

An f-MRI Study of an Adaptable EMG Prosthetic Hand with Biofeedback

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INTRODUCTION

The mutual adaptation between man-machine opens new possibilities in the development of better user-friendly interfaces that not only adapt to the user's characteristics, but also permits the adaptation of the user to the machine. There are several examples of the use of feedback to improve the man-machine interface. One example is the use of sound to acquire cues in the interaction with the machine (Rauterberg, 1999). These studies show the improvement in the interaction when we increase the number of communication channels between the man and the machine. The problem with sound cues is that need the conscious effort to be recognized. Hunter, Katz, and Davis (2003) show another example of the importance of increasing the communication channels in the interaction between man and machine. In this study, they show how the multiple sensory stimuli contribute to the conscious awareness of the body, and how it can be used to change the abnormal body awareness that occurs after limb amputation. This effect is also known as cortical reorganization, where the brain after losing the stimuli from the amputated limb, due to the cross-modality, received input signals from the adjacent neurons, resulting in what is called "phantom limb."

With the proper stimuli combination, the body image can be changed, allowing for the human body to adapt to external devices. In order to test this hypothesis, we proposed the used of an adaptable, EMG-controlled prosthetic hand with tactile feedback using electrical stimulation. Lotze (1999; Lotze, Grodd, Birbaumer, Erb, Huse, & Flor, 1999) and Maruishi et al. (2004) showed the positive effects in the use of myoelectrical prosthesis to revert cortical reorganization. Giraux, Sirigu, Schneider, and Dubernard (2001) also show the possibility to revert cortical reorganization in the brain. This is possible, due to the combination of the intentionality from the amputee to move the absent limb, which results in muscular movement, and the visual feedback provided by the myoelectric device. We think that if we include even more sensory channels—in this case, tactile feedback—the adaptation to the prosthetic device can be enhanced, resulting in subconscious control of the device.

BACKGROUND

The development of myoelectric prosthetic hands has advanced incredibly since their introduction in 1960 (Katoh, Yokoi, & Arai, 2006). The myoelectrically controlled devices are preferred over the body pow-

ered ones, because the latest are restricted in their area of application, and the cosmetic ones do not provide any advantage to their user on his activities (Stein & Walley, 1983). Still, one mayor drawback of the EMG controlled devices is the minimal or nonexistent biofeedback—that is, information on the status of the prosthetic device, hand, or leg to the body. Our body is a multimodal system that uses several channels to obtain the current status of our bodies; if one channel fails, there are still others that help to provide the missing data. The user of a prosthetic hand needs to overcome the lack of tactile and proprioceptive data with visual feedback, which causes to fatigue faster because of the increment of conscious effort to control the hand (Weir, Childress, & Licameli, 1998). These mechanisms need the implementation of a feedback source that enables the user to develop extended physiological proprioception (Simpson, 1974). We find some examples in the application of “tactile feedback” using vibration (Rios Poveda, 2002) or electrical stimulation (Nozomu, Takashi, & Yasunobu, 1998; Shimojo, Suzuki, Namiki, Saito, Kunimoto, Makino, Ogawa, Ishikawa, & Mabu-chi k, 2003; Yoshida, Sasaki, & Nakayama, 2002). On the other hand, in the man-machine interfaces studies, we find haptic interfaces that provide tactile feedback. Their direct application to prosthetics is limited, due to the fact that all these researches focus on the sensory substitution using the finger tips (Samuel, 2002). Regrettably, those cannot be applied to prosthetic devices where the user presents partial or complete loss of the arm, which are our interest in this study. Therefore, we need to find a different way to provide with sensorial information to the human body. It is been demonstrated that the brain works with correlative information; therefore, when provided with simultaneous stimuli, the brain can associate the stimuli into a unique event (Carrie Armel & Ramachandran, 2003). Using this knowledge, we can force the brain into producing new sensations, provided that the stimulus is simultaneous, so the person using a prosthetic hand can have sensorial feedback besides the visual.

INTO THE CROSS-MODAL INTERACTION

The prosthetic system in our laboratory uses an adaptive discrimination method to classify the human intention using the electromyography (EMG) signal from three

sensors placed on the forearm of the user (Katoh et al., 2006; Nishikawa, Yu, Maruishi, Watanabe, Yokoi, & Kakazu, 2000). In order to provide the tactile sensation, we use in this study transcutaneous electrical stimulation. This method does not interact directly with the nerves, is easier to develop, does not require complex surgical interventions, and the rejection from the body is minima, also it can be applied during the scanning inside the functional magnetic resonation imaging chamber.

The use of visual or auditory feedback only is not reliable enough to provide with sensory feedback for proper subconscious control of the artificial limb. In order to solve this drawback, we need to provide with tactile or proprioceptive information—that is, a way for the body to interact directly with the environment. In previous studies, the electrical stimulation has been used to provide an on-off signal as sensory feedback, with promising results, but lack of more objective system evaluation. The participants to these experiments shows an improvement in their use of the prosthetic device, and even voice the opinion of “feeling” the robot hand more as part of their bodies. Although these studies present promising results, we still need to understand more the relationship between the man and the machine for better future applications.

We transmit the tactile information from the prosthetic hand to the body using a transcutaneous electrical stimulator developed in our laboratory that works as a transducer between the forces applied over the pressure sensors installed on the finger tips and the palm of the robot hand and the biphasic square signal applied to the body (Hernandez Arieta, Yu, & Yokoi, 2004).

Experimental Setting

Using the prosthetic system described above, we performed a series of experiments to measure the activation on the somatosensory region S1 of the brain to see the effects of the electrical stimulation as tactile feedback for the myoelectric prosthetic hand. In order to measure the effects, we first evaluated the response of the body to the stimulation alone as an unrelated event. Following, we measure the brain activation to the electrical stimulation when is applied as a result of the robot hand touching and object, working along with the intention from the body and the visual feedback.

As stated above, we regulate the stimulation by changing the duty rate of the signal, thus any refer-

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