SIMULATION OF FORWARD FALLS: EFFECTS OF FALL STRATEGY AND AVAILABLE MUSCLE STRENGTH ON INJURY RISK

[1] Jia-Hsuan Lo and [1] James Ashton-Miller
[1] University of Michigan, Ann Arbor
email: joshualo@umich.edu

INTRODUCTION

Skilled use of the upper extremities can significantly reduce the magnitude of the fall-related impact force on the distal forearm during a forward fall [1]. However, simulations have shown that age-related decline in arm muscle strength reduces the ability to arrest a forward fall without a risk of torso and/or head impact [2]. It is not known whether lower extremity movement strategies used during the fall might ameliorate this effect. To investigate this we used direct dynamics simulations to test the hypothesis that the use of knee flexion in a forward fall reduces the impact severity in the presence of an age-related strength decline.

METHODS

A 2-D sagittal-symmetric, 7-segment rigid body model was used to simulate forward falls from a 20º forward inclination. Segments were connected by revolute joints, and the movement of each joint was driven by a pair of agonist and antagonist joint muscle torque actuators. Each actuator employed a Hill-type model with muscle excitation-activation dynamics [3]. A feedback proportional controller was used to drive each joint to a prescribed configuration (given target angle maintained with zero angular velocity) for the first impact. After the first impact, a final prescribed configuration was given to the controller. Gender differences were simulated by appropriate body segment and joint torque data, while age-related strength declines of 30% were assumed for healthy older adults. We simulated two fall strategies with different first impact configurations (Fig. 1): hip flexion with ("H & K") or without knee flexion ("H)", by constraining the prescribed joint angle ranges. The optimal prescribed joint configuration was then found via a global optimization method ("GCLSOLVE" [4]) that minimized the impact injury risk Φ, defined as the maximal ratio of the peak impact forces at wrist, elbow, knee and head to their corresponding fracture tolerances. The objective function was constrained by available joint torques for each age and gender group.

RESULTS AND DISCUSSION

For both young men and women, both fall strategies ('H' and 'H & K') resulted in similar impact injury risks. However, in the presence of age-related strength decline, the 'H' ("Hip Flexion Only") strategy becomes ineffective for avoiding head impact for both genders, as reflected in Φ (Fig 1). The simulations suggest that the better fall strategy for older women is to flex both hips and knees (the 'H & K' strategy) such that they land first on the hands and soon after on the knees. For the older men and young adults the hip flexion strategy ('H') was only slightly better than the 'H & K' strategy, the latter affording the largest head clearance (Fig. 1 & Table 1). The older adult falls resulted in greater injury risks (old: Φ=0.53 & 0.55 vs. young: 0.31 & 0.30 for men and women, respectively; Table 1), while their kinetic energy at impact was similar to those in the young. The optimizer selected straighter elbow angles at impact in order to compensate for strength decline, and this is the main reason for the greater Φ in the old (see θ_{Elbow} in Table 1). These results reflect a forward fall from near-upright stance; further simulations are needed to study arrest behaviors during gait.

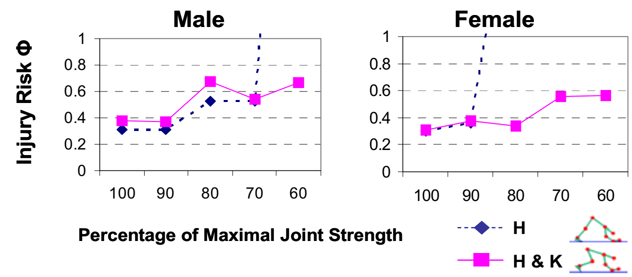

Figure 1: *Injury risk, Φ, versus joint strength relationships.*

CONCLUSIONS

1) Knee flexion reduces the risk of head impact in a forward fall arrest.
2) The hip and knee ('H & K') flexion strategy is the better of the two arrest strategies, particularly in older women.
3) Straighter impact elbow angles are required to avoid head impact in the presence of age-related strength declines.

REFERENCES

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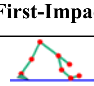
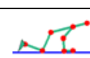
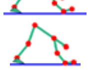
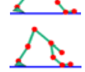
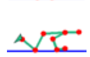
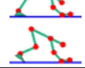
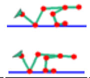
2. DeGoede KM, et al. J Biomech **36,** 413-20, 2003
3. Pandy MG, et al. J Biomech **23,** 1185-1198, 1990
4. Holmstroem K. Adv. Model. Optim. **1,** 47, 1999

Table 1: *The first-impact and final body configurations of the better forward fall arrest strategies for young/old male/female.*

	Body Wt. and Ht.	Strength Factor	Body Configuration			Impact KE (J)	θ_{Elbow} (°)	Injury Risk Φ	Max. Impact Force (N)	
			Initial	First-Impact	Final				Wrist	Knee
Young Men	75 kg, 1.75m	1				56	36	0.31	616	349
Old Men	75 kg, 1.75m	0.7				57	23	0.53	1054	529
Young Women	60 kg, 1.63m	1				46	32	0.30	607	974
Old Women	60 kg, 1.63m	0.7				44	14	0.55	1115	1722