INTRODUCTION

Negotiating sloped surfaces is a challenge in our daily environment that places unique demands on the neuromuscular system. This task has been studied in detail using quadruped models in order to gain insight into neural control of locomotion (Carlson-Kuhta, 1998; Smith, 1998). Similar studies in humans would enhance our understanding of possible strategies employed by the neuromuscular system to successfully navigate challenging environments. An initial step towards this goal would be to characterize the changes in mechanical demand and muscular activity that occur in the lower extremity during slope walking. The purpose of this study was to focus on such changes at the knee and hip, and in particular, on biarticular muscles acting at these adjacent joints.

METHODS

Ten healthy adults were recruited from the student population at Georgia Tech (5 M, 5 F, mean age = 24.3 yrs). Participants were fitted with fifteen retroreflective markers according to the Helen Hayes marker system and with four pairs of self-adhesive Ag – AgCl electrodes (over the RF, VM, BF, SM) on their self-selected limb (6 R, 4 L). Subjects performed five walking trials on a custom ramped walkway at each of five different grades (level, ± 15, ±39%). Starting positions were adjusted so each subject struck the force plate with their EMG-instrumented limb on every trial. Ground reaction forces (GRF) were sampled at 1200 Hz from a force plate (Bertec Corp., Columbus, OH) secured in the ramp structure and reinforced from below with vertical struts. Kinematic data were captured at 60 Hz using a six camera 3D Optical Capture system (Peak Performance, Englewood, CO). Electromyographic data were collected at 1200 Hz using a telemetred EMG system (Konisburg Instruments, Pasadena, CA). All data were time synchronized in the Peak Motus analysis system. GRF and kinematic data were exported to in-house software for inverse dynamics calculations. Trials where the average ASIS marker speed was in the range of 0.8 - 1.6 m/s were used for analysis. Joint moment and power data were time normalized to 300 points over the stride (200 stance, 100 swing) and then ensemble averaged across all subjects for each grade.

RESULTS AND DISCUSSION

Average joint moment data for the knee and hip joints are shown in Figure 1. The magnitudes of the joint moments increase during upslope walking, but the joint moment patterns remain relatively similar to those for level walking. For downslope walking, the joint moment magnitudes also increase, but the moment patterns are different from level walking. For example, the absence of a knee flexor in mid-stance, and an earlier onset of the stance phase hip flexor moment were observed during downslope walking.
Figure 1. Knee and hip joint moments, normalized to body mass, positive is extension. Vertical line marks toe off.

These changes during downslope stance result in a combination of joint moments that is different than that observed during level walking (i.e., there is a knee extensor and hip flexor moment during midstance), and that may be produced most efficiently by activation of the biarticular rectus femoris (RF) rather than other uniarticular knee extensors and hip flexors (Prilutsky, 2000). Since this combination of joint moments does not exist during level walking, we might expect the RF to be less active during level walking. Indeed, RF activity was observed during midstance for the two downslope conditions but not for level walking (Figure 2). RF activity also increases in magnitude as the slope decreases, which relates to the increasing knee extensor moment. In addition, although VM activity (not shown) increases in magnitude during downslope stance, its firing duration remains very similar to that of level walking, which further supports the idea of preferential RF activation.

Finally, because joint moment patterns are similar for level and upslope walking, the biarticular hamstrings should not show the same preferential activation as seen with the RF. Figure 2 shows semimembranosus (SM) firing patterns that are similar for level and upslope walking. The increasing SM activity levels correspond to the increasing hip extensor moment.

SUMMARY

These data allow us to begin analyzing the control strategies used by the nervous system and the role of biarticular muscles in such strategies. The data also suggest that a change in strategy may be necessary to successfully achieve downslope walking.

REFERENCES


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