BODY ORIENTATION AFFECTS THE DISTAL UPPER EXTREMITY IMPACT RESPONSE FOLLOWING SIMULATED FORWARD FALLS

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INTRODUCTION

Injuries to the distal upper extremity frequently occur when people attempt to protect their head and torso with outstretched arms when they impact the ground after falling. The most common injury resulting from this scenario are distal radius fractures, which account for more than 50% [1] of all fall-related injuries and cost more than $500B annually [2]. While considerable effort has been focused on preventing falls and fall-related injuries, their incidence has remained relatively constant over the last 20 years.

Previous work using a valid and reliable fall simulation method [3] presented the muscle activation patterns and kinematics of forward falls occurring from two fall heights and under three different fall conditions (straight-arm, bent-arm and self-selected). While this work provided valuable insight into the strategies individuals used to safely arrest a fall, only symmetric falls in a single body posture (trunk relative to the legs) were evaluated, which does not accurately reflect the various fall positions people adopt. Therefore, the purpose of this study was to determine the effect of asymmetric loading and body posture on the response of the upper extremity following simulated forward falls.

METHODS

The Propelled Upper Limb fall ARest Impact System (PULARIS) [3] was used to simulate forward fall conditions for 20 (9 male, 11 female) university aged participants. Participants were suspended from PULARIS in varying combinations of torso angles in the horizontal plane (sagittal plane: 0°; asymmetric: 30° and 45° relative to the sagittal plane), and torso to leg height (with respect to the ground) ratios (2:1 - legs below the hips, and 1:1 - legs even with the hips). Details of the fall protocol can be found in [3] but briefly, participants were suspended from PULARIS and raised so that the hands were 10cm above the force plates prior to release. The hands were aligned with the leading edge of the force plates (drop point) and then PULARIS was moved back (~2 m) to the start point. PULARIS was propelled forward from the start point and participants were released into free-fall at 1 m/s when they reached the drop point. Participants were instructed to arrest the fall with their left and right hands by landing onto one of two tri-axial force plates rigidly attached to the floor. Participants’ hands impacted adjacent force plates in the 0° falls, and staggered plates in the 30° and 45° degree falls (Figure 1). A few no-fall trials were interspersed throughout the protocol to instill a sense of uncertainty common with actual falls.

Figure 1: Top view of the experimental set-up showing the position of the force plates relative to the participant in the three fall directions. Note: Fz axis for the force plates is out of the page.

Participants were instrumented with a distal (radial styloid) and proximal (olecranon process) tri-axial
accelerometer (right side only). The accelerometers measured the localized impact response in the axial (parallel with the long axis of the forearm), medio-lateral, and off-axis (perpendicular to the long axis of the forearm) directions. Peak forces and accelerations along all three axes were measured and a two-way (angle x direction) ANOVA was used to compare the means of the conditions tested.

RESULTS AND DISCUSSION

The overall mean (SD) resultant impact forces were 282.2 (88.5) and 246.1 (104.5) for the left and right hands, respectively, which agree well with previously reported symmetric fall data [3]. A significant fall direction main effect was found for the right Fx and the left Fx and Fz forces. The Fx forces during the asymmetric trials were almost eight (5.5 N vs. -39.6 N) and 14 (4.4 N vs. -53.5 N) times greater in magnitude compared to the symmetric falls, for the left and right hands, respectively (Figure 2). The left hand Fy and Fz forces decreased significantly by approximately 31 % and 20%, respectively from the symmetric to the asymmetric falls (Figure 2). Taken together, the impact force results suggest that the distal forearm is being loaded more medio-laterally during the asymmetric falls compared to the falls in the sagittal plane, where medio-lateral forces are negligible in relative terms. This shifting in the force vector during asymmetric falls may result in different injury mechanisms compared to symmetric falls.

The mean (SD) resultant distal and proximal accelerations were found to be 18.7 (4.3) g and 11.2 (4.6) g, respectively. A significant direction main effect was found for the proximal medio-lateral accelerations, such that the mean medio-lateral acceleration was a maximum of approximately 4 g less for the symmetric than the asymmetric falls. These acceleration findings further support the force data in that they reflect a similar change in the direction and magnitude of the joint loading.

In addition, a significant torso angle main effect was found for the proximal axial and off-axis peak accelerations. The proximal axial acceleration increased from a mean (SD) of -1.2 (3.9) g to 2.8 (3.4) g, while the off-axis acceleration decreased from -2.8 (4.1) g to -0.6 (4.5) g between the 1:1 and the 2:1 torso to leg height ratios. These results are consistent with the fact that falling with the legs positioned below the hips would reduce the percentage of body weight that is directed through the upper extremity at impact.

Figure 2: Comparison of the mean (SD) peak forces across the three fall directions for the left and right hands (*p<0.05).

CONCLUSIONS

A forward fall initiated impact can be affected by the way an individual falls. The force and acceleration results presented here suggest that falling asymmetrically can alter the magnitude and direction of the loading vector applied to the distal upper extremity, compared to falling in the sagittal plane. Specifically, falling asymmetrically may protect the distal upper extremity from injury by distributing the forces that cause a fracture inducing moment on the dorsal aspect of the radius, to occur in a more medio-lateral direction.

REFERENCES


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