Feasibility of high resolution single shot imaging at 7T.

P. van Gelderen, J. A. de Zwart and J. H. Duyn
AMRI/LFMI/NINDS, NIH, Bethesda, MD, United States

Introduction

Diffusion weighted imaging, and in particular diffusion tensor imaging (DTI), has the potential to reveal some of the fine structure in the brain that is not accessible by conventional MRI. To attain this, one needs to achieve a high spatial resolution, while maintaining a sufficient signal to noise ratio (SNR). In addition, motion-related artifacts need to be kept at a minimum by using single-shot imaging techniques such as EPI. While the SNR constraint can be eased by using high field strength and receive coil arrays, the resolution of single shot EPI images is limited by T_2* decay, which is accelerated at higher field strength (T_2* ~ 50 ms at 3 T, ~ 30 ms at 7 T). One way to alleviate this problem is the use of parallel imaging techniques such as SENSE [2], which allow for an increase in spatial resolution in the presence of T_2* decay [1]. Here we demonstrate SENSE imaging at 7 T, and the feasibility to acquire single shot images at 1.25x1.25 mm^2 in-plane resolution.

Methods

Experiments were performed on a GE 7 T scanner, equipped with a Nova Medical 8 channel receive-only brain array and a birdcage type volume exciter. The design of the 8-channel brain array was based on the design described earlier [3]. All volunteers involved in this study gave informed consent in accordance with a NINDS IRB protocol. Prior to imaging, higher order shimming was performed using the phase information of a fast 3D interleaved EPI acquisition. The SENSE method was implemented in IDL, following [2] and [4]. As part of the imaging sequence, a set of coil sensitivity maps was acquired using identical acquisition parameters as the image acquisition, except for the addition of phase encoding steps to allow the creation of full field of view images. The EPI parameters were: TE 30 ms, TR 2 s, nominal flip angle 70°, 12 slices, 2 mm thickness, ramp sampling 50%, bandwidth 250 kHz. Two different in-plane resolutions were used: A) 144x112 matrix, resolution 1.7x1.7 mm^2, 45 ms acquisition window, SENSE rate 2; B) 192x120 matrix, 1.25x1.25 mm^2 resolution, 40 ms window, SENSE rate 3.
Since the coil sensitivity maps are measured with an interleaved EPI, it is important that the phase of the signal is stable from shot to shot. Instability will lead to ghosting in the reference and subsequently to incorrect unfolding of the undersampled (SENSE) data. To assess phase stability an experiment with a zero order navigator was performed, where data was acquired without any readout gradient for a period of 10 ms, just before the normal EPI window. The TR was 100 ms in a single slice acquisition, flip angle 20°. The phase of the navigator was fitted with a straight line to get the phase and frequency.

