Time Requirement for Young and Elderly Women to Move Into a Position for Breaking a Fall With Outstretched Hands

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Background. Risk for hip fracture during a fall is reduced by contacting the ground first with the outstretched hands. However, it is unclear whether the time required for young and elderly individuals to move the hands into a protective position exceeds that available during a typical fall.

Methods. We tested whether young (n = 30; aged 18–35 years) and elderly women (n = 30; aged 70–88 years) differed in the time required to move their hands into a protective position for breaking a fall. Participants stood either facing or sideways to shoulder-height targets (simulating forward and sideways falls, respectively), which they were instructed to contact as quickly as possible after hearing an aural go cue. Total contact time was partitioned into reaction time and movement time.

Results. Young women contacted the targets faster than elderly women in both forward (530 ± 60 vs 615 ± 88 ms; p < .001) and sideways trials (658 ± 80 vs 799 ± 145 ms; p < .001). This difference was due to faster movement times for young participants. There was no difference between groups in reaction time.

Conclusions. Previous studies have shown that during actual falls from standing, wrist and pelvis contact occur at 680 ± 116 and 715 ± 160 ms, respectively. Comparing these values to our results suggests that the typical elderly woman should be able to move her hands quickly enough to break a forward fall, but not a sideways fall.

FALLS are a major cause of injury in elderly persons and the underlying reason for 90% of hip fractures (1). In addition to bone strength, risk for hip fracture during a fall depends on the mechanics of the fall, and in particular, on the configuration of the body segments at impact. For example, fracture risk is increased 30-fold if impact occurs to the hip region, and decreased 3-fold if impact occurs to one or both outstretched hands (2–4).

The task of breaking a fall with the outstretched hands can be divided into three stages: detection of imbalance and initiation of hand movement, movement of the hands into a final landing position, and energy absorption during impact. Studies have shown that during unexpected falls in young individuals, the total time between fall initiation and impact to the wrist and pelvis (total contact time) is 680 ± 116 ms and 715 ± 160 ms, respectively (5). Impairments in the initiation of hand movement following imbalance (reaction time) and transport of the hands into a protective position (movement time) could prevent elderly individuals from meeting these time demands.

Previous studies provide inconclusive evidence on whether differences exist between young and elderly adults in the time required to move the hands into a position for breaking a fall. For example, DeGoede and colleagues (6) found that older women were 20% slower than younger women in the movement time required to lift their hands from thigh level to arrest a pendulum swinging toward their face. However, because reaction time and total contact time were not reported, their results did not provide enough information to predict whether the women tested could react and move their hands quickly enough to break a real-life fall. Other studies have presented opposing results. Kim and Ashton-Miller (7) recently reported that, when falling forward onto an inclined surface, older men had larger angular velocities at the elbow and shoulder, and faster hand contact times than did younger men. This result was interpreted to reflect increased urgency or fear, or reduced ability to control and soften impact severity, among elderly men. The researchers reported total contact times, but did not show how reaction time and arm movement time contributed to the total contact time. Furthermore, these previous studies focused only on simulations of forward falls.

In the current study, we investigated whether young and elderly women differed in the time required to move their hands to contact targets that were either in front of them or at their side, simulating the task of breaking a forward or sideways fall with the outstretched hands. We also compared our measured contact times to the range of contact times previously reported for falls from standing.

METHODS

Participants
A total of 30 young women (mean age = 22 ± 4 [standard deviation, SD] years) and 30 elderly women (mean age = 77 ± 5 years) participated in the study. Mean participant weight was 55.6 ± 9.3 kg (young) and 68.0 ± 8.8 kg (elderly). Mean participant height was 163 ± 6 cm (young) and 160 ± 7 cm (elderly). We recruited young women through university posting boards and elderly women through community
newspapers. Prospective participants were screened initially for eligibility with a telephone interview. Those women who seemed to meet our inclusion criteria based on the telephone interview were further screened on physical examination by an experienced physiotherapist. Exclusion criteria included: (a) regular exercise averaging once a week or more for the past 3 months, (b) impairment of neuromuscular function secondary to neurological disease (e.g., traumatic brain injury, Parkinson’s disease, cerebral palsy, multiple sclerosis, diabetic neuropathy), (c) amputation or other debilitating orthopedic conditions (e.g., joint replacements, rheumatoid arthritis), (d) inability to raise the arms to shoulder height, and (e) inability to follow simple instructions in English. Each participant provided written informed consent, and the experimental protocol was approved by the Research Ethics Board of Simon Fraser University.

