**Target Audience:** Scientists and practitioners relying on EPI trajectories for their work in fMRI, DWI, or PWI, and scientists in general with an interest in MR methods development.

**Introduction**: Echo-planar imaging (EPI) sequences are widely used in BOLD fMRI. These applications suffer from rigid body motion, which results in image artifacts and misalignment if not accounted for. Several methods have been proposed to prospectively account for that by updating the scan geometry to the head's position in real-time[1-4]. These methods perform sequence update by tracking external optical[1-2] or NMR-based markers[3] that are rigidly attached to the object of interest. NMR based methods typically rely either on tracking modules inserted between imaging readouts, which however prolong the scan time and suffer from unreliable field behavior at low frequencies. Recently, it has been shown that NMR field probes can also be accurately tracked by inserting high-frequency sinusoidal gradient oscillations ("tones") into empty bands of an existing imaging readout[4]. The strengths of the tones approach include its robustness against low-frequency field perturbations (main field drifts, physiologically-induced dynamic fields). However, gradient tones demand additional amplitude and slew rate from the gradient system which are no longer available for the image encoding task, requiring compromises in the image encoding sequence design. This is a problem in neuroimaging applications where the use of the maximally available gradient performance is crucial for efficient image encoding. However, EPI readouts intrinsically contain considerable power in the high frequency range which can be readily exploited for robust field probe tracking and prospective real-time sequence update without any compromise in the image encoding design. In the present work, a novel method is proposed which extracts the field probe's coordinates directly from the high frequency content of an unmodified single-shot EPI readout for real-time prospective motion correction. The method is validated in vivo by comparing temporal SNR (tSNR) and residual root-mean-square error (RMSE) values between uncorrected and prospectively corrected acquisitions of a simple fingertapping experiment for fMRI.

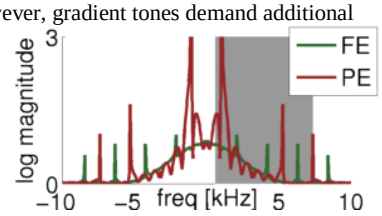

Fig. 1 Logarithmic spectrum of an EPI trajectory with the frequency band used for probe tracking (gray).

**Theory**: The spectrum of the derivative of an NMR field probe signal at position monitoring an EPI trajectory is given by $\dot{\phi}(r,f) = \gamma g_0(f) + \gamma \sum_{i=1}^{3} g_i(f) r_i$ (Eq. 1). $g_i$ denotes the complex-valued frequency component of the gradient waveform along the spatial dimension $l$, $g_0$ denotes its coupling into the homogeneous field component, $r_i$ denotes the probe's coordinates, $\dot{\phi}$ is the temporal derivative of the field probe signal, and the probe's gyromagnetic ratio. To calibrate the 4 unknowns, $g_{0-3}$, the field evolution needs to be measured at 4 known positions. Recovery of the field probe coordinates is obtained by solving Eq. 1 for $r_i$ via a linear least-squares inversion. The frequencies used for localization can be selected freely: For instance, they may be excluded in order to be robust against low frequency field perturbations or if they contain too little power.

**Methods**: The frequencies used for localization in the frequency encoding (FE) direction ranged between 600 Hz and 7.4 kHz, the ones in the phase encoding (PE) direction ranged between 2 kHz and 8.4 kHz, and a single frequency of 9.6 kHz was used for the tone. A sinusoidal gradient tone was added to the through-plane direction (nominal amplitude = 3 mT/m) for 3D position tracking. In vivo experiment In order to validate the method in vivo, the field probe array was mounted on a volunteer's head who was instructed to perform a directed fingertapping experiment with extended arm movement (10s off, 10s on, 15 repetitions) during a 300 s long series of EPI readouts (15 slices, TE = 35 ms, TR = 3s, slice update rate 5 Hz, resolution 2.5x.2.5x3.0 mm$^3$). Two repetitions were done, one with real-time sequence update and one without. The sequence update consisted of rotating all gradients and adjusting the RF excitation center frequency and was computed by performing a rigid body motion fit between the updated probes positions and the ones at the beginning of the scan. The probes positions were obtained using the proposed method. For the in vivo fMRI experiment, tSNR maps were calculated in Matlab and RMS errors of the general linear model (GLM) fit of the fMRI experiment were obtained with SPM8. Data are shown for two representative slices.

