Characterizing perturbations of human walking in the frequency domain

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1 Motivation

To understand how does the nervous system stabilizes walking in the vicinity of the locomotor limit cycle, we want to identify the plant and feedback for walking. The plant describes how small deviations in EMG trajectories from the limit cycle map to small deviations in kinematic trajectories. Feedback describes how small deviations in kinematic trajectories map to small deviations in EMG trajectories. The plant defines the control problem and feedback constitutes the nervous system's solution to the control problem.

2 State of the Art

The plant and feedback have been identified in the simpler closed-loop task of stabilizing upright stance, a system that can be usefully approximated as linear, using frequency response functions (FRFs) to implement the joint input-output (JIO) method [1-3]. In the context of the neural control of movement, the JIO method is based on the key ideas that (i) for sensory perturbations, the plant defines a mapping from EMG responses to kinematic responses; and (ii) for mechanical perturbations, feedback defines a mapping from kinematic responses to EMG responses.

3 Own Approach

We extend the JIO method from stabilization of a fixed point (standing) to stabilization of a limit cycle (walking) using an analog of the FRF to describe the input-output mapping for small perturbations of a limit cycle. Part of the solution is given by harmonic transfer functions (HTFs) [4,5]. HTFs describe the input-output mapping for linear time periodic (LTP) systems and thus approximate the input-output mapping for small perturbations of a limit cycle that do not cause phase resetting. HTF theory says that input at frequency f will produce responses at frequencies $f + kf_0$ where k is an integer and f_0 is the frequency of the limit cycle.

To include the effects of phase resetting, we use an approximation $\hat{\theta}(t)$ of absolute phase based, for example, on the times at which the heel hits the surface. If the input $v(t)$ and output $y(t)$ are defined as functions of $\hat{\theta}(t)$ instead of time t, then the LTP approximation holds and an HTF describes the input-output mapping. In addition, we compute the HTF from $v(\hat{\theta})$ to $d\hat{\theta}(\hat{\theta})/dt$ and combine both HTFs to yield a canonical frequency-domain description H of the mapping from $v(t)$ to $y(t)$ that is independent of the particular phase approximation. Extending the JIO method, the plant defines a mapping from the set of H for all EMG responses to the set of H for all kinematic responses.

4 Current Results

We have used the above approach to characterize EMG and kinematic responses to visual-scene motion during walking on a treadmill [6]. Figure 1A shows that experimental responses do show an HTF pattern in which input at frequency f produces significant responses (indicated by blue) at frequencies $f + kf_0$ for integers k. Figure 1B shows examples of experimental estimates of H converted to impulse responses functions for EMG and kinematic responses (red: positive, blue: negative).

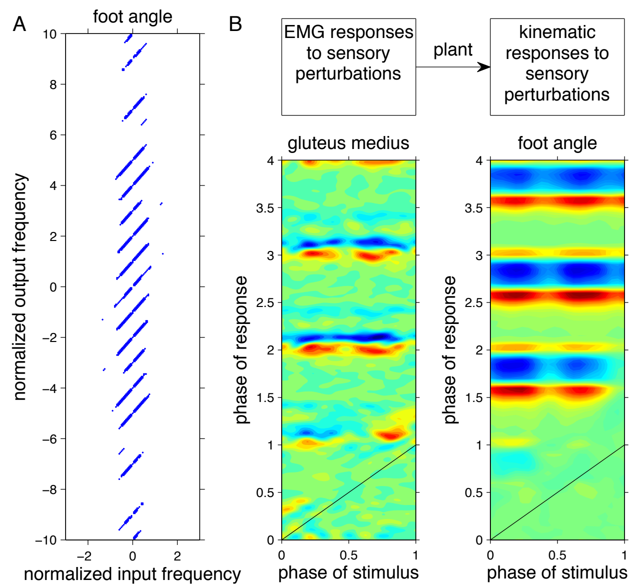

Fig 1. Responses to visual-scene motion.

5 Best Possible Outcome

Our long-term goal is to characterize EMG and kinematic responses to a variety of sensory and mechanical perturbations and use the JIO method to identify the plant and feedback for walking.

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References

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