Double-sampled EPI in fMRI: A ghost-free acquisition method with inherent field map correction capability

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Introduction

Nyquist ghosts in EPI are known to interfere with image and lower the SNR, which in turn decrease fMRI sensitivity. A double-sampled EPI (DSEPI) method has been proposed to remove ghost artifact [1], trading off stronger geometry distortion due to longer readout time. In this study, DSEPI is used to improve the SNR in visual fMRI experiment, with field map information inherent in DSEPI used to correct for geometry distortion.

Methods and materials

As opposed to conventional EPI, DSEPI sequence uses phase encoding blip on every other echo. The even and odd echoes were divided into two sets of k-space data and reconstructed separately. For field map calculation, the two central k-space lines each traversing in opposite direction were used as reference lines to correct misalignment between odd and even echoes [2], following which phase images were polynomial-fitted to remove noise influences. With TE differing by one echo spacing, the field map can be calculated from two echoes. The short TE separation also helps minimizing phase wrap (phase aliasing) problem in field map estimation. The calculated field maps were then used to remove geometric distortion [3].

Five subjects participated in this study. Visual fMRI experiments were performed with conventional EPI and DSEPI sequence on 1.5T system (Siemens Vision+). Scan parameters of fMRI included TR 2s, TE 48m, echo spacing 0.6ms, matrix size 64x64, FOV 23x23cm, slice thickness 3mm. A block design of 5 blocks (2 on, 3 off, 10 frames in each block) was applied. Flashing checkerboard visual stimulus was given in second and fourth blocks. In DSEPI experiment the two echoes were averaged before functional analysis. Functional activation maps were generated by independent component analysis (ICA) supplied in fMRlab software package.

Results

The conventional EPI, DSEPI, and corresponding T1-weighted images were shown in Figure 1. Nyquist ghosts were totally removed using DSEPI acquisition. The contour from T1WI showed that geometric distortion was stronger in DSEPI images comparing to conventional EPI images, but the distortion was successfully corrected by field map correction using the inherent information in DSEPI. The activation maps and percentage signal changes for the fMRI experiments are shown in Figs.2 and 3, respectively. DSEPI showed stronger percentage signal changes and larger activation areas than conventional EPI. The SNR was 78 for conventional EPI and 112 for DSEPI, showing SNR improvement slightly larger than square root of two. The additional SNR gain is anticipated to be from the suppression of the Nyquist ghosts.

Discussion and conclusion

In this study, DSEPI is demonstrated to provide better fMRI quality than conventional EPI by at least three factors: SNR improvement, ghost suppression, and reduced geometric distortion. The better SNR comes from the retention of signal energy from Nyquist ghosts, as well as simultaneous acquisition of two images at similar TE. Since a high field strength desirable for fMRI study also enhances Nyquist ghosts due to stronger susceptibility, we expect the advantage of DSEPI to be more prominent in higher field systems. Stronger geometric distortion in DSEPI can be reduced using field map correction, the information inherently stored in the two acquisitions in DSEPI. This property is especially important in fMRI where simultaneously monitoring of the field map in dynamic scan is advantageous to correct for distortion resulting from dynamic field fluctuations. Furthermore, this method is compatible with parallel imaging as long as the central line of k-space is acquired. We therefore conclude that DSEPI with inherent field map correction capability is an effective approach for fMRI studies.

References

[1] Yang et al., JMRB, 113:145-150,1996
[2] Roopchansingh et al., 50:839-843, 2003
[3] Chen et al., 41:1206-1213, 1999

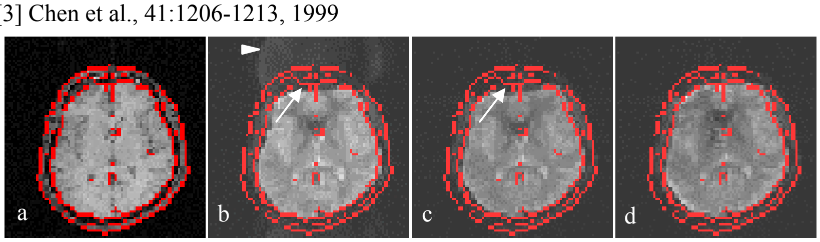

Fig 1. (a) T1-weighted, (b) conventional EPI (c) DSEPI, (d) corrected DSEPI images of one subject. Nyquist ghost can be easily seen in conventional EPI images (arrow head). Geometrical distortion existed in both conventional EPI and DSEPI images (arrow), which was corrected using field map correction (d).

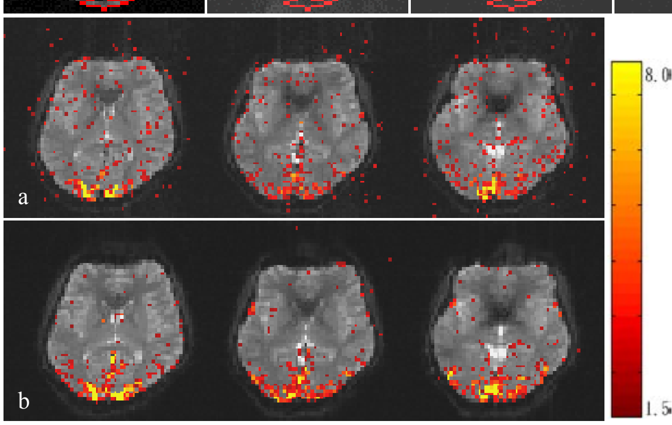

Fig 2. Activation maps of 3 selected slices of one subject: (a) conventional EPI and (b) DSEPI. Larger activation areas are seen with DSEPI. Scale represents Z value from 1.5 to 8.0

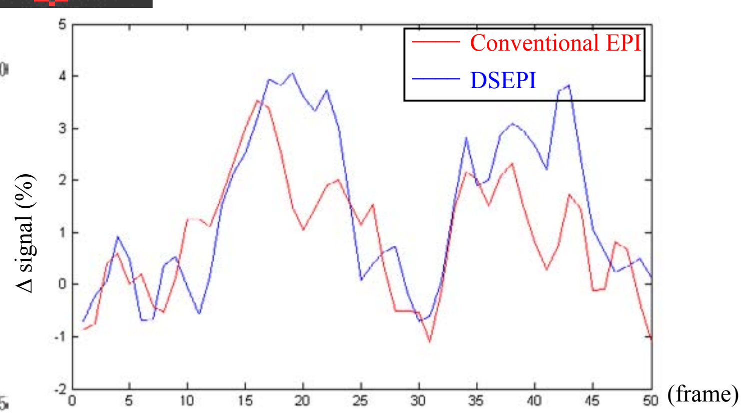

Fig 3. Time course for the percentage signal changes from the primary visual cortex of the same subject in Fig.2: conventional EPI (red) and DSEPI (blue). Better functional sensitivity is seen with DSEPI.