

Reducing distortion in EPI using partial Fourier encoding in the k_x -direction

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Introduction: It is often incorrectly believed that geometric distortion in echo-planar imaging (EPI) is related to the time of reading out the entire EPI train – rather than the time between two consecutive echoes in the EPI train, the latter which is the reciprocal of the pseudo bandwidth along k_y . Local displacements (in [m]) of an object in the phase-encoding direction arise according to [1]:

$$d_{pe}(r) = \frac{\gamma}{2\pi} \Delta B_0(r) T_{ro} FOV_{pe} \quad (1)$$

where $\Delta B_0(r)$ represents a field inhomogeneity, FOV_{pe} is the phase-encoding FOV, and $T_{ro} = N_{ro} * \Delta t_{ro}$ is the readout time for one k-space line (or echo spacing), and N_{ro} is the number of samples in the readout direction. From Eq. 1, one can reduce geometric distortion by reducing FOV_{pe} and/or by reducing T_{ro} . The former can be achieved by accelerating the traversal of k-space with parallel imaging [2-4], whilst the latter can be achieved by reducing the readout width N_{ro} .

To shorten the EPI readout and TE, the acquisition is often used with partial Fourier (PF) imaging in the k_y -direction. Particularly with higher field strength, the shorter readout train decreases blurring; while the smaller achievable TE increases SNR (offset by less data acquired per readout), increases the # slices/TR, and can decrease T2-shine-through in diffusion-weighted imaging for high matrix sizes.

In this abstract, PF-encoding in EPI is performed instead in the k_x -direction and compared with images acquired with PF in the k_y -direction. As shown in Fig. 1, the echo spacing between two consecutive echoes is reduced (Fig. 1b) – resulting in reduced geometrical distortion while keeping the SNR approximately equivalent. This approach can reduce geometric distortion by ~20% compared with EPI images acquired with PF in k_y .

| Method | TE/ T_{ro} | |
|--------|------------------|------------------|
| | 128 x 128 | 256 x 256 |
| A | 17ms/688 μ s | 20ms/916 μ s |
| B | 34ms/564 μ s | 68ms/712 μ s |

Table 1: Minimum echo time (TE) and echo spacing (T_{ro}) used for the two methods proposed in Fig. 1.

Materials & Methods:

Images were acquired using the two approaches shown in Fig. 1, where method A represents PF-encoding in k_y , and method B represents PF-encoding in k_x . GRAPPA-accelerated T2-weighted images were acquired on a phantom and on a healthy volunteer on a 3T whole-body GE EXCITE system (Waukesha, WI, USA; G = 40 mT/m, SLR = 150 mT/m/s) using an eight-channel head coil. Images were acquired using method A with $N_{oy} = 18$ and the alternative method B with N_{ox} (or ‘overscans in k_x ’) equivalent to 18 pixels. Images were acquired for both methods with a matrix size of 128 x 128 and 256 x 256 and with a TE and T_{ro} reported in Table 1. Other parameters were: a GRAPPA-acceleration factor $R = 3$; $NEX = 3$; a 4 mm slice thickness; FOV = 24 cm; TR = 4s, and a scan time of 16s. For SNR measurements, human brain images were acquired for each of the methods. Here, three repetitions and 24 slices were acquired using the same imaging parameters above, but with the same echo time (TE = 34ms for a matrix size of 128 x 128, and TE = 68ms for a matrix size of 256 x 256). For the post-processing stage, the ghost calibration [5] and GRAPPA weights [2-3] were calculated for each volume, followed by ramp sampling correction, homodyne reconstruction [6], and sum-of-squares over coils.

Results: Phantom data comparing the two alternatives is shown in Fig. 2. Zooming into the gridded region one can observe reduced distortion and blurring in B. There is also reduced distortion as indicated by the curvature of the black region. Brain data comparing the two methods are shown in Fig. 3. The distortion reduction achievable in B is most noticeable in the eyes, brain stem, and temporal lobes – as indicated by the white arrows. Although the TE is longer for method B, this may be preferred for some applications requiring T2- or T2*-weighting (such as fMRI). Measurements from human brain data revealed no significant difference in SNR between the two methods.

