one block of 12 trials in which URT were measured. An SRT block was presented first, followed by the URT block and then the other two SRT blocks. The various situations described subsequently were presented in each block to each subject in the same initially randomized, fixed sequence.

During each of the obstacle-plus-SRT trials, the red diodes were lit two or three times. Their lighting was synchronized with the appearance of the obstacle so that at one of those times the red lights appeared at 400, 200, or 0 msec before or 200 msec after the appearance of the virtual obstacle (stimulus-obstacle-intervals, SOI). In each SRT trial block, each ART and SOI combination was presented twice: once for obstacle placement at a predicted right footfall and once for placement at a left footfall. Each of these trial blocks also included three control trials in which no obstacle appeared.

In the obstacle-plus-URT trials, each ART was presented six times: three times for obstacle placement at a predicted right footfall and three times for a left footfall. The times of the appearance of the red lights and of the obstacle were not synchronized, nor were any no-obstacle trials included in this block.

After the first few trials, no young subjects needed to be reminded to respond to and only to the red lights. A few of the old subjects needed to be reminded about this several times.

**Measurement accuracy.** — Times were measured to within 1 msec. Projected obstacle position was controlled to within 2 cm and measured to within 1 cm. The walkway detected foot longitudinal placement to within 1 cm (12). The diodes lit within 10 msec of their being powered. Detection of the amplified vocal responses was estimated to occur 30 to 40 msec after those responses began, depending on their loudness. No adjustment was made for these delays in the data analysis.

**Data analysis.** — Data from trials in which subjects contacted the obstacles were not used in the statistical analysis, except to note that a failure to avoid the obstacle occurred. An obstacle avoidance score (OAS) for each ART or ART/SOI combination in each block was calculated. The
OAS was defined as the ratio of the sum of the trial scores to the total number of obstacle avoidance trials conducted. Trials were scored 1.0 if the obstacle was avoided and 0.0 if the obstacle was contacted. Some subjects sometimes avoided contacting the obstacle by rotating the forefoot laterally at the last instant and/or dorsiflexing the ankle so that only the heel contacted the walkway surface. These trials were scored 0.5 since the heel had been planted in error, but partial success in obstacle avoidance was achieved.

Vocal error rates (VER) were calculated for all SRT and for all URT trials. The VER was defined as the ratio of the number of omitted or incorrect vocal responses over those trials in which the obstacles were not contacted to the total number of correct vocal responses that should have been made over all obstacle avoidance trials. Subjects would make incorrect responses in the URT trials by saying "ah" when a yellow or green light turned on.

A compound score (CS) was calculated. This was the ratio of the number of trials in which both the obstacle was not contacted and all vocal responses were correct to the total number of attention-division-plus-obstacle-avoidance trials conducted.

Mean values and standard deviations of the outcome variable, OAS, were calculated across age and gender groups, attention-division conditions, ART and SOI. Associations among the variables were tested by repeated measures ANOVA. Differences with \( p < .05 \) were considered significant. The independent variables were age and gender (two levels each). For within-subject effects, ART and attention-division-type were additional independent variables. The effect of SOI was similarly tested, except that SRT was the only type of division tested. For within-subject SOI effects, ART and SOI were additional independent variables. Practice and fatigue effects on OAS over the three SRT trial blocks were sought, also using repeated measures ANOVA with \( p < .05 \) considered significant.

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### RESULTS

Reaction times during standing and obstacle-free walking. — (Table 1). The mean SRT and URT among the four age and gender groups ranged from 326 to 419 msec. Among the four types of RT tests, mean RTs in the old females were 29 to 54 msec slower than those of the young females, while the old males compared to the young males had mean RTs that ranged from 8 msec faster to 23 msec slower. Among the four age and gender groups, mean SRTs when walking were approximately 5 to 34 msec longer than when standing, while the corresponding mean URTs ranged from 10 msec shorter to 8 msec longer. Similarly, the mean URTs were 52 to 69 msec longer than the mean SRTs when standing, and 16 to 47 msec longer when walking.

Effect of age and available response time on obstacle avoidance. — (Table 2, Figure 2). Over all test conditions combined, the young had a significantly higher mean obstacle avoidance score (OAS) than the old. Mean OAS was significantly lower for an ART of 350 compared to 450 msec.

