How Quickly Can Healthy Adults Move Their Hands to Intercept an Approaching Object? Age and Gender Effects

Kurt M. DeGoede,1 James A. Ashton-Miller,1,2,3 Jimmy M. Liao,1 and Neil B. Alexander3,4,5

1Department of Mechanical Engineering,  
2Department of Biomedical Engineering,  
3Institute of Gerontology, and  
4Department of Internal Medicine, University of Michigan, Ann Arbor.  
5Ann Arbor VA Medical Center GRECC, Michigan.

Background. The upper extremities are often used to protect the head and torso from impact with an object or with the ground. We tested the null hypotheses that neither age nor gender would affect the time required for healthy adults to move their upper extremities into a protective posture.

Methods. Twenty young (mean age 25 years) and twenty older (mean age 70 years) volunteers, with equal gender representation, performed a seated arm-movement task under three conditions: Condition 1, in which subjects were instructed to raise the hands upon cue as quickly as possible from thigh level to a shoulder height target; Condition 2, in which subjects were instructed as in Condition 1 with the addition of intercepting a swinging pendulum at the prescribed hand target; and Condition 3, in which subjects were instructed as in Condition 2 but were asked to wait as long as possible before initiating hand movement to intercept the pendulum. Arm movements were quantified using standard kinematic techniques.

Results. Age ($p < .01$) and gender ($p < .05$) affected hand movement times. In Conditions 1 and 2, the older women required 20% longer movement times than the other subject groups (335 vs. 279 milliseconds; $p < .01$). In Condition 3, shorter movement times were achieved by young men (20%; $p = .002$) and older women (10%; $p = .056$) as compared with their respective performance in Conditions 1 and 2 because they did not fully decelerate their hands. The other groups slowed their movements in Condition 3.

Conclusions. Age, gender, and perceived threat significantly affected movement times. However, even the slowest movement times were well within the time available to deploy the hands in a forward fall to the ground.

The upper extremities are the first line of defense in protecting the head and body from impact (1, 2). This often involves moving the hands rapidly into a protective posture ready for the collision. Although the kinematics of nonprotective rapid arm movements have received some attention (3, 4), it is not known whether the speed of protective movements is adversely affected by age.

It is known that the maximum speed of a nonprotective movement is inversely related to the terminal accuracy required, as predicted by Fitts’ Law (5); that rapid nonprotective movements slow with age (6, 7); and that elderly persons are at higher risk for fall-related injuries than young persons (8, 9). It would seem reasonable that if declines in the capacity of elderly persons to move their hands rapidly in a protective manner were found, then interventions could usefully be targeted at ameliorating such a deficit.

We therefore tested the hypotheses that neither age nor gender would affect the time required to perform a protective maneuver or its maximal velocity and acceleration. Furthermore, we tested the secondary hypotheses that neither age nor gender would affect the percentage of hand movement capacity (velocity and acceleration used, expressed as a percentage of maximum available capacities) utilized for protection in a task where the consequences of failure were perceived as threatening.

Methods

A total of 40 healthy community-dwelling subjects participated in the study, equally divided into four subgroups: young men (YM), young women (YW), old men (OM), and old women (OW). The young subject group had a mean age (± standard deviation [SD]) of 25 ± 3 years, whereas the elderly subjects had a mean age of 70 ± 3 years. A geriatric physician screened the elderly subjects and excluded those with any known physical or cognitive impairments. Ninety percent of the elderly subjects exercised regularly, but only 60% of the young subjects were currently as active. Written informed consent was obtained from each subject after approval of all procedures by the institutional review board.

Subjects were asked to perform three tasks (no-threat, low-threat, and high-threat) while seated.
**No-Threat Condition**

Two no-threat trials were conducted. After practice, each subject was instructed to start with his or her hands placed on the anterior surface of the thighs and then, upon an audio cue, raise the hands forward as quickly as possible to a break-away target positioned at approximately shoulder height, with the elbow extended to 120° and the fingers pointing upward (Figure 1). Subjects were given a countdown after which a manually-triggered audio cue signaled the subjects to raise their hands to within a “few inches” of the targets.

