Higher-order feedback field control improves linewidths in MR spectroscopy at 7T

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Introduction: A homogeneous and stable magnetic field within the volume of interest is a crucial prerequisite for most MR spectroscopy experiments. To establish a homogeneous field, static B_0 shimming is commonly performed before the scan. However, hardware imperfections (magnet instability, eddy currents) and physiological effects due, e.g., to breathing or cardiac motion can cause dynamic field perturbations that cannot be addressed by static shimming. Dynamic field fluctuations can cause inaccurate spectral alignment when averaging data [1] and also inherent signal loss by increased T_2* decay and off-resonant application of RF pulses (water/fat suppression, excitation and refocusing), which cannot be corrected retrospectively.

To diminish this problem, f_0 frequency readjustment can be implemented, e.g. by B_0 detection using non-water-suppressed acquisitions interleaved with the MRS scan [2]. Yet this method is limited by its low temporal resolution and to the correction of 0^{th} order (global) field changes only, moreover requiring additional scan time. A specific solution for breathing-related field changes was proposed by B_0 shim modulation using dynamic B_0 reference data in conjunction with a breathing belt [3]. This method relies on reproducible breathing and field patterns and requires additional scan time for the B_0 reference scan. Alternatively, it was recently proposed to measure physiological field changes by means of magnetic field probes and dynamically update the B_0 shim fields based on such measurements [4,5]. A general spatiotemporal solution for the correction of field perturbations originating from outside the probed volume was recently introduced by a higher order real-time field stabilization system based on NMR probes [6]. In this work the system was extended to run concurrently with MRS sequences, and was tested for the application in single-voxel brain MRS at 7T.

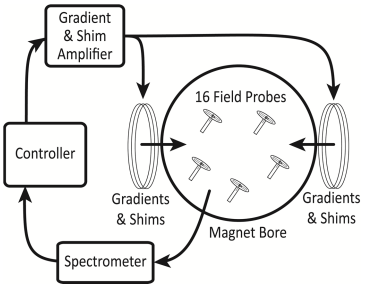

Fig.1: *Schematic of feedback system*

Methods: Setup: All experiments were performed on a 7T MRI system (Achieva, Philips Healthcare, Best, NL). For real-time shim feedback (Fig.1), 16 fluorine based T/R NMR field probes were mounted cylindrically between the 1H transmit coil and the 32 channel receive coil (Nova Medical, Wilmington, USA). After probe excitation, the signal was acquired on a custom built spectrometer [7]. The field value at each probe position was calculated by linear regression of the phase evolution over 2 ms on the controller PC, which was connected to the gradient and shim amplifiers (Resonance Research Inc., Billerica, USA) via a digital-analog converter.

Field feedback: Field stabilization is achieved in two steps. For calibration the gradient and shim field responses in all probes are measured by successively applying a fixed input voltage to each shim channel. During the MRS scan the field is repeatedly measured in each probe. A discrete proportional-integral (PI) controller [6] is used to calculate the field required to correct for deviations from a desired reference field. This correction field is applied by updating the voltages to the gradients and shims according to the calibrated responses.

