Will field shifts due to head rotation compromise motion correction?

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TARGET AUDIENCE Researchers and clinicians interested in motion correction and field mapping at ultrahigh field.

PURPOSE Ultrahigh field offers the chance to produce images with extremely high spatial resolution, but motion is a major barrier to using these sequences routinely in clinical populations. Different retrospective and prospective motion correction strategies have been proposed[1-2] but will all be compromised by the effects of changes in static field distribution with head position. This problem has been frequently tackled for single shot EPI time courses for fMRI where each acquisition provides a field map[3], but will be less tractable for multi-shot imaging sequences used for high spatial resolution imaging where local field shifts will not only cause distortion but also phase encoding artefacts distributed over the whole field of view. **Aim:** To characterise the size and location of B_0 field shifts within the brain at 7 T, for types of head movement likely to be encountered during patient imaging and hence determine whether these need to be accounted for in motion correction.

METHODS Data Acquisition: B_0 field maps data of the brain were acquired from 5 healthy volunteers on a 7 T Philips Achieva scanner (Philips Medical Systems, Best, the Netherlands) using a 32-channel receive array and a volume transmit head coil. A dual TE 3D GE sequence was used with 2 mm isotropic resolution, 300 x 300 x 200 mm^3 FOV, $TE_1/\Delta TE/TR$ = 5/4/15 ms and a flip angle of 12 deg. Each subject was imaged at 4 different head orientations to B_0: horizontal (reference orientation), two orientations produced by pitch rotation (by angles θ_1 and θ_2) and the orientation produced by roll (angle Φ), as indicated on ***Fig. 1***. Volunteers were instructed to perform relatively small rotations (the exact angle was not specified) and stay still in each orientation during the imaging**. Data Processing:** Phase images were unwrapped[4] to yield the field maps. The modulus images acquired at each orientation were co-registered using the FLIRT linear registration tool in FSL. The transform matrices were then applied to the field maps to bring them all into the same space. The angles of rotation were extracted from the rotational co-registration matrices. The field maps were masked with brain masks created using the BET brain extraction tool in FSL thresholding the magnitude images with a cut-off value of 20% of their maximum. Three B_0 field difference maps were produced for each subject by subtracting the co-registered field maps at each pitch and roll orientation from the reference orientation. **Analysis:** For each subject 8 different 5x5x5 voxel volumes of interest (VOIs) in the approximate location of the largest observed field changes were chosen (***Fig. 2***). The mean B_0 field difference within each volume was plotted as a function of the angle of rotation for roll and pitch separately (combined over all subjects) and the sensitivity of field change to angle of rotation was calculated from a simple linear fit.

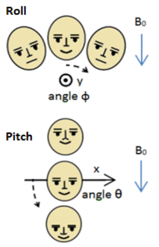

Fig. 1. *Pitch and roll axes and angles of rotation.*

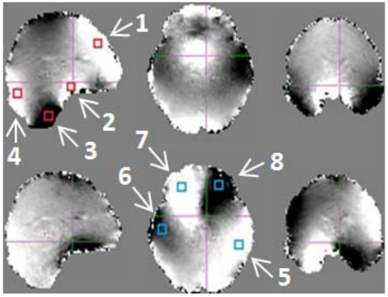

Fig. 2. *B_0 field difference maps for 2 head orientations,* ***TOP:*** *pitch* ***θ=7.87 deg***, ***BOTTOM:*** *roll* ***Φ=7.13 deg***. *Squares indicate VOIs (**red**: volumes 1-4; **blue**: volumes 5-8). Grey scale= -5 Hz to 5 Hz.*

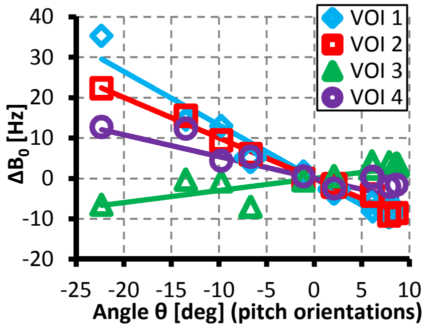

Fig. 3. *Figure showing mean field shift in the VOIs during* ***pitch*** *rotations.*

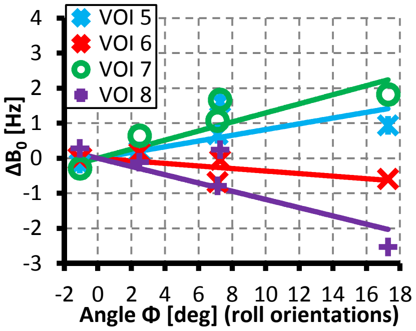

Fig. 4. *Figure showing mean field shift in the VOIs during* ***roll*** *rotations.*

Table. 1. *Linear fit parameters.*

VOI	Sensitivity [Hz/deg]
1	-1.32 ± 0.02
2	-1.00 ± 0.09
3	0.30 ± 0.17
4	-0.54 ± 0.20
5	0.08 ± 0.08
6	-0.04 ± 0.04
7	0.13 ± 0.06
8	-0.12 ± 0.09

RESULTS B_0 field difference maps were similar for all subjects and the exemplar maps at two orientations are shown in ***Fig. 2***. For pitch rotations (θ) the largest field change occurred in the centre of the frontal and occipital lobe (VOIs 1-2) and the bottom of temporal lobe and cerebellum (VOIs 3-4). The B_0 field difference in these VOIs varied linearly with the angle of pitch θ (***Fig. 3***). The sensitivity to rotation for each volume (with 95% confidence bounds) is shown in ***Table 1***. For the roll rotations (Φ) the field changes were significantly smaller and appeared in the left and right temporal lobes (VOIs 5-6), as well as in the bottom portion of the left and right temporal lobe (VOIs 7-8, ***Fig. 4, Table 1***). **CONCLUSIONS** This work shows that for rotations characteristic of the types of movements likely to be made by clinical populations (rotation angles <10deg) the field shifts will probably not exceed 10 Hz anywhere in the brain at 7 T. This is somewhat smaller than previously reported[3] (allowing for field strength difference) though this may be because the previous study used an EPI acquisition which will be confounded by distortions. These field shifts should be compared to a typical bandwidth per pixel of 100 Hz for 7 T high resolution MPRAGE sequence, suggesting that motion is not likely to lead to significant distortion. Image simulations will be used to determine whether these field shifts can also be neglected in terms of phase encoding artefacts in motion corrected data, though it seems unlikely. Since the field shifts are surprisingly consistent between subjects and show a linear change with rotation angle, an atlas of field shifts with angular displacement could be developed and used to correct k-space trajectories in non-Cartesian retrospective reconstructions of motion corrected data. However given the localized nature of the regions where significant field shifts are observed, then if not in the region of interest, such regions should be masked during image acquisition otherwise neither prospective nor retrospective correction strategies will correct images properly.

REFERENCES 1. Ooi et al. Magn Reson Med 2011; 66:73-81. **2**. Kochunov et al. HBM 2006; 27:957-962. **3.** Jezzard et al. HBM 1999; 8:80-85. **4.** Abdul-Rahman et al. Appl Opt 2007; 46:6623-6635.