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The Effect of Diffusion Weighting on Task-Induced Functional MRI

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INTRODUCTION

Functional Magnetic Resonance Imaging (FMRI) has been accepted as a tool for detecting task-induced neuronal activity. Blood Oxygenation Level Dependent (BOLD) contrast (1) is thought to be the basis of FMRI using susceptibility sensitive pulse sequences. Cortical BOLD responses may arise not only from the parenchyma close to vessels, but also from intravascular protons. There are many uncertainties concerning details of FMRI contrast. Based on the early studies of diffusion and perfusion (2,3), which reveal information about the microcirculation and surrounding tissue, we added the diffusion weighted EPI sequence to our functional imaging experiment in order to investigate FMRI contrast mechanism.

METHODS AND RESULTS

If the functional signal truly arises from those extravascular diffusing protons that are exposed to the local field inhomogeneities, then a reduction of the functional signal characterized by the diffusion constant of those protons would be expected. The study of the relationship between the functional signal and diffusion weighting would give information on the functional signal source.

We applied bi-polar gradients with strength of 0 to 2.4 G/cm simultaneously on three axes for a period of 16 ms before starting to collect EPI data. The b factor of this set of gradients ranges from 0 to 42 s/mm^2. A finger tapping paradigm was used to produce the FMRI signal. Subjects were asked to tap their fingers bilaterally for two periods separated by resting periods. The total time course was 100 second with 1 second TR. Figure 1a shows the time course with no diffusion weighting, and 1b with diffusion weighting of 42 s/mm^2 b factor. The FMRI signal is effectively eliminated.

In a second experiment, a diffusion encoded gradient-recall EPI sequence was designed in such a manner that the strength of the diffusion weighted gradients is incremented for every scan. This ramping b-factor sequence was applied during a resting period of 100 sec, and repeated during an additional 100 sec period of continuous finger tapping. Signals were averaged from pixels in the prelocalized motor area, and displayed in Fig. 2. The difference between curves of Fig. 2 is a measure of FMRI signal suppression by ramping bi-polar gradients.

Since diffusion in the human brain is in general anisotropic, the use of xyz bi-polar gradients would nevertheless give an uneven diffusion weighting. In a third experiment, we incorporated a set of isotropic diffusion-weighted gradients into the EPI sequence (4). Experiments were repeated with the same finger tapping paradigm and similar results were obtained. Effects of anisotropic diffusion in this experiment were not apparent.

Experiments were repeated using a 30° flip angle and one second TR. Similar results were obtained, significantly reducing the possibility that inflow effects contribute to the contrast. First-flow-moment-nulled diffusion weighted experiments were performed, and FMRI signals were reduced to a lesser extent, suggesting contributions from large vessels.

CONCLUSIONS

The functional signal arises from those protons having a large apparent diffusion constant, ca. ten times that of static water. Knowledge of physiology and previous experiments suggest that these protons are from water molecules within vessels as well as water molecules undergoing rapid influx and outflux near the arterial and venous ends of the capillaries. Use of small diffusion weighted gradients (b factor around 10 s/mm^2) permits analysis and suppression of signals from large draining veins.

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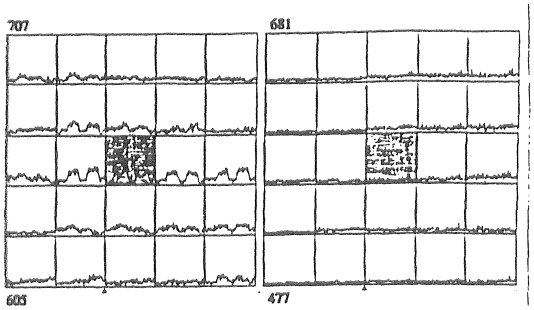

Fig. 1. Functional time-course analysis (left) without diffusion weighting, (right) with diffusion weighting of 42 s/mm^2 b factor.

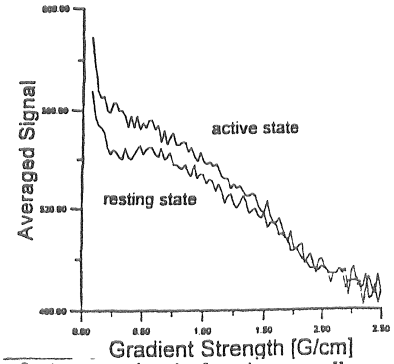

Fig. 2. Average signal of resting as well as active state vs gradient strength.