Single-shot Echo-Volumar Imaging using highly parallel detection

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Introduction

Volumetric imaging holds intrinsic sensitivity advantages. FMRI, however, benefits from single-shot acquisition, which reduces the influence of physiologic noise and head motion, and allows the high temporal resolution needed for event-related designs. Single-shot Echo-Volumar Imaging (EVI) (1,2) has been proposed to address these issues, but requires excessive amounts of encoding for conventional spatial resolutions (e.g., 3 mm).

We address the encoding problem by using high acceleration factors in the two phase encoding directions made possible by a 32-channel receive coil array (3). We demonstrate the capabilities of highly accelerated single-shot EVI with functional studies at 1.5 T with TE= 40 ms at 2 mm and 3 mm isotropic resolution. At 3 mm resolution a 64x64x48 encoding matrix was possible with 4x2 fold acceleration and 6/8 partial Fourier acquisition with effective echo spacings (esp_e) of 0.12 ms and 2.04 ms for the two phase encoding directions and a readout duration of 96 ms. At 2 mm resolution a 128x128x16 matrix was possible with 4x2 fold acceleration, 6/8 partial Fourier giving an echo spacing of 0.21 ms and 10.5 ms and a total readout time of 168 ms. Although susceptibility distortions are larger than those in EPI, the true single-shot 3D technique holds the promise of increased SNR, vastly improved temporal resolution, and more benign motion effects.

Methods

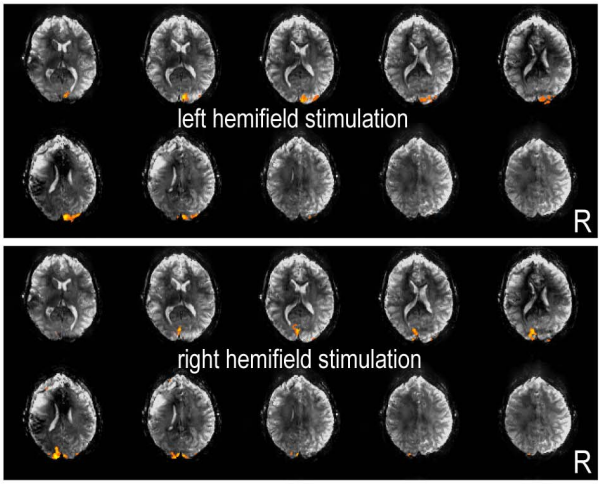
A 32-channel investigational device labeled commercial head array and standard 1.5 T whole-body scanner (Siemens Medical Solutions, Erlangen, Germany) were used for all studies. The single-shot EVI sequence used a slab-selective excitation followed by EP encoding in the kx-ky plane and inter-partition phase encoding rewinders (fly-back) rather than encoding direction reversal for the kz partitions (4). The trajectory was accelerated in the ky and kz direction with rate R = Ry x Rz 2D GRAPPA by omitting Ry lines in the ky direction and skipping Rz partitions in the kz direction. Encoding in the kz direction was additionally speed up by implementing 6/8 partial Fourier (PF) in the kx-ky plane. The PF was applied in this way to ensure that the echo spacing in the kz direction was as fast as possible since this "slow encoding" direction suffers severe distortion. Prescan GRAPPA auto-calibration signal (ACS) lines were acquired as a non-interleaved segmented scan, one excitation per partition, and minimal TE. A ghost correction prescan with no y phase encoding acquired was used to reduce ghosting.

Two sequences were used: i) 3 mm isotropic resolution scan with 64x64x48 matrix, R = 4x3, FOV of 220x220x144 mm^3, TR/TE=250 ms/40 ms, BW=2368 Hz. This results in an effective echo spacing (esp_e) of 120 µs and 2.0 ms, and a total readout duration of 96ms; and ii) 1.7 mm x 1.7 mm x 3 mm resolution scan with 128x128x16 matrix, R=4x2, FOV=220x220x48 mm^3, TR/TE=1s/41ms, and BW=2368 Hz and esp_e of 215 µs and 10.5 ms and a total readout duration of 168 ms.

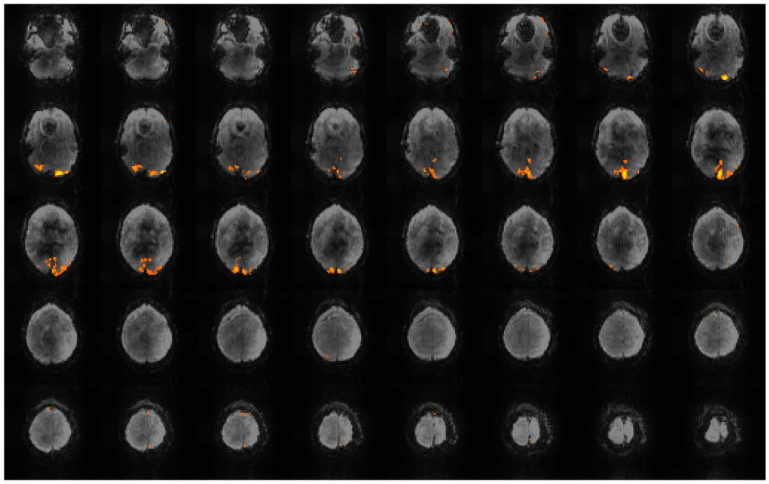
A 128-second duration visual fMRI experiment was performed using a black-and-white spatial noise stimulus presented either to the right or left visual hemi-field, 16-s block design with a fixation task to insure accurate fixation using a TR of 1 s for the high-resolution sequence and 250 ms for the 3 mm resolution study. FMRI data processing was carried out using FSL (5).

Results

The results of the fMRI analysis are shown below. Robust visual activation can be observed in both the high spatial resolution as well as the high temporal resolution case. Although the echo-spacing is larger than in traditional EPI, the distortions are still acceptable for fMRI applications.



128x128x16 matrix BOLD activation overlaid on time-series (TR=1 s) mean image. Cluster corrected threshold $p<8*10^{-7}$. The activity clearly localizes to the contralateral hemisphere.



64x64x48 matrix BOLD activation overlaid on time-series (TR=250 ms) mean image. Cluster corrected threshold $p<4*10^{-5}$. The activity is robustly seen in the visual areas around the occipital pole.

Conclusion

We have demonstrated highly accelerated single-shot EVI using an investigational device labeled commercial 32-channel head array coil in a standard 1.5 T imager. Furthermore we have shown BOLD sensitivity using visual experiment. Using parallel detection single-shot EVI is realizable at spatial resolutions commonly used in fMRI using readily commercially available hardware. We have demonstrated that EVI can reach significantly higher temporal resolution than an EPI protocol with the same TE and the same number of slices. A matrix size of 64x64x48 and a TE of 40 ms can be acquired with a TR of less than 150 ms, which is an order of magnitude faster than an equivalent EPI protocol, even when using the same acceleration factor for EPI.

References

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