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Analysis of cerebral hemodynamic fluctuations measured simultaneously by magnetic resonance imaging and near-infrared spectroscopy

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Abstract: We measure cerebral hemodynamic fluctuations simultaneously by near-infrared spectroscopy and magnetic resonance imaging during functional stimulations. Our repetitive stimulation protocol includes a variety of epochs differing in duration of stimulation and relaxation periods, which allows generating hemodynamic signals highly synchronous with stimulation sequence. Our goals are to compare results of temporal analysis of hemodynamic fluctuations measured by near-infrared spectroscopy and high-speed magnetic resonance imaging, and to compare optical maps of brain activity based on the results of temporal analysis of NIRS signals with magnetic resonance images.

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OCIS codes: (170.3880) Medical and biological imaging, (170.5280) Photon migration

1. Introduction

In recent years near-infrared spectroscopy (NIRS) was proposed as a method to study brain hemodynamics, which is simple and inexpensive compared to such "heavy-duty" methods as magnetic resonance imaging (MRI) and positron emission tomography (PET). Many results of functional cerebral hemodynamics studies by NIRS were published [1]. However, there is a lack of measurements of functional brain activity performed simultaneously with the other techniques. Indeed, we know only one paper that describes the simultaneous NIRS and MRI recording of cerebral blood oxygenation during functional stimulation [2].

One of the most important advantages of NIRS over other techniques is its high temporal resolution (potentially less than 100 ms). This allows not only to detect the hemoglobin concentration changes synchronous with the stimulation, but also to assess the dynamic characteristics of the process at different locations simultaneously. On the other hand, recent developments in MRI have provided higher temporal resolutions, which are now of the order of hundreds ms.

Recently we employed fast multichannel NIRS to analyze cerebral hemodynamic signals in the area of motor cortex with the temporal resolution of 160 ms per image [3]. In our study, we followed a measurement protocol that included a number of rest and finger-motion exercise epochs. The relative duration of repetitive stimulation and relaxation periods was different for different epochs. Usually hemodynamic signals measured at functional stimulations by NIRS are embedded in large fluctuations of the baseline, so that the only effective method to analyze such signals is the statistical testing. A remarkable result of our study was that in some subjects and at some particular durations of stimulation and relaxation periods the hemodynamic response signals were so clear, that we were able to perform much more detailed analysis than just the statistical testing. An example of such a clear signal is shown in Fig.1.

Fig. 1. Oxy- and deoxy-hemoglobin concentration changes measured by NIRS in the motor cortex of a human subject during repetitive motor stimulation. Shaded areas show stimulation periods.

We performed power spectrum, coherence, folding average and phase synchronization analyses. Utilizing results of these analyses, we constructed optical maps of brain activity. We also performed the temporal analysis of cerebral hemodynamic fluctuations at rest.

The goal of our current work is to analyze and to compare the temporal and spatial properties of cerebral hemodynamic fluctuations simultaneously measured by NIRS and BOLD MRI at rest and during repetitive functional stimulation protocol, which includes a number of epochs differing in timing of stimulation and relaxation periods.

2. Methods

For NIRS measurements we use the two-wavelength (758 and 830 nm) ISS Oximeter (ISS, Champaign, IL), which has sixteen laser diodes (eight per each wavelength) and two photo multiplier tube detectors. Laser diodes operate in a sequential multiplexing mode with variable on-time (about 10 ms for each diode). The light emitted by laser diodes is guided to the tissue through 10-m long multi-mode silica optical fibers. Two 10-m long glass fiber bundles collect the scattered light and conduct it to the detectors. The output signals from the detectors are applied to the inputs of an interface card for an IBM-PC computer, where data processing is performed.

Magnetic resonance imaging records are being performed on a GE Signa 1.5 Tesla system equipped with Echo speed gradients. An echo planar imaging (EPI) sequence runs with temporal resolution of 500 ms, echo time of 40 ms, tip angle 40 degrees, slice thickness 7 cm and three slices. The field-of-view was 24 x 24 cm with a data matrix of 64 x 64.

Currently we perform measurement on the motor cortex. Each measurement consists of the rest epoch (10 min) and three or more exercise epochs. During the rest epoch, the baseline data are acquired. During the exercise epoch, subjects are asked to begin or stop performing a finger-motion exercise by the right hand. Typical stimulation/relaxation periods for different exercise epochs are 20/20 s, 15/15 s, 15/10 s, and 10/10 s. We also plan to measure hemodynamic fluctuations in visual cortex during repetitive visual stimulations.

3. Expected results

We expect to compare results of temporal analysis of hemodynamic fluctuations measured by NIRS and BOLD MRI, and to compare optical maps of brain activity based on the results of temporal analysis of NIRS signals with magnetic resonance images.

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