EFFECT OF PLAYGROUND SURFACE MATERIALS ON PEAK FORCES DURING FALLS

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INTRODUCTION

Distal radius fracture is the most common serious injury on school playgrounds, with more than 90% of cases due to falls on the outstretched hand (Vollman et al., 2009; Sherker, 2004; Mowat et al., 1998; Mott et al., 1997). Yet current guidelines for the design, selection, and testing of playground surfaces are based only on the risk for fall-related head injury (ASTM, 2009). Information is required of the protective value of common playground materials (sand, gravel, rubber, and wood chip) in attenuating upper extremity forces and protecting against risk for distal radius fracture during falls on the outstretched hands.

Against this background, we conducted experiments where young adults landed from a safe fall onto their outstretched hands, impacting either a rigid surface or one of four common playground surfaces. We then analyzed the data to test the hypothesis that the type of surface material affects the peak vertical and horizontal force applied to the hands at impact. A secondary objective was to test the hypothesis that the configuration of the arms at impact influences peak impact forces.

METHODS

Subjects

Twelve young men participated, ranging in age from 18 to 35. All participants provided written informed consent, and the experimental protocol was approved by the Committee on Research Ethics at Simon Fraser University.

Protocol

We simulated forward falls through “torso release experiments” (Choi and Robinovitch, 2010), where the participant’s torso was suspended and then instantly released, causing them to descend 5 cm vertically and land on their outstretched hands (Figure 1). Trials were acquired for falls onto a rigid surface, and onto 15 cm thick layers of five common playground materials: sand, gravel, wood mulch, Engineering Wood Fiber (EWF), and rubber tile. The time-varying three-dimensional forces applied to the hands during impact were acquired at 500 Hz from a force plate (Bertec model 6090, Columbus, OH, USA). All playground surface materials were contained in a box having surface dimensions 82 x 56 cm, rigidly secured onto the force plate. The knees and shins rested on surgical positioning mats (allowing for consistent positioning), the height of which was adjusted so the knees were flush with the surface that the hands landing upon. For each surface, we acquired trials with the arm oriented at 20 or 40 degrees from the vertical. Three trials were acquired in each condition, and the order of presentation of the conditions was randomized.

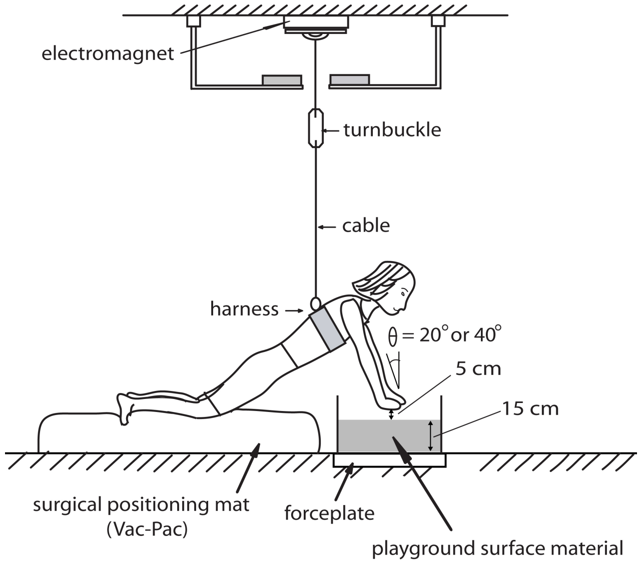

Figure 1. Schematic of “torso release experiment,” simulating falling on the outstretched hands onto a rigid surface or a playground surface material.

Data analysis

For each trial, we determined the magnitudes of the peak vertical and horizontal force (Fz_max and Fh_max, respectively), and the times (relative to the first instant of impact) of those peak forces (Figure 2). Horizontal forces were defined as the vector sum of the Fx and Fy components recorded by the force plate.

We used repeated measures analysis of variance (ANOVA) to test whether there were significant differences in the magnitudes and times to peak force between the various surface materials (6 levels) and arm configurations (2 levels). Where ANOVA results indicated a significant effect, we examined pair-wise comparisons using a Bonferroni correction to maintain the total alpha at 0.05. All analyses were conducted with the SPSS Version 18.

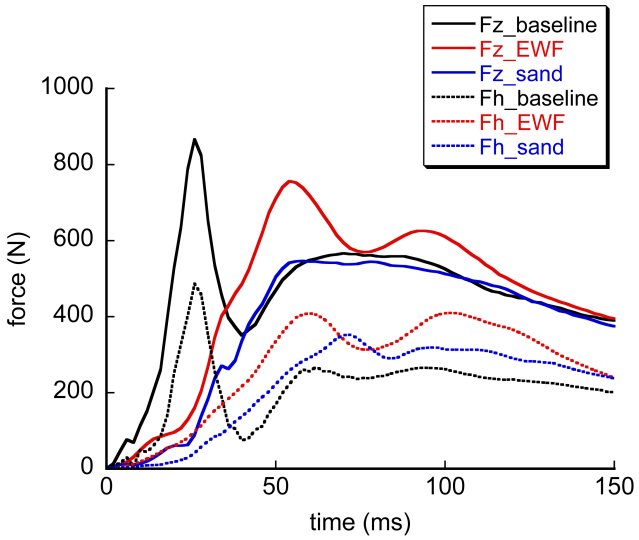

Figure 2. Sample traces of vertical and horizontal force from falls onto a rigid surface (baseline), engineered wood fiber (EWF), and sand.

