NEUROMUSCULAR ADJUSTMENTS TO HOPPING WITH AN ELASTIC ANKLE-FOOT ORTHOSIS

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INTRODUCTION

When humans hop or run on elastic surfaces, they adjust the effective stiffness of their legs to perfectly offset changes in surface stiffness [1, 2]. As a result, the addition of a surface spring in series with the leg spring does not alter global movement parameters such as ground contact time or displacement of the center of mass. The purpose of this study was to determine if humans would show similar neuromuscular adjustments when hopping with a spring in parallel to their leg spring. Farley and colleagues have demonstrated that ankle stiffness primarily determines leg stiffness during hopping [3, 4] so we focused on adding a spring in parallel with the ankle joint. We hypothesized that humans would decrease their ankle joint stiffness when hopping with a plantar flexor spring added to an ankle-foot orthosis compared to hopping without a spring added to the orthosis. This adjustment would allow them to compensate for joint stiffness added by the orthosis spring.

METHODS

Four healthy subjects (ages 24-27 years) participated in this study. The University of Michigan Institutional Review Board approved the study protocol and each participant gave informed consent. Each subject hopped on their left leg at four frequencies (2.2, 2.6, 3.0 Hz, and their preferred frequency) under two orthosis conditions. In one condition (SPRING), the subjects hopped while wearing an ankle-foot orthosis with a linear extension spring providing plantar flexor torque (k=6.7 kN/m, resulting in ~1.1 Nm/deg). In the second condition (NO SPRING), subjects hopped wearing the ankle-foot orthosis without the spring attached. After subjects practiced for ~15 seconds under the two conditions, they completed trials in a randomized order.

We collected joint kinematics, ground reaction forces, and electromyography (EMG) for two trials at each condition. We recorded spring force with a load cell. Using Visual3D software, we determined internal joint moments about the ankle, knee, and hip. We calculated leg and joint stiffnesses from vertical ground reaction force, center of mass displacement, joint displacements, and joint torques [4]. We used a three-way ANOVA to test for significant differences.

RESULTS AND DISCUSSION

At each hopping frequency, subjects demonstrated the same effective leg stiffness for both orthosis conditions ($p=0.07$). At preferred frequency leg stiffness was 6.2±2.0 kN/m for NO SPRING and 7.3±2.2 kN/m for SPRING conditions (mean±s.d.). The invariant leg stiffness was possible because subjects decreased their ankle joint stiffness ($p<0.001$) to offset orthosis stiffness added by the spring (Figure 1). The spring contributed ~24% of the total stiffness about the ankle joint (ankle stiffness + orthosis stiffness) during the preferred frequency SPRING condition and less at faster frequencies.

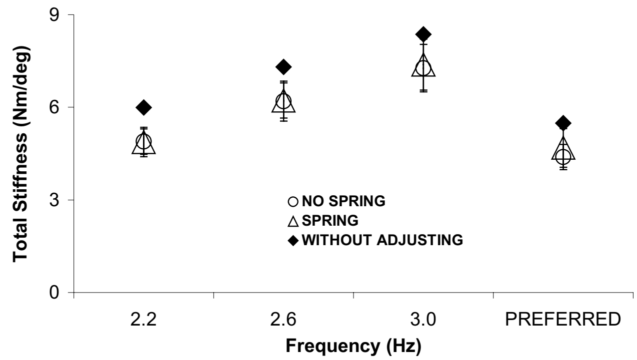

Figure 1: Total stiffness about the ankle joint. The WITHOUT ADJUSTING values reflect what the total stiffness would have been in the SPRING condition if the subjects maintained the same ankle stiffness as during the NO SPRING condition. The total stiffness was independent of orthosis condition ($p=0.46$).

As a result of the adjustments in ankle stiffness, there were no differences in peak vertical ground reaction force, center of mass displacement, or ground contact time between conditions ($p>0.20$). EMG data revealed that subjects decreased soleus, medial gastrocnemius, and lateral gastrocnemius activation amplitudes during ground contact for the SPRING condition compared to the NO SPRING condition (22%, 21%, & 22% decreases, respectively; $p<0.05$).

CONCLUSIONS

When hopping unilaterally with an energy storing ankle-foot orthosis, our subjects decreased their ankle stiffness to offset the added stiffness of the orthosis. As a result, global movement dynamics were not affected by the added orthosis stiffness. Subjects appeared to achieve the decreased ankle stiffness by reducing triceps surae activation. These findings provide important insight into the neuromuscular control of bouncing gaits (i.e. hopping and running). The results also have important implications for the design of braces and orthoses for improving human performance and/or preventing injury.

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