THE INFLUENCE OF NOVEL COMPLIANT FLOORING SYSTEMS ON IMPACT DYNAMICS DURING SIMULATED IMPACTS TO THE BACK OF THE HEAD

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SUMMARY
Novel compliant flooring systems are a promising approach for reducing fall-related injuries in older adults based on evidence of substantial force reduction during simulated falls on the hip and minimal influence on balance and mobility. In this study we observed force and acceleration attenuation of up to 80% provided by these products relative to a padded carpet during simulated head impacts.

INTRODUCTION
Fall-related injuries in adults over 65 years of age are associated with direct costs to the Canadian Health Care system in excess of $2.0 billion per year [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 minimize the social and economic burden associated with the ageing of Canada’s population, effective intervention strategies are required to stem the anticipated rise in the incidence of fall-related injuries (including TBI) over the next 25 years. One approach that is particularly relevant for the highest-risk settings (such as retirement homes, hospitals, and residential-care facilities) involves the installation of novel compliant flooring systems (NCFs). Compared to vinyl floors, some NCFs have been shown to attenuate the peak impact force applied to the proximal femur by 25-50% during simulated sideways falls to the hip [4]. Furthermore, some NCFs appear to provide these benefits with minimal concomitant impairments to balance, as supported by the results of postural sway, Timed Up-and-Go, and backwards floor perturbation tests [4,5]. The purpose of this study was to determine how NCFs influence impact dynamics during simulated impacts to the back of the head compared to traditional flooring materials.

METHODS
A low-friction drop tower system was used to translate and impact the occipital region of a medium-sized headform (National Operating Committee on Standards for Athletic Equipment) onto six different flooring conditions. These included two novel compliant flooring systems (SmartCell, Kradal), three carpet conditions with 6 mm underpadding (Commercial Carpet, Residential Carpet, Berber), and a commercial grade Vinyl. Three different drop heights were used with associated impact velocities of 1, 2, and 3 m/s (measured by an infrared light gate). It is noteworthy that impacts at 3 m/s were not conducted for the Vinyl floor in order to prevent damage to our testing system. A triaxial accelerometer mounted at the centre-of-mass of the headform recorded the acceleration profile for each impact, while a uniaxial load cell mounted beneath the flooring sample measured impact forces applied to the headform. Peak acceleration ($g_{\text{max}}$) and Head Injury Criterion (HIC) values (correlated with skull fracture and traumatic brain injury risk, [6-8]) were calculated from the resultant acceleration data. Peak force ($F_{\text{max}}$) was recorded from the load cell data.

RESULTS AND DISCUSSION
Representative force vs. time profiles for 2 m/s impacts onto each floor are provided in Figure 1, while acceleration profiles from the same trials are presented in Figure 2. A summary of the data for $g_{\text{max}}$ and $F_{\text{max}}$ is presented in Table 1, while the HIC scores across all floors are summarized in Figure 3.

Figure 1: Representative force vs. time profiles from 2 m/s impacts onto each floor condition.

Two-way ANOVAs indicated a significant interaction between floor condition and impact velocity for all three outcome parameters, characterized by increased attenuation in outcomes in the NCF conditions as impact velocity increased (p always <0.001). Subsequent one-way ANOVAs at each impact velocity indicated a significant effect of floor condition for all variables (p always <0.001). Compared to the Commercial Carpet, Dunnett’s post-hoc analysis indicated that $HIC_{\text{max}}$, $g_{\text{max}}$, and $F_{\text{max}}$ were significantly reduced at all impact velocities for both SmartCell (means of 102.5, 60.1 m/s², and 3324.4 N, respectively) and Kradal (means of 220.2, 96.3 m/s², and 5198.0 N, respectively) floors (p always <0.005). In contrast, all outcome parameters were significantly higher for the Vinyl floor compared to the Commercial Carpet (p always <0.001).

Compared to a commonly used traditional compliant flooring system (Commercial Carpet with underpadding), peak
accelerations were attenuated by approximately 25-63% on the NCFs. Similarly, \textit{HIC} scores were roughly 33-80% lower, while peak forces were 26-56% lower.

