An Evaluation of the Use of UFLARE for Rapid Acquisition of B_0 Field Maps for Undistortion of EPI

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Synopsis

Echo-planar imaging (EPI) is able to collect data very rapidly, which makes it particularly attractive for fMRI experiments. However, due to its low bandwidth in the phase-encoding direction, it suffers from geometric distortions caused by magnetic field inhomogeneity. A possible solution to this problem is to directly measure the field inhomogeneity by acquiring a field map and to use it to correct EPI distortion (1). The field map is proportional to the phase difference of two images acquired with different echo times (TEs), thus requiring some extra scan time that is dependent upon the sequence used to generate the field map. Although the use of EPI field maps has been proposed, the presence of geometric distortion in this data can result in a lack of signal where it is most needed and implies the use of some kind of interpolation to compensate for it. On the other hand, spin-echo and gradient-echo pulse sequences require longer acquisition times, which are undesirable in the context of fMRI. Ultra-fast low-angle RARE (UFLARE (2)), whilst characterised by high acquisition speed, has the advantage over EPI of being less sensitive to field inhomogeneities and therefore it is an ideal candidate for field map acquisition. This work evaluates the feasibility of B_0 field mapping for compensating echo-planar geometric distortions, using ultra-fast low angle RARE (UFLARE), and compares its performance with that of asymmetric spin-echo (asymmetric SE) and gradient-echo (GE).

Methods

All data were obtained on a 1.5 T SIGNA Horizon Echospeed scanner (General Electric, Milwaukee, USA). Initially, a phantom consisting of two bottles, one filled with water and one filled with oil, was used. The chemical shift between fat and water results in a signal displacement in an echo planar image, which mimics the effects of susceptibility gradients, while being spatially constant and thus measurable. The difference in the resonance frequencies of the two samples was estimated by collecting a spectrum using a localised, short TE, PRESS acquisition in a large voxel positioned across the two bottles. The same phantom was imaged using a single-shot EPI pulse sequence (TE=40ms, TR=6000ms, echo-spacing=832µs, matrix=64x64, slice locations=5, slice thickness=5mm). Three different kinds of field maps were also acquired, using a) two SEs with different TEs, the second having an asymmetric delay equal to half the difference in TE (total acquisition time=3min 36sec); b) two 2D GEs with different TEs (acquisition time=3 min 20 sec); c) two UFLARE sequences with different TEs (acquisition time=12 sec). The difference in TE was calculated in order to obtain a phase difference of $3/4\pi$ for the frequency shift between the oil and water measured by the MRS experiment. This delay was the same for all three field mapping sequences (ΔTE = 1.874 ms), in order to produce the same phase difference between pairs of images. For the UFLARE, the displaced version was used, retaining only the even echoes. Refocusing pulses of 135 were used, and 6 dummy cycles were discarded in order to reach the pseudo steady state. In the second acquisition the evolution delay was set equal to 1.874 ms to create a dependency of the phase on field spatial variation. Unwrapping of the phase difference was performed using the procedure described by Cusack and Papadakis (3), and maps of the pixel shift were created as described by Cusack et al (4), using a software package freely available (http://www.mrc-cbu.cam.ac.uk/Imaging/fieldmap_undistort). The actual pixel shift measured on the EPI images was then compared with the expected shift calculated from the frequency difference, and with the average pixel displacement estimated by the three field maps. Next, a healthy volunteer underwent a similar scanning protocol, using 24 slice locations in order to cover the whole brain. In this case, a ΔTE of 4.54 ms was chosen in order to minimise the chemical shift between water and lipids. For the EPI scan, a matrix of 128x128 and an echo spacing of 1536 µs were used. When covering the whole brain, UFLARE field map acquisition time was 42 sec. In-vivo EPI data were corrected using the above mentioned software package.

Results

The distance between the water and the oil spectral peaks was $\Delta\nu \approx 200$ Hz. The expected pixel shift (due solely to the central resonance frequency shift) on an EPI with an echo spacing of 832µs and a 64x64 matrix is therefore 10.5 pixels. The average pixel shift measured on the EPI images was approximately 11.0 pixels. The shift maps were of good quality for all three acquisitions. The average pixel shifts, measured in square regions of interest positioned in the middle of the two samples on the shift maps were, respectively: 11.1 pixels for the SE, 13 pixels for the GE, and 10.6 pixels for the UFLARE. In vivo experiments showed that with all three types of field maps the anatomical mismatch between EPI and high resolution anatomical images is minimised (Fig 1).

Discussion

We have shown that reliable whole brain field maps can be acquired efficiently using UFLARE, giving results in good agreement with theory and with those results obtained using well established field mapping acquisitions . This acquisition can be added to any fMRI experiment without any significant increase of the scanning time.

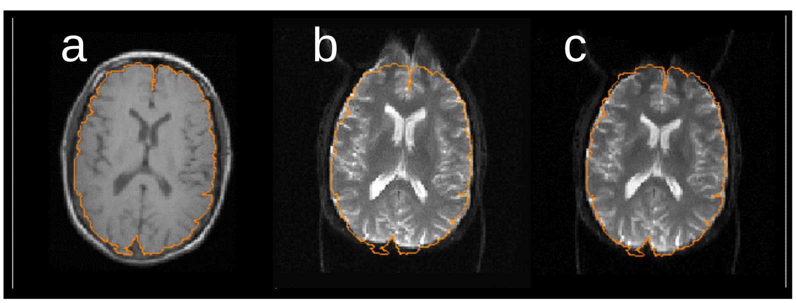

Fig 1. EPI correction using field-mapping: a) High-resolution anatomical image; b) uncorrected EPI; c) EPI corrected using UFLARE fieldmap.
The outline of the brain from the anatomical images is superimposed on the EPIs to show the improvement in shape match.

References

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