INTRODUCTION

The longitudinal arch of the human foot is an elastic structure with passive and active connective tissues that allow for energy storage and return during locomotion. Activity of intrinsic muscles such as the abductor hallucis (ABDH) and flexor hallucis brevis (FHB) is necessary for arch support during standing, and stimulation of these muscles results in arch lift and center of pressure (COP) movement. Extrinsic muscles also activate during external arch loading, but show greater activation in posturally demanding tasks such as tandem stance and unstable shoe wearing. It has been proposed that intrinsic foot muscles behave as local stabilizers of the arch and extrinsic foot muscles as primary movers of the foot and ankle, but it is unknown how these groups of muscles function during stances of varying postural demand and foot positions.

The purpose of this study was to evaluate activity of extrinsic and intrinsic foot muscles during common functional and sport postures of varying balance difficulty. It was hypothesized that these two groups of muscles would function differently, and that extrinsic muscles would be more active in single-leg stances due to the increased balance difficulty.

METHODS

Twenty healthy young adults free from pain and lower extremity injury for the past six months were recruited for the study (7 Males, 13 Females; Age: 27.5 ± 5.6 yrs; Weight: 669.8 ± 149 N) according to guidelines by the Institutional Review Board. The supporting foot, defined as contralateral to the preferred kicking foot, was examined. Paired fine-wire intramuscular electrodes were inserted into ABDH, FHB, flexor hallucis longus (FHL), and tibialis posterior (TP) muscles in the supporting foot of each subject. Surface electromyography (EMG) was collected from peroneus longus (PER) and tibialis anterior (TA). EMG data were collected using a wireless Noraxon system (Scottsdale, AZ) sampled at 3000 Hz, and bandpass filtered between 30 Hz and 500 Hz for surface data and 30 Hz and 1000 Hz for fine-wire data using a fourth-order Butterworth filter. Root mean square (RMS) signal amplitude was calculated over a 3 second epoch and normalized to the maximal voluntary isometric contractions for dorsiflexion, inversion, and eversion of the ankle, flexion of metatarsal-phalangeal (MTP) joints, and abduction of the first digit during manual muscle testing. Ground reaction force (GRF) data of each foot in each platform were collected with two force plates (Advanced Medical Technology Inc., Watertown, MA) in parallel setting. Sampling rate was 1500 Hz and synchronized with EMG. GRF were low-pass filtered using a fourth-order Butterworth filter with a 6 Hz low-pass cutoff. The postural demands of six balancing tasks were evaluated by COP velocity in a 3 second epoch of same duration for averaging EMG.

Subjects held six standing postures: bilateral stance (BLS), single-leg stance (SLS), bilateral squat (BSQ), single-leg squat (SSQ), bilateral calf raise (BCR), and single-leg calf raise (SCR) – in a random order for five seconds each. This sequence was repeated three times and measures were averaged for each posture. To keep the postures static in the three single-leg postures, the subjects were allowed light-touch on a supporting structure. This was conducted to compare differences between muscles and postures using Tukey post-hoc tests for pairwise comparisons with significance set at α=0.05.
RESULTS AND DISCUSSION

The average COP sway velocity of six standing postures were, increasing in order, BLS (1.8 ± 0.9 cm/s), SCR (2.1 ± 1.0 cm/s), BSQ (2.4 ± 0.9 cm/s), BCR (3.4 ± 1.5 cm/s), SSQ (3.9 ± 2.4 cm/s), SLS (4.8 ± 1.6 cm/s). We would expect SCR to be the most challenging of the postures because of the greatly decreased base of support. But COP sway to be slower in SCR, likely because all subjects had to use a light touch cue to retain balance in this position.

Figure 1: Averaged RMS EMG of three muscle groups in six standing postures. Int: intrinsic foot muscles, Ext: extrinsic foot muscles, TA: tibialis anterior muscle.

RMS of each muscle of six standing postures was summarized in Table 1. The ANOVA revealed significant differences in muscle activation level across tasks (F=13.2, p<0.001) with post-hoc testing revealing three groups: (1) ABDH/FHB (intrinsic foot muscles), (2) FHL/TP/PER (extrinsic foot muscles), and (3) TA. Also, significant differences in muscle activation level within postural changes revealed BLS, BSQ < BCR, SSQ < SLS < SCR.

Figure 1 shows RMS EMG of three muscle groups in six standing postures. With increasing postural demand, intrinsic and extrinsic muscle groups increase activity in a similar manner. TA acts as a postural muscle only increasing in postures where it is demanded, primarily squatting.

CONCLUSIONS

Our results indicate the intrinsic and extrinsic foot muscles activate as unique groups. The activity of intrinsic and extrinsic foot muscles increases with postures of increasing balance difficulty in a similar manner.

REFERENCES


Table 1: Mean (SD) EMG root mean square (RMS) signal amplitude as a % of maximum voluntary contraction during bilateral stance (BLS), single-leg stance (SLS), bilateral squat (BSQ), single-leg squat (SSQ), bilateral calf raise (BCR), and single-leg calf raise (SCR), for abductor hallucis (ABDH), flexor hallucis brevis (FHB), flexor hallucis longus (FHL), and tibialis posterior (TP), peroneus longus (PER) and tibialis anterior (TA).

<table>
<thead>
<tr>
<th></th>
<th>ABDH</th>
<th>FHB</th>
<th>FHL</th>
<th>TP</th>
<th>PER</th>
<th>TA</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLS</td>
<td>12.2 (14.3)</td>
<td>12.2 (17.5)</td>
<td>5.8 (5.6)</td>
<td>9.0 (8.9)</td>
<td>5.7 (4.5)</td>
<td>2.3 (1.2)</td>
</tr>
<tr>
<td>BSQ</td>
<td>14.0 (11.9)</td>
<td>18.1 (30.3)</td>
<td>4.2 (4.8)</td>
<td>10.5 (6.9)</td>
<td>7.6 (5.5)</td>
<td>38.5 (23.2)</td>
</tr>
<tr>
<td>BCR</td>
<td>53.4 (38.1)</td>
<td>45.6 (31.3)</td>
<td>44.5 (32.9)</td>
<td>24.0 (23.4)</td>
<td>37.1 (15.6)</td>
<td>8.9 (5.1)</td>
</tr>
<tr>
<td>SSQ</td>
<td>51.7 (34.4)</td>
<td>43.2 (28.4)</td>
<td>21.9 (19.6)</td>
<td>42.3 (31.3)</td>
<td>36.4 (27.6)</td>
<td>33.0 (18.6)</td>
</tr>
<tr>
<td>SLS</td>
<td>74.0 (31.3)</td>
<td>65.2 (42.9)</td>
<td>23.3 (15.0)</td>
<td>53.9 (37.3)</td>
<td>48.2 (24.2)</td>
<td>28.6 (15.9)</td>
</tr>
<tr>
<td>SCR</td>
<td>86.3 (52.4)</td>
<td>78.8 (40.5)</td>
<td>69.2 (43.9)</td>
<td>42.0 (35.1)</td>
<td>75.2 (26.1)</td>
<td>19.7 (10.6)</td>
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</table>