1 Introduction: BCI and NIRS

A non-invasive brain-computer Interface (BCI) offers a direct interaction between the human brain and an external device without any surgical risk. Currently, electroencephalography (EEG) has been the most studied non-invasive interface because of its portability and low set-up cost. However, susceptibility to electromagnetic noise has been a barrier to promoting practical non-invasive BCIs in some cases.

We focused on optical measurements of the cerebral cortex using near-infrared spectroscopy (NIRS). NIRS can non-invasively monitor physical changes in the concentrations of oxygenated and deoxygenated hemoglobin. Optical topography (OT) was developed as a noninvasive imaging modality for functional mapping based on a NIRS measurement at multiple positions. It functions as a practical, unrestrictive, non-invasive brain measurement method that does not require large equipment like other neuroimaging method do.

2 Method: Command Detection

We developed a prototype of a BCI system using the OT equipment. The methodology of BCI based on NIRS, which we call “Optical BCI”, will present a practical unrestrictive non-invasive brain-switch that does not require large equipment like other neuroimaging methods do. The block diagram in Fig. 1 illustrates the concept of this BCI system. The features of optical BCI are: (1) It causes no physical harm, (2) It places low constraint on the operator, (3) It is especially well suited for measuring the forehead in the area where the prefrontal cortex works for several higher-order brain functions such as planning complex cognitive behaviors.

The system measures the activity pattern of each individual while he/she performs predetermined tasks, which should change the hemodynamics of measuring. The repeatability of hemodynamic patterns by the task dominates a performance as “operation command” (e.g. a predetermined calculation task).

3 Experiments: Visualization and Interaction

The controllability of BCI improves by making a circuit with two kinds of learning, the learning of human parameters by a machine and the learning of system behavior by a person.

For the purpose of human learning, an appropriate visualization and interactive representation is essential in order to recognize comprehensive information for the operator. Generally, these factors will improve the human learning:

- The original multidimensional information should be represented intuitively by task-related pattern analysis.
- Immediate perception helps people notice and correlate the results to their internal state of themselves.
- Strong motivation and curiosity for the operation encourages learning.

The picture shows a scene of our experiment. The railway model train is used as a representation of an output state. As the voltage increases over a certain point, the light of the model turns on, and then the train starts moving and accelerates. Subjects (operators) were asked to try to control the movement of the model train by starting and stopping a predetermined mental task, and watching the motion of the train was the source of perceptual feedback and motivation-to-learn. The operator has learned interactive control by watching his/her current hemodynamic response, which usually follows neural activity with a delay of a few seconds.

On the practical side, such full-time appraisal with interactive feedback allows free timing control (GO-STOP) switching.

This full-time perceptual feedback from a real-time analysis related to a specific pattern of task state functions as a comprehensible representation of the physical response associated with an immediate mental state. This real-time visualization allows users to discover what kind of his/her mental activity this NIRS measurement system can stably observe, and it improves neurofeedback training interactively. The ability to observe the hemodynamic state of brain activity would enable us to discover the self-internal state objectively and to spur advance in education, therapy, and rehabilitation. We believe the optical BCI will promote such applications in more daily environments.