HIGH-RESOLUTION, REAL-TIME MOTOR CONTROL OF PROSTHETIC HANDS IN HUMANS AFTER LONG-TERM AMPUTATION

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ABSTRACT

To explore the ability to use peripheral neural and myoelectric signals to control advanced prosthetic hands, six human subjects (S1-S6) received one or two 100-electrode Utah Slanted Electrode Arrays (USEAs; Blackrock Microsystems) implanted chronically (1-9 months) in residual median and/or ulnar nerves for recording from motor fibers and for stimulation of sensory fibers (George et al., MEC17) after long-term (2- to 25-y) transradial amputations. S5 and S6 also received a 32-electrode electromyogram (EMG) assembly implanted in residual forearm muscles (Ripple, LLC). Motor control was provided by real-time decodes of myoelectric and neural signals; myoelectric signals provided the dominant control in subjects with both implants. EMG power and neural firing rate provided the features used for Kalman-filter decode algorithms. During initial "training" sessions, subjects viewed individuated digit or wrist movements of a virtual hand and attempted to mimic these movements with their phantom hand. The neural and EMG activity associated with the imagined phantom movements was then used to select neural and EMG channels from among 720 single-ended or differential possibilities (Nieveen et al., MEC17), and to set the parameters of the Kalman filter. The Kalman filter output was used to control a virtual or physical prosthetic hand in subsequent "testing" sessions. Experiments were conducted either in a MuJoCo (Roboti, LLC) virtual reality environment; or with a simple sensorized, motorized physical prosthetic hand (Open Bionics); or with a more advanced, motorized and sensorized prosthetic hand (DEKA) having 6 DOFs and 19 receptive fields. Recent subjects successfully controlled up to nine real-time degrees-of-freedom (DOFs) involving 18 digit and wrist movements of a virtual hand in a formal target-touching test (e.g., 53 successes in 54 trials). One subject achieved up to 12 apparent DOFs in informal tests. Both proportional position and velocity control were achieved. Additionally, subjects successfully combined individual DOF movements into novel grasps (e.g., "pinch") that had not been explicitly trained. EMG decodes remained stable for over a week (e.g., 26 successes in 26 trials in a 3-DOF, 4-level novel virtual grasp-matching task). S6 controlled the digits and wrist of the DEKA physical hand in both trained and untrained movements and grasps. Subjects also successfully used USEA-evoked sensory feedback to guide their motor behaviors in real-time closed-loop control. These results document an unprecedented level of real-time proportional control of a prosthetic hand in humans with long-term hand amputation. Future research includes translating these approaches to a wireless, practical take-home system.