Protocol

For all participants, we calculated maximum isometric shoulder flexor and shoulder abductor torques ($\tau$). A handheld dynamometer (Nicholas Manual Muscle Tester [MMT] 01160; Lafayette Instrument Co., Lafayette, IN) was used to record the peak force ($F$) generated by the participant during an isometric 5-second resistance. The distance ($d$) between the dynamometer (point of force application) and the participant’s shoulder joint center was measured using a standard measuring tape. We calculated shoulder torques using the equation $\tau = Fd$. Each participant’s shoulder torques were normalized to body weight ($N$) $\times$ body height (m), and then averaged over three trials.

To simulate breaking a fall with the outstretched hands, we instructed participants to contact a pair of shoulder-height targets (one for each hand) that were mounted on a standing frame (Figure 1). We conducted two sets of 10 trials in pseudorandom order, with a pseudorandom time interval (approximately 10–30 seconds) between successive trials. In the set of forward trials, the participant stood facing the targets. In sideways trials, the participant stood sideways with the targets at her side such that her dominant hand was closest to the targets. The participant’s distance from the targets was adjusted so that her elbows would be flexed 45° at hand impact. Each target was padded with 20 cm-thick foam to minimize the resulting contact forces and reduce the participant’s hesitation to strike the targets. The participant began each trial with her hands relaxed at her sides and her feet in a stationary position. We instructed her to contact the targets as “quickly as possible” with both hands after hearing an aural go cue. C. We identified the contact time by the sudden increase in compressive force applied to a force plate mounted behind the dominant-hand target. This example is from a forward trial with an elderly participant. The aural go cue was provided at $t = 0$, and the vertical line indicates the contact time at 617 ms.

Figure 1. Side view of experimental setup for (A) forward trials and (B) sideways trials. In forward trials, the participant stood facing shoulder-height targets. In sideways trials, the participant stood sideways with her dominant arm closest to the targets. The target distance, $d$, was adjusted so that impact occurred with the elbows flexed at 45°. The participant was instructed to contact the targets as “quickly as possible” with both hands after hearing an aural go cue. C. We identified the contact time by the sudden increase in compressive force applied to a force plate mounted behind the dominant-hand target. This example is from a forward trial with an elderly participant. The aural go cue was provided at $t = 0$, and the vertical line indicates the contact time at 617 ms.
and acquired simultaneously using computer-based data acquisition software (Qtrac; Qualisys).

### Data Analysis

For each trial, we calculated reaction time as the time interval between the aural go cue and the onset of hand movement, and contact time as the time interval between the go cue and contact of the dominant-hand target. Movement time was determined as the difference between contact time and reaction time (i.e., the interval between the onset of hand movement and contact of the dominant hand. The onset of hand movement was defined as the instant when the hand surface marker began moving in a steady upward motion, as determined from visual inspection (by a single blinded investigator) of data acquired by the motion measurement system. Contact time was identified by a sharp increase in the normal force applied to the force plate (Figure 1C), again from visual inspection of force plate data.

### Statistics

Statistical analysis was performed using a repeated-measures analysis of variance, with movement direction (forward vs sideways) as the repeating factor and age category (young vs elderly) as the grouping factor. Dependent variables were reaction time, movement time, and total contact time. Where the analysis of variance revealed a significant effect of movement direction or age, post hoc t tests were conducted to identify the source of these differences. Pearson correlations were used to examine associations between continuous variables. Statistical tests were run using SPSS statistical analysis software (SPSS, Inc., Chicago, IL). After applying a Bonferroni correction for the set of comparisons, p values less than or equal to .005 were considered statistically significant.

### RESULTS

#### Effects of Age Differences and Movement Direction on Total Contact Time

In both sets of trials, young participants were able to contact the hand targets faster than were elderly participants (Table 1). Mean contact time was 16% longer for elderly participants than for young participants in forward trials (615 ± 88 vs 530 ± 60 ms, mean difference = 85 ms, 95% CI, 46–124 ms; t = 4.4, df = 58, p < .0001) and 21% longer for elderly participants in sideways trials (799 ± 145 vs 658 ± 80 ms, mean difference = 141 ms, 95% CI, 80–201 ms; t = 4.7, df = 58, p < .0001).

