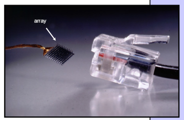
The BrainGate™ Pilot Trial: Building and Testing a Novel Direct Neural Output for Patients with Severe Motor Impairment

Mijail Serruya, MD, PhD[1]; Abraham Caplan[1], Maryam Saleh[1], Daniel Morris[3], John Donoghue, PhD[1,2]

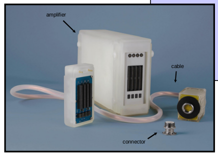
[1]Cyberkinetics Neurotechnology Systems, Foxboro, MA, [2]Brown University, [3]Stanford University.

BrainGate Neural Interface System

The BrainGate System is an investigational medical device which is intended to decode neural signals, normally associated with movement commands, in order to allow a disabled individual to control a computer interface.



BrainGate Implant



BrainGate Cable Assembly

BrainGate Cart

Study Overview

An open-label, 12-month, longitudinal, feasibility clinical study of the BrainGate™ Neural Interface System (Cyberkinetics, Inc.) was initiated, under Food and Drug Administration (FDA) Investigational Device Exemption (IDE) and Institutional Review Board (IRB) approvals, in May 2004. The study is designed to gather preliminary safety and efficacy data on the BrainGate™ System when used by people unable to use their arms or hands in a useful manner (quadriplegia or tetraplegia) to control a computer with thoughts.

Initial Study Participant

As of September 2004, one person has been enrolled, implanted and is actively participating in the study at the Sargent Rehabilitation Center study site. Patient 001 is a 25 year-old ventilator-dependent male who is unable to move either upper extremity due to a C4 spinal cord injury suffered in July 2001.

Surgical Implantation

In June 2004, after obtaining informed consent, a surgical procedure consisting of an incision and 3 cm diameter craniotomy located above the right primary motor cortex was conducted under general anesthesia. A 4x4 mm, 100 channel sensor was implanted on the surface of the cortex, in the precentral gyrus immediately posterior to the superior frontal sulcus,[1] as identified on presurgical MRI. This area of the motor cortex is primarily responsible for voluntary motor control of the contralateral hand and arm [2],[3],[4]. The surgery lasted approximately 3 hours and was uneventful. The patient was discharged to his primary residence 3 days post-surgery where he recovered for three weeks prior to initiation of device testing.

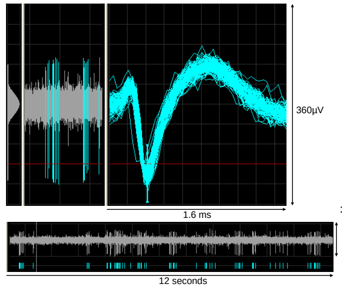
[1] Yousry TA, Schmid UD, et. al., *Localization of the motor hand area to a knob on the precentral gyrus*, Brain (1997) 120, 141-157.
[2] Seitz RJ et. al., *Plasticity of the Human Motor Cortex, Brain Plasticity*, Advances in Neurology, 73:321-333.
[3] Kleinschmidt A, et. al., *Somatotopy in the Human Motor Cortex Hand Area. A High-Resolution Functional MRI Study*., European Journal of Neuroscience, 1997, 9:2178-2186.
[4] Sanes JN and Donoghue JP, *Plasticity and Primary Motor Cortex*, Annu. Rev. Neurosci, 2000, 23:393-415.

Case Report
Preliminary Observations of Device Efficacy

Neural Activity in MI of a Person with Quadriplegia

We identified neural waveforms in recordings from 15 sessions run from 8/27/2004 - 10/12/2004. Recordings were similar to those obtained in prior studies in monkeys [5],[6],[7].

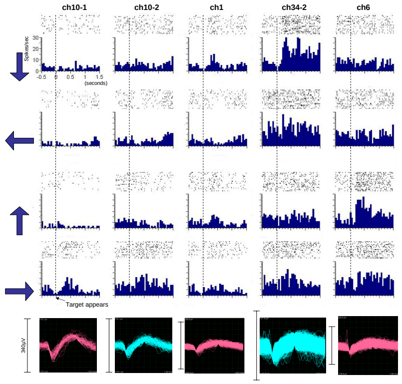
[5] Paninski L, Fellows MR, Hatsopoulos NG, Donoghue JP. *Spatiotemporal tuning of motor cortical neurons for hand position and velocity*. J Neurophysiol. 2004 Jan;91(1):515-32.
[6] Serruya M, Hatsopoulos N, Fellows M, Paninski L, Donoghue J. *Robustness of neuroprosthetic decoding algorithms*. Biol Cybern. 2003 Mar;88(3):219-28.
[7] Serruya MD, Hatsopoulos NG, Paninski L, Fellows MR, Donoghue JP. *Instant neural control of a movement signal.* Nature. 2002 Mar 14:416(6877):141-2.



