When hopping and running, the leg(s) in contact with the ground can be modeled as a simple linear spring (see Fig 1). The stiffness of the leg spring ($k_{\text{leg}}$) is defined as the ratio of maximum force during foot contact to $\Delta L$. When hopping, $k_{\text{leg}}$ increases as surface stiffness decreases (Farley et al., 1998). Adjustments to ankle stiffness were found to be the greatest contributor to changes in $k_{\text{leg}}$, whereas the timing of muscle onset did not change. Hortobagyi and DeVita (2000), however, found significant relationships between muscle preactivation times and leg stiffness when subjects stepped downward. They also reported differences between young and old subjects.

Motor control researchers have argued that joint stiffness is increased prior to ground contact when landing from a jump and is accomplished by preactivation of leg musculature (e.g., Santello & McDonagh, 1998). The lack of agreement over the role of muscle preactivation in leg stiffness was the primary motivation for this study. We hypothesized that differences in preactivation times of leg musculature would accompany differences in leg stiffness, which were identified previously between men and women (Heise et al., 1997).

**METHODS**

Ten healthy women and ten healthy men volunteered as subjects. Each participant attended one test session which included a 10-min warm-up walk at 1.57 m/s followed by hopping on a force platform at a preferred frequency while EMG data and vertical ground reaction force data were recorded. Surface EMG electrodes were positioned over the bellies of muscles rectus femoris (RF), vastus lateralis (VL), and gastrocnemius (GAST) after appropriate skin preparation. During hopping, vertical ground reaction force data and the EMG signals were sampled at 1000 Hz for 5 s. Data from all channels were then stored in digital format on a microcomputer.

Hopping frequency and $k_{\text{leg}}$ were determined from force platform data (Farley et al., 1991). EMG data were full-wave rectified and muscle onset was identified using an interactive, computer-graphics program that plotted the rectified signal of each channel. Preactivation time for each muscle was calculated as the difference between muscle onset time,
determined manually, and the time when vertical GRF reached body weight. The mean of three hopping cycles for each subject was used for statistical analysis. A two factor ANOVA was used to detect differences between genders and between muscles.

RESULTS AND DISCUSSION

Preferred hopping frequency was the same between women and men (2.2 Hz). As reported by Heise et al. (1997), leg stiffness was significantly different between women and men (see Table 1). Mean values were similar to those previously reported (Chelly & Denis, 2001; Farley et al., 1991).

<table>
<thead>
<tr>
<th></th>
<th>WOMEN</th>
<th>MEN</th>
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<tbody>
<tr>
<td>$k_{leg}$ (kN/m)</td>
<td>18.9 ± 0.6</td>
<td>24.6 ± 2.4 *</td>
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</table>

Table 1: Leg stiffness between women and men (mean ± SE; * $p < .05$).

The sequence of muscle onset is in agreement with previous findings (Farley et al., 1998; Hortobaghi & DeVita, 2000). GAST activity was initiated prior to the knee extensors (see Fig 2).

Men activated muscles significantly earlier than women (see Fig 2), which may partly explain why men exhibited higher leg stiffness. We also observed an increase in the amplitude of activity after onset in all subjects. Although this was not formally measured in the present study, it agrees with the measurements of Santello and McDonagh (1998). For men, this observation, coupled with their earlier preactivation time, may lead to greater tension in muscle and therefore, increased joint stiffness. A more complete analysis which includes joint stiffnesses and EMG amplitudes is required to better address this conjecture.

In summary, the differences in leg stiffness between men and women were accompanied by differences in muscle preactivation times.

REFERENCES


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