RESULTS

The magnitude of peak vertical force associated with arm configuration ($F=57.2$, $p<0.001$) and surface material ($F=13.7$, $p<0.001$), and there was a significant interaction between arm configuration and surface materials ($F=3.6$, $p=0.023$). When compared to the rigid condition, peak vertical force was reduced 24% by sand (from 857 N to 651 N), 19% by gravel, 13% by mulch, 11% by EWF, and only 4% by rubber tile. The average magnitude of peak vertical force was greater in the 20 than 40 degree arm configuration (805 versus 703 N) (Figure 3).

The magnitude of peak horizontal force associated with arm configuration ($F=40.7$, $p<0.001$), but not with surface material ($F=1.9$, $p=0.159$), and again there was a significant interaction ($F=4.9$, $p=0.01$). The peak horizontal force was greater in the 40 than 20 degree arm configuration (671 N versus 576 N).

Time to peak vertical peak force associated with surface material ($F=7.7$, $p=0.001$), but not with arm configuration ($F=0.7$, $p=0.40$), and there were no interactions ($F=2.1$, $p=0.108$). The time to peak force was quickest in the baseline condition (38 ms), followed by rubber (42 ms), gravel (51 ms), EWF (55 ms), sand (58 ms), and mulch (59 ms) (Table 1). Similarly, time to peak horizontal force associated with surface material ($F=24.3$, $p<0.001$), but not with arm configuration ($F=0.1$, $p=0.72$), and there were no interactions ($F=2.8$, $p=0.065$).

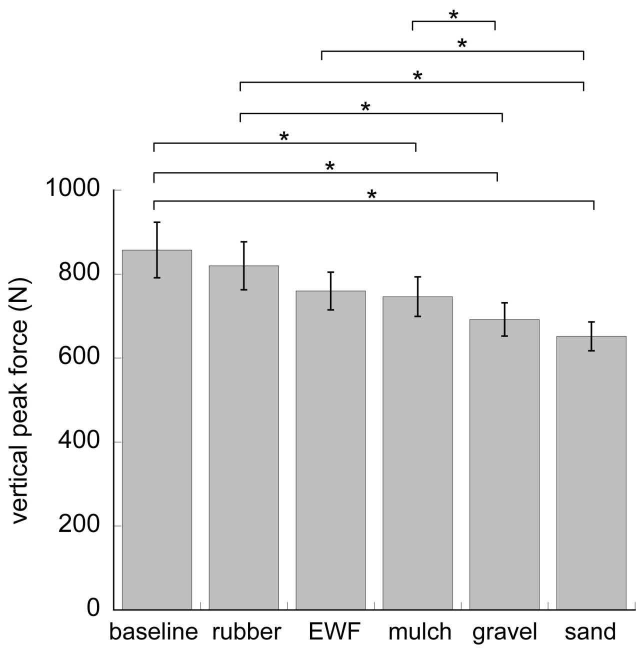

Figure 3. Effect of surface material on peak vertical force. Asterisks (*) indicate significant differences between conditions.

Table 1. Mean (SE) values of time to peak force for the various impact surface.

	baseline	rubber	EWF	mulch	gravel	sand
Time to Fz_max (ms)	38.0 (6.1)	41.7 (6.2)	55.0 (2.5)	59.3 (3.4)	51.0 (3.4)	58.2 (6.5)
Time to Fh_max (ms)	37.8 (2.5)	51.6 (5.9)	68.0 (3.2)	64.0 (2.0)	79.6 (3.9)	85.4 (6.8)

DISCUSSION

In this biomechanical study of falls onto the outstretched hands, we found that, when compared to falls onto a rigid surface, common playground surface materials caused a moderate but significant reduction in peak vertical force (between 4 and 24%), but had no effect on peak horizontal force. We also found that playground surface materials significantly increased the time to peak vertical and horizontal force (by 10 to 126%), thus reducing the rate of load application.

We found that sand provided the greatest reduction in peak vertical force, and the greatest increase in time to peak horizontal force, among the five surface materials tested. These findings agree with the results of a recent clinical study by Howard et al. (PLoS Med, 2009), which reported than upper extremity fractures were 4.9 times more frequent on EWF than sand playground surfaces. However, these authors surmised that "fracture rates are lower on sand because of lower surface friction," and our results suggest a different mechanism. For the range of arm configurations we examined, neither sand nor EWF influenced the peak horizontal (frictional) force. However, sand attenuated peak vertical force more than twice as much as EWF, and this probably explains its superior protective value.

ACKNOWLEDGEMENTS

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