INTRODUCTION
Falls become more common in adults as they age and often result in serious injuries such as fractures. Distal radius, or Colles’ fractures are the most common type of upper extremity fall-related fracture (Donaldson, et al. 1990). Even after they are healed, Colles’ fractures can continue to compromise normal function and activities of daily living (Madhok and Bhopal 1992).

Using the upper extremities to safely arrest the momentum of the body during a fall to the ground is a time-critical and complex motor event, the difficulty of which may be exacerbated by age. A primary research focus of experiments that simulate forward falls has been the quantification of upper extremity impact forces and reduction of these forces by manipulating landing biomechanics (DeGoede, Ashton-Miller et al. 2002). Experimental simulations of forwards falls onto the hands have been designed to safely circumvent many hazards of subjecting young and older subjects to upper extremity impacts. However, the availability of ample time to consider and pre-plan the motor task may influence execution of the motor task. It is possible that the motion of the upper extremities immediately following a postural disturbance that results in a forward fall may depart from the expected synchronous and symmetrical motions observed during these simulated falls.

Therefore, the aim of this study was to quantify the symmetry and synchronicity between the upper extremities, as well as to examine the overall motion of the arms relative to the torso during the descent phase of a fall resulting from an unexpected trip.

METHODS
Eight adults aged 65 years and older were evaluated in this study. A six camera system (Motion Analysis, Santa Rosa, CA) was used to record kinematic motion of 19 passively reflective markers used to create a 13-segment model of the body. Subjects walked at a self selected velocity and were protected from all fall to the ground by a safety harness system. They were informed they would be tripped during one of a series of walking trials, but they were not informed during which trial this would occur or the means by which the trip would be induced. The trip was induced during mid swing by a concealed, pneumatically driven obstacle that rose to a height of 5 cm in about 150 ms from the floor; the presence of which the subjects were previously unaware. A rope held by an investigator, plainly visible across the pathway, was used as a decoy.

Upper extremity kinematics (elbow flexion, shoulder flexion, and shoulder abduction) were analyzed from the instant of the trip up to, and including, the last data point available in the recording. The data was further divided into two time periods, based on trunk flexion angle. Time segment one (T1) included kinematic data from the instant the trip occurred until the trunk reached 50% of its maximum flexion angle. Time segment two (T2) included kinematic data from this point until the last point of data collection.

The cross-correlation (xcorr) between the right and left extremities for T1 and T2 of each arm motion was calculated (MATLAB). For between-subject comparisons the maximum xcorr was extracted from the cross correlation function and normalized using the equation:

$$\text{XCORR}_{\text{max}} = \max \left( \frac{\text{xcorr}_{xy}}{(\text{xcorr}_{xx} \times \text{xcorr}_{yy})} \right)^2$$

This calculation was used as a general metric of the similarities of the time series for each arm motion. The phase shift, tau (τ), at the point in time when the maximum cross correlation value occurred was also extracted from the cross correlation function. The XCORR$_{\text{max}}$ represented symmetry and the phase shift represented synchronicity.
A summary representation of upper extremity position was also computed. Position of the limbs relative to the torso was examined at three time points: the instant of the trip, the point dividing \( T_1 \) and \( T_2 \), and the last point of the data series. The difference in flexion between right and left limbs was calculated for the overall data set (Figure 1).

The \( \text{XCORR}_{\text{max}} \) values and phase shift for each of the three motions analyzed were compared between \( T_1 \) and \( T_2 \) using repeated measures ANOVA and post hoc paired t-tests with Bonferroni corrections. The right and left upper extremity summary positions at the three points were compared using paired t-tests (SPSS version 12.0).

**RESULTS AND DISCUSSION**

Upper extremity motion becomes more symmetric over the course of the fall. In other words, \( \text{XCORR}_{\text{max}} \) for \( T_2 \) was larger than \( T_1 \) \((p=0.021)\). On average, \( \text{XCORR}_{\text{max}} \) for shoulder flexion increased significantly from 0.34 to 0.84 \((p=0.002)\). Elbow flexion \( \text{XCORR}_{\text{max}} \) increased from 0.77 to 0.90 and shoulder abduction \( \text{XCORR}_{\text{max}} \) decreased from 0.92 to 0.88. For both elbow flexion and shoulder abduction there was not a significant change in the \( \text{XCORR}_{\text{max}} \), but throughout the motion they were both close to 1.0, representing very strong symmetry.

The differences in phase shift between upper extremity motion during \( T_1 \) and \( T_2 \) were not significant \((p=0.147)\). However, a post hoc power analysis revealed that the statistical power was low \((0.363)\). When the data of one subject, a clear outlier, was removed, the phase shift significantly decreased from \( T_1 \) to \( T_2 \) \((p=0.040)\) and the statistical power increased to 0.678.

The motion of the upper extremities relative to the torso changed throughout the fall. The flexion of the upper extremities significantly increased from time point 1 to 2 \((p=0.014)\) and between time points 1 and 3 \((p=0.004)\), but not between time points 2 and 3 \((p=0.727)\).

Figure 1 suggests that towards the end of the fall all individuals exhibit little difference in flexion of their arms. In addition, the three time points analyzed demonstrated both arms were positioned approximately \(38^\circ\) relative to the torso in the beginning of the fall and progressed to \(95^\circ\) out in front of their torso. This configuration allows for preparation in minimizing injury at impact.

The purpose of this study was to investigate the symmetry and synchronicity of the upper extremities, as well as overall arm motion during a trip-induced fall. The results indicate that during the initial phase of the fall, the upper extremities were generally less symmetric and synchronous. However, as ground contact becomes imminent, the upper extremities’ motions became significantly more symmetric. There was also a trend for the phase shift \((\tau)\) between the right and left arms to decrease over the course of the fall.

The present data suggest that available preplanning time inherent in experimental protocols to safely investigate the use of the upper extremities to arrest body momentum during a fall are reasonable surrogates. By increasing the understanding of the limits of upper extremity function, it may be possible to improve fall arrest strategies and decrease the incidence of fall-related injuries in older adults.

![Figure 1](image-url)

**Figure 1:** Difference between right and left flexion angles of all subjects during entire fall.

**REFERENCES**

