EFFECT OF ELBOW ANGLE AND ROTATIONAL VELOCITY ON IMPACT FORCE DURING OF A FALL ONTO AN OUTSTRETCHED HAND

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INTRODUCTION

The wrist is the most common fracture site in the body (Donaldson et al. 1990). To determine the load likely to act on the hand while arresting a fall onto an outstretched hand a recent model analysis (Chiu, Robinovitch 1998) assumed a straight arm configuration upon initial impact with the ground. However, a study of untrained young males arresting self initiated falls from standing height found that initial ground contact occurred with an elbow angle of ~150°(Dietz et al. 1981), and impact forces were up to 60 % lower than those predicted with the above model. To resolve this discrepancy we developed a dynamic model of the upper extremity to test the hypothesis that both elbow angle and angular velocity can significantly alter the peak impact force when arresting a fall with the arms.

PROCEDURES

Each arm was modeled as two rigid links (length: L_1 and L_2) hinged at the elbow (Figure 1). The effective half-mass of the rest of the body, M=0.25BW, was connected at the shoulder through a spring and damper in parallel (K_1). At the ground, the interface between the hand and the landing surface was modeled with a non-linear element (K_2):

$$F_2 = kx^3(1 + b\dot{x}), \qquad (1)$$

used previously in a model of heal strike during running(Gerristen et al. 1995). A

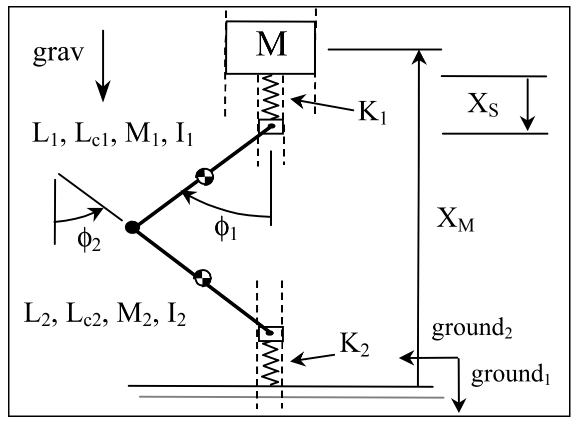

Figure 1: Rigid body dynamic model of the arm striking the ground while arresting a fall with outstretched arms

rotational spring and damper (not shown), in parallel, provide elbow restoring torque.

The model system had four degrees of freedom: X_M – the vertical position of torso, X_S – the position of the center of rotation of the shoulder, ϕ_1 and ϕ_2 – the absolute angle of the upper arm and forearm respectively, and is subject to one kinematic constraint:

$$L_1\dot{\phi}_1 \cos(\phi_1) + L_2\dot{\phi}_2 \cos(\phi_2) = 0. \qquad (2)$$

The parameter values for the shoulder and the hand-ground interface stiffness and damping were based upon data from tests conducted in 40 healthy subjects with a ballistic pendulum (unpublished data). The elbow parameters were selected such that the total elbow deflection matched the results from experimental trials with one healthy young subject measured using an Optotrak® camera system at 300 Hz.

RESULTS AND DISCUSSION

Simulations with the above model compared favorably with experimental data. The data from Deitz, et al., (1981) showed a peak force of approximately 1,100 N for a fall onto a stiff surface with an estimated impact velocity of 2.24 m/s (for the center of mass); additionally the elbow had an initial rotational velocity of 2 rad/sec. Model simulation under the same conditions yielded a peak impact force of 950 N (12 % error) for a 78 kg BW. To verify the overall nature of the response, a simulation of a fall with an impact velocity of 2.7 m/s was compared to the data from the young adult experimental trial (BW=72 kg) with the same impact velocity (Figure 2). The peak force from the experiment was 15 % lower than the peak force in the simulation, but in the experiment the force plate was padded with ¼" of neoprene.

Simulating a full fall to the floor (V_{impact}=3.0 m/s, BW=78 kg) onto a stiff surface, with no initial elbow velocity, produced a peak force of 1,350 N. The force increased to 1,640 N by changing the initial elbow angle from 150^o to 179.9°, and decreased to 950 N when reducing it 120°. So, each degree decrement in initial elbow angle decreased impact force by 0.9%.

With the elbow fixed at an initial configuration of 150°, altering the initial rotational velocity of the elbow at ground contact further modified the peak force. Extending the elbow at impact with a velocity of just five times that observed in the self-initiated falls, as can occur when actively reaching for the ground prior to impact, resulted in a 40% higher peak impact force of 1,910 N. Flexing the elbow, by pulling the hands toward the body, with the same angular velocity lowered the peak impact force by 35 % to 875 N.

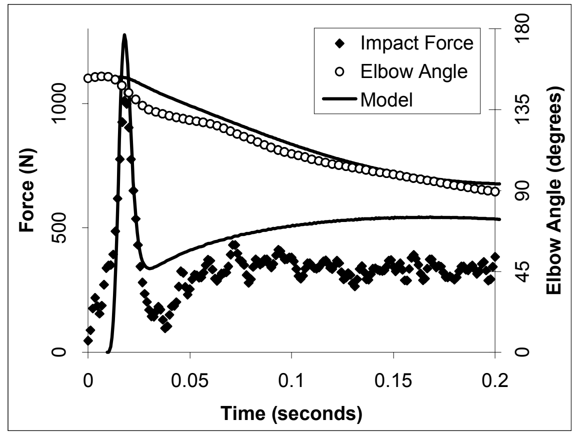

Figure 2: Experimental and simulated impact force and elbow angle data for the arrest of a forward fall with the arms.

SUMMARY

These results demonstrate that the peak impact force applied to the hands during the initial phase of a fall arrest can be modified significantly by altering the initial position and angular velocity of the elbow at ground contact. These findings suggest that it may be possible to affect the risk of wrist fracture in a fall, independent of the body's impact velocity and ground surface material properties.

REFERENCES

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