Adaptive FID-navigators for respiration monitoring in multi-slice fMRI applications

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Introduction: Functional magnetic resonance imaging (fMRI) measures activation-induced signal changes by means of the blood-oxygenation-level-depended (BOLD) contrast. Since signal changes are typically only 1-3%, the method is intrinsically sensitive to all signal instabilities including physiological noise from respiratory and cardiac cycles. Respiration induces a periodic B_0-shift [1-3], leading mainly to sub-voxel shifts in phase-encoding direction in single-shot EPI acquisitions. The observed B_0-fluctuation scales with the magnetic field and - in particular at fields ≥3T – may severely degrade the accuracy of the fMRI analysis. In this work, we propose a simple pulse sequence adaptation that enables a reliable and continuous monitoring of the respiration cycle sampling at ~10Hz. The respiration-induced B_0-shift is traced by monitoring the phase of the FID signal. After introduction of a slice-wise normalization, the method turns out to be thoroughly compatible with multi-slice acquisitions potentially substituting an often used respiration belt. The dynamic frequency information can be used to correct image position errors and to correct for residual respiration-induced fluctuations in subsequent post-processing steps.

Theory: The respiration-induced B_0-shift in the head mainly originates from the moving diaphragm and chest wall, and changing air volume in the lungs. As shown previously [1], the absolute B_0-shift decreases with distance from the lung (reciprocal cubic). In terms of a respiratory FID-navigator this has to be considered when performing multi-slice experiments. Moreover, the sensitivity can be adjusted by the choice of TE.

Methods: All measurements were performed on a clinical 3T scanner (Magnetom Trio, A Tim System, Siemens Medical Solutions, Erlangen, Germany). A FID-navigator ADC window was implemented in a GRE and an EPI sequence at variable TEs after RF-excitation. Evaluation of the FID-navigator is implemented in the image reconstruction environment (ICE) enabling real-time correction of the B_0-fluctuations. Navigator data of the first volume served as a reference for calculating changes in B_0 in successive volumes. Further low-frequency drifts in B_0 were cancelled out by applying a sliding window technique. For verification, a resting-state fMRI experiment was performed (TR/TE=3000/35, 120 scans, matrix=64x64) with additional breathing monitoring using a respiration belt. Resting state fMRI data were analyzed using FEAT in FSL. Spatial probability maps (SPM) were calculated using the time courses of the respiratory signal derived from the belt and the navigator, respectively.

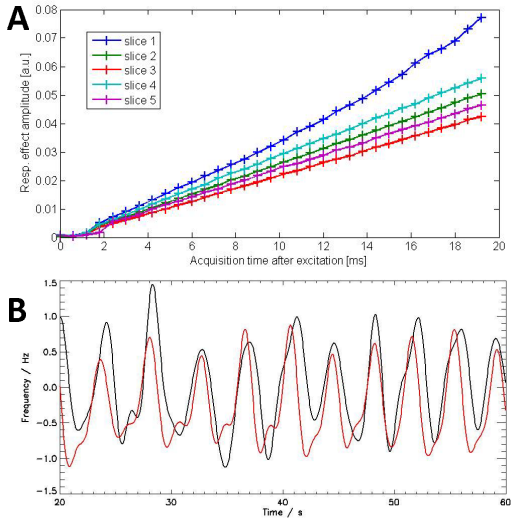

Fig.1. ***(A)*** *Respiration effect observed during FID-navigator acquisition between TE=2-22ms in 5 axial slices; respiration signal was sinus-fitted, plot shows the amplitude of the sinus for a GRE scan (note that the slices are interleaved).* ***(B)*** *Low-pass filtered respiration belt signal (red) and FID-navigator data (black). Belt signals normalized to the FID amplitudes.*

Results During initial investigations, the FID-navigator signals from the modified GRE sequence were investigated (5 axial slices, 3mm slices with 6 mm distance). In line with the expected decrease of the B_0 effect along the z-axis, results clearly exhibited decreasing amplitudes in the respiration-induced phase in cranial direction (fig.1a). For sufficient sensitivity, a FID-navigator echo time of TE=5ms was chosen for subsequent measurements with the EPI sequence. The FID-navigator phase during EPI experiments showed a good correlation (r=0.72) with the signals from the respiratory belt (fig.1b). SPM maps of a resting state fMRI experiment using (a) the signal derived from the FID-navigator and (b) the monitoring signal from the respiration-belt demonstrate very similar correlation pattern (Fig. 2).

Discussion and conclusion: Results demonstrate that the proposed technique provides accurate respiratory monitoring even in multi-slice EPI experiments. Extending previously suggested approaches [1-5], the proposed scheme enables correction of (a) global B0 shift in real-time during image reconstruction and (b) the correction of residual respiration effects in further post-processing steps (e.g. using additional regressor during fMRI analysis). For robust B0 calculation, a FID-navigator window with duration of 50-100 us and at an echo time ~5ms provides sufficient information. Thus, the overall performance of the sequence is not affected for typical EPI experiments. Since no respiration belt and user-interaction is required, the method proofs to provide a simple and robust way to acquire fMRI data of highest quality.

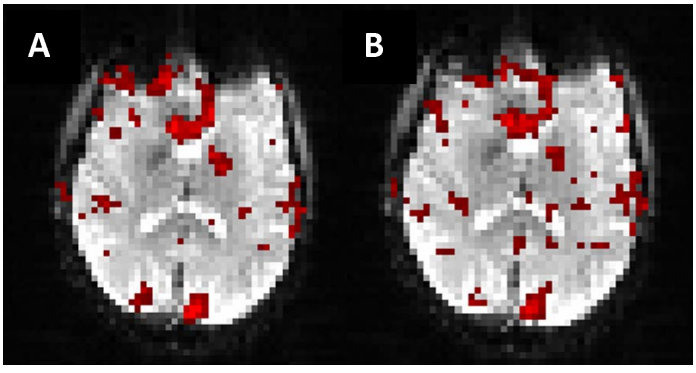

Fig. 2: *Spatial probability maps (z>3.2) are shown overlaid on the original fMRI.* ***(A)*** *Map using the navigator signal and* ***(B)*** *derived from the respiration belt. Both maps exhibit very similar correlation pattern.*

References

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