EFFECT OF FLOOR STIFFNESS ON IMPACT FORCES DURING FALLS ON THE HIP

Andrew C.T. Laing, Iman Tootoonchi, Stephen N. Robinovitch
Injury Prevention and Mobility Laboratory, School of Kinesiology, Simon Fraser University,
Burnaby, BC, Canada E-mail: aclaing@sfu.ca Website: www.sfu.ca/ipml/

INTRODUCTION

Over 90% of hip fractures are due to falls (Spaite et al., 1990), and fracture risk during a fall depends on the impact force applied to the proximal femur (Cummings and Nevitt, 1989). Accordingly, interventions that attenuate impact forces have considerable potential for reducing hip fracture incidence. One possible strategy for achieving this (especially relevant to high-risk environments such as nursing homes or senior centres) is to reduce the stiffness of the floor (Maki and Fernie, 1990; Gardner et al., 1998; Casalena et al., 1998a,b). However, previous studies have not quantified the relationship between floor stiffness and peak force. Our goal in the current study was to determine this relationship for safe fall heights, and test the hypothesis that peak force during impact to the hip associates with fall height and floor stiffness.

METHODS

Seven adult females (of mean age 22.7 ± 2.4 yrs and mean body mass 57.4 ± 5.8 kg) provided informed consent and completed the study protocol. During the trials, the subject rested her lower limbs and upper body on rigid platforms (Figure 1), and her pelvis on a linear-stiffness springboard that (in the undeflected condition) was flush to the surface of the platforms. A nylon sling and electromagnet was then used to lift and instantly release the pelvis from heights of 1.25 cm and 5 cm above the springboard (Robinovitch et al., 1997). The springboards had stiffness values \((k_f)\) of 7.6, 17.6, 31.0, 86.4, and 733 kN/m (measured by impulse response). Impact forces were recorded from a forceplate under the springboard (Bertec, model 4060H), which we sampled at 960Hz. We acquired four trials for each combination of fall height and floor stiffness.

In each trial, contact force rose to a peak value and then decayed to a final resting force, reflecting single-degree-of-freedom behaviour (Figure 2). We used a 2-factor repeated measures ANOVA to determine whether peak impact force (normalized by body mass) was affected by floor stiffness and fall height. We also compared experimental trends to those predicted by a four-parameter mathematical (vibratory) model (inset to Figure 1). Model parameters were characterized using curve-fitting routines to determine the natural frequency and damping ratio, and corresponding values of \(m_b\), \(k_b\), and \(b_b\).
RESULTS AND DISCUSSION

Peak impact force associated with both floor stiffness and fall height (p<0.001). At the 5cm fall height, average values of peak force were 54% lower in the 7.6 kN/m floor than the 733 kN/m floor. However, in the 1.25 cm fall, the same reduction in floor stiffness caused only 32% attenuation in impact force. Model predictions mimicked these experimental trends.

These trends reflect the complex effect that floor stiffness ($k_f$) has on the system’s energy absorption and dissipation characteristics. Reducing $k_f$ causes a reduction in system stiffness, and a decrease in energy dissipation (since the velocity across the damper is decreased). At higher fall heights (including any fall from standing height), the former effect dominates, and reductions in $k_f$ lead to a substantial attenuation in peak force. At low fall heights, the two effects tend to cancel each other, and peak force is nearly constant.

An important consideration for future studies is determining the threshold in $k_f$, below which balance maintenance and recovery is substantially impaired.

Figure 2: Typical force vs. time traces

Figure 3: Model output and experimental peak force vs. floor stiffness results (mean across subjects +/- 1 SE) at 1.25 and 5cm fall heights.

SUMMARY

This study investigated the relationship between floor stiffness and peak impact forces during falls on the hip. We found that peak force was reduced by 54% by reducing the floor stiffness from 733 to 7.6 kN/m. These trends are supported by predictions from a four-parameter vibratory model. These data support the notion that low stiffness floors may significantly reduce hip fracture risk during a fall.

REFERENCES


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