SHOE CUSHIONING REDUCES IMPACT AND MUSCLE ACTIVATION DURING LANDINGS FROM UNEXPECTED, BUT NOT SELF-INITIATED, DROPS

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The aim of this study was to examine the effects of shoe cushioning on impact biomechanics and muscular responses during drop landings. Twelve male subjects performed bipedal landings from self-initiated and unexpected drops from a 60-cm height wearing highly-cushioned basketball shoes and minimally cushioned control shoes. Sagittal plane kinematics, ground reaction forces, accelerations of the shoe heel-cup, and EMG signals of four lower-limb muscles were collected simultaneously. During self-initiated landing, the shoe intervention did not significantly change the characteristics of impact force and muscle activity patterns. However, in the situation when relevant muscles are not activated on purpose, such as the landings from unexpected drops, wearing a highly-cushioned shoe decreases peak impact and muscle post-activation.

KEY WORDS: shoe cushioning, peak impacts, muscle activation, drop landing.

INTRODUCTION: Lower extremity injuries are closely associated with impact, as repetitive and excessive loading induces both acute trauma (Beynnon et al., 2005) and overuse damages (Borowski et al., 2008). Many injuries occur during landing activities, which generate peak vertical ground reaction force (GRF) as high as 3.5 to 6 times body weight (BW) (Bobbert et al., 1987). Except for impact magnitude, the peak force occurrence time, loading rate, musculoskeletal preparations, and shoe configurations were factors that are related with impact (Lieberman et al., 2010). To reduce the risk of impact-related injuries in athletic activities, footwear manufacturers have focused on designing shoes that can reduce impact loading, and thus the concept of “cushioning” has been widely used since the 1970s. Muscle activities shortly before and after ground contact are associated with preparing for and responding to the impact, and thus executing the movement task, e.g. running or landing, (Chumanov et al., 2012; Nigg & Wakeling, 2001). The relationship between impact force and muscle responses has been studied using both experiments and modeling over the past decade (Brüggemann et al., 2011). The impact can be regarded as an input signal into the human locomotor system, and it initiates lower extremity soft tissue vibrations. The central nervous system responds to the signal by activating corresponding muscle groups, and the musculoskeletal system controls the activation level to avoid a resonance situation (Nigg & Wakeling, 2001). This type of neuromuscular adaptation has been shown to minimize vibrations and affect leg posture during ground contact (Boyer & Nigg, 2006).

With respect to footwear, different shoe conditions can potentially modify the mechanical input into the musculoskeletal system resulting from a given impact situation, especially in unanticipated events or landings. However, to date, few rigorous scientific studies have been conducted to investigate the role of footwear during more strenuous landing tasks based on the interaction between the impact force and muscle adjustments, which may further be utilized in the functional design of footwear. Therefore, the aim of this study was to explore the effect of different footwear on impact, muscle activity (pre- and post-activation), and their possible interactions during bipedal landings from self-initiated and unexpected drops.

METHODS: Twelve male basketball players (age: 23.7±2.7 years, height: 178.3±2.5 cm, mass: 70.1±4.6 kg) with 5 - 6 years of experience in basketball were recruited. The approval of ethical committee was written. They wore two types of shoes, highly-cushioned basketball shoe (Bball) and minimally-cushioned control shoe (CC), to achieve 5 trials of drop landing by using an elevated platform. Two types of shoes that differed in both the forefoot and heel cushioning properties were used in this study. All subjects used size 9 U.S. shoes.
Landing measurement consisted of bipedal self-initiated and unexpected drop landings (SIDL and UDL) from a 60-cm height. For the UDL task, the participants were instructed to stand still on the elevated platform. The base of platform was then dropped by manually removing a bolt, which caused a sudden drop with unpredictable timing. The participants then fell down onto the force plate without warning (Fu et al., 2013). The order in which SIDL and UDL were executed, as well as the order in which the shoes were tested, were random.

Sagittal plane kinematics (Vicon, 120Hz), ground reaction forces (GRF, Kistler, 1200Hz), accelerations of the shoe heel counter (Biovision, 1200Hz), and myoelectric signals for the tibialis anterior (TA), lateral gastrocnemius (LG), rectus femoris (RF), and biceps femoris (BF) muscles (Biovision, 1200Hz) were collected simultaneously.

The main variables discussed in this study for the impact force were the peak vertical GRF ($F_{z_{\text{max}}}$) and the peak acceleration of the shoe heel-cup ($a_{\text{heel}}$); while for muscle activity were the root mean square of EMG (EMG$^{\text{RMS}}$), which was performed in the interval 50 ms prior to contact to the time of first contact (pre-activation) and contact to 50 ms after initial contact (post-activation). The EMG amplitudes were normalized as a percentage of the highest value recorded during the entire contact phase of the all trials of DJ. A 2 (Bball, CC) × 2 (SIDL, UDL) ANOVA with repeated measures was used to determine the effect of shoe and landing tasks on impact performance and muscle activities. The significant level was set at $\alpha = 0.05$.

