Adaptation to changes in impact loading conditions during running

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Introduction
Although adaptations in lower leg kinematics have previously been observed between barefoot and shod running (De Wit, et al., 2000), few studies have been able to detect the more subtle adaptations induced by different footwear conditions (McNair and Marshall, 1994). The purpose of this study was to determine whether accelerometry-based measures of lower leg kinematics could better differentiate changes to impact loading compared to traditional displacement measurements. Attention was focused on the initial high frequency movement transients in response to loads experienced at running ground contact.

Methods
Eight healthy male subjects (mass = 69.7kg ± 8.2, age = 28yrs ± 5.5) ran over a Kistler force platform, centred along a 30m runway, at a speed of 4.5m/s (±5%). All subjects completed 3 sets of 10 trials whilst running barefoot (BF) and wearing two different athletic shoes (S1 and S2). Mechanical impact testing results rated S1 as the hardest shoe (peak = 11.34g compared to S2 = 10.02g).

Sagittal plane angular kinematics were determined from a) displacement data recorded at 240Hz using a 6-camera ProReflex system and b) three-dimensional accelerations of the shank recorded at 2000Hz using two lightweight tri-axial accelerometers. The balsa wood mounted accelerometers were firmly glued and taped to the proximal and distal aspects of the tibia. To improve the coupling of the accelerometers to the bone, the overlying skin was stretched, both about the ankle and knee, prior to accelerometer attachment. In order to determine the shank kinematics in the sagittal plane from the recorded accelerations, the signals were transformed from the accelerometer-oriented axis system to a tibial axis system by using small marker triads that were attached to the accelerometers during a static measurement. The 240Hz and accelerometry data were filtered at 15Hz and 125Hz, respectively using a Butterworth digital low-pass filter. Power spectra of these signals were used to determine the mean power frequency (MPF). Significant differences were determined between conditions using a two-way ANOVA (p<0.05).

Results
The initial vertical impact force peaks were found to be lower for the barefoot condition (1369N ± 218) compared to the two shod conditions (S1= 1713N ± 268 and S2= 1671N ± 456). Peak angular velocity (AV) derived from displacement data was not significantly different across shod conditions. Larger AVs were found using accelerometers and a significant difference was detected between barefoot and shod conditions (Table 1).

For both peak shank angular acceleration (AA) and MPF, there was a significant interaction between sampling frequency and footwear condition (p<0.05). Post hoc analysis showed that no differences could be detected between the three footwear conditions using the 240Hz. However, using accelerometry it was possible to detect significant larger angular accelerations in the BF compared to shod conditions, but also significantly larger accelerations whilst wearing S1 compared to S2. Significant changes in MPF were again observed between BF and shod from the accelerometry approach and although there was a trend for higher MPFs for S1 compared to S2, the relationship was non significant (p=0.098).
Table 1: Peak shank kinematics and MPF. (* - significantly different to other shod conditions (p<0.05))

<table>
<thead>
<tr>
<th></th>
<th>BF</th>
<th>S1</th>
<th>S2</th>
<th>BF</th>
<th>S1</th>
<th>S2</th>
</tr>
</thead>
<tbody>
<tr>
<td>AV (rad/s)</td>
<td>9.6±0.7</td>
<td>9.7±0.6</td>
<td>9.8±0.5</td>
<td>12.4±1.2 *</td>
<td>11.7±2.0</td>
<td>11.7±1.9</td>
</tr>
<tr>
<td>AA (rad/s²)</td>
<td>140±28</td>
<td>133±41</td>
<td>131±27</td>
<td>1321 ±244 *</td>
<td>812±321 *</td>
<td>682±259 *</td>
</tr>
<tr>
<td>MPF</td>
<td>10±0.9</td>
<td>8.5±0.9</td>
<td>8.7±1.3</td>
<td>46.7 ±3.6 *</td>
<td>40.6±4.3</td>
<td>37.8±5.1</td>
</tr>
</tbody>
</table>

Discussion

Adjustments in lower limb kinematics during running in different shod conditions were found using accelerometry based measurements. In contrast, the same movement transients (in response to ground contact) calculated using displacement data was unable to detect any differences between shod conditions. Despite similar peak impact forces, higher peak angular accelerations were found for shoe S1 compared to S2. This likely reflects subtle adjustments in stiffness setting of the ankle and/or knee joints prior to impact (e.g. Farley et al., 1998), and will be the focus of further research. Previously, McNair and Marshall (1994) found no difference in axial shank acceleration when wearing different running shoes. The present measurements were based on anterior-posterior components of shank acceleration which are likely to be more sensitive to impact conditions as they are often larger than the axial acceleration during running (Lafortune, 1991). The accelerometry approach allowed both group and individual changes to be clearly identified for different impact loading conditions. This underlines the importance of monitoring movement transients for the examination of adaptation strategies during running.

References