Iranian Journal of Medical Physics
Vol. 9, No. 4, Autumn 2012, 275-280
Received: February 13, 2012; Accepted: July 21, 2012

Original Article

Effect of Phase-Encoding Reduction on Geometric Distortion and BOLD Signal Changes in fMRI

Golestan Karami[1], Mohammad Ali Oghabian[2]*, Fariborz Faeghi[3], Mohammad Rasoul Tohidnia[4]

Abstract

Introduction
Echo-planar imaging (EPI) is a group of fast data acquisition methods commonly used in fMRI studies. It acquires multiple image lines in k-space after a single excitation, which leads to a very short scan time. A well-known problem with EPI is that it is more sensitive to distortions due to the used encoding scheme. Source of distortion is inhomogeneity in the static B_0 field that causes more geometric distortion in phase encoding direction. This inhomogeneity is induced mainly by the magnetic susceptibility differences between various structures within the object placed inside the scanner, often at air-tissue or bone-tissue interfaces. Methods of reducing EPI distortion are mainly based on decreasing steps of the phase encoding. Reducing steps of phase encoding can be applied by reducing field of view, slice thickness, and/or the use of parallel acquisition technique.
Materials and Methods
We obtained three data acquisitions with different FOVs including: conventional low resolution, conventional high resolution, and zoomed high resolution EPIs. Moreover we used SENSE technique for phase encoding reduction. All experiments were carried out on three Tesla scanners (Siemens, TIM, and Germany) equipped with 12 channel head coil. Ten subjects participated in the experiments.
Results
The data were processed by FSL software and were evaluated by ANOVA. Distortion was assessed by obtaining low displacement voxels map, and calculated from a field map image.
Conclusion
We showed that image distortion can be reduced by decreasing slice thickness and phase encoding steps. Distortion reduction in zoomed technique resulted the lowest level, but at the cost of signal-to-noise loss. Moreover, the SENSE technique was shown to decrease the amount of image distortion, efficiently.

Keywords: BOLD Signal, Echo Planar Imaging, EPI, fMRI, Geometric Distortion

1- Kermanshah University of Medical Sciences, Kermanshah, Iran
2-Neuroimaging and Analysis group, Research Center of Molecular and Cellular Imaging, Tehran university of Medical Sciences, Tehran, Iran
*Corresponding author: Tel: +98 21 66907518; Email: oghabian@tums.ac.ir
3- School of Para Medicine, Shahid Beheshti University of Medical Sciences, Tehran, Iran
4-Department of Radiology, School of Para Medicine, Kermanshah University of Medical Sciences, Kermanshah, Iran

1. Introduction

Echo planar imaging (EPI) is the most common technique used in fMRI. This sequence can indicate the blood oxygenation level dependent (BOLD) contrast with relatively high temporal resolution [1]. In this pulse sequence, due to the lack of 180° pulses, T_2* contrast, which has a high sensitivity to changes in the local magnetic field such as the changes in local blood oxygen, can be obtained. Here, microscopic deviation in magnetic field between materials with different susceptibility leads to image distortion [2]. Unfortunately, other sources of field inhomogeneity exist which come from eddy current, chemical shift, mis-shimming of static magnetic field [3], and local field distribution due to tissue /air and tissue/fat interfaces [4, 5].

Two kinds of artifact can be induced by differing susceptibilities: local signal loss due to intra-voxel dephasing and geometric distortion due to voxel shift. Intra-voxel dephasing increases when the voxel size is large [6]. On the other hand, the voxel size has twofold nature. When voxel size is reduced, signal loss leads to low signal-to-noise ratio (SNR), therefore, we need to increase scan time which in turn degrades fMRI data.

It has been shown that the optimal use of parameters improves quality of fMRI activation regions in EPI. Phase-encoding steps are the most effective parameters which affect scan time as well. The highest image distortion is seen in phase encoding direction which depends on phase-encoding steps. Distortion can be reduced by reducing FOV in phase encoding direction [7], and reducing read out time or data acquisition time [8].

2. Materials and Methods

Experiments were carried out on 3Tesla scanner (Siemens, TIM system, Germany) equipped with a 12 channel head coil.

Ten subjects (female, age 25 to 30, right-handed) participated in the experiments.

