Studying sensory reweighting in human walking from a controls perspective

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1 Motivation

The use of sensory inputs for human locomotion is critical for many functions such as control of upright posture and locomotive speed. Surprisingly, there are few investigations of how the senses reweight during human walking and such studies have not been performed in a control theoretic framework amenable to a systematic study of neural control mechanisms. Within the context of standing postural control, sensory reweighting has been formalized using linear time-invariant (LTI) approaches [1]-[3] as a process in which more reliable estimates of self-motion are used for neural control. To study sensory reweighting during walking, one must characterize the nonlinear responses that are produced by sensory perturbations.

2 State of the Art

Here we focus on reweighting of visual inputs. Most studies of vision and locomotion [4]-[5] use a limited set of kinematic markers (e.g., often only one), foot switches or videotaped body movement relative to an external reference to measure gait cycle characteristics or whole body measurements (e.g., average speed). We have previously shown that broad-band stimuli can be used to probe responses of trunk kinematics to visual stimuli [6] using traditional LTI frequency response functions (FRFs), and would like to extend these investigations to study sensory reweighting in the entire body.

3 Own Approach

FRFs do not fully characterize the responses of the leg segments to visual scene motion due the nonlinear limit-cycle nature of locomotion. To take into account the limit-cycle dynamics of gait, we characterize responses in the frequency domain using harmonic transfer functions (HTFs), which describe input-output mappings for linear time periodic (LTP) systems [7] and thus approximate the input-output mapping for small perturbations of a limit cycle that do not cause phase resetting. To include the effects of phase resetting, we approximate absolute phase using heel-strike times, replace time with approximate phase, and compute the HTFs from both the visual-scene motion to the derivative of approximate phase and from visual-scene motion to the kinematic responses variables.

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4 Current results

We studied multiple segments of the body during treadmill walking in an experiment [8] which studied visual reweighting during two types (translation/rotation) of visual scene motion. Using standard LTI FRFs, responses of trunk kinematics to visual scene motion were found to be proportionally lower when amplitude of scene motion increased. This reweighting of visual scene motion was not different in magnitude between translating and rotating visual scene motion using these standard approaches. We have recently employed these HTF analyses to characterize the kinematic responses of all segments to visual scene motion in the frequency domain, with significant responses observed at multiple input and output frequencies. The Impulse response function of the foot elevation angle, for example, reveals both a resetting of gait cycle phase and a transient response to visual scene motion.

5 Best Possible Outcome

As leg segments contribute to the reweighting of trunk motion and may show additional reweighting effects not observable in the trunk, detailing their responses are critical during sensory reweighting experiments. The best possible outcome is that coordinative relationships that emerge with the use of these HTF analyses will provide insight into sensory reweighting and the use of different types of visual information during treadmill walking. Also, using HTFs to characterize both kinematic and EMG responses may allow us to identity the musculoskeletal plant for walking, as is possible in standing postural control [9]. Thus, using HTFs we will identify the plant component of the control problem and how sensory reweighting leads to robust control.

References

1. Peterka RJ, Benolken MS (1995) Role of somatosensory and vestibular cues in attenuating visually induced human postural sway. Exp Brain Res 105: 101-110.
2. Oie KS, Kiemel T, Jeka JJ (2002) Multisensory fusion: simultaneous re-weighting of vision and touch for the control of human posture. Brain Res Cogn Brain Res 14: 164-176.
3. Mahboobin A, Loughlin PJ, Redfern MS, Sparto PJ (2005) Sensory re-weighting in human postural control during moving-scene perturbations. Exp Brain Res 167:260-7.
4. Konczak J (1994) Effects of optic flow on the kinematics of human gait: a comparison of young and older adults. J Mot Behav 26:225-236.
5. Prokop T, Schubert M, Berger W (1997) Visual influence on human locomotion. Modulation to changes in optic flow. Exp Brain Res 114:63-70.
6. Logan D, Kiemel T, Dominici N, Cappellini G, Ivanenko, YP Lacquaniti F, Jeka JJ (2010). The many roles of vision during walking. Exp Brain Res, 206:337-350.
7. Wereley NM (1991) Analysis and control of linear periodically time varying systems. PhD dissertation, Dept. of Aeronautics and Astronautics, MIT, Cambridge, MA.
8. Logan D, Kiemel T, Cappellini G, Sylos-Labini F, Ivanenko YP, Lacquaniti F, Jeka JJ (2010) Visual reweighting in locomotion. Society for Neuroscience, San Diego, CA.
9. Kiemel T, Elahi AJ, Jeka JJ (2008) Identification of the plant for upright stance in humans: multiple movement patterns from a single neural strategy. J Neurophysiol 100:3394 –3406.