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Performance of FMRI using Spin-Echo and Gradient-Echo High-Resolution Single-Shot EPI at 3 T

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INTRODUCTION:

Improvements in signal-to-noise ratio (SNR), system stability, and shimming methods have been made in the context of FMRI at 3 T. First, we demonstrate that because physiological fluctuations in the brain dominate noise, an increase in SNR and system stability does not immediately translate to higher functional contrast-to-noise. Second, we demonstrate for the first time using high-resolution EPI an effective method, based on observations of Ogawa *et al* (1) and Menon *et al* (2), for directly visualizing veins using resting-state blood oxygenation level dependent (BOLD) contrast. This method is particularly effective since the venous information is imbedded in the functional time course series. Third, we demonstrate that the highest FMRI signal changes correspond directly to regions in the vicinity of vessels. It is hypothesized that this effect is due to a combination of the long readout window of high-resolution EPI and intravascular T2 changes in voxels that are largely within vessels (3).

METHODS:

We performed single-shot spin-echo and gradient-echo EPI on a Bruker Biospec 3 T/60 cm scanner (4) equipped with a local three-axis balanced-torque gradient coil designed by E. C. Wong. The highest resolution used was 128 × 128 with a FOV of 24 cm and a slice thickness of 5 mm ($1.8 \times 1.8 \times 5$ mm^3 voxel). The signal bandwidth was ±125 kHz. Axial slices containing the primary motor cortex were scanned. In comparison to 1994 data (4), the noise level was reduced by a factor of two. The improvement was made in two steps: 1) The regular mixer was replaced by mirror image rejection, resulting in $2^{1/2}$ improvement. 2) The 14-bit A/D converter was replaced by a 16-bit ADC4322 from Analogic. Additionally, the long-time stability of the system was improved by replacing switching gradient amplifiers with analog amplifiers from Techron and by reducing the speed of the master clock on the processing-control board. All time-course series consisted of 200 images with bilateral finger tapping carried out using 20 sec off—20 sec on cycles.

RESULTS:

Gradient EPI images, TE = 30 ms, previously had an SNR of about 95 (4). For the same person and region, the SNR is now 210. The physiological noise was previously about two times the thermal noise. Now, it is four times larger. The improvement in functional contrast is minimal and does not exceed 20%. Figure 1 demonstrates large vessel effects on functional response. The maximum change for gradient EPI, TE = 50 ms, was about 40%, while for TE = 105 ms, the change increased to about 70% in the same pixel. The change was visible to the naked eye when browsing through a time-course of images. Fig. 1d demonstrates the large vessel effect on spin-echo EPI. The effect is apparently due to long readout, ~80 ms, and the intravascular T2 effect of blood. The maximum change was about 30%, whereas other pixels in the motor cortex showed changes in the 10 - 20% range.

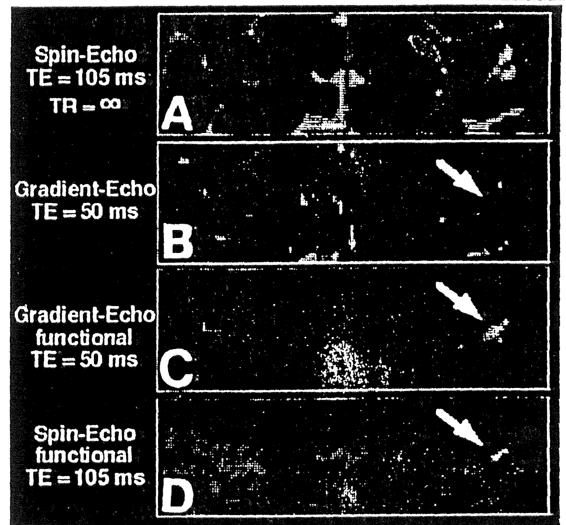

Figure 1. a) High resolution $1.8 \times 1.8 \times 5$ mm^3 anatomical image. b) High-resolution image of resting-state gradient-echo EPI demonstrating the BOLD effect at largest vessels, indicated by the arrow at the vessel in the vicinity of the primary motor cortex. c) High-resolution functional image using gradient-echo EPI. The most pronounced effect aligns precisely with the vessel indicated in b. d) High-resolution functional image created using spin-echo EPI also demonstrating that the most pronounced effect is in an area that is identical to that of the gradient-echo effect.

DISCUSSION AND CONCLUSIONS:

There are three general conclusions. First, higher field strength and better SNR can only aid FMRI if physiological fluctuations are filtered. Second, this is the first demonstration using high-resolution EPI of signal drop out in the vicinity of veins because T2* of venous blood is less than T2* of tissue at higher field strengths. This effect is particularly useful because venous location is embedded in the images obtained for the FMRI study. Third, spin-echo sequences also show largest signal change in the vicinity of large vessels. This is not a contradiction to the various models of spin-echo-dephasing, but rather a result of the extremely long readout time for EPI such that much of the image is also T2* weighted (middle to edge of k-space). It is also possible that the T2 contribution of intravascular spins (heavily weighted by the large blood volume in the particular voxel containing the vein) is significant.

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