Discussion: A number of MR applications that require the use of fast imaging rely on EPI for its robustness to motion and short scan time. Perhaps the most predominant problem with EPI is that it can suffer from severe geometric distortion. Here we propose a relatively simple method to reduce distortion by performing PF encoding in the k_x -direction, instead of in the k_y -direction. Since geometric distortion is proportional to the readout width N_{ro} , for an equivalent scan time, geometric distortion can be reduced by ~20% compared to images acquired with PF-encoding in k_y . It would seem from Fig. 1 that a larger reduction should be achieved. However, the relation between N_{ro} and T_{ro} is not linear – due to differences in the amount of ramp times versus the plateau time [1]. Despite this, the reduction in distortion is noticeable in both the phantom and human data shown in Figs. 2 and 3. One disadvantage of this method is that the minimum achievable TE is longer (refer Table 1). However, in situations requiring T2- or T2*-weighting – where TE > 34ms for a 128 x 128 matrix size, and TE > 68ms for a 256 x 256 matrix size ($N_{ox} = 18$) – the SNR will be approximately equivalent for the two methods, as long as $N_{ox} = N_{oy}$. According to our SNR measurements calculated on images acquired with the same TE, the SNR is indeed approximately the same for both methods – despite that, due to ramp sampling, method B collects more sample points per k_y -line.

References: [1] Skare S. MRM 2006;55:1298–1307. [2] Griswold M. MRM 2002;47:1202-1210. [3] Qu P. JMR 2005;174(1):60-67. [4] Bammer R. MRM 2001;46(3):548-554. [5] Nordell A. ISMRM 2007:1833. [6] Noll DC. IEEE Trans. Med. Imag. 1991;10(2):154. **Acknowledgements:** This work was supported in part by the NIH (2R01EB002711, 1R01EB008706, 1R21EB006860), the Center of Advanced MR Technology at Stanford (P41RR09784), Lucas Foundation, Oak Foundation, and the Swedish Research Council (K2007-53P-20322-01-4). We would like to thank Bronwen Holdsworth, Heiko Schmiedeskamp, and Murat Aksoy for their help.

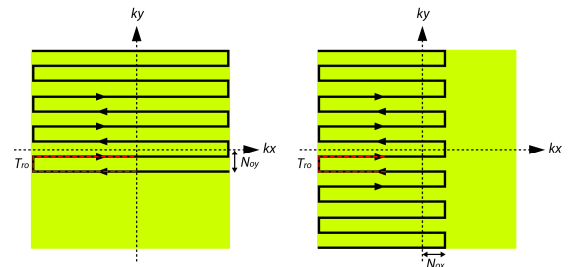


Figure 1. EPI trajectory with partial Fourier encoding in (A) the k_y -direction, and (B) the k_x -direction. In (B) the echo spacing (T_{ro} ; shown by the red-dashed lines) between consecutive echoes is reduced. N_{oy} and N_{ox} represent the ‘number of overscans’ in the k_y - and k_x -direction, respectively.

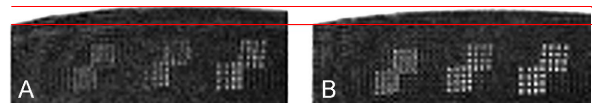


Figure 2. Phantom data acquired at a matrix size of 256 x 256 ($R=3$) with PF-encoding in (A) k_y ($T_{ro} = 916\mu$ s), and (B) the k_x ($T_{ro} = 916\mu$ s). The red line indicates the extent of distortion reduction by using B.

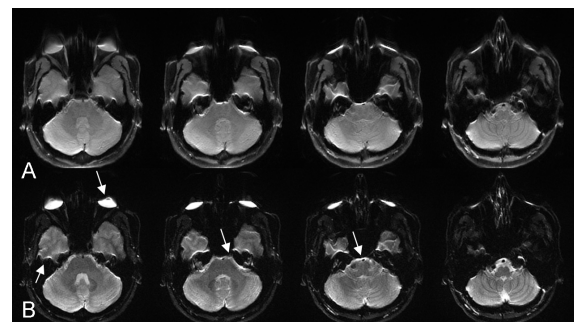


Figure 3. EPI images of a healthy volunteer acquired with PF-encoding in (A) k_y (TE = 20ms) and (B) k_x (TE = 68ms). Imaging parameters were: a matrix size of 256 x 256, FOV=24cm, TR=4s, $R=NEX=3$, scan time = 16s.