Higher-order monitoring of physiological field fluctuations in brain MRI at 7T
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Introduction: Signal encoding in MRI relies on spatially and temporally varying magnetic fields. Especially at ultra-high field strengths, the encoding process may be disturbed by slight field fluctuations originating in breathing and body motion of the subject [1-3]. It has been shown that resulting artifacts in brain images can be reduced by f0-demodulation based on navigators [3], or on concurrently monitored B0 and gradient evolutions using NMR field probes [4-6]. When the dynamic field source such as a moving chest wall is close to the imaging volume however, the field perturbations likely also include significant contributions from dynamic higher-order fields, accounting for residual artifacts in the images. To investigate these higher-order contributions, concurrent field monitoring of up to full 2nd-order spherical harmonics has been performed in this work. This added information enables higher-order image reconstruction [7] and may also improve conventional reconstruction by yielding more accurate estimates of the 0th- and 1st-order fields.

Methods: T2*-weighted anatomical GRE images (0.75x0.75x2 mm3, FOV 220x220 mm2, TE 25ms, TR 800ms) of the brain were acquired from three healthy volunteers on a 7T Philips Achieva whole body MR system. The subjects were instructed to perform different breathing or motion tasks during the measurements to create field perturbations of varying strength and spatial distribution. The tasks included: a) breathe normally, no motion; b) breathe deeply; c) breathe deeply with the upper part of thorax; d) move hand to upper sternum and back to the leg; e) move hand to chin and back to the leg; f) shrug the shoulders. For concurrent magnetic field monitoring [5], 13 fluorine NMR probes were mounted on the outside of a 16-channel receive head-coil (Nova Medical, MA, USA), in an approximately cylindrical arrangement. Probe signals were acquired via receive channels of the MR system after conversion to the proton carrier frequency by analogue RF mixers (ZX05-10L+, Mini-Circuits, NY, USA). To assess the effect of linear and higher-order field monitoring, image reconstruction, including f0-demodulation, was performed based on:

1) 0th- and 1st-order reference fields, monitored without the subject in the scanner (‘uncorrected’)
2) 0th- and 1st-order concurrently monitored fields, obtained from a subset of 4 probes (‘4 probes’)
3) 0th- and 1st-order concurrently monitored fields, obtained from a 2nd-order fit on data from all probes (‘13 probes’)
4) higher-order reconstruction [7] including the 2nd-order concurrently monitored fields (‘higher-order’).

Results: As expected, moving the perturbation source closer to the imaging volume caused larger field perturbations with significant higher-order field components (Fig. 1), and correspondingly more severe artifacts in conventional images. The most prominent artifacts consisted of ghosting and strong intensity modulation in the image, consistent with previous observations [3,4]. For moderate field perturbations, such as caused by deep breathing or moving one hand to the sternum, reconstruction based on 4-probes monitoring was sufficient to largely recover good image quality (Fig. 2). Images acquired in the presence of larger field perturbations, such as chest breathing, shoulder and hand-to-chin movements, were additionally improved by performing first-order reconstruction based on monitoring with 13 probes (Fig. 3). However, residual artifacts were still observed, partly even causing the 13-probe data to be inferior to the 4-probe data in regions of the image (Fig. 3, detail). In the case shown in the figure, these artifacts were successfully eliminated by higher-order reconstruction. For the most severe perturbations, none of the reconstruction approaches recovered good image quality, which may partly be due to subtle motion of the imaging slice.

Conclusion: The results of this investigation suggest that higher-order field fluctuations caused by physiological motion can significantly contribute to artifact formation in long-TE scans. In these cases, mere f0-demodulation is not sufficient to recover image fidelity and even first-order field monitoring is limited by the underlying field model. Higher-order field monitoring has been found to improve these situations significantly, yielding best results in combination with higher-order image reconstruction.