**Low-Threat Condition**

The next set of four trials was similar to the no-threat trials except that the cue to initiate movement also signaled the release of a 1.73-m-long ceiling-mounted ballistic pendulum (bob mass, 3.4 kg). The pendulum swung toward the subject in an anterior-posterior direction in the mid-sagittal plane from an angular position of 27° from the vertical (Figure 1). The pendulum reached the target interception zone approximately 700 milliseconds after release with an impact velocity of 1.8 m/s. Safety ropes prevented the pendulum from reaching the subject’s face.

**High-Threat Condition**

Eight additional trials were performed in which the subjects were asked to wait “as long as possible following the cued release of the pendulum” before initiating movement to intercept the oncoming pendulum, thus getting their hands into position “just in time.”

The pendulum was constructed of a pair of aluminum tubes (outer diameter, 2.6 cm), which were attached to a single hinge joint at the ceiling and were connected together at the bob. The bob consisted of a mounting block, a load cell, and a 12-cm by 20-cm plywood impactor for each hand. The impactor surface was covered with a layer of 2.4-cm-thick stiff foam padding.

An OPTOTRAK (Northern Digital, Waterloo, Ontario, Canada) system was used to measure arm segment and pendulum kinematic data at 300 Hz from a right lateral view. The kinematic data were low-pass filtered (4th order Butterworth; MATLAB, Natick, MA) with a cut-off frequency of 50 Hz. Pairs of infrared light-emitting diode markers were placed on the upper arm, the forearm, and the impactor head and laterally at the base of the neck and on the back of the chair.

Three measures of human performance were used to analyze the data (Figure 2): (i) the movement time (MT), which was determined as the time from when the velocity of the wrist first exceeded 0.2 m/s until it decreased below 0.4 m/s or until impact occurred (when the force measured at the pendulum exceeded 10 N); (ii) the maximum linear acceleration; and (iii) the maximum linear velocity reached by the wrist during the motion. For each subject the three measures from the best trial were calculated for every test condition, where “best” was defined as the trial with the shortest movement time. The 5 out of 120 best trials in which the movement distance was less than 2 SD below the group mean were excluded in favor of the next fastest trial.

---

**Figure 1.** Subjects were seated in an adjustable chair with the hands initially placed on the anterior surface of the thighs. The ceiling-mounted pendulum swung toward the subject at shoulder height from an initial release angle of 27°. The kinematic marker locations are shown by the small filled circles. The dashed lines outline the final arm position.

**Figure 2.** Average velocity profiles from all 320 high-threat trials. Trials were sorted into four groups: A, those with movement time (MT) greater than 450 milliseconds; B, those with MT between 350 and 450 milliseconds; C, those with MT between 250 and 350 milliseconds; and D, those with MT less than 250 milliseconds. The four curves show the ±1 standard deviation band for each of the four groups, revealing the typical “bell-shaped” curve. Shown are the three measurements used in this study: MT, maximum acceleration of the hand, and maximum velocity of the hand prior to impact.
The primary hypothesis was tested using a two-way analysis of variance (ANOVA) examining the effects of age and gender on the fastest movement time achieved by each subject in the three test conditions. Post-hoc, two-sided, independent t tests were then used to study directional effects. The first of the secondary hypotheses was tested using a Pearson correlation investigating the relationships between the primary outcome (MT) and the capacity measure variables (velocity and acceleration) in the no-threat task. To determine the capacity utilization of each subject group under the high-threat condition, paired two-tailed t tests were used to compare the level of velocity or acceleration employed under the high-threat condition with the corresponding measure in the no-threat condition. A p value less than .05 was considered statistically significant. Unless otherwise indicated, measures are presented as mean ± SD.

