Brain Freedom from Body : Neuronal Activity during Goal-Approach by Behavior and Goal-Operation by BMI in the Rat

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Abstract: The present study focuses on brain-body interaction and reports how neuronal activity is involved in and limited by body movements. The core method is a high-performance brain–machine interface (BMI) system, which uses long-term stable recording of multiple neuronal activity and real-time spike-sorting with combination of independent component analysis and newly developed multi-electrodes. The system detects in real time precise firing frequency and synchrony of neighboring individual neurons of behaving animals. The tasks we employed are goal-approach and goal-operation tasks for rats. In the former task, the rats are required to approach a wall (goal) to get reward. In the latter task, they have to operate the wall by their neuronal activity with the BMI and draw it to get reward. We present here that firings of the hippocampal neuronal populations were remarkably enhanced when they were working to operate the external goal. This result suggests that the hippocampal neuronal activity can directly operate devices in external environments and it can be highly active when the brain is released from restraint by body movements.

Keywords: Brain-body interaction, Brain-machine interface, Hippocampus, Neuron.

1. INTRODUCTION

Although great progress has been made in analyses of electrophysiological data from behaving animals, it still remains unclear how really dynamic activity of individual neurons and their functional connectivity are in the working brains. One of the main reasons for that lack of clarity might be that physical limitations of body movements generating behaviors often restrain the freedom of neuronal dynamics. Indeed, as a great psychologist J. J. Gibson has indicated [1], coding of external information is dependent on and modulated by behaviors operating external environments. Neuronal activity to code external valid information, therefore, must be based on brain-body interaction for behavior and affected and restrained by body movements. In this study, we specifically focuses on the interaction between neural activity and body movements. We investigate real neuronal dynamics underlying recognition of and intention to a goal by comparing neuronal activity when the animals approach the goal by behavior with their body movements and when they operate and draw the goal by their neuronal activity with a brain-machine interface (BMI).

We have developed a high-performance BMI system to detect actual dynamics of neuronal populations of the working brains. Using the BMI system, neuronal codes, i.e., firing frequency and synchrony of neurons, in the brain of the behaving animal can directly control external devices in real time instead of the animal's behavior. The keys to constructing the BMI system are recording multineuronal activities from behaving animals for long periods, detecting firing frequencies of individual neurons and firing synchrony among many neighboring neurons, making neuronal codes to control external devices, and showing dynamic and flexible changes of the neuronal codes in the working brain.

2. METHODS

2.1 Animals and apparatus

Male Wistar albino rats were used. The rats were trained in an operant chamber of 22(H) × 49(W) × 46(D) cm. One wall of the chamber has illuminated sensor holes to detect the nose-poke behavior of rats. A food dispenser behind the wall delivered 25-mg food pellets to a magazine located at the center of the wall. All experimental procedures accorded with NIH and Kyoto University guidelines for Animal Research.

2.2 Long-term recording of multineuronal activity

Approximately one week after surgery for electrode implantation, the multi-electrodes (dodecatrodes) [2] were lowered into the brain using the microdrive [3]. The activity detected from the dodecatrodes was judged to be multineuronal if its peak amplitude was more than two times greater than the noise, i.e. the signal-to-noise ratio was greater than 2.0. When multineuronal activity was detected, the rat was returned to its home cage. If activity remained present after one or more days, then the data were judged to be stable and suitable for long-term recording [3].

2.3 Real-time spike sorting with ICA

We have developed a system for real-time automatic sorting of multineuronal activity with independent component analysis (ICA) and call it RASICA [2]. The ICA used is a powerful method of solving both the spike-overlapping and nonstationary waveform problems [4,5] and can compensate the electrode drift to render the spike-sorting stable with very little computational expense.