Anatomical reference images were acquired with a fast low-angle shot (FLASH-2D) pulse sequence (matrix size; 256× 256, slice thickness; 4 mm, 30 axial slices). Two-dimensional fast gradient-echo pulse sequence was used to map the B0 field for air/tissue susceptibility evaluation and correction [9]: (echo times; (TE)=7.38 and 4.92 ms, repetition time; (TR)=468 ms, both with the same spatial resolution and slice orientation as the EPI data).

2.1. Technique for Phase encoding reduction via FOV and slice thickness reduction:

For this purpose, three different data acquisition methods were used.

Conventional EPI: matrix size; 64×64, voxel size; 4×4×2 mm^3, and FOV; 256×256 mm.

Conventional High Resolution EPI: matrix size; 96×96, voxel size; 2×2×4 mm^3, and FOV; 196×196 mm.

Zoomed High Resolution EPI: matrix size; 96×48, voxel size; 2×2×4 mm^3, and FOV; 196×96 mm. In this approach, the size of field of view in the direction of phase encoding has been reduced up to the half of the dimension in the direction of the frequency encoding. This method is known as Zooming method [7]

2.2. Technique for phase encoding step reduction using SENSE tool

In this approach, matrix size of 96×96, voxel size of 2×2×4 mm^3, FOV of 196×196 mm, and a sensitivity encoding (SENSE) factor of 2 was used for high spatial resolution acquisition.

2.3. Verification and evaluation of the results:

In order to compare images and assess the results, percentage of signal change as well as amount of distortion was measured for different images. The BOLD signal is related to changes in physiological conditions. The fractional signal change from the resting state to the activated state provides signal change. low displacement voxels map was used to investigate the degree of distortion applying to a field map measurement method. In fact, voxel displacement map is obtained by a scalar multiplication series of field map.(FMfreq = FMrad/deltaTE, VDM=FMfreq/pixelBW) .

First, some areas of the brain were derived from brain of samples relevant to known areas on the Talairach atlas [10]. These areas were selected in visual brain regions which are prone to distortion. In this context, the presented task was a simple visual task with black and white images. The Brodmann area 17 is the main location of activity in proposed masks. In addition, the masks of some areas such as occipital pole, frontal pole, and orbitofrontal pole were created which are more susceptible to distortion artifact. ANOVA test was performed to compare the results from different tasks.

3. Results and Discussion

3.1.1- Percentage of signal change with variation of FOV and slice thickness

According to Table 1 and figure 1, the results related to percentage of signal change (%SC) could be discussed from three view points.

Assessment of signal variation in terms of reduction in the voxel size: the percentage of signal change has decreased from 2.16 to 1.99 by reduction in voxel size from 32 mm^3 to 16 mm^3.

Assessment of the signal in terms of reduction in phase encoding steps while maintaining high resolution property: the percentage of signal change in conventional high resolution method was shown to be 1.99 compared to zoomed imaging which was reduced to 0.84. Therefore, reducing the phase encoding steps Cause signal loss while maintaining resolution.

Assessment of the signal in terms of reduction in phase encoding steps compared to resolution: according to Table 1, the percentage of signal change has decreased from 2.16 to 0.84, when using conventional mode in comparison to zoomed mode. By decreasing voxel size an efficient increase in BOLD signal occurs than by reducing phase encoding steps.

