Development of an afferent neural interface designed to mimic natural proprioception

Lee Miller

We have developed an efferent brain machine interface (BMI) that allows monkey subjects to grasp objects despite a peripheral nerve block causing complete paralysis of the flexor muscles below the elbow. We anticipate that such a system might ultimately provide spinal cord injured patients with control of arm and hand movements through normal cognitive processes, and greatly enhance their independence and well-being. However, a major issue to be addressed in the development of more effective BMIs is the need to provide somatosensory feedback. Proprioception is essential for normal movement. Its loss largely eliminates the ability to plan movement dynamics or to make rapid corrections to limb perturbations. Existing BMIs rely exclusively on visual feedback, which may account in part, for their relatively limited performance. The representation of proprioceptive signals within the cortex has been far less studied than has touch, and while some progress has been made toward restoring touch through intracortical microstimulation of somatosensory cortex (S1), there has been as yet, very little corresponding success for proprioception.

We have completed a series of multi-electrode recording experiments designed to study the way limb movements are encoded by neurons in area 2 of S1. These neurons signal limb movement, whether generated actively by the monkey or as the result of a passive limb displacement. The discharge of most neurons is tuned to the direction of hand movement, and can be summarized reasonably accurately by a single “preferred direction” (PD). Much as in motor cortex, there is a roughly sinusoidal modulation of firing rate for movement directions away from this PD. Many of these neurons are also influenced by external forces that oppose movement. Furthermore, there is evidence of an efference copy component of S1 activity that precedes the onset of active movement, and is well aligned spatially with the later, afferent component. The representation of movement direction by populations of neurons is linearly separable, as is the brain state representing active and passive movements. The latter is likely due to the interaction of kinematic and force representation.

We have now begun a new series of experiments, the goal of which is to use our knowledge of the representation of limb state by S1, to evoke a sensation of directed limb movement by stimulating electrodes within S1 to recreate natural patterns of cortical activity. We have shown that stimulation of multiple electrodes, each with subliminal currents, yields an effect greater than the theoretical linear combination of the individual electrodes. By stimulating small groups of electrodes with similar PDs, we have succeeded in inducing perceptions of limb motion that appear to be similar to those caused by actual movement. We are working to develop a neuroprosthesis based on continuously varying stimulation of many electrodes, in order to restore a sense of limb state to patients with high-level spinal cord injury.