National Institute for Physiological Sciences(NIPS)

Mini- Workshop

"Neural Decoding and Brain-Computer Interfaces"

Date; July 1 (Mon), 2013
Place; Conference Room at NIPS 1F

Organizers; Tadashi Isa (NIPS), Yukio Nishimura (NIPS), Hidenori Watanabe (NIPS), Tatsuya Umeda (Yokohama City Univ.)

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Program

10:00-10:10 **Opening remark**
Tadashi Isa (NIPS)

Session 1 "Motor Decoding"

10:10-10:40 **Sparse Bayesian inference methods for decoding 3D reach and grasp kinematics and joint angles with primary motor cortical ensembles**
Kazutaka Takahashi, University of Chicago, USA

10:40-11:10 **A novel tool for understanding motor and cognitive functions**
Naotaka Fujii, RIKEN BSI, Wako, Japan

11:10-11:20 **Coffee break**

11:20-11:50 **Brain Machine Interface based on musculo-skeletal model**
Yasuharu Koike, Tokyo Institute of Technology, Japan

11:50-13:00 **Discussion with Lunch**

Session 2 "Somatosensory decoding"

13:00-13:30 **Sensory feedback interfaces in the dorsal root ganglia**
Douglas Weber, University of Pittsburgh, USA

13:30-14:00 **Encoding the forelimb joint kinematics by the dorsal root ganglion neurons in monkeys**
Tatsuya Umeda, Yokohama City University, Japan

14:00-14:30 **Sensory Responses in the Motor Cortex and their implications for Brain-Machine Interfaces**
Aaron Suminski, University of Chicago, USA

14:30-14:50 **Coffee break**

Session 3 "Closed loop BCI"

14:50-15:20 **Restoring Volitional Control via Artificial neural connection**
Yukio Nishimura, NIPS, Japan

15:20-15:50 **Physiological mechanism of deep brain stimulation**
Atsushi Nambu, NIPS, Japan

15:50-16:10 **Coffee break**

Session 4 "Clinical application"

16:10-16:40 **Efficacy of Brain-Machine-Interfaces in chronic stroke rehabilitation**
Ander Ramos-Murguialday, University of Tübingen, Germany

16:40-17:10 **Brain machine interfaces using human electrocorticograms**
Masayuki Hirata, Osaka University, Japan

17:10-17:40 **Decoding sensorimotor cortex excitability using scalp electroencephalogram in humans**
Junichi Ushiba, Keio University, Japan

17:40-18:00 **Closing remark**
Yukio Nishimura (NIPS)

18:00-20:00 **Discussion with Dinner**

Sparse Bayesian inference methods for decoding 3D reach and grasp kinematics and joint angles with primary motor cortical ensembles

Kazutaka Takahashi
University of Chicago

Sparse Bayesian inference methods are applied to decode three-dimensional (3D) reach to grasp movement based on recordings of primary motor cortical (M1) ensembles from rhesus macaque. For three linear or nonlinear models tested, variational Bayes (VB) inference in combination with automatic relevance determination (ARD) is used for variable selection to avoid overfitting. The sparse Bayesian linear regression model achieved the overall best performance across objects and target locations. We assessed the sensitivity of M1 units in decoding and evaluated the proximal and distal representations of joint angles in population decoding. Our results suggest that the M1 ensembles recorded from the precentral gyrus area carry more proximal than distal information.

Novel tools for understanding motor and cognitive functions

Naotaka Fujii
RIKEN BSI, Wako, Japan

Electrocorticogram (ECoG) captures neural population activity. ECoG array implanted chronically can provide stable signal over years so that it is suitable for extracting motor intention in BCI development. We succeeded to decode 3-dimensional trajectories of arm motion in monkeys from ECoG signal and showed stable decoding performance without recalibrating the decoder for more than a year. ECoG was also thought to be useful in describing neural functions in terms of network connectivity because of higher temporal resolution and wider area coverage. To reveal the network functions, we applied data mining analysis of inter-regional connectivity of ECoG signal and found dynamical modulation of meta-module structures in primate during social cognitive tasks. ECoG recording and data mining approach are powerful tools for extracting latent network structures in motor and cognitive processing.

Brain Machine Interface based on musculo-skeletal model

Yasuharu Koike
Tokyo Institute of Technology

Non-invasive measurement method, such as EEG, fMRI or NIRS, has been used for Brain Computer Interface. EEG has nice temporal resolution, and it is used for BCI, such as amplitudes of different frequency bands; imagining movement of different parts of the body; slow cortical potentials and gamma band rhythms. Although EEG-based BMIs are generally portable and easy to use in practical application, few studies have tried to reconstruct kinematic information in time series.
Recently, Electrocorticography (ECoG) is an alternative approach to less invasive BMIs. In this talk, we introduce reconstruction of muscle activity time series using EEG or ECoG recordings and controlling wrist robot by reconstructed muscle activitiy signals.

