INTRODUCTION

Several studies have demonstrated that the magnitude of the toe-out angle is inversely associated with the external knee adductor moment during the late-stance phase of walking [1-7]. In simple terms, presumably an increased toe out angle would lead the moment arm of the ground reaction force to be located closer to the knee joint center during the later part of stance and would thus result in a lower adduction moment [4,5]. It has been hypothesized that increasing the toe-out angle would then be a strategy to decrease the pressure on the medial compartment of the knee adopted by persons with osteoarthritis [2, 5].

To our knowledge, this relationship between toe-out angle and knee adduction moment has been observed only for walking and in this work we sought to verify whether a similar relationship is also observed during running.

METHODS

We analyzed nine healthy young adults (4 males and 5 females), with the following age, mass and height (mean ± standard deviation): 30±5 years, 62±9 Kg and 1.66±0.11 cm, respectively. The subjects performed two tasks (walking and running) at three different conditions (normal and with a self selected feet rotated externally (toe-out) or rotated internally (toe-in)). Each condition was executed 10 times along an 8m runway at a self-selected speed. All the subjects gave informed consent. We collected three-dimensional (3D) surface marker data using the Cleveland Clinic marker set at 150Hz with an eight-camera video-based motion analysis system (Motion Analysis Corporation, Santa Rosa, CA). Ground reaction forces and torques were measured at 600Hz by one force plate (Advanced Mechanical Technology, Inc). The raw kinematic and kinetic data were filtered using a low-pass Butterworth filter with a cutoff frequency of 6Hz and 100Hz respectively. We analyzed only the data for the right lower limb.

The data were analyzed with the Visual 3D software. The external moments were calculated in the frontal plane and normalized to each subject’s body weight. The toe-out angle of each leg was computed as the angle formed by the intersection of the long axis of the foot and the direction of forward progression at the horizontal plane [2,7]. We analyzed the first and second peaks of the external knee adduction moment in the frontal plane during the stance phase of walk and the single peak during the stance phase of running.

Normality of the data was verified with Shapiro-Wilk test. Two-tailed paired t-tests were used to compare the different conditions, with Bonferroni correction for multiple comparisons. A significance level of 0.05 was used for all statistical tests.

RESULTS AND DISCUSSION

The three conditions had significant differences in the toe-out angle (normal foot, toe-out and toe-in) during the first and second knee adduction moment peak of walking and the single peak of running.

During walking, t-test revealed differences between the knee adduction moment values for all conditions for the first peak: normal foot/toe-out t(5)=4.5, p<0.05; normal foot/toe-in t(8)=10.8, p<0.05; toe-in/toe-out t(5)=11.1, p<0.05 and just between normal foot and toe-out for the second peak t(5)=4.4, p<0.05 (p<0.05). During running, no differences were observed.
The mean (±SD) of knee adduction moment peaks in the three conditions are shown in table 1 and are consistent with the literature [8,9]. The differences found in the second knee adduction moment peak between the normal and the toe-out conditions is confirmed by other studies [1, 4-7]. However, the relationship noted between the greater degree of toe-out angle and the peak knee adduction moment during early stance of the gait is still unclear in the literature. Lin et al. [6] found that this first peak increased when healthy teenagers walked with a 30° increase in their foot progression angle. On the other hand, Guo et al. [4] did not observe a similar effect when their subjects walked with a 15° increased in the toe-out angle, but these last authors concluded that is not possible to affirm if the different findings of their study and those of Lin et al. was due to subjects walking with different amounts of toe-out or because they were distinctly different populations.

In addition, the toe-in condition, that is not commonly tested in other studies, showed a significant difference in the first peak knee adduction moment during gait, but didn’t appear to cause these differences during running and in the second knee adduction moment peak. Nevertheless, Fregly [10] noted that the decreased toe-out angle during gait had the most influence on the first peak (4 to 8% additional reductions) but increased the second one (0 to 3%). In contrast, increased toe out angle had the most influence on the second peak (5 to 9% additional reductions) while simultaneously decreasing the first one (0 to 4%).

The external knee adduction moment during walking exhibits two peaks during stance phase. The first peak is generally larger than the second, and it is highly correlated with increased disease severity, pain and rate of disease progression [11], as in individuals with medial compartment osteoarthritis [5] and meniscal lesions [3].

Recently, Walter et al. [11] studied an individual with a force-measuring knee implant and their findings suggest that reducing the peak external knee adduction moment does not necessarily guarantee a corresponding decrease in the medial-compartment contact force. Walter et al. showed that gait modifications can significantly reduce both peaks of the external knee adduction moment curve without producing corresponding significant reductions of the medial-compartment contact force. However, these results were obtained from one single subject and this issue is still under debate.

REFERENCES

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Table 1: Mean (±SD) of knee adduction moment peaks and toe-out angles in the three conditions studied: normal, toe-out and toe-in during walking and running.

<table>
<thead>
<tr>
<th>Knee adduction moment (Nm/kg)</th>
<th>Normal</th>
<th>Toe-out</th>
<th>Toe-in</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking – first peak</td>
<td>-0.32±0.13</td>
<td>-0.39±0.15</td>
<td>-0.39±0.15</td>
</tr>
<tr>
<td>Walking – second peak</td>
<td>-0.31±0.05</td>
<td>-0.11±0.15</td>
<td>-0.39±0.15</td>
</tr>
<tr>
<td>Running</td>
<td>-0.36±0.18</td>
<td>-0.39±0.26</td>
<td>-0.39±0.15</td>
</tr>
<tr>
<td>Toe-out Angle (°)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Walking – first peak</td>
<td>5.6±2.0</td>
<td>28.5±4.9</td>
<td>-13.5±9.2</td>
</tr>
<tr>
<td>Walking – second peak</td>
<td>5.3±3.7</td>
<td>29.4±4.5</td>
<td>-14.1±10.7</td>
</tr>
<tr>
<td>Running</td>
<td>13.0±10.5</td>
<td>30.7±6.6</td>
<td>-11.0±9.2</td>
</tr>
</tbody>
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