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Evaluating the protective capacity of novel compliant flooring systems during simulated head impacts using a surrogate human headform

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Novel compliant flooring systems substantially reduce forces and accelerations during simulated 'worst-case' head impacts

INTRODUCTION

Fall-related injuries in adults over the age of 65 are associated with direct costs of over $2.0 billion per year in Canada alone [1], a large portion of which may be attributed to fall-related traumatic brain injury (TBI). TBI are caused by falls in up to 90% of cases [2], and are responsible for over half of all fall-related deaths in seniors [3]. In order to reduce the social and economic burdens associated with expected increases in fall-related injuries (including TBI) due to North America's ageing population, effective intervention strategies are required.

One intervention approach that is particularly relevant for high-risk settings (e.g. retirement homes, hospitals) involves the installation of **novel compliant flooring systems (NCFs)**. Compared to vinyl floors, some NCFs have been shown to decrease the peak force applied to the proximal femur by 25-50% during simulated sideways falls [4]. Furthermore, some NCFs appear to provide these benefits with minimal concomitant impairments to balance control (characterized by postural sway, Timed Up-and-Go, and floor perturbation tests [4,5]. However, it remains unknown whether NCFs influence impact dynamics during simulated 'worst-case' head impacts compared to traditional flooring materials.

Objectives

The goals of this study, using indices of skull fracture and TBI risk, were to determine:

1) a 'worst-case' impact condition based on the orientation of a surrogate human headform during impact; and

2) the effect of novel compliant flooring systems on headform impact dynamics compared to a commercial-grade carpet with underpadding.

METHODS

Apparatus:

a) Mechanical Drop Tower
b) Triaxial accelerometer at COM of surrogate headform (NOCSAE)
c) Infrared light gate velocimeter to record impact velocity
d) Flooring sample
e) Uniaxial load cell beneath impact surface

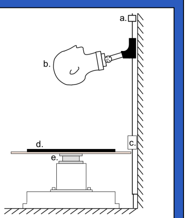

Figure 1: Schematic of the mechanical head impact simulator

Part 1. Worst-case Orientation:

Floor Condition: Commercial-grade Carpet (*CC*)
Impact Velocities: 1.5, 2.5, 3.5 m/s
Head Orientations: Front (*F*), Back (*B*), Side (*S*)
Statistical Techniques:
Two Factor ANOVA (Impact Velocity, Orientation)
Tukey's Post-hoc

Part 2. NCFs vs. Traditional Flooring Systems:

Floor Condition: 6 floors (Figure 2)
Impact Velocities: 1.5, 2.5, 3.5 m/s
Head Orientations: Back (*B*)
Statistical Techniques:
Two Factor ANOVA (Impact Velocity, Floor Condition)
Dunnett's Post-hoc (*CC* as control floor)

Figure 2: Floor conditions tested (clockwise from top left): Vinyl (*V*), Commercial Carpet (*CC*), Residential Carpet (*RC*), Berber Carpet (*BC*), SmartCell (*SC*), Kradal (*KR*),

***Dependent Variables*:**

1) Peak Impact Force (F_{max})
2) Peak Resultant Acceleration (g_{max})
3) Head Injury Criterion (*HIC*)

$$HIC = \max\left[(t_1 - t_0)\left[\frac{1}{(t_1 - t_0)}\int_{t=t1}^{t2} a_r\,dt\right]^{2.5}\right]$$

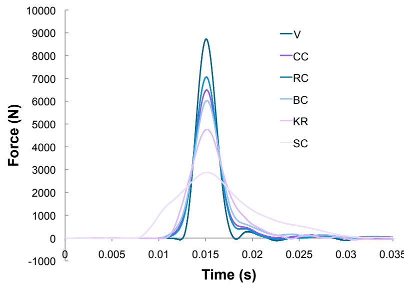

Figure 3: Representative force profiles for 2.5 m/s impacts onto each floor condition (back of the head (*B*) orientation)

RESULTS

Part 1. Worst-case Orientation:

Worst-case impacts were on the back of the headform

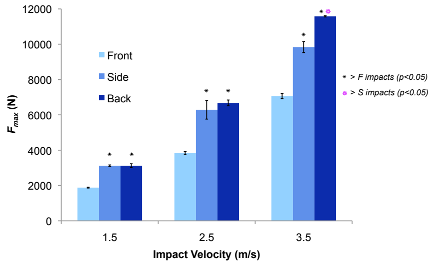

Figure 4: Peak forces following impacts to the front, side, and back of the surrogate headform

Part 2. NCFs vs. Traditional Flooring Systems:

NCFs attenuate impact forces/accelerations by up to 80%

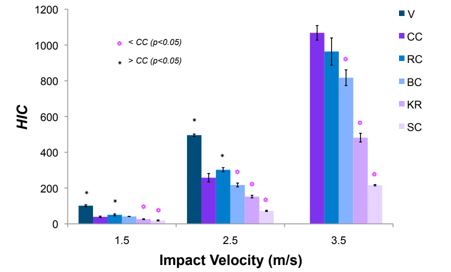

Figure 5: Head Injury Criterion (*HIC*) scores for impacts across floors and impact velocities. Note: 3.5 m/s impacts not completed on the Vinyl (V) floor

Floor	g_{max} (g)			F_{max} (N)		
	1.5 m/s	2.5 m/s	3.5 m/s	1.5 m/s	2.5 m/s	3.5 m/s
CC	54.7 (3.4)	122.7 (3.8)	262.1 (11.1)	3118.7 (111.0)	6675.9 (164.6)	11583.1 (33.5)
V	**89.7 (6.0)	**170.0 (3.0)	-	**4675.5 (10.5)	**8721.4 (42.7)	-
BC	57.0 (0.7)	113.7 (7.2)	*213.6 (5.7)	3044.5 (92.9)	*5896.1 (252.9)	*10775.7 (130.7)
RC	**65.9 (3.6)	**137.7 (6.5)	*217.4 (4.8)	**3376.2 (83.3)	6961.2 (118.1)	11355.5 (300.1)
SC	*30.6 (2.3)	*51.7 (1.3)	*97.9 (3.0)	*1739.7 (19.7)	*2952.8 (13.5)	*5280.8 (204.6)
KR	*41.0 (1.8)	*91.2 (3.9)	*156.6 (1.4)	*2288.7 (14.7)	*4753.4 (20.8)	*8551.8 (40.2)

Table 1: Summary of peak accelerations (g_{max}) and peak forces (F_{max}) applied for each floor condition across impact velocities. * denotes <CC, ** denotes >CC (p<0.05)

IMPLICATIONS

- Novel compliant floors (NCFs) reduce impact forces and accelerations applied to a surrogate headform compared to both commercial-grade vinyl and carpet with underpadding
- Traditional compliant floors (e.g. carpets) may provide protective capacity compared to stiffer products such as Vinyl
  - However, these benefits were modest in comparison to those provided by NCFs
- Protective capacity of NCFs was greater at higher impact velocities
  - Suggests that floors didn't bottom out
- Combined with reports of minimal influence on balance control, some NCFs may be a feasible approach for reducing fall-related injuries in seniors
- These results provide support for clinical trials of NCFs in high-risk settings

REFERENCES

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