Sensory feedback interfaces in the dorsal root ganglia

Douglas J. Weber
University of Pittsburgh

Over the last 2 decades, advances in microsystems engineering have enabled the development of neural prostheses that interface directly with neurons in the brain, spinal cord and peripheral nerves. These so-called "neural interfaces" serve as bi-directional communication channels, allowing information to be read-out by decoding signals recorded from neurons or written-in via patterned electrical stimulation of neurons. We are exploiting these technologies for two purposes: 1) to advance our understanding of how the nervous system senses and controls limb motion, and 2) to develop advanced prosthetic devices that interface directly with the nervous system for control. My talk will focus on research in my lab that is aimed at understanding how somatosensory neurons encode information about touch, force, limb position and motion. By recording and decoding the output of these neurons, we can provide limb-state feedback for controlling functional electrical stimulation (FES) systems to reanimate paralyzed limbs. Conversely, patterned stimulation of somatosensory neurons can be used to provide amputees with touch and proprioception for prosthetic limbs. Such feedback will be essential for users of the dexterous prosthetic limbs developed recently by the DARPA-funded Revolutionizing Prosthetics Program. Ultimately, these bidirectional neural interfaces will make the prosthesis feel and function like a native limb.

Encoding the forelimb joint kinematics by the dorsal root ganglion neurons in monkeys

Tatsuya Umeda
Yokohama City University

The activity of a single peripheral afferent is correlated with joint kinematics of the extremity. In this study, we investigated whether population of dorsal root ganglion (DRG) neurons could encode forelimb joint kinematics of behaving monkeys and send the information to the primary sensory cortex. Two multi-electrode arrays (each array containing 48 channels) were chronically implanted in the DRGs at the level of C7 and C8 spinal segments of two monkeys. Neuronal responses to reaching and grasping movements were simultaneously recorded and 3-D trajectories of hand/arm movements were tracked by using an optical motion capture system. 14 and 12-16 neurons were recorded in monkey 1 and 2, respectively. The DRG ensemble included muscle spindle, cutaneous and joint receptors. Using a sparse linear regression analysis, forelimb joint kinematics could be reconstructed from the temporal firing pattern of a subset of DRG ensembles (R=0.8 for elbow joint angle, 0.6 for elbow joint angle velocity). Furthermore, we recorded electrocorticogram (ECoG) signals from the primary sensory cortex of one monkey, concurrently with DRG recording. The sparse regression analysis showed that joint kinematics information encoded by the DRG population activity potentially transferred to the primary sensory cortex.

Sensory Responses in the Motor Cortex and their implications for Brain-Machine Interfaces

Aaron Suminski
Department of Organismal Biology & Anatomy, University of Chicago

The brain typically utilizes a rich supply of feedback from multiple sensory modalities to control movement. Brain-machine interfaces (BMI) offer the promise of recovered functionality to individuals suffering from severe motor dysfunction by recording movement commands directly from the patient's primary motor cortex (MI) and rerouting them to an external device, such as a computer cursor or a prosthetic arm. Most current BMI implantations depend solely on visual feedback for closed-loop control; thereby neglecting other potentially beneficial feedback modalities. In this talk, I will describe recent experimental evidence demonstrating strong visual and somatosensory influences on the activity of MI neurons and discuss the usefulness of these sensory-like responses in brain-machine interface training and control. Furthermore, I will show that the control of a cursor driven by the activity of neural ensembles in MI is significantly improved when visual and somatosensory information about the cursor position is available to the BMI user. These findings demonstrate two important facts. First, that the term 'motor' cortex conceals the unmistakable sensory-like responses of neurons in the precentral gyrus. Second, they demonstrate the need for augmenting cortically-controlled BMIs with multiple forms of natural or surrogate sensory feedback.

Restoring Volitional Control via Artificial neural connection

Yukio Nishimura
Department of Developmental Physiology, National Institutes for Physiological Sciences, Okazaki, Japan

Functional loss of limb control in individuals with spinal cord injury or stroke is attributed to interruption of descending pathways to spinal network. Although neural circuits locate below and above the lesion remain most of their function. I will show an artificial neuronal connection that bridges supra-spinal system and spinal network beyond the lesion site restores lost function. The artificial connection was produced by a brain-computer interface that can detect the neural activity and converted in real-time to activity-contingent electrical stimuli delivered to nervous system. A promising application is to bridge impaired biological connections, as demonstrated for cortically controlled electrical stimulation to a spinal site. Our results document that monkey utilized artificial connection instead of physiological connections. Recent work has shown that volitionally controlled walking in individuals with spinal cord lesion can be restored by EMG-controlled magnetic stimulation to lumbar vertebra. A second application of the artificial connection is to produce Hebbian synaptic plasticity through cortically spike-triggered stimulation to a spinal related site, which can strengthen physiological mono-synaptic connections between the motor cortex and spinal cord. These results suggest that artificial neural connections can compensate for interrupted descending pathways. Furthermore, these paradigms have numerous potential applications, depending on the input signals, the computed transform and the output targets.

