THE CONTROL BOTTLENECK INDEX: A NOVEL OUTCOME METRIC PROVIDING GENERALIZABLE AND ACTIONABLE ASSESSMENT OF UPPER-LIMB PROSTHETIC SYSTEMS

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ABSTRACT

Assessment tools for upper limb prostheses lack generalizability and provide little actionable information to improve outcomes. We have developed the Control Bottleneck Index (CBI), a new outcome measure driven by a computational motor control framework that can provide useful and actionable information regarding system performance. The CBI uses an existing hierarchical Kalman filter model (Blustein & Sensinger 2016, Johnson et al. 2016, Berniker & Kording 2008) to predict system parameters including sensory feedback uncertainty, controller uncertainty, and internal model uncertainty based on human psychophysics results. The CBI tasks include a baseline grasping task, a movement matching task without feedback and a two-alternative forced choice task to determine the just noticeable difference of a perturbation. Here we present this human movement assessment tool and demonstrate its responsiveness to changes in system parameters. The CBI is not task specific but we describe an implementation using a time-constrained grasping task in the Multi-Joint dynamics with Contact (MuJoCo) physics engine with endpoint visual feedback and EMG control (Todorov et al. 2012). We show that when sensory noise and control noise are experimentally adjusted, the CBI can predict changes in the expected underlying motor control model parameters. By inversely calculating model parameters using experimental results, this assessment framework can determine the relative levels of uncertainty of different system components in a human controlling a prosthesis. The results of the CBI can directly inform clinical improvements. For example, if a human performer exhibits a high level of sensory feedback uncertainty, then clinicians can direct improvements to the feedback systems on the prosthesis. The CBI represents a new assessment tool that provides generalizable and actionable information for clinicians working to improve upper limb prosthetic systems.