All participants were able to contact the hand targets faster in forward trials than in sideways trials. For all participants combined, mean contact time was 27% longer in sideways trials than in forward trials (728 ± 136 vs 572 ± 86 ms, mean difference = 156 ms, 95% CI, 139–173 ms, t = 18.0, df = 59, p < .001). For young participants, mean contact time was 24% longer in sideways trials compared to forward trials (658 ± 80 vs 530 ± 60 ms, mean difference = 128 ms, 95% CI, 116–140 ms, t = 22.3, df = 29, p < .001); for elderly participants, mean contact time was 30% longer in sideways trials (799 ± 145 vs 615 ± 88 ms, mean difference = 184 ms, 95% CI, 154–214 ms, t = 12.4, df = 29, p < .001).

#### Effect of Age Differences on Reaction and Movement Times

We observed age-related slowing in movement time but not in reaction time (Table 1). Although reaction times were not significantly different between young and elderly participants, reaction time in the elderly women tended to be slightly slower than in the young women, by 9% in forward trials (231 ± 42 vs 212 ± 35 ms, mean difference = 19 ms, 95% CI, 1–39 ms, t = 1.9, df = 58, p = .065) and 14% in sideways trials (252 ± 60 vs 221 ± 35 ms, mean difference = 31 ms, 95% CI, 6–57 ms, t = 2.5, df = 58, p = .017); however, mean movement time for elderly participants was 21% slower than for young participants in forward trials (384 ± 75 vs 318 ± 40 ms, mean difference = 66 ms, 95% CI, 35–97 ms, t = 4.3, df = 58, p < .001) and 25% slower in sideways trials (547 ± 128 vs 437 ± 62 ms, mean difference = 109 ms, 95% CI, 57–161 ms, t = 4.2, df = 58, p < .001).

#### Total Contact Time, Reaction Time, and Movement Time Relationships

Differences in contact time related more to differences in movement time than reaction time for both forward and sideways trials (Figure 2). For forward trials, contact time increased as both reaction time and movement time increased (r = 0.631, p < .001; r = 0.894, p < .001, respectively). Similarly, for sideways trials, contact time increased as both reaction time and movement time increased (r = 0.581, p < .001; r = 0.931, p < .001, respectively). Although there was not a significant association between reaction time and movement time in either forward (p = .097) or sideways (p = .062) trials, it was common to see slowing in both variables among the slowest.

### Table 1. Outcome Variables From Hand Contact Trials in Young and Elderly Women

<table>
<thead>
<tr>
<th></th>
<th>Forward Trials</th>
<th>Sideways Trials</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Young</td>
<td>Elderly</td>
</tr>
<tr>
<td>Contact time, ms²</td>
<td>30, 30</td>
<td>530 ± 60</td>
</tr>
<tr>
<td>Reaction time, ms¹</td>
<td>30, 30</td>
<td>212 ± 35</td>
</tr>
<tr>
<td>Movement time, ms²</td>
<td>30, 30</td>
<td>318 ± 40</td>
</tr>
</tbody>
</table>

Note: Data are means ± standard deviation.

*ny is the sample size of young participants; ne is the sample size of elderly participants.

Significance of difference between young and elderly columns, based on independent samples t test. Values less than or equal to .005 are considered statistically significant.

Data are for the dominant hand.
elderly participants (Figure 3). Furthermore, there was a relationship between increased forward reaction time and increased sideways reaction time ($r = 0.748$, $p < .001$), and between increased forward movement time and increased sideways movement time ($r = 0.900$, $p < .001$).

**Effect of Shoulder Strength on Movement Time**

We found a significant, but weak relationship between shoulder strength and movement time. Normalized shoulder flexor torque increased as movement time decreased for both forward ($r = -0.487$, $p < .001$) and sideways directions ($r = -0.466$, $p < .001$). Normalized shoulder abductor torque also increased as movement time decreased for forward ($r = -0.488$, $p < .001$) and sideways directions ($r = -0.448$, $p < .001$). However, after adjusting for age, these correlations did not reach statistical significance ($r = -0.24$, $p = .06$ and $r = -0.22$, $p = .094$ for flexor torque and movement time in the forward and sideways directions, respectively; $r = -0.23$, $p = .08$ and $r = -0.18$, $p = .18$ for abductor torque and movement time in the forward and sideways directions).

