

Upper and Lower Limb Disturbance Rejection of Self-Triggered and Computer-Cued Load Perturbations

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INTRODUCTION

People are capable of producing changes in grip and postural support forces in one hand to anticipate load perturbations that are self-generated by the other hand (Dufosse et al., 1985; Blakemore et al., 1998; Diedrichsen et al., 2003). We investigated whether humans could produce similar anticipatory actions in the lower limbs in response to perturbations triggered by a hand. In addition to testing upper/lower limb task coordination, we replicated bimanual results from the literature to gauge the upper limb effect with our protocol. For both the upper and lower limbs, we compared disturbance rejection when the perturbations were self-triggered, randomly automated, or predictably automated with visual and auditory stimuli.

METHODS

Healthy subjects ($n = 12$) were presented with a simple motor task: to minimize the motion of their hand or feet when exposed to a large and sudden change in load. We used a custom apparatus capable of presenting programmable loads to a subject through a motorized platform. For each trial, subjects were asked to oppose a load and attempt to maintain a stationary position while the load was rapidly removed according to the time-function: $W \cdot e^{-20t} (1 + 10t)$, where W was 14 N at the hand or 20 Nm about the ankles.

The experiment included three conditions for unloading: a) after an unpredictable delay (*Uncued*), b) upon a computer-initiated trigger accompanied by predictable audio-visual cues (*Computer-Cued*), and

c) upon a subject-initiated trigger through a handheld pushbutton (*Self-Triggered*). In addition to regular trials, we included *catch trials* where the load was surreptitiously held upon triggering. Subjects completed one series of testing using a hand to oppose the load and a second series of testing using both feet to oppose the load.

Acceleration following unloading was used as a measure of performance, where small acceleration magnitude indicated better compensation for the load release. We used peak acceleration in the first 200 ms following triggering as a performance metric. We used ANOVAs to test for significant differences between conditions.

RESULTS

In both hand and feet disturbance rejection tests, subjects were able to compensate for the unloading better when it was self-triggered than when it was triggered by computer. The general response showed similar characteristics for both sets of tests (hand and feet). When computer-triggered, subjects were able to compensate better when a timing cue was presented. The mean acceleration waveforms were smallest for Self-Triggered, intermediate for Computer-Cued, and largest for Uncued (Figure 1).

Post hoc analyses of variance with multiple comparison procedures indicate significant differences in the peak acceleration. When compared to the Uncued condition in the upper limb tests, the Computer-Cued and Self-Triggered conditions produced smaller peak accelerations by 6.7% and 24.2%,

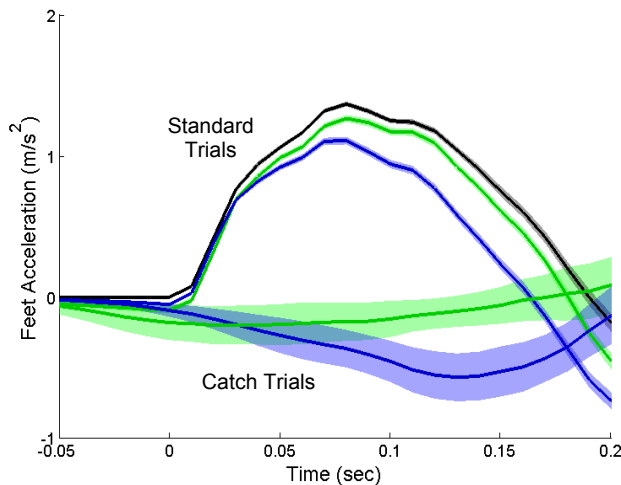


Figure 1: Average acceleration patterns for lower limb tests of all subjects showed larger magnitudes for Uncued (grey) and Computer-Cued (green) standard trials than for Self-Triggered (blue). Self-Triggered catch trials (blue) generally had larger magnitudes than Computer-Cued catch trials (green). The shaded regions indicate 95% confidence intervals. These results were consistent with those from the upper limb analysis.

respectively ($p < 0.001$). Likewise, for the lower limb tests, Computer-Cued was 5.3% smaller ($p = 0.0031$) and Self-Triggered was 16.3% smaller ($p < 0.001$) than the Uncued. The peak accelerations for both Self-Triggered conditions were also significantly smaller than their respective Computer-Cued conditions ($p < 0.001$).

Subjects exhibited more active compensation for the expected but missing load release during the catch trials for the Self-Triggered condition than for the catch trials for the Computer-Cued condition. Although acceleration for some trials remained flat, indicating no active compensation, the acceleration profile for many catch trials resembled the inversion of that produced in standard trials. Mean acceleration waveforms depicted in Figure 1 were intermediate between flat and large inversion profiles.

Peak acceleration magnitudes in the Self-Triggered catch conditions were larger than peak accelerations in the Computer-Cued catch conditions for both hand and feet ($p < 0.001$).

DISCUSSION

Our results indicate that subjects develop anticipatory adjustments in the lower limbs based on upper limb dynamics. The effects observed were similar in character and magnitude as those demonstrated from bimanual unloading tasks performed on the same apparatus. Given that lower limb neuromuscular commands incorporate predictions of interaction forces from the upper limbs, we suggest that upper limb guided lower limb motion may be a productive means of neurological rehabilitation (Danek et al., 2005), similar to what has been suggested for bimanual guidance (Lum et al., 2002). In contrast, interaction forces from external agents (i.e. robots or therapists) can not be anticipated or incorporated into lower limb neuromuscular control during therapy in the same manner demonstrated here by upper limb interaction forces.

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