RESULTS

The ANOVA used to test the primary hypotheses showed significant age (p = .009) and gender (p = .02) effects between groups for MT. Within groups, there was a strong test condition effect (p = .0002), with a significant interaction: condition × age × gender (p = .0002). Examination of the group means revealed different patterns in the results obtained under the three test conditions (Table 1).

In the no-threat condition, OW MT was significantly slower than the other groups (Table 1). The OW used a 20% (56 milliseconds) longer MT than the other subject groups in the no-threat condition. Peak velocity was highly correlated with maximum acceleration: \( R^2 = .80 \) across all subjects. Both measures were independent predictors of the MT, with acceleration providing the superior correlation: \( R^2 = .64 \). Subject performance did not change significantly for any of the measurements in the low-threat condition compared with the no-threat condition.

In the high-threat condition, the YM displayed significantly shorter MT than all other subject groups (YM: 226 milliseconds; YW: 274 milliseconds; OM: 285 milliseconds; OW: 292 milliseconds) (see Table 1). The mean ± SD point-to-point distance moved by the hands was 31 ± 3 cm. Distances were similar for the other test conditions. We observed that the distance was shorter for older subjects than for younger subjects (30 vs 32 cm), although this difference was not significant. MT was not correlated to the start-stop straight-line distance for any subject group (\( R^2 < .1 \)).

A reduced usage of capacity could be expected in the high-threat case, if a more cautious strategy employed a submaximal movement velocity, because of the perceived threat associated with missing the desired target. In the no- and low-threat conditions, adjustments could still be made to the final hand positioning after the initial movement.

Capacity usage varied with age and gender. The OM exhibited significantly lower maximal acceleration (39% lower) and peak velocity (22% lower) during the high-threat condition as compared with the low-threat condition (Figure 3). Likewise, the YW also demonstrated a significantly lower acceleration (30% lower), although the peak velocity

<table>
<thead>
<tr>
<th>Table 1. Minimum Movement Times (MT) for Each Subject Group Under Each of the Three Test Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-Threat Condition (ms)</td>
</tr>
<tr>
<td>OM</td>
</tr>
<tr>
<td>YM</td>
</tr>
<tr>
<td>OW</td>
</tr>
<tr>
<td>YW</td>
</tr>
</tbody>
</table>

Notes: Values are means with standard deviations in parentheses. OM = old men (aged 70 ± 3 y); YM = young men (aged 25 ± 3 y); OW = old women (aged 70 ± 3 y); YW = young women (aged 25 ± 3 y).
*YM MT lower than all other groups in the high-threat condition (OM: p = .001; YW: p = .005)
†OW MT higher than all other groups in the no-threat condition (OM: p = .006; YW: p = .003).
‡YM MT lower in the high-threat condition than in the low-threat condition (p = .002).

Figure 3. Group comparison of the peak velocity and acceleration in the no-threat and high-threat conditions for the minimum movement time trials of every subject. Error bars indicate the standard error for each measurement. YM, young men; YW, young women; OM, old men; OW, old women.
physical risk-taking behavior. This may be one of the first effects on MT found in lower-extremity protective measures (12). Simple reaction times have been shown to be approximately 700 milliseconds from the initial balance disturbance (1). Small reaction times have been shown to be approximately 200 milliseconds in healthy adults (10,11), leaving a residual 500 milliseconds MT to move the arms into position for impact. The MT reported here, which ranged from 226 to 292 milliseconds, suggest that healthy adults should have sufficient time to deploy the hands properly to arrest a fall to the floor. However, the speed-accuracy trade-off will mean that tasks requiring greater accuracy, such as grabbing a support rail to arrest a fall, may take longer. In a recent study, elderly women arrested 21% of noninjurious falls in such a manner (12).

Strength loss with age has been well documented. For example, upper-extremity strength has been shown to decrease by approximately 20% in both men and women between the ages of 30 and 70 years (13). Between the ages of 20 and 75 years, MT has been found to increase by 50% and 100% in nonprotective movements performed by women (7) and men (6), respectively. In the no- and low-threat conditions, however, we did not observe such a slowing in the OM sub-
jects, but we did find a 24% difference (70 milliseconds) between YW and OM, indicating a moderate reduction in OW capacity. The absence of a pronounced age effect in the no-threat condition could be due to a sampling bias because this sample of older subjects was highly active (14). The modest age effect is consistent with the relatively small age effects on MT found in lower-extremity protective responses (15).

