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NeuroImage Human Brain Mapping 2002 Meeting

Order to appear: 41

Simultaneous estimation of I_0, R_2*, and field map using a multi-echo spiral acquisition

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Subject: Imaging Techniques

Abstract

INTRODUCTION

Recent multi-echo studies have shown an echotime (TE) dependence in components of the fMRI signal, with interest in using R_2* as a measure of functional activation [1,2]. However, macroscopic effects of R_2* and the field map cause degradations and distortions in single-shot gradient echo images. Correcting these distortions can lead to more accurate gradient-echo imaging in general, and more accurate R_2* maps for functional studies.

To account for interactions between R_2*, I_0, and field inhomogeneities, we performed a regularized nonlinear least-squares joint estimation of the I_0 image, R_2* map and field map based on modeling the signal equation. This approach was compared with standard estimation methods for R_2* (log-linear and nonlinear fitting) during a functional experiment.

METHODS

A multi-echo spiral pulse sequence with 4 echo times (TE=4.8/25.28/45.76/66.24ms, TR/FA/FOV=500ms/45/20cm, Matrix size=62, 400 time points) was implemented on a 3T GE Signa scanner. The first image was delayed by an additional 2.5 ms in order to form a standard field map. This field map was used as an initial estimate in our iterative algorithm and was also used to correct the time-series images for the standard method using a conjugate phase reconstruction [3,4].

We developed a cost function that models the signal equation with field inhomogeneities and R_2* taken into account. Our cost function depends on the current estimates of the field map, R_2* map, and image, so we alternate reconstructing the image using our current estimate of the R_2* and field maps and updating the R_2* and field maps using the current estimate of the image. We take advantage of the linearity of the image reconstruction problem and use the conjugate gradient method to find an estimate of the image using the data from all of the echoes. Gradient descent was used to update the field and R_2* maps.

RESULTS

A simulation object with R_2* and field inhomogeneity was used to compare the various estimation methods. Typical values for gray and white matter R_2* were used [5]. Figure 1 shows the simulation results. Errors in the field map resulted in overestimation of R_2* for the standard estimation schemes. The NRMSE over the object for R_2* was 31%, 20%, and 5% for the ln-linear, linear, and simultaneous estimation methods, respectively.

A finger-tapping task (20s off/20s on/5 repeats) was presented to one subject. Figure 2 shows task correlation results (using 240 images) for each method for one slice. The simultaneous estimation method has an increased amount of activation compared to the standard methods, without an appreciable increase of false positives outside the motor cortex.

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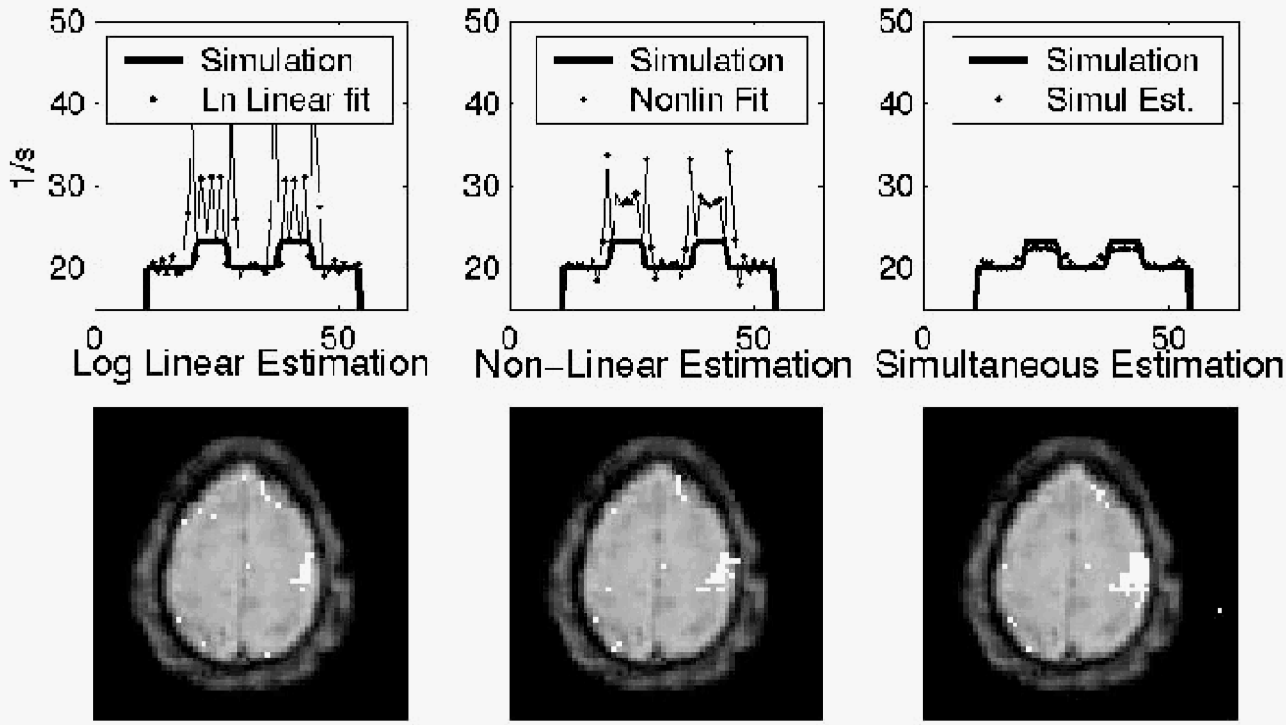

DISCUSSION

Our regularized nonlinear least-squares joint estimation method shows increased accuracy in determining R_2*, field map, and I_0 in the simulation study. The method uses the timing of the k-space readout and models the signal equation using current estimates of the parameters. This aided in accurate quantitation of tissue parameters and detection of BOLD R_2* modulation.

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Supported in part by Whitaker Foundation Graduate Fellowship.

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