Restoring touch through intracortical microstimulation

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Abstract—Our ability to manipulate objects dexterously relies fundamentally on sensory signals from the hand. Restoring motor function with an upper-limb neuroprosthesis thus requires that somatosensory feedback be provided to the tetraplegic patient or amputee. With this in mind, we review the results of a series of experiments investigating the sensory consequences of electrically stimulating neurons in somatosensory cortex. We demonstrate that sensory information that is critical for object manipulation—information about contact location, contact force, and contact timing—can be conveyed intuitively through intracortical microstimulation.

I. INTRODUCTION

Touch is critical for effective object manipulation, but current prosthetic upper limbs make no provision for delivering tactile feedback to the user. For individuals who require use of prosthetic limbs, this lack of feedback transforms a mundane task into one that requires extreme concentration and effort. Although vibrotactile motors and sensory substitution devices can be used to convey gross sensations, a direct neural interface is required to provide detailed and intuitive sensory feedback. In light of this, the new generation of neuroprostheses will enable electrical stimulation of sensory neurons.

One approach to restoring touch for amputees and tetraplegic patients equipped with a prosthetic arm consists of activating neurons in somatosensory cortex through electrical stimulation. The hope is that we can develop regimes of stimulation that convey sensory information intuitively so that these patients can achieve the same dexterity with the prosthetic limb that intact patients enjoy with their native limbs. Specifically, we hope to convert patterns of activation on the sensors of the prosthetic arm into patterns of activation in the brain that mimic, to the extent possible, those observed in the brain of intact individuals.

II. APPROACH

To develop these sensory encoding algorithms, we trained non-human primates to perform tasks in which they discriminated the force or location of indentations delivered to the palmar surface of the hand. Once the animals were trained, we implanted multielectrode arrays within the hand representations of areas 3b and 1. We then had the animals perform perceptual discrimination tasks, replacing a subset of stimuli with intracortical microstimulation (ICMS) applied to areas 3b and 1 of primary somatosensory cortex.

III. RESULTS

First, we show that the sensory magnitude of ICMS trains increases with amplitude and characterize the relationship between the growth of the sensory magnitude of ICMS trains to that of mechanical indentations. This function can then be used to convert the output of force sensors on the prosthesis into tactile sensations of appropriate sensory magnitude. We demonstrate our sensory encoding algorithm by showing that an animal can perform a force discrimination task equally well whether the tactile stimuli are applied to its finger or to a prosthetic finger. We also examine the effects of various ICMS parameters (pulse frequency, pulse phase duration, number of stimulated electrodes, stimulation synchrony, etc.) on sensitivity to stimulation. Second, we show that ICMS through individual electrodes elicits a localized tactile percept, a perceptual phenomenon that can be used to convey information about contact location. Third, we propose that the timing of contact events can be signaled through phasic ICMS at the onset and offset of object contact that mimics the ubiquitous on and off responses observed in S1 to complement slowly-varying force-related feedback. We anticipate that the proposed biomimetic feedback will considerably increase the dexterity and embodiment of upper-limb neuroprostheses and will constitute an important step in restoring touch to individuals who have lost it.

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