2.4 Neuronal codes to control tasks and devices

With the RASICA, we select any of the recorded individual neurons to detect specific patterns of frequency or synchrony of their firings. The detected patterns of firing frequency and synchrony are respectively defined as *frequency code* and *synchrony code*. When the system detects these neuronal codes, it transmits TTL signals to a computer that controls the tasks and the reward dispenser.

2.5 Tasks by behavior and neuronal codes

We have constructed goal-approach and goal-operation tasks, conducted by behavior with body movements and neuronal codes with BMI respectively. Fig.1 is a rat performing both of the tasks. Fig.2 is a schematic drawing of the goal-operation task.

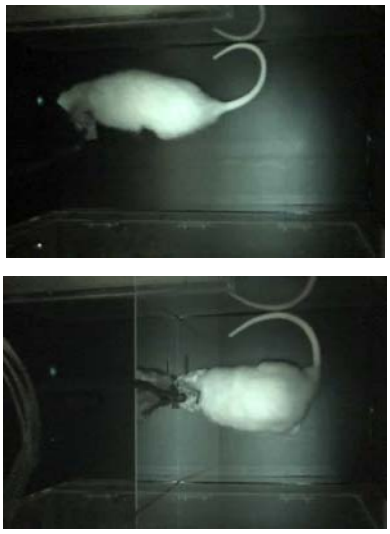

Fig. 1 Upper photo: A rat performing the goal-approach task. It moves from the right-side wall to the left-side one and conduct a nose-poke to the illuminated hole to get reward of pellets. Lower photo: The same rat performing the goal-operation task with BMI. The goal (the hole on the left wall) is being operated and drawn to the rat by neuronal codes.

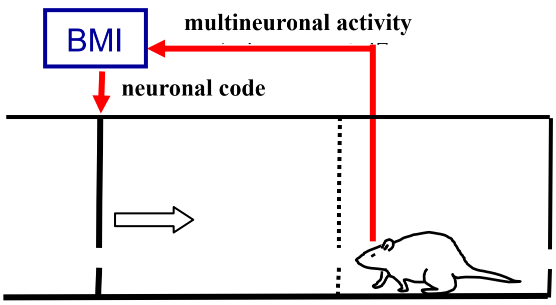

Fig. 2 Schematic drawing of the goal-operation task. The goal (the hole on the left wall) is being operated and drawn to the rat by neuronal codes with BMI.

3. RESULTS AND DISCUSSION

We analyzed activity of hippocampal CA1 neurons when the rat was performing the goal-approach task and the goal-operation task. In the former task, neuronal activity was just recorded during movements to the goal. In the latter task, the frequency code from the hippocampal neurons drew the left wall to the rat. Fig. 3 is an example of data showing changes of firing frequencies of the neurons during the 2 days of training of the tasks. The result shows that hippocampal neuronal activity can be used to control external devices and be remarkably enhanced when the animals use not their body movements but their neuronal firing to reach goals.

The present study suggests that neuronal activity can be highly active when the brain is released from restraint by body movements. This fact possibly contributes to development of high-performance brain-machine interfaces in the near future.

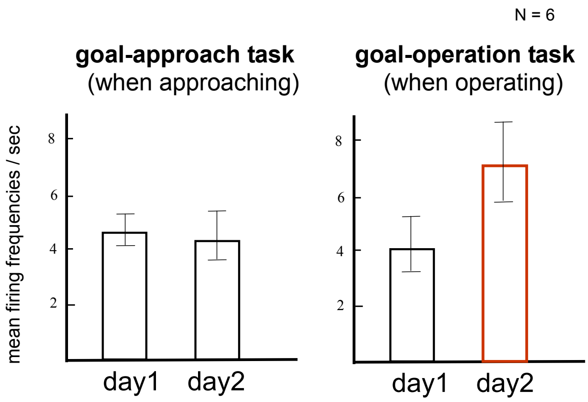

Fig. 3 Mean firing frequencies of the hippocampal CA1 neurons during 2 days of training of the goal-approach and goal-operation task.

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