Real-Time Functional Brain Mapping

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Abstract. In this paper, we present the application of brain-computer interface (BCI) technology to the mapping of brain function. Functional mapping seeks to identify those areas in the brain that are involved in producing a particular function, such as receptive speech, and is particularly important for surgical planning prior to resective brain surgery. The presented mapping procedure can be rapidly applied, is comparatively inexpensive, procedurally simple, and also congruent to existing techniques. We expect that this will directly lead to a reduction in patient morbidity and will increase the population of patients that can be effectively treated.

Keywords: ECoG, Brain Mapping, Gamma, Electrical Cortical Stimulation, Epilepsy

1. Introduction

The traditional applications of brain-computer interface (BCI) research have focused mostly on communication and control. The past several years have seen the application of BCI techniques to other important areas, such as attention monitoring, stroke rehabilitation, or functional mapping. Functional mapping seeks to identify those areas in the brain that are involved in producing a particular function, such as receptive or expressive speech, and is particularly important for surgical planning prior to resective brain surgery.

Traditionally, different methods have been used to produce this functional map, most notably electrical cortical stimulation (ECS) mapping, but they all have substantial problems. Patients undergoing resective brain surgery would benefit greatly from a mapping methodology that is safe, can be rapidly applied, is comparatively inexpensive, procedurally simple, and also congruent to existing techniques.

Over the past several years, we have been developing a novel functional mapping procedure. This technique is based on a new detection algorithm, called SIGFRIED [Schalk et al., 2008; Schalk et al., 2008], which is incorporated into our general-purpose BCI software, called BCI2000 [Schalk et al., 2004]. Together with appropriate signal acquisition hardware, this procedure interprets, without configuration by an expert and at the patient's bedside, changes in electrocorticographic (ECoG) signals that are passively recorded from electrode grids that are already implanted in the patient for clinical reasons. Within minutes, this novel method identifies, on a 2D or 3D topographical display that is updated in real time as the patient performs different tasks, those cortical locations whose activity changes in response to the task (see Fig. 1 for results of our mapping in one patient).

2. Material and Methods

The concept of our real-time functional brain mapping procedure is illustrated in the left panel of Fig. 1. Prior to functional mapping, we acquire post-operative CT scans (A_1) and pre-operative structural MRI scans (B_1). From these scans, we reconstruct the grid position (A_2) and cortical surface (B_2), which provides a subject-specific anatomical model (D) for our functional mapping technique (E). At the bedside, we engage the subject in different tasks, such as auditory stimulation (C_1), which modulates brain signals (C_2) in the gamma band (70-110 Hz). BCI2000 software applies the SIGFRIED method to detect these task-related changes, and maps the results in real time onto the subject-specific anatomic model (E).

3. Results

In the right panel of Fig. 1, we present exemplary results from one subject who was implanted over the left hemisphere with 120 electrocorticographic electrodes for the purpose of functional brain mapping and for localizing epileptic foci. Location and duration of the implantation were solely determined by clinical criteria. A lateral x-ray (F) and an operative photograph (G) depict the configuration of two grids and three strips. In the example shown in H and J, we presented the subject with voice and tone stimuli that induced cortical power changes in the gamma band. To identify brain regions related to receptive language, the software statistically contrasted the brain signal changes induced by tones with those induced by voice stimuli. The 2-dimensional interface to the investigator (H) presented functional activations in real time using a topographical interface that represents the electrode grid. The interface contained a display of cortical activation at each location for each task condition (i.e., voice, tones or language). Each display contained one circle at each electrode's location. The size of each circle and its tint was proportional to the magnitude of cortical activation. The 3-dimensional interface to the investigator (J) presented the same functional information in real time on the patient-specific anatomical model. The results for cortical stimulation (ECS) mapping of receptive language function (F, red) are congruent with those achieved using our passive SIGFRIED-based method (H/J).

To date, together with our collaborators, we validated the efficacy of our new method for functional mapping in three studies with adult and pediatric patients [Brunner et al., 2009] at the bedside and in intra-operative scenarios [Roland et al., 2010]. We also showcased our method in several relevant conferences and in four dedicated workshops on electrocorticography organized by our group. Finally, we provided our prototype to several clinics in the USA and in Europe, and licensed the technology to a corporate partner. The initial version of the resulting product is about to be rolled out to clinical testing.

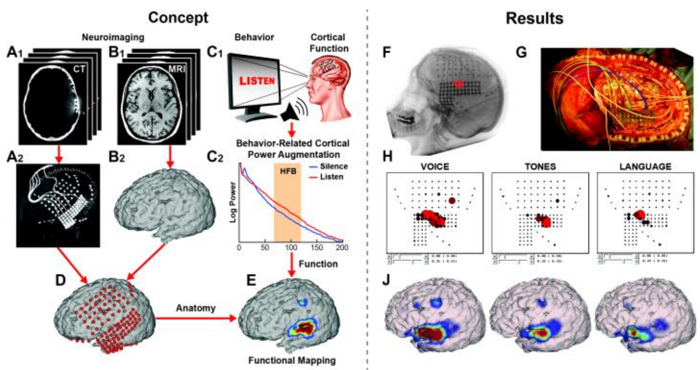

Figure 1. *Functional Brain Mapping of Language Cortex.*

4. Discussion

Our present method gives results that have high concordance to those derived using ECS mapping and has the potential to improve clinical diagnosis. Because our procedure rapidly, accurately, and safely maps functional cortex, its widespread integration in resective brain surgery protocols will directly lead to a reduction in patient morbidity and will increase the population of patients that can be effectively treated.

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