Combined Echo Volumar Imaging (EVI) and Localized Excitation for Motion Insensitive Fetal fMRI

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TARGET AUDIENCE This research will benefit those researchers interested in fetal functional brain studies and sequence optimization.

PURPOSE Echo Volume Imaging (EVI) is an extension of the well-known Echo Planar Imaging (EPI) sequence that allows the acquisition of a whole fMRI volume following a single RF excitation; this leads to a repetition time TR in the order of a few hundreds of milliseconds depending on the field of view (FOV) and image resolution. The main benefits are increased temporal resolution and robustness to motion [1]. The downside is that EVI is extremely sensitive to B_0 field inhomogeneities and T2* signal decay limits the achievable image resolution; these factors have so far limited the usage of EVI in functional MR imaging.

Fetal fMRI is an emerging field of research [2-4]. Initial studies used standard multi-slice 2D EPI and were therefore very sensitive to fetal motion requiring careful application of motion correction algorithms [4]. Combining selective excitation of the fetal brain, avoids the need to spatially encoding the maternal tissues, and using an EVI readout would greatly reduce the TR and therefore motion sensitivity. Moreover, the maternal tissue offers an optimal environment for EVI usage since B_0 field inhomogeneities are much less pronounced than in adult fMRI experiments because of the lack of air-tissue boundaries within the fetal head and the womb. Furthermore, T2* values were recently measured across the fetal brain and shown to be much longer than in the adult brain [5] paving the way for EVI applications.

In this work we have developed an EVI sequence featuring localised excitation [6], and test it on three adult volunteers and also performed a primarily acquisition test of the fetal brain *in utero*.

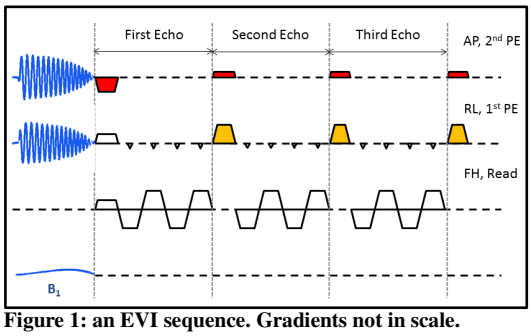

Figure 1: an EVI sequence. Gradients not in scale.

METHODS The data used in this study came from 3 healthy adults (males, age range: 24 to 33 years) and 1 fetus (gestational age of 30+4 weeks) who had been assessed as normal. Informed consent was obtained for all examinations. Scans were performed on a Philips (Best, the Netherlands) Achieva 3T scanner with 32 channel receiver coils – a head coil to image the ventricles in adult brain and a cardiac torso coil for fetal imaging. The ventricle region was chosen to ensure a good shimming and long T2*. To achieve EVI, an existing multi-echo EPI sequence was modified. This sequence is schematically represented in Figure 1; Pencil beam (PB) excitation gradients and B1 are shown in blue. These excite a cylindrical column aligned with the foot-head (FH) axis. A multi-echo EPI gradient pattern with readout along this axis and primary phase encoding (PE) along the right-left (RL) was augmented by extra PE gradients on the anterior-posterior (AP) axis (shown in red) to achieve EVI encoding. The number of PE lines was kept even to improve consistency between adjacent k-space planes [7], avoiding ghosting along the second phase encode direction. To achieve maximal encoding rate, ramp sampling was used on the EVI readout with 0.377 ms required per data line. Prior to testing on a fetus, the acoustic noise produced by the sequence was measured using a calibrated MR compatible microphone, but the sound level exceeded established local guidelines. A coarser resolution was therefore adopted allowing lower gradient amplitudes for the fetal test leading to a readout window per k-space line of 0.355 ms. For all localised acquisitions, the FOV was 200×100×100 mm^3, with an excited PB diameter of 70 mm and 15° flip angle. The FOV was encoded at a resolution of 3.5×3.5×3.5 mm^3 for the adult scans (matrix size 56×28×29, total readout time 348 ms) and 5×5×5 mm^3 for the fetus (matrix size 40×18×20, total readout time 154 ms). For comparison, multi-shot 3D EPI images (29 shots with TR = 500 ms for the adult cases and 20 shots for the fetus) with matching FOV and resolution to the EVI images were also acquired with a TE of 80 ms. Furthermore, to provide a visual anatomical reference to the adult cases, high resolution 3D multi-shot EPI images were acquired with a FOV of 240×200×240 mm^3, resolution of 2×2×2 mm^3 and TE of 80 ms. To minimize geometric distortions in all acquisitions, image-based shimming [8] was performed over the adult or fetal brains and the shim values kept the same throughout the exams. Each acquisition was accompanied by a B_0 field map that was acquired using a 3D dual gradient echo sequence with ΔTE = 2.3 ms and resolution of 5×5×5 mm^3.

