MPRAGE Using EPI Navigators for Prospective Motion Correction

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Introduction Previous work has demonstrated computationally efficient methods for rigidly registering EPI volumes to each other. This allows estimation of subject head motion that occurs between acquisitions of individual volumes within the TR where the motion occurred [1]. Normally these methods have been applied to EPI volumes with resolutions suitable for fMRI analysis. In contrast to this previous work, we have investigated applying these algorithms to low-resolution EPI volumes collected as navigators during the dead times in longer pulse sequences. In particular, we have focused on inserting 32^3 EPI volumes (FOV 256 mm), acquired in 3D with an EPI factor of 32, allowing us to measure a whole volume with satisfactory SNR in less than 500 ms. These navigators can be inserted into any larger sequence that has dead times of 500 ms or longer to allow for real-time motion correction.

Acquiring full image volumes as navigators allows us to avoid several pitfalls common in other navigators that sample less of k-space. In particular, we do not have to acquire initial maps [2], or be concerned about out-of-plane rotations [3] because of the availability of complete volume data. As a trade-off for acquiring a complete volume we must sample at substantially lower resolutions than most other navigators. However, theoretically this lower resolution is not an impediment to performing rigid registration – spatial resolution in the image domain controls aliasing in the Fourier domain of the magnitude image while quantization is the limiting factor in detecting shifts – and our experimental results confirm this.

MPRAGE sequences require long TI and TR in order to maintain optimal contrast between grey and white matter [5]. The large dead times in the sequence make it an ideal candidate for insertion of our EPI navigators. We use a 2 degree flip angle for the EPI acquisition in order to ensure the excitation developed by the MPRAGE is not unduly affected by the 32 extra excitation pulses per EPI volume. We insert the EPI acquisition after the MPRAGE inversion pulse and as close as possible to the MPRAGE readout block (partition encoding). We leave less than 100 ms between the end of the EPI readouts and the beginning of the MPRAGE readouts so that we can produce a new motion estimate from the most recent EPI navigator before beginning the MPRAGE readouts. This allows us to receive the feedback from the estimation algorithm and correct the location of the MPRAGE readouts to keep up with patient motion. This setup cannot correct for motion during the actual MPRAGE readouts, but compensates very well for infrequent motions, even if they are large, as the motion will at most corrupt one MPRAGE readout block before being picked up by the next EPI navigator.

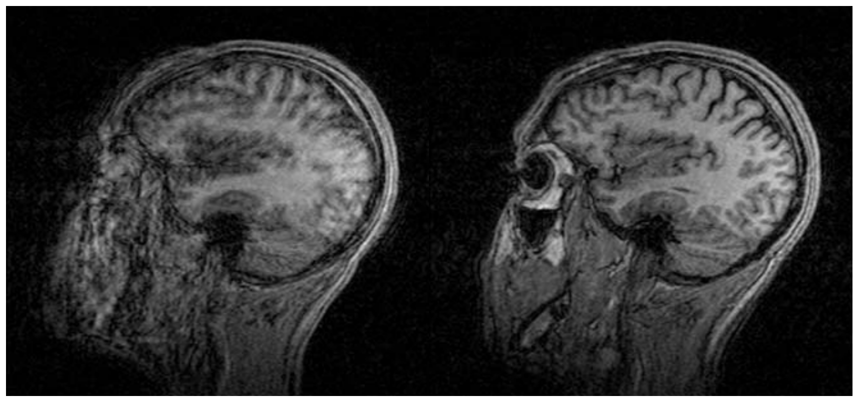

Figure 1. MPRAGE without correction (left), and with new EPI-based motion correction (right)

Methods & Materials Our sequence was run on a Siemens (Erlangen, Germany) 1.5 T Avanto scanner using a 12-channel head coil. Our EPI navigators had TE of 6.9 ms, TR of 14 ms, and a bandwidth of 3906 Hz/pixel, while the MPRAGE had TI of 1100 ms, TR of 2500 ms, and bandwidth of 195 Hz/pixel. Two separate MPRAGE volumes were acquired; in one the motion estimates were applied as corrections, in the other estimates were calculated but discarded. A healthy volunteer was imaged and was asked to perform a head motion approximately every 20 MPRAGE TRs. The subject was not informed of whether motion correction was being applied or not during the scan.

Results & Discussion The MPRAGE images acquired with motion correction off and on are shown in Fig. 1. The correction has significantly enhanced the ability to resolve anatomical structures since ghosting and blurring have been substantially reduced. We note that despite the extra EPI excitation pulses, the grey/white contrast in the MPRAGE images is still acceptable. The motion corrected volumes are suitable for segmentation in FreeSurfer [6].

Fig. 2 shows one EPI navigator image from our series. Due the low resolution of our volume we still have enough SNR to perform high quality motion estimates despite the high bandwidth and low flip angle. Additionally, despite the reduced tissue contrast in the navigator, we still find that there are significant features that the motion-estimation algorithm can rely upon.

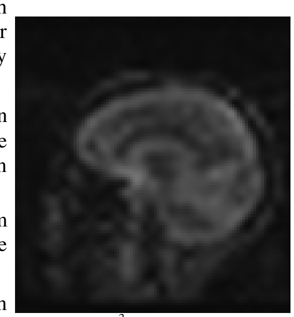

Figure 2. 32^3 EPI navigator

Conclusions We have demonstrated successful application of full-volume EPI navigators as a motion-correction technique in MPRAGE imaging. Our results show that our navigated sequence can substantially improve image quality when subjects make infrequent motions (max 8 degrees). The principal remaining challenge in this sequence is the correction of motion during the MPRAGE readouts. Our proposal can be extended to deal with this by putting a second EPI navigator immediately after the MPRAGE readouts and repeating acquisition of any MPRAGE k-space lines that are substantially motion corrupted [4].

More generally this application illustrates the possibility of using full EPI volumes as navigators in sequences with significant blocks of dead time. We have demonstrated that satisfactory EPI volumes can be acquired and registered in short enough time windows to make practical navigators.

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References

[1] S. Thesen, O. Heid, E. Mueller, L. R. Schad, "Prospective Acquisition Correction for Head Motion With Image-Based Tracking for Real-Time fMRI" MRM 2000 44:457-465 [2] A. J. W. van der Kouwe, T. Benner, A. M. Dale, "Real-Time Rigid Body Motion Correction and Shimming Using Cloverleaf Navigators" MRM 2006 56:1019-1032 [3] N. S. White, A. Shankaranarayanan, E. T. Hahn, A. Gaddipati, C. Roddey, A. M. Dale. Prospective Motion Correction Using Nonlinear Predictive Filtering, ISMRM 15th Scientific Meeting, Berlin, Germany, May 2007. [4] A. Shankaranarayanan, C. Roddey, N. S. White, E. T. Han, D. Rettmann, J. Santos, E. Schmidt, A. M. Dale. Motion Insensitive 3D Imaging Using a Novel Real-Time Image-Based 3D PROspective MOtion Correction Method (3D PROMO). ISMRM 15th Scientific Meeting, Berlin, Germany, 2007. [5] A. J. W. van der Kouwe, T. Benner, D. H. Salat, B. Fischl, "Brain morphometry with multiecho MPRAGE", NeuroImage 40:559-569 [6] Cortical Surface-Based Analysis I: Segmentation and Surface Reconstruction, Dale, A.M., Fischl, B., Sereno, M.I., (1999). NeuroImage 9(2):179-194