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Abstract
Humans are easily able to maintain their balance while applying force with their hands to move or stabilize objects. Based on Newton's laws, the applied force must be counteracted by ground reaction force (GRF) to maintain balance. However, because the GRF is partitioned between the two legs there is no unique solution. Furthermore, central nervous system (CNS) can employ an infinite number of muscle activation patterns to achieve ground reaction force (GRF) vectors needed to satisfy both the task-level goal and balance. This study examines the postural response when hand position must remain stable as an external force is applied in different directions during normal stance. We investigated whether the CNS uses an invariant strategy to compensate for forces acting in different directions.

Keywords
responses, stance, postural, during, hand, perturbations, multidirectional

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POSTURAL RESPONSES TO MULTIDIRECTIONAL PERTURBATIONS TO THE HAND DURING STANCE

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INTRODUCTION

Humans are easily able to maintain their balance while applying force with their hands to move or stabilize objects. Based on Newton's laws, the applied force must be counteracted by ground reaction force (GRF) to maintain balance. However, because the GRF is partitioned between the two legs there is no unique solution. Furthermore, central nervous system (CNS) can employ an infinite number of muscle activation patterns to achieve ground reaction force (GRF) vectors needed to satisfy both the task-level goal and balance. This study examines the postural response when hand position must remain stable as an external force is applied in different directions during normal stance. We investigated whether the CNS uses an invariant strategy to compensate for forces acting in different directions.

MATERIALS AND METHODS

Ten healthy subjects participated in the present study. Subjects stood at their normal stance width on two multi-axis force plates while grasping the handle of a two degree-of-freedom robotic manipulandum with the dominant hand. A 6-axis force-torque sensor attached to the handle measured the reaction forces applied by the subject. The position of the handle was displayed on a monitor 50 cm from the subject. Surface EMG was sampled at 1 KHz bilaterally from leg muscles and unilaterally from the muscles of the dominant arm. At the beginning of each trial the subject was instructed to move the cursor into a target window and hold it there for a period of 4 seconds, during which a ramp-and-hold force was applied to the hand. There were 48 trials, comprising 8 force directions presented in random order. Force and EMG were analyzed for 3 intervals: 1) 500 ms before the increase in hand force 2) 100-300 ms from the onset of the force 3) 500 ms during the steady-state hold.

RESULTS

A typical steady-state response for one subject is shown in Figure 1. For each subject, the average GRF and root-mean-square EMG during interval 1 were calculated and subtracted from the corresponding values in intervals 2 and 3. The horizontal GRFs from individual trials and the average EMG across trials are plotted in polar coordinates as functions of the direction of applied force at the hand. The GRF directions and magnitudes are not uniformly distributed, unlike the force applied to the hand, although the resultant GRF vector is equal and opposite to the hand force for all directions (Figure 1A). The activity of leg muscles appears to be strongly tuned for specific hand force directions.

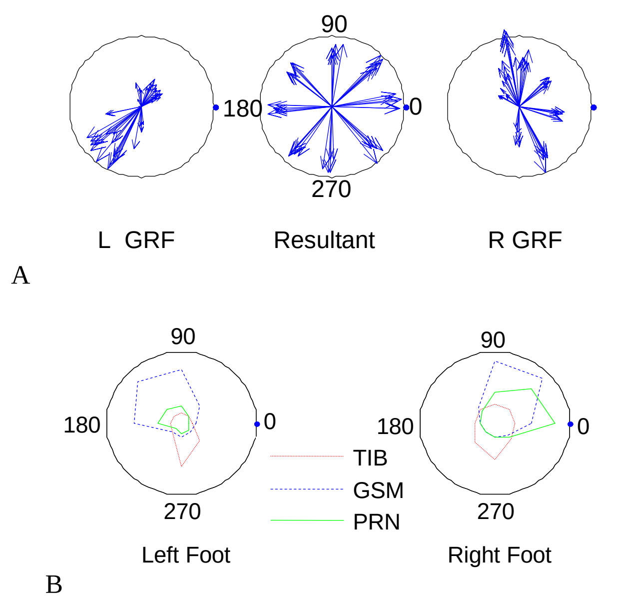

Figure 1: (A) GRF vectors, (B) EMG tuning curves

DISCUSSION AND CONCLUSIONS

GRFs of the left and right foot tend to be oriented in opposite directions with large components that cancel force but create torque. This may be needed to cancel torque created by the force applied to the hand. Similar GRF features have been reported to unexpected perturbations of the support surface [1]. Muscle tuning curves were narrowly tuned with a direction of maximum activation that showed mirror symmetry across the legs. The principal difference in muscle activation between legs is seen in Peroneus longus. Its action may be responsible for the difference in the medial/lateral component of the GRF between the left and right legs.

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