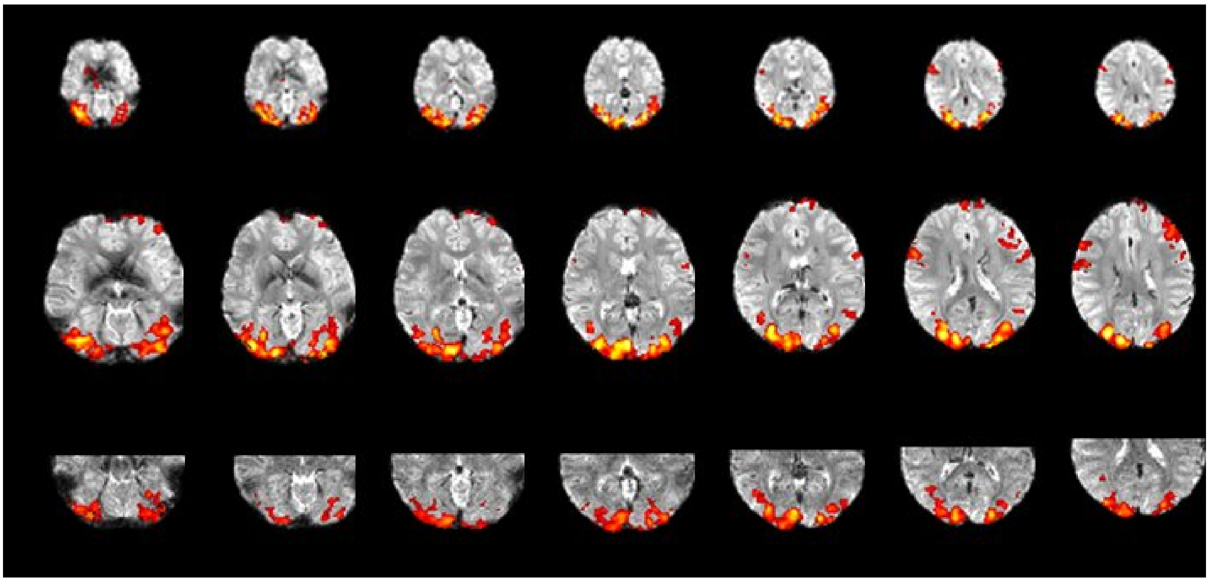

Figure 1. Active areas in various FOV

Table 1. Percentage of signal change in different FOVs

Protocol	Field of View	Matrix Size	Voxel Size	Inferior Occipital Gyrus	Visual	Occipital Pole	Mean %SC
Zoomed	192×96	96×48	16 mm^3	1.05	1.05	0.56	0.84±.56
Con. High resolution	192×192	96×96	16 mm^3	1.81	2.40	1.76	1.99±.67
Conventional	256×256	64×64	32 mm^3	2.05	2.45	1.98	2.16±.99

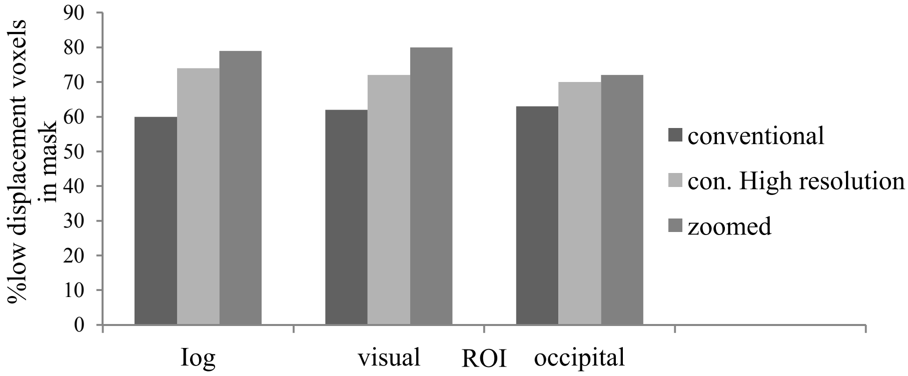

Figure 2. Percentage of low displacement voxels in different FOVs

3.1.2. Percentage of low displacement voxels with variation of FOV and slice thickness

According to Figure 2, the results related to the percentage of low displacement voxels can be considered from two main view points:

Decreasing voxel size: by decreasing the voxel size from 32 mm^3 to 16 mm^3, the percentage of low displacement voxels has increased from 60% to 70%. Therefore, the increase in distortion is caused by "intra-voxel" dephasing in larger voxels.

Reducing phase encoding steps while maintaining resolution: in the zoomed method, percentage of low displacement voxels is 76% compared to 70% when the conventional high resolution method is used. Decrease in phase encoding steps does not alter the image distortion.

3.1.3. Percentage of signal change with SENSE technique

According to Table 2, Percentage of signal changes was shown to be 2.52 without SENSE technique but decreased slightly to 2.25 when SENSE technique was used. SENSE technique has no significant effect on the amount of changes in BOLD in the active ROI. The clusters size in SENSE technique gets smaller, but that is more prevalent outside the active area.

