Spinal Cord Injured Subjects use Ankle-Foot Load Feedback to Modulate Hip Torque during Locomotion

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INTRODUCTION

The purpose of this research was to examine the effect of ankle-foot load on hip joint torque production during locomotion in people with spinal cord injury (SCI). In adult SCI subjects, the amplitude of limb load has an effect on the muscle activity during stepping (Harkema et al. 1997). Similarly, temporal modulations of limb loading have been shown to modulate the timing of stance / swing transitions in an infant population (Pang and Yang 2000). Although these effects have been identified, there is a tight coupling between gait kinematics and the timing of limb loading during walking. This interaction has made it difficult to investigate the afferent source and specific effects of limb load feedback on locomotor activity independent of kinematics. The likely sources of limb load feedback for locomotion are the muscle afferents of the ankle plantarflexors and the cutaneous afferents of the foot sole based on studies in animals (Conway et al. 1987). As a result, we tested the following hypotheses using a novel method to manipulate the timing of limb loading within the gait cycle of adult SCI subjects: 1) subjects increase both hip flexor and extensor torque when ankle-foot load feedback is presented during the stance phase and 2) temporal variations in the timing of ankle-foot loading result in subsequent temporal modulations in hip torque profile.

METHODS

Nine incomplete SCI subjects (ASIA C - D) stepped with assistance from a Lokomat during treadmill and airstepping conditions. During airstepping, subjects wore a powered ankle-foot orthosis on one limb. The orthosis allowed sagittal plane rotation about the ankle. A pneumatic cylinder, attached to the orthosis was used to apply an ankle-foot load to the subjects. When pressurized the cylinder created a dorsiflexor torque (~0.5 Nm/kg) about ankle. The timing of the applied load within the gait cycle was

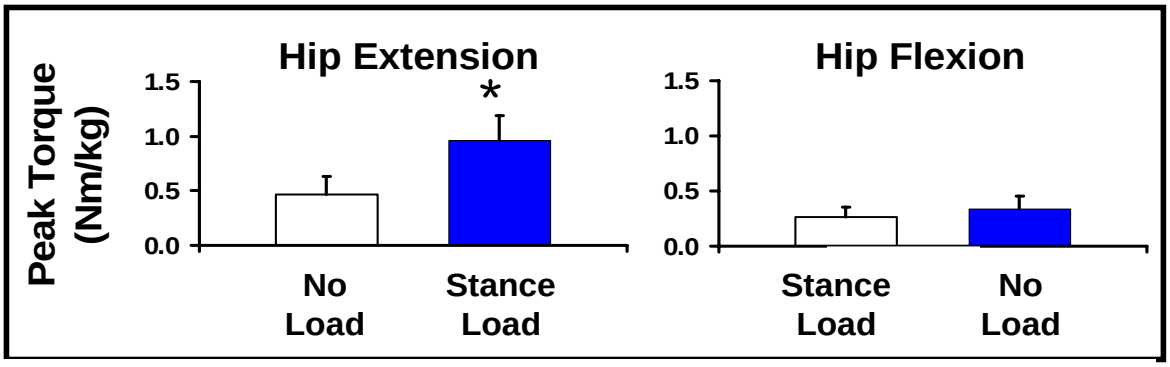

Figure 1: Mean + S.E. peak hip torques from all subjects during the NO LOAD and STANCE conditions.

triggered by hip position. We recorded EMG, joint kinematics and joint torques from both lower limbs. Subjects stepped during a TREADMILL (standard treadmill walking, no ankle-foot orthosis) and five airstepping conditions. The airstepping conditions consisted of NO LOAD (ankle-foot orthosis allowed unrestricted ankle sagittal rotation), STANCE (dorsiflexion torque applied during normal stance time), EARLY (dorsiflexion torque applied 200 msec earlier in the gait cycle than STANCE), LATE (dorsiflexion torque applied 200 msec later in the gait cycle than STANCE) and SWING (dorsiflexion torque applied during normal swing time).

RESULTS AND DISCUSSION

Peak hip extension torque increased significantly from 0.47 Nm/kg to 0.96 Nm/kg (104% increase) and peak hip flexion torque increased 25% from 0.09 Nm/kg to 0.12 Nm/kg between NO LOAD and STANCE (Figure 1). During STANCE, subjects also increased positive hip extensor work by 215% (7.4 to 23.2 J) and positive hip flexor work by 22% (5.1 to 6.2 J) compared to NO LOAD. In addition, negative hip extensor work increased by 10% (3.7 to 4.1) while negative hip flexor work decreased by 29% (3.0 to 2.1 J). Similar changes were also observed during the EARLY and LATE conditions compared to NO LOAD (Figure 2). During SWING, subjects increased peak hip flexion by 80% compared to NO LOAD.

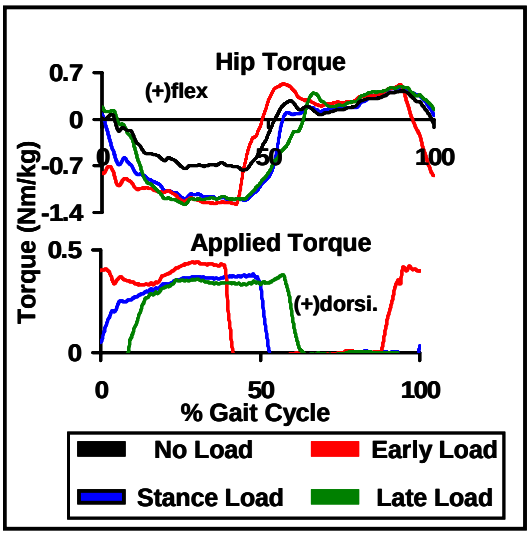

Figure 2: Mean hip torque and applied limb load from a single subject.

The timing of hip torque profiles was modulated by varying the timing of applied ankle loading (Figure 2). When the onset of the applied load was shifted, a corresponding shift in the onset time of hip extension was observed. The onset of hip flexion occurred earlier when ankle load was removed earlier in the gait cycle during the EARLY condition. However, when load release was delayed during the LATE condition the onset of hip flexion did not make a corresponding shift.

SUMMARY/CONCLUSIONS

These findings are consistent with previous research and support our hypotheses that humans with incomplete SCI use ankle-foot load feedback to modulate the amplitude and timing of hip joint kinetics. Subjects increased hip torque when provided with cyclical ankle loading. When the timing of limb load was shifted within the gait cycle subjects made a corresponding shift in hip joint torque profile.

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