Physiological mechanism of deep brain stimulation

Atsushi Nambu
Division of System Neurophysiology, National Institute for Physiological Sciences and Department of Physiological Sciences, Graduate University for Advanced Studies, Myodaiji, Okazaki 444-8585, Japan

To elucidate the mechanism of deep brain stimulation (DBS) targeting the internal segment of the globus pallidus (GPi), neuronal activity of the GPi and the external segment of the globus pallidus (GPe) was examined during local electrical microstimulation in normal awake monkeys. Single pulse stimulation of the GPi evoked brief inhibition in neighboring GPi neurons, which was mediated by gamma-aminobutyric acid type A (GABA-A) receptors. High-frequency stimulation of the GPi completely inhibited spontaneous firings of GPi neurons by activation of GABA-A and gamma-aminobutyric acid type B receptors. Local single pulse stimulation directly excited some GPi neurons. Such directly evoked responses were also inhibited by high-frequency stimulation through GABA-A receptors. In contrast to the GPi, single pulse and high-frequency stimulation of the GPe induced complex responses composed of GABAergic inhibition and glutamatergic excitation in neighboring GPe neurons. Cortically evoked triphasic responses of GPi neurons were completely inhibited during high-frequency GPi stimulation. These findings suggest that GPi-DBS dissociates inputs and outputs in the GPi by intense GABAergic inhibition and disrupts information flow through the GPi.
We also tried closed-loop DBS targeting the subthalamic nucleus (STN). Stimulation was generated based on the activity of the primary motor cortex, and was applied to the STN. This procedure successfully ameliorated parkinsonian symptoms in the 1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine (MPTP) induced primate model.

Efficacy of Brain-Machine-Interfaces in chronic stroke rehabilitation

Ander Ramos-Murguialday
University of Tübingen, Germany

Recently, a controlled double blind and randomized study proved the efficacy of using Brain-Machine-Interfaces (BMIs) to restore motor function in chronic paralysed stroke patients. After a strict inclusion criteria, 32 patients were selected to participate in the study and were divided in 2 groups depending on the feedback they obtained when using the BMI. One group received contingent feedback (i.e. the brain oscillations controlled the movement of an orthotic device) and the second one received sham feedback (i.e. movements of the orthosis were randomized and were not linked to brain activity). Both groups received identical behavioral physiotherapy and were controlled for placebo effects. Only the group receiving contingent feedback presented significant gain in motor scores (Fugl-Meyer scores), significant increase in BMI performance, significant lateralization of BOLD response towards perilesional ares and significant increase in EMG activity on the apralyzed muscles. Neurophysiological correlates of thee findings will be discussed.

Brain machine interfaces using human electrocorticograms

Masayuki Hirata
Osaka University, Japan

Brain machine interfaces (BMIs) using electrocorticograms (ECoGs) are a promising candidate of the clinical application of high performance BMIs. We demonstrated that gamma power, especially that within the central sulcus, is an excellent feature to decode movement onset and type, independent of the severity of motor dysfunction. Using the decoding features, real time control of a robotic arm was successfully performed by the patients that subdural grid electrodes were placed to treat intractable epilepsy or intractable pain. Most recently we started a clinical trial in severe ALS patients using a wired BMI system involving the temporary placement of newly-developed personlized electrodes.
A fully implantable wireless system is indispensable for clinical application of ECoG BMIs to reduce infection risk. We are now developing the implantable system, which includes a 128-ch integrated amplifier circuit, 3D personalized high density electrodes, a wireless data transfer system and a wireless battery charger. We aim to put the implantable system to clinical use as soon as possible.

Decoding sensorimotor cortex excitability using scalp electroencephalogram in humans

Junichi Ushiba, Ph.D.
Department of Biosciences and Informatics, Faculty of Science and Technology, Keio University, Japan.

Brain-Computer Interface (BCI) is a technology to bypass motor output neural pathways by directly translating motor-related brain signals into commands for control of motor-driven orthosis or neuromuscular electrical stimulation. Since extrinsic feedback is expected to promote motor learning, approaches using BCI might facilitate neural plasticity and restore lost function after stroke (Shindo et al. J Rehabil Med 2011). Such rehabilitation-oriented BCI exploits electroencephalogram mu and beta oscillations recorded over the sensorimotor areas, and their event-related desynchronization (ERD) following motor attempting is used as a feature that represent increased sensorimotor cortex excitability. However, it remains unclear whether the sensorimotor cortex excitability is actually correlated with ERD. Thus, we assessed the association of ERD with primary motor cortex (M1) excitability during motor imagery of right wrist movement (Takemi et al., J Neurophysiol 2013). M1 excitability was tested by motor evoked potentials (MEPs), short-interval intracortical inhibition (SICI) and intracortical facilitation (ICF) using transcranial magnetic stimulation. Data showed that the large ERD during wrist motor imagery was associated with significantly increased MEP amplitudes and reduced SICI, but no significant changes in ICF. From these results, we concluded that ERD magnitude during wrist motor imagery represents M1 excitability. The recent clinical trial with a single case A-B-A-B design to test the importance of BCI closed-loop fashion will be also introduced in this talk.
This study was conduced under collaboration with Department of Rehabilitation Medicine, Keio University School of Medicine (Professor Meigen Liu), and was supported by the Strategic Research Program for Brain Sciences (SRPBS) from the Ministry of Education, Culture, Sports, Science and Technology Japan.


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