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High density electromyography data of normally limbed and transradial amputee subjects for multifunction prosthetic control

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ABSTRACT

Pattern recognition based control of powered upper limb myoelectric prostheses offers a means of extracting more information from the available muscles than conventional methods. By identifying repeatable patterns of muscle activity across multiple muscle sites rather than relying on independent EMG signals it is possible to provide more natural, reliable control of myoelectric prostheses. The purposes of this study were to (1) determine if participants can perform distinctive muscle activation patterns associated with multiple wrist and hand movements reliably and (2) to show that high density EMG can be applied individually to determine the electrode location of a clinically acceptable number of electrodes (maximally eight) to classify multiple wrist and hand movements reliably in transradial amputees. Eight normally limbed subjects (five female, three male) and four transradial amputee subjects (two traumatic and congenital) subjects participated in this study, which examined the classification accuracies of a pattern recognition control system. It was found that tasks could be classified with high accuracy (85–98%) with normally limbed subjects (10–13 tasks) and with amputees (4–6) tasks. In healthy subjects, reducing the number of electrodes to eight did not affect accuracy significantly when those electrodes were optimally placed, but did reduce accuracy significantly when those electrodes were distributed evenly. In the amputee subjects, reducing the number of electrodes up to 4 did not affect classification accuracy or the number of tasks with high accuracy, independent of whether those remaining electrodes were evenly distributed or optimally placed. The findings in healthy subjects suggest that high density EMG testing is a useful tool to identify optimal electrode sites for pattern recognition control, but its use in amputees still has to be proven. Instead of just identifying the electrode sites where EMG activity is strong, clinicians will be able to choose the electrode sites that provide the most important information for classification.

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1. Introduction

Myoelectrically controlled prosthetics have been well accepted by upper extremity amputees for many years (Parker and Scott, 1986) and technological advances in myoelectric control systems have increased the popularity of the device. Reductions in weight and improvements in socket comfort have also contributed to the growing acceptance of myoelectric prosthetics (Parker et al., 2006). There has been a considerable amount of research advancing the technology of myoelectric prosthetic control. Over the last 50 years myoelectric control systems have developed from single muscle control of one prosthesis function to muscle group activity control of multiple prostheses functions (Parker et al., 2006). Progress in technology however, has not been paralleled with research using clinical populations to test the usability of new devices. Advanced systems have the ability to control multiple hand functions but they have yet to be applied in the clinical setting. Commercially available prosthetics are still only capable of controlling one or two degrees of freedom (Englehart and Hudgins, 2003). Increasing the number of functions in upper limb prosthetics is important for user acceptance and satisfaction (Sebelius et al., 2005). Multifunction devices are not easily integrated into clinical settings because they often require more training, more complex operation and the ability to impart reliable control decreases as additional degrees of freedom are introduced into the control system.

Current upper limb myoelectric prosthetics often use an agonist/antagonist muscle pair to control a single function (Parker and Scott, 1986). While additional degrees of freedom can be controlled, this requires the user to alternate between different

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functions (Light et al., 2002). A more intuitive multifunction control method is desired. Pattern recognition myoelectric control systems provide multiple functions of the prosthetic device. Classifiers within these systems recognize the specific muscle activity patterns produced during different movement contractions and select the appropriate output function (i.e. open or close the hand). These types of control systems have generally been tested with normally limbed subjects performing in a controlled environment while limited studies have included amputee subjects in their investigations. Of those studies that used amputees to test pattern recognition control for multifunction myoelectric prostheses, there is significant variability (Lundborg, 2000; Sebelius et al., 2005, 2006; Hudgins et al., 1993; Boostani and Moradi, 2003; Fukuda et al., 2003; Ajiboye and Weir, 2005). The number of participants in those studies that included amputee subjects has ranged from 1 (Lundborg, 2000) to 10 amputees (Boostani and Moradi, 2003) along with normally limbed subjects to test the control systems. Including amputee subjects in prosthetics research is important. In order to integrate multifunction control systems into the clinical setting, classification accuracies need to reach acceptable levels in amputee subjects. Clinical populations are the end user of prosthetic devices, therefore investigating their success with multifunction control systems is necessary. Muscular differences amongst amputee subjects are the result of different surgical procedures, the type of deficiency (congenital versus traumatic amputations), and time since amputation (Herberts et al., 1978). Each amputee subject presents a unique case that requires individualized attention.

