Simultaneous low-field magnetic resonance imaging and magnetoencephalography

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INTRODUCTION

Magnetic resonance imaging (MRI) enables non-invasive imaging of the human brain. In high fields (ca 1 T and above), MR images have exquisite signal-to-noise ratio (SNR) and contrast. In low fields (ca 100 μT and below), the SNR is compromised but other advantages resulting from the weaker magnetic field, such as combination with magnetoencephalography (MEG), appear. Simultaneous MEG and MRI constitute a hybrid brain imaging modality (MEG-MRI) with both functional and anatomic information.

HARDWARE AND METHODS

In high-field MRI, the main coil is usually superconducting. In low fields, the coils used for sample polarization and for maintaining the sample magnetization precession during measurement can be resistive. In addition, the relative homogeneity requirements are several orders of magnitude lower. However, in high fields, resistive detector coils can be used, whereas superconducting detectors are needed in low fields. This is because Faraday induction works better with rapidly oscillating magnetic fields (ca 1 MHz and above, in high fields) than with slowly oscillating fields (ca 10 kHz or less, in low fields).

In high fields, the main magnetic field is constantly on and the free induction decay (FID) signals are initiated with radio-frequency pulses. In low fields, the setting can be the same, or, two orthogonal coils can be used: a polarization coil and a measurement coil of which the former is on only during polarization.

In low fields, superconducting quantum interference devices (SQUIDs) are used as detectors due to their sensitivity (down to 1 $\mathrm{fT}/\sqrt{\mathrm{Hz}}$) [1]. Another, emerging, detector is the mixed sensor whose $1/f$ noise has prevented its usage so far at low frequencies f [2]. A big advantage is that SQUIDs and mixed sensors can be used in both low-field MRI and MEG. In the MEG-MRI imaging setting, a magnetically shielded room is needed for exclusion of the earth's magnetic field and external electromagnetic noise.

Parallel MRI is an established and rapidly developing area of high-field MRI. An array of receive coils can be used for diminishing imaging time. In MEG-MRI, by default, several superconducting detectors are positioned around the head. The detectors' differing spatial profiles can be used for spatial encoding, and reduction in imaging time, as in high fields.

In low fields, the absence of susceptibility effects improves image quality [3]. An improvement of T_1 contrast can also be achieved [4]. Furthermore, the low-field line width is several orders of magnitude narrower than in high fields. MEG-MRI combines the two imaging modalities in the same physical coordinate system, which makes MEG source

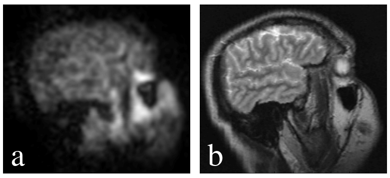

Figure 1: MRI images of the same brain: at 46 μT (a) and at 1.5 T (b) [5], with permission.

localization more accurate. The low-field MRI images may be matched with high-field images to gain anatomic detail. For a comparison between such images, see Fig. 1.

Challenges are posed by the used electromagnetic fields to the ultra-sensitive detectors and signal processing — e.g. as the polarization field switches on and off. Also, according to Maxwell's equations, any magnetic field gradient causes concomitant gradients. Such effects due to position encoding gradients may degrade image quality.

SAFETY

Low-field MRI reduces the risk of metallic projectiles and enables the imaging of subjects with metallic implants. The weaker position encoding gradients also reduce the acoustic noise considerably compared to high-field MRI. Both MEG and MRI are non-invasive imaging modalities and so is their combination.

DISCUSSION

MEG-MRI offers a completely new imaging modality with unique advantages such as improved T_1 contrast. Low-field MRI features cheaper and safer equipment. MEG reveals functional information from the brain down to millisecond resolution. MEG-MRI offers multichannel data which can be used to speed up low-field MRI measurements. MEG-MRI with seven SQUIDs has already been demonstrated — systems with larger arrays of SQUIDs are under development. A 4-year project (called MEGMRI) funded by the European Union is running at Helsinki University of Technology since May 2008.

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