**Results**: Fig. 2a shows the motion in the case without motion correction and in the experiment corrected by the proposed method (2b). In both experiments, a strong correlation between the fingertapping paradigm is present. A slow drift is present in the uncorrected case. Fig. 3 shows tSNR maps for both experiments (3a corrected, 3b uncorrected) and Fig. 4 shows the RMSE maps of the same slices (4a corrected, 4b uncorrected). For both measures, the application of prospective motion correction using the proposed method yielded better results than in the uncorrected case.

**Discussion and Conclusions**: It is proposed to use the field evolution of the EPI trajectory itself to perform prospective sequence updates by measuring the positions of a field probe array. The method works without any modifications to the prescribed EPI gradients and allows to freely choose frequencies for probe tracking at which the MR system's field behaviour is reproducible, which renders it very robust against undesired field fluctuations. It is particularly applicable in neuroimaging applications such as fMRI. The results show that the application of the proposed method improves tSNR values and reduces the RMSE error of the GLM used in the SPM analysis. Another strength of the setup used in this work is its ability to account for undesired field fluctuations via concurrent field monitoring. This is particularly beneficial for quantitative analysis of fMRI time series suffering from dynamic field drifts stemming from system instability and from physiological activity.

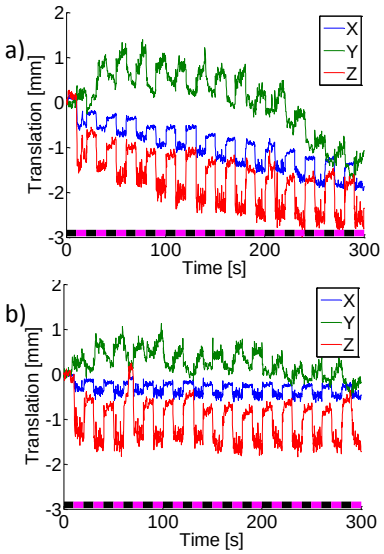

**Fig. 2** Translational motion of the subject during the experiment. **Top:** Motion correction OFF. **Bottom:** Motion correction ON.

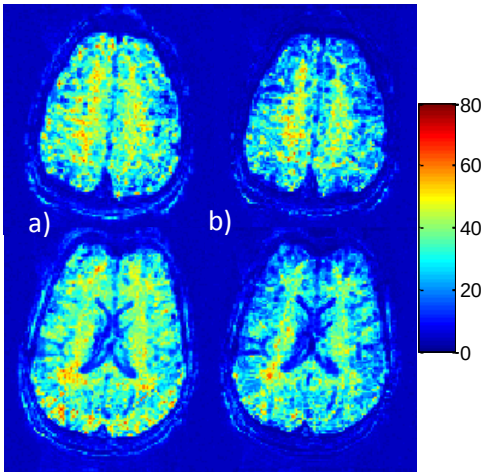

**Fig. 3** Temporal SNR for image time series. **Left:** Motion Correction ON. **Right:** Motion correction OFF.

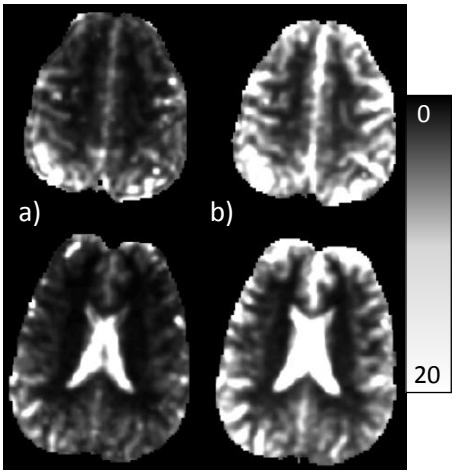

**Fig. 4** Residual mean squared error as obtained by SPM. **Left:** Motion Correction ON. **Right:** Motion correction off.

References: [1] Zaitsev et al. Neuroimage 31:1038–1050. [2] Aksoy et al. MRM 59:1138–1150. [3] Ooi et al. MRM 62:943–954. [4] Haeberlin et al. Procs. ISMRM, 2012, #595. [5] Barmet et al. Procs. ISMRM, 2010, #216.