TWO-DOF, DYNAMIC EMG-BASED ESTIMATION OF HAND-WRIST FORCES WITH A MINIMUM NUMBER OF ELECTRODES

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ABSTRACT

Introduction:
Commercial hand-wrist prostheses realize partial function for amputees via electromyogram (EMG) control derived from remnant muscles. Most EMG-based prostheses provide only one degree of freedom (DoF) of control at a time. Recent studies have used different approaches to overcome this challenge, with two main limitations. First, most studies used a large number of high-density electrodes. None of them studied the possibility of minimizing the number of electrodes for practical commercial prosthesis use. Second, very few studies have investigated the feasibility of 2-DoF control for the hand and wrist concurrently. Our study explored the minimum number of electrodes required for 2-DoF simultaneous hand-wrist force estimation.

Methods:
Nine able-bodied subjects participated. Sixteen conventional bipolar EMG electrodes were equally spaced around the proximal forearm. The subject's hand was secured to a load cell which measured hand open-close (Opn-Cls) force, and their wrist was fixed to a 3-DoF load cell which measured extension-flexion (Ext-Flx), radial-ulnar deviation (Rad-Uln) or pronation-supination (Pro-Sup) force. The subject was required to perform constant-posture, dynamic force tracking based on a computer-generated random moving target (0.75 Hz bandwidth). First, 1-DoF trials tested the four forces separately. Second, 2-DoF trials tested hand Opn-Cls always paired with one of the three wrist forces. Each task had four trials, two of which were used for training and two for testing, of a linear least squares regression EMG-force model. Backward stepwise selection was used to reduce the number of electrodes from 16 to 1.

Results:
For the 1-DoF models, two-way RANOVA found an effect due to number of electrodes [F(1.8, 14.7) = 99, p_{GG} <0.001], but not DoF [F(3, 24) = 0.54, *p*=0.66]. *Post hoc* paired *t*-tests (Bonferroni corrected) only found error higher when comparing 1 electrode to more than 1 (*p*≤0.001); and 13 electrodes to 10 (*p*=0.006; this difference is argued to be a false positive). The errors for the four respective forces, Opn-Cls, Ext-Flx, Rad-Uln and Pro-Sup, were 8.8 ± 3.3, 8.3 ± 2.0, 9.0 ± 1.6 and 8.7 ± 2.2 %MVC.

For 2-DoF models trained from 1- and 2-DoF trials and tested on 2-DoF trials, the RANOVA main effect of number of electrodes was significant [F(1.6, 12.9) = 99, $p_{GG} = 10^{-6}$], but DoF was not [F(2, 16) = 0.07, *p*=0.9]. *Post hoc* analysis of number of electrodes only found that 1 electrode exhibited higher error than more than 1 (*p*<0.003), 2 electrodes higher than more than 3 (*p*<0.003), 3 electrodes higher than more than 5 (*p*<0.02), 4 electrodes higher than more than 5 (*p*<0.03), and 5 electrodes higher than 6 or 10–13 (*p*<0.05). With four electrodes, the 2-DoF errors for Ext-Flx, Rad-Uln and Pro-Sup (each paired with hand Opn-Cls) were 9.2 ± 2.0, 9.2 ± 1.6 and 9.2 ± 1.4 %MVC, respectively.

Conclusion:
While low errors in a lab study do not necessarily reflect improved performance in a prosthesis, such studies in able-bodied subjects are useful in refining algorithms before undertaking more expensive field studies using a prosthesis. Our 2-DoF results showed a similar error level as our 1-DoF results. As few as four conventional electrodes provided good performance for estimating 2-DoF simultaneous hand-wrist forces. Testing these techniques in a hand-wrist prosthesis is an appropriate next research step.

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