A Novel framework for predicting the effectiveness of sensory feedback information during powered upper limb prosthesis control

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HUMANS move their arms and hands with seemingly effortless dexterity. For persons with upper limb amputations, this natural ability is lost, and the control of powered prostheses is too cognitively burdensome to restore able-bodied function. Movements are imprecise and require an exhausting level of attention [1]. Providing additional sensory feedback is an intuitive solution for lowering visual demand; however, an effective feedback strategy remains elusive [2]. Significant challenges are involved in designing the feedback delivery (modality, device, etc.) and in choosing the feedback information (joint angle, grasp force, etc.). In this work we address the most effective feedback information without the confounding effects of physical feedback delivery, using a sensorimotor adaptation paradigm that reveals the sources of uncertainty.

Sensorimotor adaptation studies theorize that the nervous system performs coordinated movements by predicting the state of the body and correcting the prediction using delayed sensory feedback [3]. To predict the next state (e.g. position and velocity) of the body, the nervous system needs an internal model that describes the dynamics of the body and any contextual object involved in a task [4]. The internal model is composed of estimated body and contextual parameters that each have some level of uncertainty (due to motor, sensor, and environment variability) [5]. In response to an error, the brain can attribute the source of the error to a misestimate of either body or contextual dynamics—in other words, the brain assigns uncertainty to either body or contextual parameters [6]. To reduce error in a new movement, the brain can adapt the uncertain parameters using relevant feedback. Therefore, the assignment of uncertainty reveals whether body or contextual feedback has the greatest potential to reduce uncertainty and improve performance.

Uncertainty assignment is investigated by testing the adaptation transfer between contextual dynamics and body dynamics [7], [8]. In this work, we performed simulations of adaptation transfer experiments to begin our examination of uncertainty assignment during prosthesis control. The simulated task was to command a cursor to reach a target along a single-degree-of-freedom axis. Body dynamics were implemented by modeling the cursor with a continually present viscosity and inertia. Contextual dynamics were implemented as an added cursor inertia to simulate an inertial perturbation. A Kalman filter and a probabilistic source estimation process (based on [6]) were used to model the nervous system's adaptation of body and contextual parameters in response to the inertial perturbations.

We compared the effect of electromyographic (EMG) control signal characteristics to those of force control signal characteristics to assess the difference between prosthesis conditions and able-bodied conditions. Powered prosthesis users control their artificial arms with EMG signals and use primarily visual feedback as guidance [9]. Thus feedforward variability is increased and feedback is reduced, relative to able-bodied conditions. Our preliminary results suggest that this increased feedforward variability shifts uncertainty assignment towards higher body uncertainty, predicting that body feedback information will be most effective in improving performance.

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