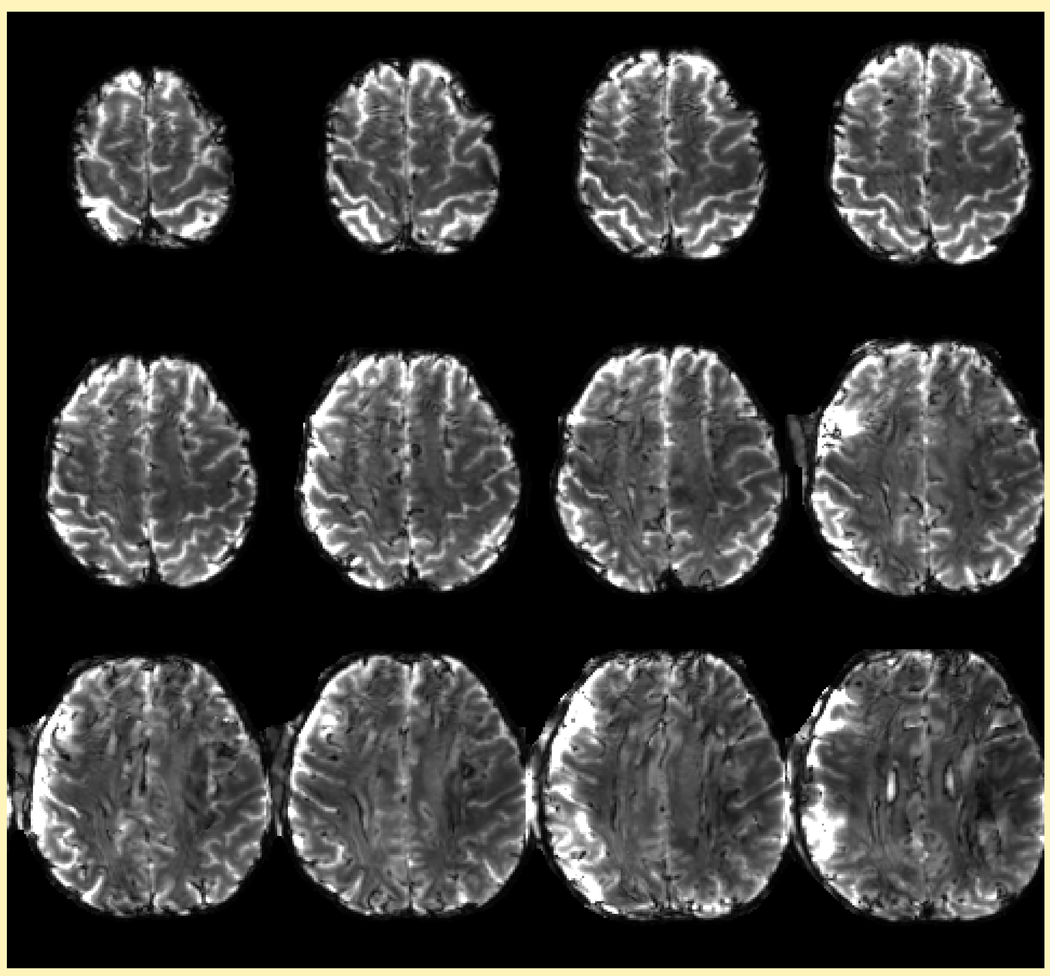

Figure 2.
Example of high resolution EPI. The nominal resolution is 1.25 mm^2, acquired with SENSE rate 3.

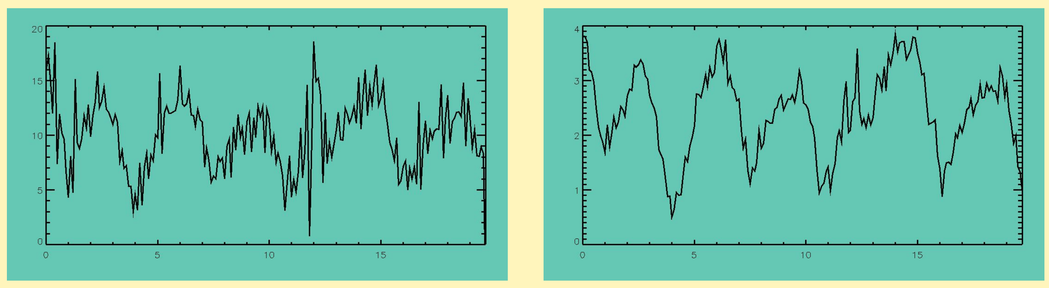

Figure 4.
Phase (left) and and frequency (right) of a navigator data set, acquired with TR 100 ms. The navigator was 10 ms long. Horizontal is the time in seconds, vertical phase in degree and frequency in Hz. The periodic modulation is likely related to cardiac and respiratory effects.

