INTRODUCTION

Over 90% of hip fractures in the elderly are caused by falls. Yet most falls in this population do not result in serious injury. Evidence suggests that hip fracture risk during a fall depends primarily on the kinematic state of the body at impact, and that specific protective responses strongly affect fall impact kinematics and fracture risk (Nevitt and Cummings, 1993; Schwartz et al., 1998; Parkkari et al., 1999; Hsiao and Robinovitch, 1998). These include rotating the trunk during descent to avoid hip impact, absorbing energy in the lower extremity muscles during descent, and “braking the fall” with the outstretched hands. Exercise programs that enhance these responses have a strong likelihood for reducing fall-related injuries.

In order to guide the design of such programs, biomechanical studies are required to determine the cause of age-related differences in ability to land safely during a fall. In the present study, we addressed this need by testing (through safe experiments with human subjects) whether differences exist between young and elderly women in the ability to break a fall with the outstretched hands. We focused on two components that govern the efficacy this response: (a) how quickly the hands can be moved into a protective position, and (b) the ability to absorb energy in the upper extremity muscles immediately after the instant of impact.

METHODS

Eighteen young (Y) women (mean age = 22 ± 3 yrs) and 20 elderly (E) women (mean age = 78 ± 6 yrs) participated in the experiment. The experiment was approved by the local IRB, and all subjects provided written informed consent. During upper extremity contact trials, the subject stood with the hands at the sides, facing shoulder-height padded targets, and attempted to contact the targets with the hands “as quickly as possible” after hearing an aural cue. The target distance was adjusted so impact occurred with the elbows flexed at 45 degrees. Over 10 repeated trials, we determined average values of: (a) the time between the go cue and the onset of hand movement (“reaction time (RT);” detected using a seven-camera motion measurement system (Qualisys, Inc.)), and (b) the time between the onset of hand movement and contact of the target (“movement time (MT);” measured from force platforms (Bertec Corp.) mounted under the contact targets).

During upper extremity energy absorption trials, the subject stood leaning at an angle θ from the vertical (initially set to 15°) with her arms fully extended and her hands contacting force platforms. She was instructed to then slowly lower her body weight (similar to the descent phase of a push-up). If the subject was able to complete the task at a given angle, the experiment was repeated with θ increased by 15°, up to a maximum of 90°. At each angle, we determined the average magnitude over three repeated trials of upper extremity energy absorption (NRG) for the dominant side (computed as the integral of the measured force-deflection curve).

We used independent sample t-tests (with Bonferonni correction) to determine whether there were differences between Y and E in upper extremity RT, MT, and NRG, and correlation to determine whether there was association between these three outcome variables.

RESULTS

In the contact experiments, we observed age-related slowing in MT (mean Y value = 316 ± 29 ms; mean E value = 395 ± 85 ms; P = 0.001), but not RT (mean Y value = 207 ± 37 ms; mean E value = 236 ± 37 ms; P = 0.02). In the energy absorption experiments, we found that peak magnitudes of NRG were greater for Y than for E subjects (mean = 0.308 ± 0.039 (SD) versus 0.172 ± 0.057 J/(kg*m); p < 0.001). This reflected Y subject’s ability to generate greater contact forces (3.29 ± 0.34 versus 2.10 ± 0.73 N/kg; p < 0.001), since no difference existed between Y and E in peak arm deflection (0.102 ± 0.012 versus 0.097 ± 0.021 m/m; p = 0.39).

We also found that there was no association between RT and MT (R = 0.25; p = 0.124), and no association between RT and NRG (R = -0.29; p = 0.075). There was, however, association between MT and NRG (R = -0.60; p = 0.001; Figure 1).

DISCUSSION

These results suggest that declines occur with age in ability to brake a fall with the outstretched hands, and that this is due to slowing of movement time and reduction in ability to absorb energy in the upper extremity muscles during impact. Slowing of reaction time with age is less striking (or non-existent). Our results also suggest that individuals with reduced energy absorption capacity tend to have slower movement times. These individuals represent important targets for exercise-based fracture prevention programs.

To put our results in context, consider that the time interval between the onset of a destabilizing perturbation and contact between the hands and the ground during a fall averages 680 ± 116 ms (Hsiao and Robinovitch, 1998). This is very similar to the total contact times (sum of RT and MT) observed in the current study (which averaged 523 ± 52 ms for Y, and 631 ± 94 ms for E), indicating the strict time requirements for braking a fall with the outstretched hands. Furthermore, recent (unpublished) experiments from our laboratory indicate that, during a forward fall from standing, the kinetic energy of the body at the instant of wrist impact averages 0.590 ± 0.338 J/(kg*m). Therefore (assuming equal energy-absorbing capacity in the non-dominant and dominant side), our current results suggest that most Y but not E adult females can absorb sufficient energy in their upper extremity muscles to halt the downward movement of the body during a fall, and thereby prevent impact to the head or pelvis.

There are several limitations to this study. For safety, we conducted the energy absorption trials under slow rates of muscle stretching, and therefore we may have underestimated attainable muscle forces (and energy absorptions) under faster rates of stretching. Also, we focused on the role of upper extremity impact in preventing hip fracture and head impact, which represent enormous public health problems. However, it should be recognized that one’s risk for wrist fracture during a fall is greatly increased by braking the fall with an outstretched hand.

Accordingly, programs to train safe landing responses should identify and training individuals to “brake the fall” in a way that also minimizes their risk for upper extremity injury (DeGoede et al., 2001).

ACKNOWLEDGEMENTS

Supported by grants from the CDC (R49CC019355), NIH (RO1AR46890), a CIHR New Investigator award, and a MSFHR Scholar award.

REFERENCES