RESULTS:
Impacts: In SIDL, no significant differences were observed in $F_{\text{peak}}$ and $a_{\text{heel}}$ between the two shoe conditions (Fig.1 & Tab.1). However, for UDL, $F_{\text{peak}}$ was significantly lower ($p = 0.041$) and $a_{\text{heel}}$ was significantly decreased ($p = 0.038$) when wearing basketball shoes compared to wearing control shoes (Tab.1). Additionally, an increase in $F_{\text{peak}}$ ($p = 0.027$) accompanied by an earlier occurrence time of $F_{\text{peak}}$ ($t_{F_{\text{peak}}}$) ($p = 0.039$) were observed for UDL compared to SIDL for the control shoes only (Tab.1).

![Figure 1: Representative vertical GRF-time and heel acceleration-time curves during the contact phase (time %) of a self-initiated and an unexpected drop landing in basketball shoe (Bball) and control condition (CC).](image-url)
Table 1
Comparison of impact signal variables (mean ± SD) in subjects wearing basketball shoes (Bball) and control shoes (CC) in self-initiated and unexpected drop landings (SIDL and UDL).

<table>
<thead>
<tr>
<th>Landing task</th>
<th>Shoe group</th>
<th>F_{peak} (BW)</th>
<th>t_{F_{peak}} (ms)</th>
<th>h_{heel} (g)</th>
<th>t_{h_{heel}} (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIDL</td>
<td>Bball</td>
<td>3.59±0.81</td>
<td>54.4±8.1</td>
<td>29.4±7.2</td>
<td>29.7±16.1</td>
</tr>
<tr>
<td></td>
<td>CC</td>
<td>3.60±0.64‡</td>
<td>54.3±9.5‡</td>
<td>32.7±7.4</td>
<td>28.1±11.2</td>
</tr>
<tr>
<td>UDL</td>
<td>Bball</td>
<td>4.06±0.71†</td>
<td>53.2±10.9†</td>
<td>28.9±7.3†</td>
<td>27.0±15.4</td>
</tr>
<tr>
<td></td>
<td>CC</td>
<td>4.73±0.84</td>
<td>47.7±13.7</td>
<td>35.8±7.9</td>
<td>25.8±11.2</td>
</tr>
</tbody>
</table>

* Significantly different from CC in same landing task with \( p < 0.05 \).
‡ Significantly different from UDL in CC condition with \( p < 0.05 \).

**Muscle pre-activation (-50 ms):** For tested muscles, there was no significant shoe effect on EMG amplitude in either SIDL or UDL (Fig.2). When comparing landing tasks, the EMG_{RMS} of TA, LG, RF, and BF muscles were significantly lower in UDL compared to SIDL (\( p < 0.05 \)).

**Muscle post-activation (+50 ms):** In SIDL, no significant differences in the EMG_{RMS} were observed for any of the tested muscles between the two shoe conditions during the post-activation phase (Fig.2). In UDL, however, the EMG_{RMS} of TA (\( p = 0.033 \)), RF (\( p = 0.032 \)), and BF (\( p = 0.031 \)) muscles was significantly lower in Bball compared to CC, and the EMG_{RMS} of LG also showed a 22.5% decrease (\( p = 0.088 \)) when wearing basketball shoes. Similar to the results for the pre-activation phase, when assessing the effect of landing task the EMG_{RMS} of all muscles were significantly lower for UDL than SIDL (\( p < 0.05 \)), except for the EMG amplitude of the BF in CC condition.

**Figure 2:** Comparison of pre-activation and post-activation of the tibialis anterior (TA), lateral gastrocnemius (LG), rectus femoris (RF), and biceps femoris (BF) between basketball shoe (Bball) and control condition (CC) in self-initiated and unexpected drop landings (SIDL and UDL). *indicates significant differences. Right-pointing brackets indicate significant differences between shoe types only for the UDL task. Upper-pointing brackets indicate significant differences between landing tasks for both shoe types, while lower-pointing brackets indicate significant differences between landing tasks only for the Bball type.
CONCLUSION: In the current study, we used two different landing maneuvers, self-initiated drop landings and unexpected drop landings, to evaluate the influence of shoe cushioning on impact biomechanics and muscle activation. During active landings from self-initiated drops, shoe cushioning did not significantly change the impact characteristics or muscle activity patterns. This is in agreement with most previous relevant studies of active drop landings which found that kinematic variables, peak GRFs, and accelerations of the lower extremity did not vary significantly with different midsoles. This suggests that shoe cushioning may have only a limited role in reducing the impact provided appropriate neuromuscular adjustments occur properly during active movements (e.g. self-initiated drop jumps and running).

However, in the situation when relevant muscles are not activated on purpose, such as the landings from unexpected drops in the current study, wearing a highly-cushioned shoe decreases peak impact and muscle post-activation. Since landing impact forces were lower when wearing highly-cushioned shoes, it seems reasonable to assume that the magnitude of soft-tissue vibration should be reduced and less muscle activity would be required accordingly (Nigg & Wakeling, 2001). This hypothesis, however, needs further confirmation. Potentially, this beneficial effect of footwear may be further developed for preventing impact-related injuries during unanticipated landings or whilst in a fatigued condition.

REFERENCES:


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