There are relatively few studies of the effect of age on physical risk-taking behavior. This may be one of the first studies to physically quantify the effect of age on risk-taking when an individual is faced with performing a familiar protective task, because risk-taking is more commonly assessed using subjective self-report measures (16,17). Others have found that older adults are more conservative or error-averse in making nonprotective rapid movements (18). In the present high-threat test condition, subjects self-selected the level of risk associated with the task. The most aggressive (risky) strategy required the subjects to use their full capacity and accelerate their hands until the time of impact. All the subjects, however, decelerated to some degree before impact in the high-threat condition, suggesting that not even the YM and OW used this most aggressive strategy.

Movement time could be expected to be shorter in the high-threat condition because it was not necessary to decelerate the hand before intercepting the target. Thus, in the no-threat and low-threat protocols the average velocity was 51% of the peak velocity (19), but in the high-threat case the subjects achieved an average velocity that was 64% of the peak velocity. However, only the YM and the OW were willing to use a strategy aggressive enough to lower their MT from that of the no-threat condition.

YM and OW used the same peak velocity and acceleration in the high-threat protocol as in the no-threat protocol, whereas OM used lower levels of velocity and acceleration under the higher risk conditions and YW used a lower level of acceleration. This suggests that the OM and YW were concerned with the accuracy of their hand positioning when attempting the most time-critical task, apparently choosing slower but more accurate movements.

One limitation of the present study was that we could not be absolutely certain that we measured maximum capacity in the no-threat case. We believe, however, that because neither acceleration nor peak velocity increased when the threat of an approaching pendulum was introduced in the low-threat condition, our capacity measures were reasonable. Another limitation of this study was the lack of experimenter control over the trajectory of the upper extremities in these movement tasks. Whereas this has validity in terms of how activities of daily living are performed, it limits how precisely one can compare movement times. This is because subjects used a variety of trajectories to reach the interception point and did not achieve identical final elbow angles in every trial. The finding that MT was not correlated to the point-to-point straight-line length of the hand trajectory used by the subject might be surprising. However, the explanation for this is that there was a strong correlation between distance and peak velocity, with the subjects who had larger point-to-point distances also having higher peak velocities. Despite the seated posture, the range of hand movement distances was not dissimilar to those used in positioning the arms for impact in a forward fall (20).

Taking larger risks in activities of daily living may put an individual at greater risk for falls. YM and OW demonstrated the highest risk-taking in this study. Risk-taking strategies could also affect fall arrest strategies. For example, using a submaximal movement velocity to achieve greater accuracy could result in the hand arriving too late to acquire a targeted hand support. Furthermore, the data indicate that it is important to consider subject perceptions of
the amount of risk involved when assessing a patient’s ability to make a rapid protective movement. Our results clearly demonstrate that results obtained from no- and low-threat test conditions could not reliably be used to predict performance in what subjects perceive to be a high-threat condition when the spatial accuracy required remains unchanged. Last, although we did observe significant slowing of MT with age, it would not appear to be large enough to affect the biomechanics of fall arrests with the arms.

Acknowledgments

This study was funded by PHS Grant P01 AG10542 and Grant P30 AG 08808. We thank Janet Grenier and Julie Grunewalt for their assistance with this study, Linda Nyquist, PhD, for contributions on the psychological aspects of the manuscript, and Ken Guire for statistical consultations.

Address correspondence to James A. Ashton-Miller, PhD, University of Michigan, MEAM, GGB 3208, Ann Arbor, MI 48109-2125. E-mail: jaam@umich.edu

Kurt M. DeGoede is currently at Elizabethtown College, Elizabethtown, PA.

References


Received September 7, 2000
Accepted September 12, 2000