

Control of Multiple Degrees of Freedom during Human Upright Stance

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A common method to investigate the properties of a biological closed-loop system is to “open the loop” so that different processes can be studied in isolation. Opening the loop is often criticized because the system is investigated under nonphysiological conditions and subjected to nonphysiological inputs. Moreover, opening the loop is not always possible, such as in the case of human upright stance, because the plant alone is unstable. Remove all feedback and standing is no longer possible. Here we implement a closed-loop system identification (CLSI) method to determine properties of the control system during human upright stance.

We characterize the postural control system as consisting of two processes: the mapping from muscle motor commands to sway (the plant) and the mapping from sway to muscle motor commands (feedback). The plant depends on musculo-tendon dynamics and body dynamics. Feedback depends on sensory dynamics, sensory integration, and the control strategy. Using a linear approximation, each of these mappings can be characterized by an open-loop frequency response function (FRF). Given that postural control involves multiple mechanical degrees of freedom, the number of plant and feedback inputs are potentially large. However, under certain conditions the effective number of plant and feedback inputs may be much smaller. Our experimental results indicate that during weakly perturbed upright stance: 1) at least two mechanical perturbations are required to identify feedback; 2) there is evidence of a time delay; and 3) the nervous system does not place a large cost on minimizing center-of-mass displacements, but instead may be optimizing muscle activation.