Two Degrees of Freedom EMG-Force at the Wrist in Able-Bodied Subjects Using a Minimum Number of Electrodes: Pilot Testing of Limb-Absent Subjects

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BACKGROUND: Traditional hand-wrist prostheses provide proportional control of only 1 degree of freedom (DoF) at a time, requiring the user to mode-switch between them. Research using large numbers of electrodes on able-bodied subjects has related the EMG of the forearm muscles to two degrees of freedom at the wrist. Initial evaluation in limb-absent subjects also shows this relationship, albeit with higher errors. However, using such large numbers of electrodes in a commercial prosthesis is not presently practical. Hence, we studied the ability to extract EMG-force information using a minimum number of electrodes.

METHODS: For 10 able-bodied subjects, 16 conventional bipolar electrodes were mounted transversely about the proximal forearm. The hand was secured to a load cell which measured forces generated during wrist extension-flexion, radial-ulnar deviation and pronation-supination. A screen target produced slowly-moving (quasi-static) force targets along one of these three contraction dimensions per trial, and also produced targets with equal levels of co-contraction for pairs of dimensions (2-DoF tasks). Effort ranged over 0–30% MVC. Linear, static, 1-DoF and 2-DoF models relating EMG amplitude to force were then trained, using regularized linear least squares. Initially, all 16 electrodes were used as inputs. Thereafter, backward stepwise selection of the training data sequentially reduced the number of electrodes. RMS error on a separate test trial was evaluated at each step.

RESULTS: For 1-DoF models, stepping down to fewer than two electrodes was unacceptable; and retaining more than two electrodes provided limited benefit. This result was expected and consistent with existing prosthesis practice. With 2 electrodes, the 1-DoF average error ranged from 6.5–9.5%, depending on the DoF; pronation-supination exhibited the highest errors. For 2-DoF tasks, there was little or no change in error stepping from 16 down to 4 electrodes. Errors generally increased progressively as the number of selected electrodes decreased from 4 to 1. With 4 electrodes, the 2-DoF error averaged 6.3–8.1%, depending on the DoFs. Minimum errors occurred when combining flexion-extension with ulnar-radial deviation.

This experiment was piloted with 4 unilateral limb-absent subjects. Force was measured from their sound side and mirrored contractions produced on the limb-absent side. Electrodes were mounted on the limb-absent side. For 1-DoF models using 2 electrodes, errors ranged from 12.8–18.3%, depending on the DoF. For 2-DoF models using 4 electrodes, errors ranged from 13.8–16.1%. Result trends matched those of the able-bodied subjects, but with higher errors overall.

CONCLUSION: These results are encouraging that as few as 4 conventional electrodes, optimally located about the forearm, could provide 2 DoFs of simultaneous, independent and proportional control with error rates similar to the 1-DoF approach currently used for commercial prosthesis control.