Correction of fast motion by field monitoring in the head frame of reference

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Introduction: Rigid body motion can be corrected by updating the sequence geometry in real-time to the current position of the object of interest. This can be achieved by tracking the position of external markers rigidly attached to the object of interest[1-4]. In this fashion, it is possible to align successive image encoding readouts at a rate of 20-60 Hz. However, these methods assume negligible motion during data acquisition, which cannot be ignored in the case of fast motion during long readouts such as EPIs lasting several tens of milliseconds. Fast motion can be a problem with patients suffering from tremor, where the motion bandwidths reach 5 Hz or more[5]. Even in the case of consistent spin excitation, these methods fail because of a mismatch between the assumed k-space trajectory and the distorted effective trajectory in the moving object of interest. Hence it is necessary to know the dynamic field evolution in the moving object frame of reference. In this work, we show that concurrent field monitoring in the head frame of reference inherently corrects for very fast motion during a 40 ms single shot EPI readout. Results are shown for both a phantom and an in vivo brain scan.

Methods: All experiments were performed during the execution of an EPI readout (FOV = 0.21x0.21 m², $\text{resolution}_{\text{Phantom}}$=2x2x3 mm³, T_{Acq}= 40 ms, $T_{\text{R,Phantom}}$=1s, $\text{resolution}_{\text{in-vivo}}$=2.5x2.5x3 mm³, $T_{\text{R,in-vivo}}$ =3s). *Phantom experiment:* A spherical water-filled phantom was placed on a ring structure within the FOV of a 3T Philips Achieva system. An array of 4 ^{19}F NMR field probes[6] was rigidly attached to the phantom's surface for field monitoring in the phantom's frame of reference. 50 repetitions were carried out, in which the phantom was removed by hand from equilibrium and was then released to return therein during readout. Two of the 50 repetitions were selected for image reconstruction: one with strong motion and one where the phantom was not moved. Image reconstruction was done based on both the concurrently monitored dynamic field data and a calibrated k-space trajectory for comparison. *In vivo experiment:* The field probe array was put onto a head setup worn by a healthy volunteer who was instructed to shake his head to perform small, fast motion resembling tremor (approx. 5 Hz). 15 slices were imaged during a total acquisition duration of 180 s and real-time slice tracking was performed (update rate 5 Hz) based on the field probe data and using a method similar to the one proposed in Ref. 4. One slice in which strong motion was apparent during the readout (time = 45 s) was selected and image reconstruction was done based on both the concurrently monitored dynamic field data and a pre-measured reference k-space trajectory for comparison.

Results: Fig. 1 shows the measured rigid body motion parameters of the field probe array. Fig. 2 illustrates the effect of motion during the readout on the k-space trajectory in the moving phantom's frame of reference. A strong drift occurs between the beginning of the scan (top) and the end (bottom). Fig. 3 illustrates the same effect on image quality. In the case of motion, the image reconstruction based on a reference trajectory appears blurry and has strong ghosting (Fig. 3, bottom left). In contrast, concurrent field monitoring results in a sharp image and strongly reduces ghosting (Fig. 3, bottom right). To control for possible calibration errors, the corresponding image reconstructions are shown at the top of Fig. 3 when the phantom was at rest. Fig. 4 illustrates the result of the in vivo experiment in which strong ghosts occur if the image is reconstructed with the reference trajectory. Concurrent field monitoring in the head frame of reference again strongly reduces the ghosting (Fig. 4, bottom).

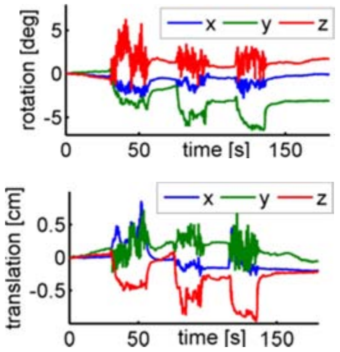

Fig.1: Tremor-like translational and rotational motion performed by the volunteer during the image acquisition.

Discussion: It is shown in vivo and in a phantom that concurrent field monitoring in the head frame of reference successfully corrects for motion during EPI readouts. The proposed solution can be used in applications with very fast rigid body motion, such as tremor patients.

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] Deuschl et Al. Movement Disorders 1998; 13:2-23. **[6]** Barmet et al. Procs. ISMRM, 2010, #216.

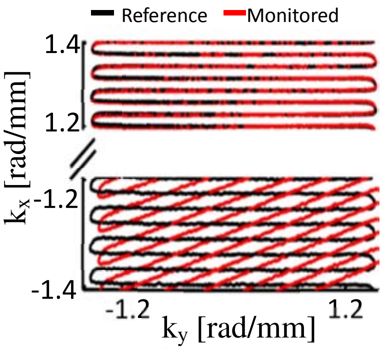

Fig.2: Upper and lower part of the measured k-space trajectory. Motion during the readout is reflected with increasing angle between the monitored and the reference trajectory.

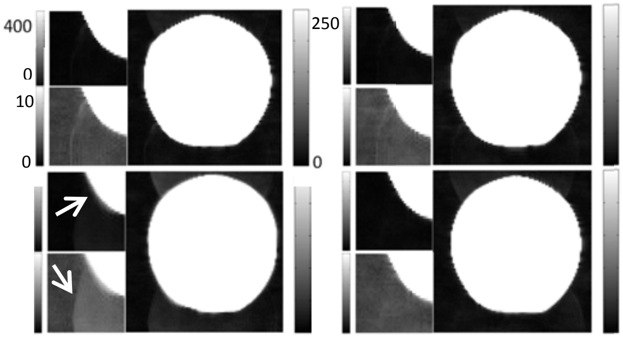

Fig.3: **Top left**: small ghosts are visible due to a slight error in reference trajectory calibration. The object appears sharp. **Bottom left**: Motion during the readout causes stronger ghosts and blurring at the object edge. **Top right**: No artifacts at rest if reconstructed with monitoring data. **Bottom right**: Field monitoring in the moving phantom's frame of reference clearly reduces ghosting and preserves image sharpness.

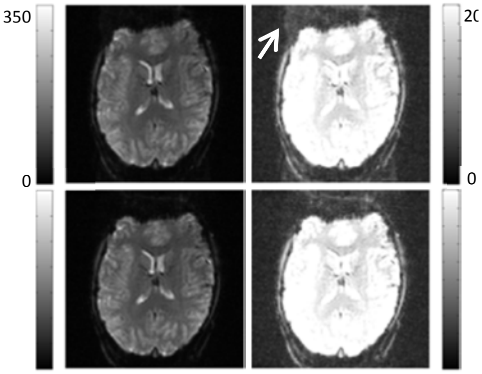

Fig.4 Bottom: Field monitoring-based image reconstruction of a single-shot EPI under motion. **Top**: Ghosting due to motion during the imaging readout reconstructed with the reference trajectory. The ghosts do not stem from trajectory calibration errors.