The Effect of Tibialis Anterior Fatigue on Body Sway in Single-Stance Standing

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Introduction. The regulation of balance during upright standing involves continuous muscular activity, associated with body sway. In single stance standing, the base of support is narrower compared to double stance standing and the body becomes more unstable. The result is an increased body sway, emphasizing the role of individual muscles in regulating the sway motion (1). Local fatigue in a muscle takes place as a result of an intensive activity of this muscle and is reflected by certain changes in its electromyogram (EMG) signal in either the time or frequency domains (2). In this study, we investigated the effect of Tibialis Anterior fatigue on body sway during standing on one leg.

Methods. Ten male subjects volunteered to participate in this study. Each test consisted of 2 trials, during which the following were on-line monitored. Foot ground reaction forces, center of pressure (CoP), ankle joint angle, and EMG of the Tibialis Anterior (TA), Gastrocnemius (GM) and Peroneal (PE). Each trial lasted 30 s, during which the subject was required to stand on one leg, as still as possible, with his/her dominant leg on a forceplate and the contralateral knee flexed upwards at 90 deg so that the shank was in the horizontal position. The subjects were asked to stand with their hands resting on their waists. The trials were separated by a 4 min isotonic effort of the TA, in which the subject was in a seated position and during which a weight of 10 kg mass was suspended on the foot, while maintaining the ankle angle in the neutral position. An on-line goniometer feedback was provided to the tested subject for controlling the angle. Before each test, the non-fatigue maximal voluntary contraction (MVC) was determined. Each test was repeated at least three times. Differences between the non-fatigue and fatigue conditions were tested using a Wilcoxon signed rank test.

Results. Table 1 presents summary of the forceplate data. A comparison between the non-fatigue and fatigue conditions reveals the following. The root mean square (RMS) of the reactive forces significantly (p<0.05) increased from 2.61 to 3.90 N and from 3.77 to 5.01 N in the medio-lateral (ML) and vertical directions, respectively. The center of pressure (CoP) RMS in the ML direction increased from 0.57 to 0.68 cm. During the isotonic effort the TA activity increased from 45%MVC to 52%MVC (p<0.05) and the mean power frequency (MPF) decreased by 19.8% (p<0.05).

Summary of the EMG data in the standing trials is presented in Table 2. The EMG RMS in the TA increased from 15.2%MVC in the non-fatigue trial to 22.4%MVC in the fatigue trial. In parallel the MPF decreased from 107.6 Hz to 96.7 Hz. It should be mentioned that the time and frequency domain measures of both the GM and PE muscles did not change significantly as a result of fatiguing of the TA.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Force [N]</th>
<th>Center of Pressure [cm]</th>
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<tbody>
<tr>
<td></td>
<td>ML</td>
<td>AP</td>
</tr>
<tr>
<td>Non-fatigue</td>
<td>2.61(0.95)</td>
<td>2.36(0.75)</td>
</tr>
<tr>
<td>Fatigue</td>
<td>3.90(2.43)*</td>
<td>2.61(1.00)</td>
</tr>
</tbody>
</table>

Table 1. Average (SD) of RMS of Force Plate data in standing trials for all subjects (ML= medio-lateral direction, AP= antero-posterior direction).

*-Significantly different (P<0.05) between non-fatigue and fatigue conditions.

between the CoP drift and ankle angle change.
Table 2. Average (SD) of RMS and MPF of the EMG data, in the standing trials, for all subjects (TA= Tibialis Anterior, GM= Gastrocnemius, PE= Peroneus, RMS= root mean square, MPF= mean power frequency).

* - Significantly different (P<0.05) between non-fatigue and fatigue conditions.

The TA activity (in %MVC) during the course of the single leg standing trial is shown in Fig. 1. It is noted that, in the first 10 sec of the trial, the average TA activity was higher in the fatigue compared to the non-fatigue condition. Fig. 2 presents the CoP in the antero-posterior (AP) direction (top panel), and the ankle angle (bottom panel) in the single-stance standing trial. Linear regressions for the average data of all the subjects are drawn. The Pearson correlations between the CoP and ankle angle lines revealed that in the fatigue state the correlation is significant (r = 0.68, P<0.05) and it is non-significant in the non-fatigue state (r = 0.19, P>0.05).

Figure 1. Average (6 subjects) of the Tibialis Anterior activity (in %MVC) during a 20 s single leg standing trial, before and after fatigue. (Solid line = non-fatigue state; dashed line = fatigue state; vertical bars denote one SD; *** - significant difference between two states, P<0.05).

Discussion. The central issue in this study was to examine the relationship between fatigue of the TA muscle, ankle angle displacement, ground force reaction and CoP in single-stance standing. Development of TA fatigue under the 4 min isotonic effort was associated with a significant increase in the muscle activity, expressed in %MVC, and a significant decrease in the MPF EMG. It was also found that TA fatigue was associated with increased reactive forces in the vertical and ML directions and an increased CoP excursion in the ML component. It has been reported that exercising muscles to fatigue may disrupt
the ability of reproducing the joint angles due to a decline in proprioception (3). It is speculated that the changes in the ML direction observed in this study can be associated with a decline in proprioception and disruption of the ability to reproduce the ankle and subtalar joints angles. An interesting finding was revealed by comparing the changes due to fatigue of the ankle angle to those of the CoP in the AP direction. In the non-fatigue state the correlation between the CoP drift and ankle angle change was insignificant. These seemingly uncoordinated trends would necessitate compensatory angular adjustments at the knee and/or hip joints. Such adjustments are possible as long as the system is redundant. However, in the fatigue condition the correlation between the CoP drift and ankle angle change was significant: it was noted that the posterior excursion of the CoP was accompanied by a consistent change in the ankle, towards plantar flexion. It is thus suggested that the TA fatigue is associated with a reduced redundancy of the musculo-skeletal system.

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References
1. Levin, O., Mizrahi, J., Adam D., Verbitsky, O. and Isakov, E. on the correlation between force plate data and EMG in various standing conditions. Fifth annual conference of the international functional electrical stimulation society, June 2000, Denmark.