Figure 3 indicates that a percentage of signal change in conventional high resolution method is higher than of conventional with SENSE technique.

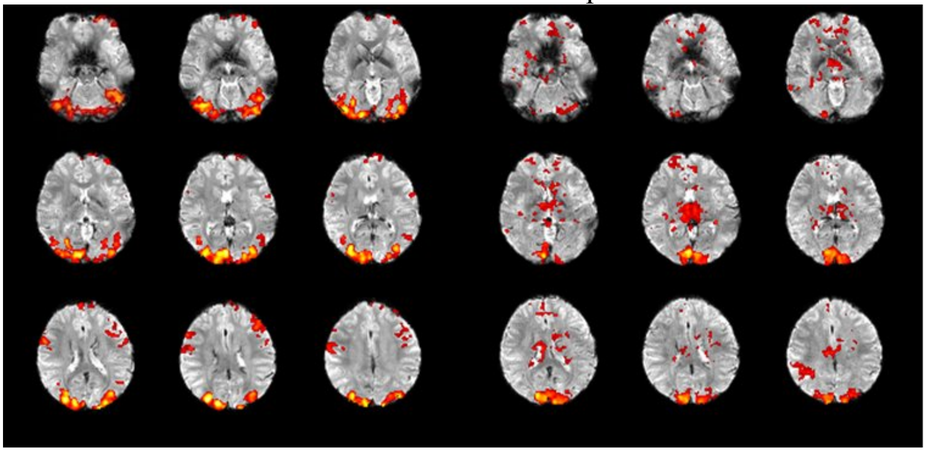
Figure 3. Active areas with (right) and without (left) SENSE

Table 2. Percentage of signal change in ROIs with and without SENSE technique

Protocol	Matrix Size	Inferior Occipital Gyrus	Visual	Occipital	Mean %SC
Con.l high resolution without SENSE	96×96	2.3±.95	3.09±.87	2.18±.65	2.52±.87
With SENSE	96×96	2.26±.85	2.73±1.0	1.76±.75	2.25±.93

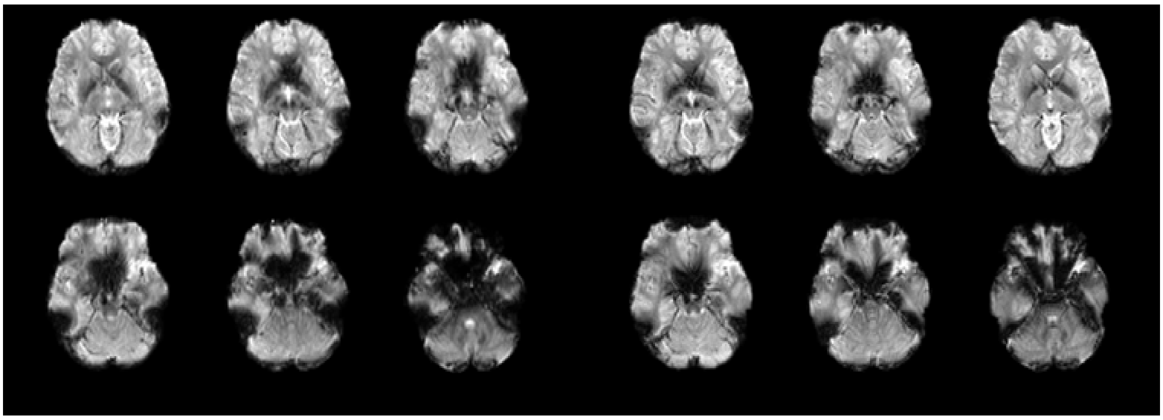

Figure 4. Image distortion with (left) and without (right) SENSE

Table 3. Percentage of low displacement voxels in ROIs, with and without SENSE technique

Protocol	Matrix Size	Frontal Pole	Orbitoforental Cortex	Inferior Occipital Gurus	Visual	Occipital Pole	Mean %Low Displacement Voxel
Con.High Resolution without SENSE	96×96	40	29.60	71.25	76.40	68.25	57.10±2.37
With SENSE	96×96	47.60	40	82.50	82.75	72.75	65.12±2.41

3.2. Distortion with SENSE

Percentage of low displacement voxels without SENSE technique is 57% compared to 65% when SENSE is used.