Unit recorded on 9/28/2004.
Sampling rate 30kS/sec.

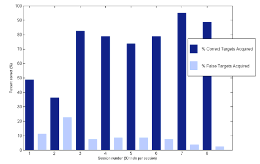
Spike Rates Tuned to Direction of Imagined Movement

Perievent spike rasters and spike rate histograms for Center Out task in a closed loop experiment.



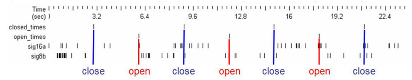
50ms bin size
Closed loop experiment, Data collected on 9/20/2004 12:28pm

Performance Results on Closed-Loop Center-Out Task Across Sessions (8/27/04-9/20/04)

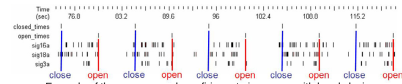


In 7/8 sessions, the patient's neural cursor selected significantly more intended targets than false positive/unintended targets. Significance calculated using one-sided z-test at alpha 0.01.

Spike Rates Tuned to Imagined Hand Opening and Closing



Example of two neurons with opposite tuning properties upon imagined hand opening and closing.
Data recorded on 7/26/2004, 3:32pm



Example of three neurons whose firing rate increases with hand closing
Data recorded on 7/26/2004, 3:32pm

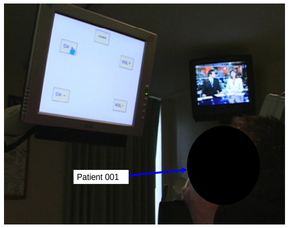
Closed-Loop Prosthetic Hand Control

Hand close

Hand open

This robotic hand was driven to open and close by signals derived from MI during imaged actions.
Prosthetic Hand provided by Liberating Technologies Inc. Holliston, MA.

Closed-Loop TV Control using Neural Interface



The patient has used his neural cursor for environmental control. In combination with infrared technology[1], he turned his television on/off, changed channels and adjusted volume (see figure). The patient was able to hold a discussion with a nearby attendant and control the television.

1 Productby Innotech Systems

Preliminary Observations of Device Safety

There were no post-surgical complications which is supported by the continued ability to record neural activity. No adverse events or other study-related complications have been reported. Safety assessments include daily checks of connector, weekly nurse visits, and monthly physician exams including neurological and mental status exams.

Connector and Surrounding Skin 3 months Post-Surgery

Summary of Initial Observations

- Motor cortex neurons of humans remain active years after spinal cord injury
- Modulation of neural activity is possible in MI in the absence of limb movement
- Using the BrainGate system, the initial participant has immediately gained control of a computer interface, with no special training, and can operate the cursor while performing other voluntary motor tasks.
- The control signal provided has the potential for 3 dimensions of control from the signals obtained in MI and this signal has been used to control a range of potentially useful devices including computers, robots, and prosthetic limbs.

These observations suggest that the system should be useful in any disabled patient with an intact motor cortex.
This initial case report suggests that the BrainGate System, which uses a tested, validated sensor implant which is removable and replaceable, may offer patients with severe disability a universal operating system with which they can control devices in the environment around them.

Future Goals

- enable individuals with paralysis to use e-mail and telephones to communicate
- provide access to environmental controls, such as bed positioning, television, lights, and thermostats through a desktop application
- improve mobility by interfacing with powered wheelchairs
- provide patients with the ability to adjust their body position to avoid pressure sores
- facilitate control over all of these actions and a range of other software and external device applications through a single, universal integrated interface.

The BrainGate feasibility trial is being expanded to other clinical sites. Product development is being focused on creation of a streamlined operating system and on the design and testing of a totally implantable sensor system.

CAUTION: Investigational device. Limited by Federal (USA) law to investigational use – only being studied in the USA.