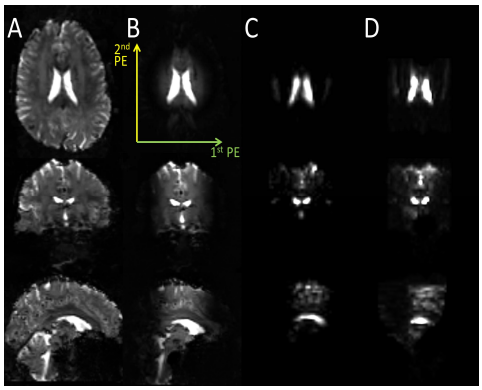

Figure 2: example of adult images. (A) 3D-EPI with large FOV. (B) 3D-EPI with large FOV and PB excitation. (C) 3D-EPI with small FOV and localized excitation. (D) EVI with PB excitation. Phase encode directions indicated in green (1st) and vellow (2nd).

3D-EPI and EVI data were reconstructed offline. Ghost correction along the first phase encode (RL) was achieved using a self-reference method as proposed in [9] and corrected for geometric distortions [10]: along the RL direction for the 3D-EPI data and considering only the slower PE direction for EVI.

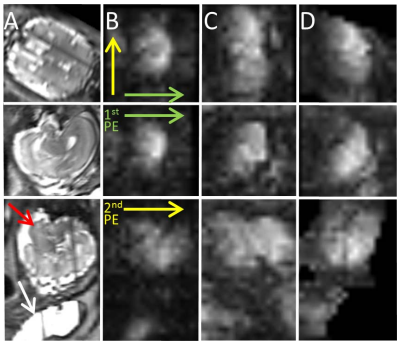

Figure 3: fetal images along orthogonal planes: (A) anatomical T2-weighted image showing the fetal brain (red arrow) and the mother's bladder (white). (B) 3D-EPI with PB excitation. (C) EVI. (D) EVI after distortion correction along the slow phase encode direction. Phase encode directions shown in green (fast) and yellow (slow).

RESULTS Acquisitions were successful in all three adult volunteers and in the fetal brain, although the quality of the achieved shim was poorer in the latter case; for example, for one of the adults, the average residual field after image based shimming was of 22±30 Hz within the brain (mean and standard deviation), whereas in the fetal case these values were 61±46 Hz. A possible explanation for this is that in the fetal case a very small region encompassing the head was used to shim which may have led to a sub-optimal solution elsewhere within the PB. Furthermore, since the fetus was moving substantially between sequences, it could have moved outside the shimmed area. Figure 2 shows the images from the same adult subject along the three orthogonal planes for high resolution 3D-EPI images with standard excitation (A) and with PB excitation (B), 3D-EPI image with 200×100×100 mm^3 FOV and 3.5 mm isotropic resolution (C), and matching EVI (D). Distortion correction was performed on all of these acquisitions enabling geometrical matching of the EVI to the 3D-EPI acquisitions. The fetal images (three orthogonal planes) are displayed in Figure 3 and include: a single-shot multi-slice Fast Spin Echo T2-weighted anatomical image as reference (A), the standard 3D-EPI image with localized excitation (B), the equivalent EVI image prior to (C) and after applying geometric distortion correction (D). Although the resolution of the images is coarser than the adult equivalent, it is still possible to identify the mother's bladder (white arrow) and the fetal brain (red arrow).

CONCLUSIONS By using EVI combined with localized excitation it was possible to scan the whole fetal brain within approximately 150 ms attaining a 5.0 mm isotropic resolution. The next step is to further optimize the sequence to reduce acoustic noise with less sacrifice in readout rate. Once this has been achieved, we plan to acquire resting state fMRI data on a group of fetuses, so as to test robustness to motion, and compare the recovered brain networks to those estimated using multi-slice 2D-EPI acquisitions.

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