Effect of divided attention on obstacle avoidance. — (Table 2, Figure 2). Attention division by either the SRT or URT tests caused significant decreases in mean OAS for both the young and old subjects. At a 350 msec ART, mean OAS for the young decreased from no-division values by .126 and .171 (14.7 and 19.9%) for SRT and URT division, while for the old it decreased by .233 and .260 (32.0 and 35.7%). In these SRT trials, the young avoided the obstacles in almost three-fourths of their trials, while the old avoided them in fewer than one-half of their trials. OAS differences between SRT and URT division were not significant.

**Table 2. Effect of Age, Type of Attention Division, and Available Response Time (msec) on Mean Obstacle Avoidance Scores**

<table>
<thead>
<tr>
<th>ART</th>
<th>No Division</th>
<th>SRT Division</th>
<th>URT Division</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>YA</td>
<td>OA</td>
<td>YA</td>
</tr>
<tr>
<td>350 msec</td>
<td>0.859</td>
<td>0.728</td>
<td>0.733</td>
</tr>
<tr>
<td></td>
<td>(0.16)</td>
<td>(0.17)</td>
<td>(0.17)</td>
</tr>
<tr>
<td>450 msec</td>
<td>1.000</td>
<td>0.968</td>
<td>0.974</td>
</tr>
<tr>
<td></td>
<td>(NA)</td>
<td>(0.07)</td>
<td>(0.04)</td>
</tr>
</tbody>
</table>

Notes: Standard deviations in parentheses. ART = available response time. YA = young adults; OA = old adults. SRT = synchronized reaction time; URT = unsynchronized reaction time.

ANOVA Results for SRT
- \( p < .001, F = 30.31 \) for significant Age difference
- \( p < .001, F = 106.35 \) for significant ART difference
- \( p < .001, F = 27.40 \) for significant SRT difference

ANOVA Results for URT
- \( p = .008, F = 8.05 \) for significant Age difference
- \( p < .001, F = 119.11 \) for significant ART difference
- \( p < .001, F = 26.32 \) for significant URT difference

ANOVA Results for SRT
- \( p = .033, F = 4.98 \) for significant Age \( \times \) SRT interaction
- \( p = .032, F = 5.04 \) for significant ART \( \times \) SRT interaction
- \( p = .057, F = 3.91 \) for nonsignificant Age \( \times \) ART interaction

ANOVA Results for URT
- \( p = .263, F = 1.30 \) for nonsignificant Age \( \times \) URT interaction
- \( p = .015, F = 6.64 \) for significant ART \( \times \) URT interaction
- \( p = .015, F = 6.64 \) for significant Age \( \times \) ART interaction
Obstacle avoidance scores for individual subjects. — (Figure 3). For ART of 350 msec only one old subject consistently had relatively low OAS across the three attention-division conditions. Most of the subjects did at least moderately well, relative to the other subjects, under at least one division condition.

Interaction effects. — (Table 2). Attention division by the SRT tests decreased mean OAS significantly more in the old than in the young (p = .033 for an Age × SRT-division interaction effect). This interaction was nonsignificant for the URT tests. ART reduction in the URT trials decreased mean OAS significantly more in the old than in the young (p = .015 for an Age × ART interaction effect), but this interaction only bordered on significance for the SRT trials. The combination of ART reduction and either SRT or URT attention division significantly decreased OAS (p = .032 for ART × SRT and p = .015 for ART × URT division interactions).

Vocal error rates. — (Table 3). The old in the mean had VER that were more than twice those of the young adults. VER for the URT trials were significantly higher than those for the SRT trials.

Compound scores. — (Table 4). With SRT division at an ART of 350 msec, the old were able to avoid the obstacle while simultaneously giving correct vocal responses in only 44% of their trials, but the young could do this in over 70% of their trials. In addition to significant age and ART effects on mean compound scores (p < .001), those scores were lower for URT than for SRT division (p < .05). Compound scores for URT division with a 350 msec ART were approximately 41% and 66% in the old and young groups.
Table 4. Effect of Age, Type of Attention Division, and Available Response Time on Mean Compound Scores

<table>
<thead>
<tr>
<th>ART*</th>
<th>SRT Division†</th>
<th>URT Division</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>YA</td>
<td>OA</td>
</tr>
<tr>
<td>350 msec</td>
<td>0.709</td>
<td>0.440</td>
</tr>
<tr>
<td></td>
<td>(0.16)</td>
<td>(0.21)</td>
</tr>
<tr>
<td>450 msec</td>
<td>0.943</td>
<td>0.761</td>
</tr>
<tr>
<td></td>
<td>(0.05)</td>
<td>(0.21)</td>
</tr>
</tbody>
</table>

Notes: Standard deviations in parentheses. ART = available response time; SRT = synchronized reaction time; URT = unsynchronized reaction time; YA = young adults; OA = old adults.
* p < .001 by repeated measures ANOVA for significant ART difference.
† p < .05 by repeated measures ANOVA for significant Age difference.
§ p < .035 by repeated measures ANOVA for significant ART difference.