High density EMG is a noninvasive technique that collects myoelectric signals from many closely spaced electrodes (Drost et al., 2006). The information collected from high density EMG can be used to create topographical maps of EMG amplitude at each electrode location and to examine the muscle activity patterns during different tasks (Merletti and Parker, 2004). Energy maps illustrate which electrode locations experience strong myoelectric activity during each task performed. These maps can be examined to determine if distinguishable muscle activation patterns are produced for different tasks for each subject. They can also be used to determine if an individual is able to reproduce the same activity pattern for a given task over a number of repetitions and over a period of time (i.e. from trial to trial). The application of multi-channel surface EMG is convenient and has been shown to have high reliability (Holtermann et al., 2005). While research using high density EMG with amputee subjects is limited, recently we have shown that amputee subjects are able to elicit distinct and repeatable patterns for at least a subset of the tasks suggesting promise for amputee control of multifunction myoelectric prosthetics (Daley et al., 2010).

The energy maps generated from the high density EMG data illustrate which electrode locations experience strong myoelectric activity during each task performed. These maps can be examined to determine if distinguishable muscle activation patterns are produced for different tasks for each subject. Reproducible and distinguishable muscle activation patterns are important for multifunction control of myoelectric prosthetic devices.

While high density EMG systems allow the collection of many channels of data, it is important to consider the number of electrodes that is clinically acceptable in a prosthetic device (Huang et al., 2008). It has been shown that classification accuracies improve with an increased number of electrodes to a certain point at which increases in classification accuracy start to diminish with more electrodes (Zhou et al., 2007; Parker et al., 2006). The relationship between the number of tasks that can be reliably classified and the number of electrodes used in a pattern recognition classifier has never been investigated. Channel reduction of high density EMG measurements allows this relationship to be investigated and may help clinicians identify optimal electrode sites for myoelectric control.

The purposes of this work were (1) to determine if participants can perform distinctive muscle activation patterns that are reliably associated with multiple wrist and hand movements and (2) to show that high density EMG can be applied to individually determine the electrode location of a clinically acceptable number of electrodes to classify multiple wrist and hand movements reliably in transradial amputees.

2. Methods

2.1. Subjects

Eight normally limbed subjects (five female, three male) and four transradial amputee subjects (two traumatic and two congenital) participated in this study. Normally limbed subjects were between the ages of 21 and 27 (mean age = 23 ± 1.1 years) and had no history of neuromuscular disorders. Transradial amputee subjects were recruited through the Institute of Biomedical Engineering at the University of New Brunswick. The congenital amputees included one male (24 years old) and one female (17 years old) and the traumatic amputees included one female (41 years old) and one male (61 years old). Table 1 presents the general information about each amputee subject and their experience with prosthetic arms. The university research ethics board approved this research.

2.2. Instrumentation

A high density EMG system (REFA 128 model, TMS International) was used for data collection. The REFA 128 model is a stationary system measuring multiple monopolar electrophysiological variables. Signal filtering was performed with the PC software. A 60 Hz notch filter was also used to remove noise. The sampling frequency was set at 2000 Hz (TMSI User Manual, 2006).

2.3. Skin preparation and electrode placement

Participants' skin was cleaned prior to electrode placements using rubbing alcohol. An AgAgCl paste was then applied to the subjects' forearm to reduce skin impedance.

Up to 64 channels of EMG were used with the high density EMG system and the pre-gelled electrodes were placed in a grid formation over the forearm to collect as much data from a large surface area. The areas on the forearm that experienced muscle activity during given movements were illustrated in energy maps. For normally limbed subjects 64 electrodes were evenly distributed around the whole forearm in an eight by eight grid formation with the ground electrode placed on the elbow.

The number of electrodes (and consequently the grid formations) used with transradial amputee subjects varied because of different residual limb lengths. The number of electrodes used for each amputee subject and the number of movements completed are listed in Table 2.

The electrode placement procedures were generally the same for the amputee subjects. The only difference being the number of electrodes placed down the length of the forearm. A minimal inter-electrode distance of 2 cm was used to determine the number of electrodes per column for each amputee.

Two electrode configurations were considered: (1) when features were extracted from the monopolar electrode recordings and (2) when monopolar electrodes were then grouped into pairs down the length of the arm, and subtracted in the signal processing, prior to features extraction. Method 2 effectively created

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