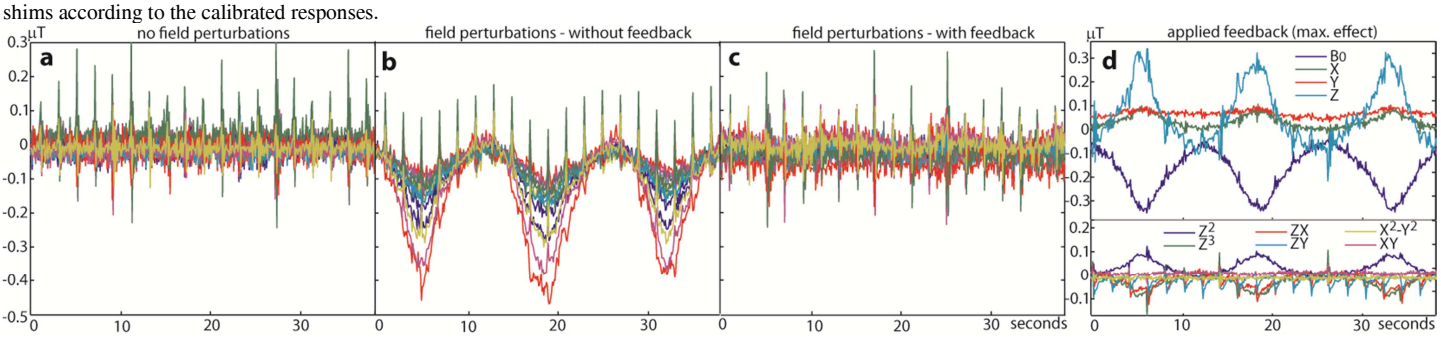

Fig. 2: *Field measurements in 16 probes during the phantom experiments (a-c). a: Scan without field perturbations, b: Scan with field perturbations, but without feedback stabilization. c: Scan with field perturbations and feedback stabilization. d: Applied gradient and shim terms to stabilize the field. The plots are scaled to show the maximum field excursion over all probes relating to each gradient/shim coil.*

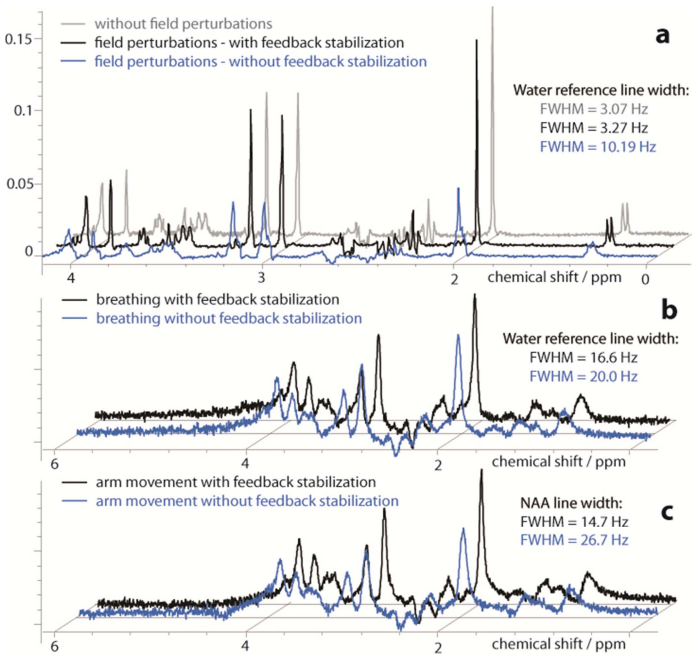

Fig. 3: *Phantom (a) and in-vivo (b,c) data with and without feedback*

MRS measurements: Single-voxel PRESS experiments (TE=35ms, TR=2000ms, Voxel=$(2cm)^3$, VAPOR water suppression, 128 averages) were carried out in a spherical MRS phantom and in the brain in-vivo (visual cortex). Probe excitation and acquisition (TR_{probe}=100ms, T_{acq}=2ms) was performed interleaved with the sequence in periods where no RF pulses or gradients were applied. In the phantom scans field perturbations equivalent to breathing were induced by moving a water bottle (5L) periodically between 54 and 65cm distance from the phantom along the z-direction. In-vivo, perturbations were caused by breathing and by the subject moving a hand to the chin. The scans were performed three times: without field perturbations (phantom only), and twice with field perturbations, once with and once without field stabilization.

Results and Discussion: As expected, the phantom scan without field perturbations shows a constant field evolution in all probes (2a). The spikes visible in all field measurements (2a-c) are likely related to minor mechanical gradient oscillation induced by a sequence gradient. The moving water bottle induced typical breathing-like field changes in the probes (2b), which can be largely corrected (2c) by feedback stabilization (2d). Only for the fast gradient effects, the feedback bandwidth was insufficient. In the phantom, greatly improved spectral quality is achieved when turning on feedback stabilization, which is also reflected in the FWHM of the water reference (3a). Similarly, feedback stabilization yielded improved SNR and narrower line-widths in both in-vivo experiments (3b,c).

Conclusion: Higher-order feedback shim control improves field stability and linewidths in high-field brain MRS. The method is most valuable at high field and in combination with baseline shims of high-quality. Along with single-voxel MRS, it holds promise also for improving the robustness of MR spectroscopic imaging.

References: 1: Bolan et al MRM 52(6): 1239-45. **2:**Klose et al MRM 14, 26–30, **3:**van Gelderen et al MRM. 57:362–368, **4:**Pruessmann et al U.S. patent 7,208,951 **5:**Boer et al ISMRM2012:143, **6:**Duerst et al ISMRM2012:216, **7:**Dietrich et al. ISMRM2012:700