**DISCUSSION**

We found that elderly women are slower than young women in moving their hands into a protective position for breaking a forward or sideways fall. Furthermore, this was due primarily to slower movement times, as opposed to differences in reaction times. To place our results in context, consider that previous studies have shown that, during actual falls from standing, the interval between fall initiation and contact to the wrist averages $680 \pm 116$ ms, and the interval between fall initiation and impact to the pelvis averages $715 \pm 160$ ms (5). In our forward trials, 100% of young participants and 83% of elderly participants had total contact times longer than the threshold time for pelvis impact during an actual fall. In sideways fall simulations, 7 of the 30 young participants (23%) and 23 of the 30 elderly participants (77%) had contact times that were longer than the threshold time for pelvis impact during an actual fall.
times less than 680 ms. During our sideways trials, 63% of young and only 13% of elderly women had total contact times less than 680 ms. These results suggest that the typical young woman can meet the time requirements for breaking either a forward or sideways fall (as one would expect from common experience). They also suggest that the typical elderly woman should be able to react and move her hands quickly enough to break a forward fall, but not a sideways fall.

Our results are in agreement with previous reports of age-related declines in reaction time and movement time (8–10). Furthermore, although the comparison is complicated by the different methods used in the two studies, our movement times are similar to those reported by DeGoede and colleagues (6) for simulated falls on the outstretched hands. In DeGoede’s study, participants were asked to contact shoulder-height targets as quickly as possible with the hands, from a seated position. Trials were conducted under three conditions: no-threat (participants contacted stationary targets), low-threat (participants contacted targets on a swinging pendulum, which was released just as hand movement was initiated), and high-threat (participants contacted targets on a swinging pendulum, and were instructed to wait as long as possible before initiating hand movement). Movement time for the older women was 20% slower than that for the younger women in the no- and low-threat conditions (335 ± 39 [SD] vs 281 ± 30 ms for the no-threat condition; 338 ± 39 vs 277 ± 49 ms for the low-threat condition). Furthermore, movement time in women did not differ significantly between the no-threat, low-threat, and high-threat trials. This finding supports the notion that performance in a reduced threat situation (such as our experiment) may be a reasonable indicator of protective abilities during a real-life fall.

There are important limitations to this study. Due to safety concerns, our experiments did not involve actual falls, and there are several reasons why response times may be different in an actual fall. For example, the fear and urgency associated with falling may affect response times in a complex manner. Furthermore, falls produce a range of impact configurations (5), and we cannot rule out the possibility of different trends had we used a different impact configuration. Moreover, detecting the onset of imbalance is the first stage in initiating a protective response during an actual fall, and older adults take longer than do younger adults to respond to a postural perturbation. However, these delays are relatively small when compared to age-related changes in movement time (11). For example, in examining single-step recoveries from a forward fall initiated by tether release, Wojcik and colleagues (12) found that, although total step times averaged 60 ms faster in young than in elderly women, the difference in average reaction times was only 13 ms—similar to the differences observed in our study. A further limitation of our study is that, despite our efforts to screen prospective participants for obvious neurological disease or musculoskeletal impairment, our findings may not be related to the effect of age per se, but rather to subclinical neurological or musculoskeletal dysfunction. Finally, our between-group differences in reaction time (which averaged 19 ms [or 9%] in forward trials, and 31 ms [or 14%] in sideways trials) bordered on statistical significance. We expect that a larger sample size would have revealed a statistically significant difference.

Conclusion

Our study provides important new information on age-related differences in the ability to move the hands into a position for breaking a fall—a protective response that has been shown to substantially reduce hip fracture risk. We found that, in simulated forward falls, both young and elderly groups had average contact times that were faster that the time typically available during a fall. However, in simulated sideways falls (which are most likely to produce hip fracture), most elderly participants were unable to achieve contact times within the time available during a fall. Further research is required to determine whether exercise programs can improve the efficacy of upper extremity fall-protective responses.

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