According to Table 3 and Figure 4, the percentage of low displacement voxels with SENSE is better than without SENSE technique. Therefore, SENSE technique decreases the amount of image distortion.

In terms different areas of brain, figure 3 indicates that areas such as orbito-frontal cortex that are adjacent to sinuses are prone to distortion caused by differing susceptibility between the tissues. Distortion in orbito-frontal cortex was shown to be the highest in all modes, although, this decreases with SENSE compared with other methods.

4. Conclusion

Different parameters affecting image distortion and signal strength in fMRI data were assessed and their results including percentage of signal changes in activated areas of brain and percentage of voxel displacement in such areas were presented.

We showed that both reduction in voxel size and phase encoding steps as in zoomed technique reduce image distortion due to susceptibility artifact in air-tissue interface. Although, both these strategies decrease BOLD signal changes, the effect is not trivial for the BOLD detection in main activation areas of the brain.

In functional studies, a thinner and continuous slice with small voxels improves the quality of image and its registration with reference image as well as reducing susceptibility artifact and distortion. However, to cover the entire volume of brain by a thinner slice, scan time should be lengthened. This, in turn, reduces SNR.

Since high temporal resolution is very important in fMRI acquisition, reducing slice thickness for lower EPI distortion is not preferable as this increases scan time. Data acquisition methods by variable slice thickness are suggested. In this approach, at the lower parts of the brain, signal loss and fluctuations are reduced by a thinner slice. The upper parts of the brain with less sensitivity to susceptibility artifacts are imaged by a thicker slice.

Some authors, as in paper [8], attempted to investigate the effect of reduction in FOV on percentage of signal change and distortion. The comparison of the results derived from this study indicates that signal, noise, and signal to noise ratio in zoomed technique was significantly reduced compared with the conventional technique. Distortion in zoomed method was significantly reduced especially in the susceptible areas, compared with the conventional method. In the meantime, the signal is also maintained.

Investigating the effect of SENSE, we found that single shot-gradient recalled echo-EPI (SS-GRE-EPI) with SENSE at high magnetic fields is an effective way to acquire the active regions in the brain, although, other parameters such as TE must be considered.

Acknowledgements

This work was performed in partial fulfillment of the requirement for MSc degree of Ms. Golestan Karami, Kermanshah University of Medical science, Kermanshah, Iran.

References

1. Stehling MK, Turner R, Mansfield P. Echo-planar imaging: magnetic resonance imaging in a fraction of a second. Science. 1991 Oct 4;254(5028):43-50.
2. Denolin V. Sources of contrast and acquisition methods in functional MRI of the Human Brain. Bruxelles: Université Libre de Bruxelles; 2002.
3. Balteau E, Hutton C, Weiskopf N. Improved shimming for fMRI specifically optimizing the local BOLD sensitivity. Neuroimage. 2010 Jan 1;49(1):327-36.
4. Jezzard P, Clare S. Sources of distortion in functional MRI data. Hum Brain Mapp. 1999;8(2-3):80-5.
5. Cordes D, Turski PA, Sorenson JA. Compensation of susceptibility-induced signal loss in echo-planar imaging for functional applications. Magn Reson Imaging. 2000 Nov;18(9):1055-68.
6. Bellgowan PS, Bandettini PA, van Gelderen P, Martin A, Bodurka J. Improved BOLD detection in the medial temporal region using parallel imaging and voxel volume reduction. Neuroimage. 2006 Feb 15;29(4):1244-51.-
7. Olman CA, Davachi L, Inati S. Distortion and signal loss in medial temporal lobe. PLoS One. 2009;4(12):e8160.-
8. Preibisch C, Pilatus U, Bunke J, Hoogenraad F, Zanella F, Lanfermann H. Functional MRI using sensitivity-encoded echo planar imaging (SENSE-EPI). Neuroimage. 2003 Jun;19(2 Pt 1):412-21.-
9. Zeng H, Constable RT. Image distortion correction in EPI: comparison of field mapping with point spread function mapping. Magn Reson Med. 2002 Jul;48(1):137-46.-
10. Lancaster JL, Woldorff MG, Parsons LM . Automated Talairach atlas labels for functional brain mapping. Human Brain Mapping . 2000 (10):120-31