Chapter 28
Multimodal Neuroimaging to Visualize Human Visual Processing

Sunao Iwaki
National Institute of Advanced Industrial Science and Technology (AIST), Japan

ABSTRACT

Each non-invasive neuroimaging modality has its own inherent limitations resulting from temporal and special inaccuracies due to the nature of information that can be measured. While functional magnetic resonance imaging (fMRI) techniques provide excellent spatial resolution, (up to sub-millimeter resolution), their temporal resolution is limited by the hemodynamic time constant. Conversely, magnetoencephalography (MEG) and electroencephalography (EEG), which measure temporal changes in neural current directly, have temporal resolution of approximately a few milliseconds. However, their spatial accuracy is limited by the non-unique nature of the problem of estimating the spatial distribution of neural currents from the measurement of voltage (EEG) or magnetic field (MEG) distributions from outside of the brain. In this chapter, recent developments in multimodal neuroimaging are introduced to allow for the reconstruction of human brain dynamics with high spatial accuracy without compromising temporal resolution. Specifically, the author describes a technique to combine data from MEG, MRI, and fMRI to visualize human visual processing while perceiving a three-dimensional (3-D) shape.

INTRODUCTION

Information processing, which takes place in neural networks in human cerebral cortical areas, plays a key role in perception, cognition, attention, memory and language. To investigate these crucial functions in the human brain, several noninvasive techniques were recently developed. However, none of these noninvasive techniques is capable of achieving sufficient temporal and spatial resolution at the same time to illustrate precise neural dynamics taking place in the living human brain.

Functional magnetic resonance imaging (fMRI) makes it possible to precisely visualize the spatial distribution of human brain activity with a resolution that is typically approximately a few

DOI: 10.4018/978-1-4666-2113-8.ch028

millimeters. However, fMRI measures hemodynamic changes (blood oxygenation level dependent (BOLD) signals) (Ogawa, 1990; Belliveau, 1991), which are an indirect measure of neural activity. These changes peak a few seconds after the onset of neural firing in an area, and therefore, this technique has limited temporal resolution.

Although electroencephalography (EEG) and magnetoencephalography (MEG) can record temporal changes of post-synaptic neural activity with good temporal resolution (on the order of milliseconds), the principal difficulty in interpreting EEG and/or MEG data is in reconstructing the spatial distribution of the neural activity in the brain from EEG or MEG distributions measured at sensors located at a distance from the brain area from which activity is being assessed. Because of the difficulty of solving this problem, we have to introduce prior knowledge of brain activity to obtain a unique solution. This paper describes a technique to utilize three-dimensional structural models of the human brain derived from structural MRI scans (Dale, 1999) and spatial distributions of brain activity from functional MRI scans (Dale, 2000) to impose neurophysiologically plausible constraints on the MEG/EEG spatial resolution problem.

MEG/EEG FORWARD FORMULATION

We define the primary current distribution, which is a major generator of MEG/EEG signals, as p = $[p_1, p_2, \ldots, p_N]$, and the measured distribution of MEG/EEG as b = $[b_1, b_2, \ldots, b_M]$ where N is the total number of possible neural current sources in the brain and M is the number of sensors. According to the Maxwell equation for quasi-static electromagnetic fields and the Biot-Savart law (Geselowitz, 1967, 1970; Sarvas, 1987; Hämäläinen, 1993), b is related to p as shown in equation (1). By introducing an M-by-N gain matrix L, which is called the lead field matrix, describing a geometric relationship between the possible source locations and the sensor locations or a sensitivity distribution of each sensor, the following equation is obtained:

Figure 1. Spatial and temporal resolution of various neuroimaging modalities