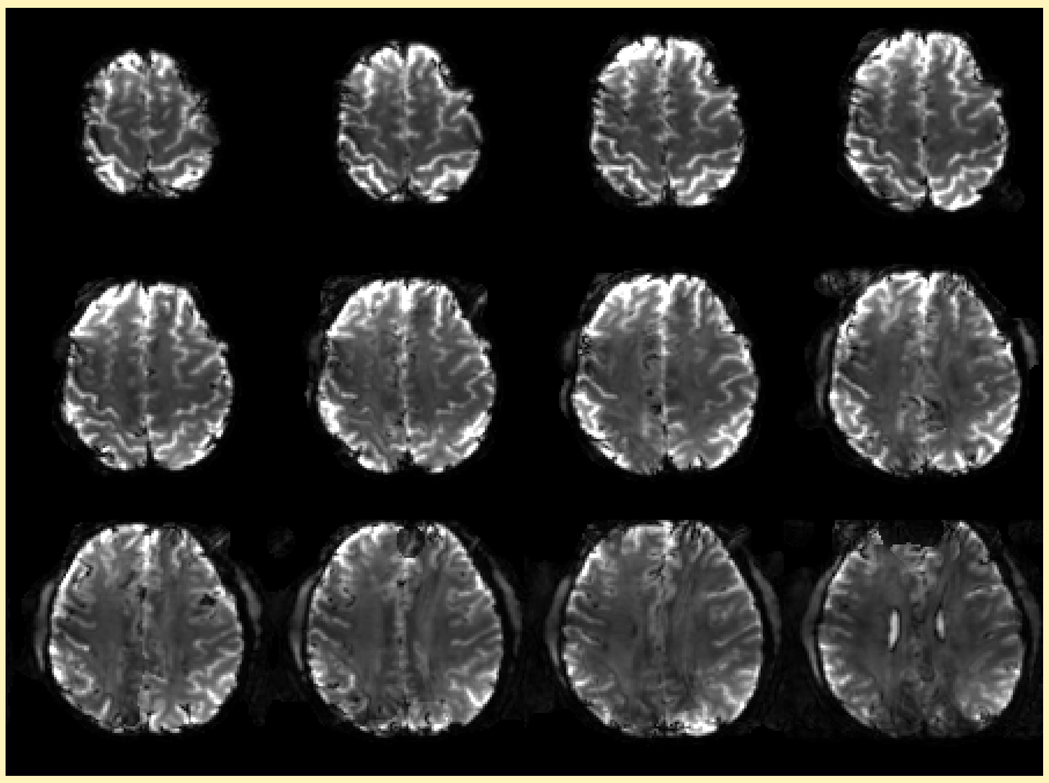

Figure 1.
Example of intermediate resolution EPI. The nominal resolution is 1.7 mm^2, acquired with SENSE rate 2. Note that slices 10 and 12 have spots of decreased amplitude in the front due to ghosting in the reference images.

Results & Discussion

Examples of single shot SENSE-EPI image quality at 7 T are given in Figure 1 and 2. Figure 1 shows twelve axial slices with 1.7x1.7 mm^2 resolution, Figure 2 shows the same slices at 1.25x1.25 mm^2 resolution. The images demonstrate that, in spite of the low T_2* at 7 T, high resolution single shot imaging is possible with high image quality and SNR. The lower slices of the high resolution data show some areas with increased instensity on the left side due to the scaling of the SENSE reference images. As there is no body coil reference possible, the reference is calculated from a combination of the eight coil images. These have hot spots close to the coil elements that can not always be corrected in this method. Note this is a scaling factor that cancels out in the calculation of a diffusion map.
The SNR varies widely due to the high image contrast; in the 1.72 mm^2 images it was 50-350, with 70-120 for most tissue voxels, in the 1.252 mm^2 scan it was 20-100, with 30-40 in most tissue voxels. The stability (the ratio of the SD over time and the average per voxel) is shown in Fig. 3.
In the current implementation the coil reference is acquired as an interleaved EPI, which appears to suffer occasionally from respiratory and/or motion induced artifacts. This is demonstrated in Fig. 4, which shows the fitted phase and frequency of a navigator echo. There is a clear periodic modulation visible in both plots. Analysis of the phase of images acquired with a TR of 100ms showed there is also significant spatial non-uniformity in the phase modulation, ie. different parts of the brain require a different correction which is not possible with a simple zero or first order navigator. It is however possible to acquire the reference data at a lower resolution in a single shot.
The results indicate the feasibility of single shot diffusion imaging at 7.0 T. We are currently working on increasing the number of channels to further improve resolution through increasing SNR and SENSE performance.

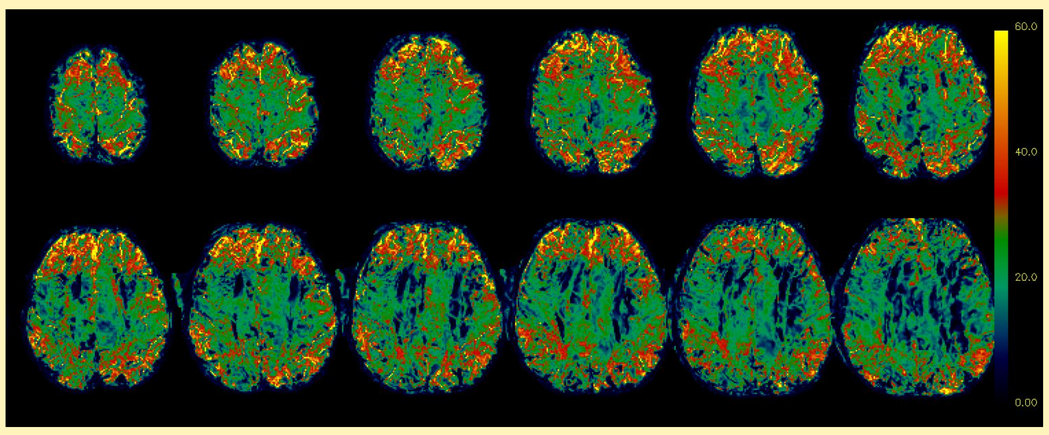

Figure 3.
Stability of the high resolution EPI calculated as SD over time divided by the average. Note that in the lower slices the SENSE ghosting from the edges of the brain and skull compromises the stability.

References

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