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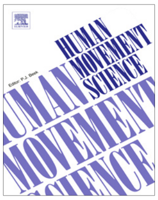

Learning to modulate the partial powers of a single sEMG power spectrum through a novel human–computer interface

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ABSTRACT

New human–computer interfaces that use bioelectrical signals as input are allowing study of the flexibility of the human neuromuscular system. We have developed a myoelectric human–computer interface which enables users to navigate a cursor to targets through manipulations of partial powers within a single surface electromyography (sEMG) signal. Users obtain two-dimensional control through simultaneous adjustments of powers in two frequency bands within the sEMG spectrum, creating power profiles corresponding to cursor positions. It is unlikely that these types of bioelectrical manipulations are required during routine muscle contractions. Here, we formally establish the neuromuscular ability to voluntarily modulate single-site sEMG power profiles in a group of naïve subjects under restricted and controlled conditions using a wrist muscle. All subjects used the same pre-selected frequency bands for control and underwent the same training, allowing a description of the average learning progress throughout eight sessions. We show that subjects steadily increased target hit rates from 48% to 71% and exhibited greater control of the cursor's trajectories following practice. Our results point towards an adaptable neuromuscular skill, which may allow humans to utilize single muscle sites as limited general-purpose signal generators. Ultimately, the goal is to translate this neuromuscular ability to practical interfaces for the disabled by using a spared muscle to control external machines.

1. Introduction

Recent advances in technology have led to the development of a range of different devices enabling communication paths between the human body and machines – collectively referred to as human–computer interfaces (HCI). Some of these devices utilize the human body's natural bio-electrical signals by translating impulses to external commands. The ultimate purpose of HCI devices is to restore some amount of lost independence of disabled subjects by allowing them to act on their environment through alternative means. HCI research also allows investigations into the adaptability of the human electrophysiological system and how it may function beyond its original purpose. Here, we report results from 12 subjects learning to use a novel interface that requires the ability to manipulate the surface electromyogram (sEMG) recorded from one single muscle site in order to control a cursor in two-dimensions simultaneously. It is unlikely that these types of bioelectrical

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manipulations are required during routine muscle contractions. Our main objective is to formally establish the human body's ability to use our system, and in particular to describe the learning progress as it occurs over multiple testing sessions.

1.1. Motivation: electromyography human–computer interfaces for the disabled

One strong motivation behind HCI research is to develop control and communication tools for individuals with restricted physical abilities, often caused by accidents or diseases of the central nervous system. Although EMG-driven interfaces are not a viable option for individuals in a 'locked in' state, a large group of even the severely disabled population has limited access to muscles. For example, in the case of high spinal cord injury, these are usually muscles innervated at the brain stem rather than the spinal cord (i.e. head muscles). Other injuries or diseases that cause paralysis may spare muscles on other parts of the body.

Our device is one of many EMG-driven devices for control of external machines that all require subjects to manipulate EMG in different ways. The most commonly known application of EMG occurs in control of powered prostheses (Oskoei & Hu, 2007; Roche, Rehbaum, Farina, & Aszmann, 2014; Scheme & Englehart, 2011; Zecca, Micera, Carrozza, & Dario, 2002); however, other interfaces also exist that utilize EMG in slightly different ways (Chin, Barreto, Cremades, & Adjouadi, 2008; Cler & Stepp, 2015; Hands, Larson, & Stepp, 2014; Larson, Terry, & Stepp, 2012; Song, Jung, Lee, & Bien, 2009; Thorp, Larson, & Stepp, 2014). For example, Cler and Stepp (2015) have developed a novel spelling device in which users navigate and select keys on a keyboard based on sEMG recorded at five different facial sites. EMG has also been used to control powered wheelchairs (Oonishi, Oh, & Hori, 2010; Song et al., 2009) and in cursor control paradigms, where positions were determined by the contractions recorded on the neck and/or face (Hands & Stepp, 2016; Thorp et al., 2014; Williams & Kirsch, 2008).

For control of EMG-driven devices, typically at least one recording site per degree of freedom is needed for continuous control; thus to achieve two-dimensional continuous control of a device, at least two intact recording sites would be employed. Alternatively, a device may be controlled via gesture recognition, in which contractions are analyzed by more sophisticated computational algorithms in order to automatically recognize one of many gestures (De Luca, 1979; Engelhart & Hudgins, 2003; Scheme & Englehart, 2011; Zecca et al., 2002). These gestures are then translated to specific commands. The most novel aspect of our device is that we extract two continuous control-channels from one single signal by simultaneously analyzing the power in two separate frequency bands within the sEMG power spectrum. Essentially, users learn to contract their muscle to create specific power profiles in two bands, which are then translated into cursor coordinates on a computer screen. This motor skill is entirely novel to our subjects and, as it involves an esoteric understanding of signal power properties, subjects appear to approach the task using a trial-and-error learning strategy. From a practical perspective, extracting two control signals from one single sEMG channel allows interfaces with fewer electrodes and associated electronics, which ultimately allows less bodily intrusion for individuals with few available muscle sites.

Our signal processing methods are more closely aligned with some Brain–Computer Interface (BCI) systems (Wolpaw, McFarland, & Bizzi, 2004), than traditional EMG based systems. BCIs allow characterization of novel electrically-based neurological skills (e.g. Birbaumer, 2006; Wolpaw, Birbaumer, McFarland, Pfurtscheller, & Vaughan, 2002). Similarly, EMG devices allow characterization of novel electrically-based motor skills involving the recruitment and tuning of hundreds of motor units from one or several underlying muscles which all act cooperatively. Our device aims to co-opt the electrical manipulation abilities of the neuromuscular system to control an outside machine. Any associated muscle movement is an unneeded byproduct of the objective to control the machine via the electrical signal.

1.2. Aims and objectives

The primary aims of the current study were to formally establish the ability to intentionally manipulate a single sEMG signal so as to simultaneously place two desired power levels in two separate frequency bands (and thus use our HCI device) and to describe the learning curve associated with this particular skill. In a previous pilot study, we reported preliminary results with our device in four subjects using the *auricularis superior* (AS) muscle (located above the ear) to perform a standard cursor-to-target task. The frequency bands used for control were specifically chosen for each subject and training was staged to one target at a time (Perez-Maldonado, Wexler, & Joshi, 2010). Here, we explore three-target learning from a naïve state in a larger subject sample. Rather than identifying personalized frequency bands, we selected the bands prior to testing to explore the body's ability to adapt to non-personalized bands. Finally, we chose to use the *extensor pollicis longus* (EPL) muscle, located on the wrist, to investigate the generalization of the neuromuscular ability to muscles innervated at the spinal cord. In our current study, we observe the performance of 12 naïve subjects over the course of eight one-hour long testing sessions to investigate the progression of performance from the initial encounter with the device.

2. Method

2.1. Subjects

Twelve able-bodied female subjects took part in the experiment (mean age: 21; range: 18–37), all of which had no prior experience with the myoelectric HCI. The subjects provided written consent as required by the University of California, Davis Institutional Review Board (protocol #251192) and received psychology course credits per session completed.