Figure 4. Mean obstacle avoidance score for each stimulus/obstacle interval used in the SRT division trials for the young and old adults. ART = available response time; RT = reaction time.

Practice and fatigue effects. — (Table 5). Although the mean OAS tended to improve in the young and to decline in the old through the three blocks of SRT trials, no significant practice (improvement in OAS) or fatigue (decline in OAS) effects were found in obstacle avoidance in either age group.

DISCUSSION

The main goal of the study was to determine whether dividing attention would affect old more than young healthy adults in their abilities to avoid gait path obstacles under time-critical conditions. The chief finding is that attention division significantly decreased obstacle avoidance scores in both the young and old adults, and significantly more for the old than for the young. In our earlier study of obstacle avoidance under time-critical conditions (12), subjects’ attention was not divided from the avoidance task. Only available response time differences strongly affected OAS in that study. Age effects on OAS just bordered on statistical significance, and no interaction effects were statistically significant. The addition of attention division in the present study resulted in statistically significant differences among OAS with age as well as with ART, and for Age × Division, Age × ART, and ART × Division interactions.

The no-division mean OAS for the young and old subjects in the present study were nearly the same as those reported by Chen et al. (12). Since the two studies used two different subject groups, these OAS seem generalizable to populations of healthy adults.

Age differences in mean vocal SRT and URT were generally 13 to 27 msec, or close to the lower-extremity-force-development mean SRT age difference reported by Ashton-Miller et al. (14). The large values of the vocal SRT and URT may have resulted in part from not correcting them for the LED display (10 msec) and microphone (30 to 40 msec) delays. Although the differences in mean SRT between standing and no-obstacle walking tests were statistically significant, they were small. This is consistent with the finding of Sajiki et al. (15) that mean vocal reaction times differed between standing and walking by only 6 msec.

The OAS for SRT trials did not differ significantly from those for URT trials in either the young or old groups. The SRT and the URT tests used here were not the same as standard simple and choice RT tests. The SRT tests were simultaneous with the obstacle avoidance task. During the URT trials, in contrast to SRT trial procedures, lights flashed at regular intervals; a light of some color was always on; and light flashes were not synchronized with obstacle appearance. Perhaps if the SOI had been controlled also in the URT trials, the Age × URT interaction might have become significant.

In the SRT trials, use of different stimulus obstacle intervals significantly affected OAS. In the mean, OAS were smallest when SOI were 200 msec. Use of additional and more finely graded values of SOI might be useful in research on sensorimotor information processing.

The vocal error rate in the old was at least twice that in the young in both the SRT and URT division trials. Both age groups had substantially larger VER in the URT trials than in the SRT trials, despite no significant differences in the corresponding OAS. The large variance in the VER for both age groups (Table 3) implies that some subjects could
coordinate obstacle avoidance and vocal response tasks well, while others could not.

Addition of the reaction time tasks in this study degraded obstacle avoidance abilities of the old significantly more than it did in the young. However, the poorer performance of the older subjects may not relate directly to the dual task nature of this study; that is, the requirement for subjects to divide their attention among both the obstacle clearance and the reaction time tasks. The old had longer reaction times when standing and they had somewhat lower rates-of-success in division-free obstacle avoidance. That is, they performed each individual task less well than did the young. Age-related declines in performance on a given type of task increase as task parameters are manipulated to make the task more demanding (11). Thus, old subjects may be more affected than young adults by the dual task format utilized for the present study merely because, given their poorer performance on each task independently, performing the two tasks in combination presented a task significantly more difficult for them than for young adults.

In daily life, attention while moving about is seldom fully focused on avoidance of gait path obstacles that might be encountered. Present study findings suggest that, since attention while walking is often divided, even quite healthy and physically fit old adults are at substantially greater risk than young adults for tripping over obstacles that come suddenly into the field of view. Our earlier study (12) found that, when subjects’ attention was not divided from the obstacle avoidance task, age effects on avoidance abilities just bordered on statistical significance. Those findings indicate that healthy old adults essentially have the biomechanical capacities needed to avoid obstacles in the time-critical situations encountered while walking. The additional results provided by the present study suggest that healthy old adults are at greater risk for tripping, not so much because of declines in biomechanical capacities, but because of declines in their abilities to attend to multiple tasks simultaneously.

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