CONCLUSIONS

This study demonstrates that the novel compliant floors tested (SmartCell and Kradal) are capable of substantially reducing indices of skull fracture and TBI risk ($g_{\text{max}}$, \textit{HIC}, $F_{\text{max}}$) [6-8] compared to traditional flooring materials during simulated falls involving head impact. These trends are in agreement with previous reports of the force attenuative properties of novel compliant floors for simulated impacts to the hip in which two novel compliant flooring systems, including SmartCell, reduced the impact force applied to the proximal femur by 25- 50% [4].

Towards the goal of fall-related injury prevention, it is imperative that balance and mobility are not compromised by altering the stiffness of a flooring surface in an attempt to reduce impact forces and accelerations. Previous work has demonstrated that certain novel compliant floors (including SmartCell) have minimal influence on clinical measures of balance in community-dwelling older women [4,5]. Although traditional compliant flooring products including carpet may provide some degree of impact attenuation compared to harder surfaces such as vinyl, their protective capacity appears modest when compared to the novel compliant floors tested in this study. These results provide further support for the promise of novel compliant floors as an effective intervention strategy to reduce fall-related injuries in seniors.

REFERENCES


Table 1: Means (SD) for peak acceleration ($g_{\text{max}}$) and peak force ($F_{\text{max}}$) applied to the surrogate headform during impacts at 1, 2, and 3 m/s across the six flooring conditions tested. Note that 3 m/s impacts were not performed for Vinyl in order to protect the mechanical integrity of our test system. * indicates significant (p<0.05) decrease and ** indicates significant (p<0.05) increase compared to Commercial Carpet.

<table>
<thead>
<tr>
<th>Floor</th>
<th>1 m/s</th>
<th>2 m/s</th>
<th>3 m/s</th>
<th>1 m/s</th>
<th>2 m/s</th>
<th>3 m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vinyl</td>
<td><strong>89.7 (6.0)</strong></td>
<td><strong>170.0 (3.0)</strong></td>
<td>-</td>
<td><strong>4675.5 (10.5)</strong></td>
<td><strong>8721.4 (42.7)</strong></td>
<td>-</td>
</tr>
<tr>
<td>SmartCell</td>
<td><em>30.6 (2.3)</em>*</td>
<td><em>51.7 (1.3)</em>*</td>
<td><em>97.9 (3.0)</em>*</td>
<td><em>1739.7 (19.7)</em>*</td>
<td><em>2952.8 (13.5)</em>*</td>
<td><em>5280.8 (204.6)</em>*</td>
</tr>
<tr>
<td>Kradal</td>
<td><em>41.0 (1.8)</em>*</td>
<td><em>91.2 (3.9)</em>*</td>
<td><em>156.6 (1.4)</em>*</td>
<td><em>2288.7 (14.7)</em>*</td>
<td><em>4753.4 (20.8)</em>*</td>
<td><em>8551.8 (40.2)</em>*</td>
</tr>
<tr>
<td>Berber</td>
<td>57.0 (0.7)</td>
<td>113.7 (7.2)</td>
<td>*213.6 (5.7)</td>
<td>3044.5 (92.9)</td>
<td>*5896.1 (252.9)</td>
<td>*10775.7 (130.7)</td>
</tr>
<tr>
<td>Res. Carpet</td>
<td><strong>65.9 (3.6)</strong></td>
<td><strong>137.7 (6.5)</strong></td>
<td><strong>217.4 (4.8)</strong></td>
<td><strong>3376.2 (83.3)</strong></td>
<td>6961.2 (118.1)</td>
<td>11355.5 (300.1)</td>
</tr>
<tr>
<td>Com. Carpet</td>
<td>54.7 (3.4)</td>
<td>122.7 (3.8)</td>
<td>262.1 (11.1)</td>
<td>3118.7 (111.0)</td>
<td>6675.9 (164.6)</td>
<td>11583.1 (33.5)</td>
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