Challenges of closing the loop in upper-limb prosthetics

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Background

Sensory feedback is critical for grasping in able-bodied subjects. Consequently, closing the loop in upper-limb prosthetics by providing sensory feedback to the amputee is expected to improve prosthesis utility. Nevertheless, even though amputees rate the prospect of sensory feedback highly, its benefits in daily life are still very much debated. We address this issue by building a concise knowledge base about variety of different factors that influence closed-loop control and we demonstrate tangible performance benefits when using a practical feedback system.

Material and Methods

To this goal, we systematically evaluated in a variety of studies from our group: 1) the interaction between feedforward control and feedback (i.e., benefit of feedback as a function of motor learning and skill acquisition); 2) choice of optimal feedback variables (e.g., force, aperture, velocity, biofeedback); 3) different feedback interfaces and information coding schemes (e.g., number of channels/resolution, spatial, intensity and frequency coding); 4) how feedback alters the subjective experience (e.g. prosthesis embodiment, perceived workload); 5) influence of indirect feedback sources (e.g., muscle proprioception, socket vibration) and 6) dependency between task complexity and closed-loop control performance. Accordingly, the studies also varied in complexity, ranging from lab-based psychometric evaluations to applied clinical experiments in which amputees tested different feedback solutions (vibro-tactile, electro-tactile) across different tasks (e.g., box and blocks, fine force steering, ballistic grasping) and time-spans (one day to several weeks).

Results and Conclusions

We demonstrate that, in the context of prosthesis control, feedback’s complex, multifaceted nature is likely responsible for inconsistent literature results. More specifically, we identify factors such as task complexity, user experience, quality of implicit feedback and interface intelligibility to have detrimental influence on performance of implemented feedback solutions. We used these insights to implement and evaluate a novel vibro-tactile feedback interface for multi-functional, dexterous prostheses in a clinically relevant setting. Finally, we demonstrate, for the first time, that the proposed solution improves not only the prosthesis control efficiency but also the overall subjective experience.

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