Fast 3D B_1 mapping with single-shot EPI

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Introduction

Accurate field mapping is integral to the success of ultra-high field MRI. Knowledge of the spatial variations in transmitted RF fields (B_1^+) allows for the calibration of RF pulse amplitude, guides the design of adiabatic and other B_1^+-insensitive pulses, and enables real-time pulse designs that capitalize on parallel transmission technologies (e.g., spectral-spatial excitations and RF shimming). Maps of the receive field (B_1^-) permit post-proccessing image intensity corrections and facilitate the design of RF coils for high-field applications. Static field variations (ΔB_0) maps are used in an array of applications from RF pulse calibration to post-processing image distortion correction. One of the challenges currently facing high-field MRI research is the fast acquisition and calculation of all such field map data without sacrificing accuracy of the measurements. Here, we demonstrate a workflow for measuring/calculating all relevant fields at 3×3×5 mm resolution through the entire human brain in less than three minutes at 7 T. This approach differs from previously reported fast mapping protocols in that a single-shot EPI read-out is employed such that a multi flip-angle fitting technique can be utilized to calculate the RF fields without the time penalty associated with long TR, non EPI sequences.

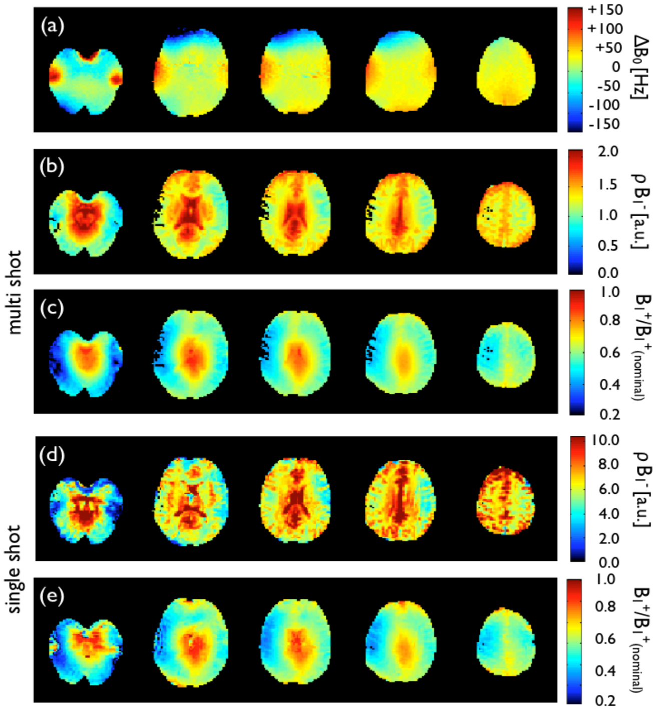

Fig. 1: In-vivo data (5 axial slices): ΔB_0 maps used in EPI distortion correction (a); ρB_1^- maps (b) and (d) (multi-shot) and B_1^+ maps (c) and (e) (single-shot) obtained using fitting method of data acquired with multi-shot and single-shot EPI read-out, correspondingly. High-frequency spatial noise apparent in (d) and (e) is due to single-shot EPI artifacts and low SNR.

Methods

In our field mapping protocol, we first measure ΔB_0 in the brain of a healthy human subject using a 3D GRE scan (3×3×5 mm resolution, 33 axial slices, $T_R = 4.0$ ms, flip angle = 10°) with a double echo acquisition ($T_{E,1} = 1.6$ ms, $T_{E,2} = 2.6$ ms) and 2nd order static shimming. Total scan time is 16 s. ΔB_0 is calculated from the phase difference of the two acquisitions and the known ΔT_E of 1 ms. RF field mapping is based upon a voxel-by-voxel, least-squares fitting of signal intensity from a multi flip-angle series of GRE images—a method previously adopted to generate B_1^+ maps for sparse spokes RF pulse designs [1,2]. In addition to accuracy, this technique has the benefit of returning an estimate of the collective quantity ρB_1^- as one of the fitting parameters. The main disadvantage of this fitting-based approach to measuring B_1^+ and ρB_1^- is the lengthy scan duration required to accommodate ≥10 dynamics with varying flip angles while keeping T_R long enough that the resulting signal is independent of T_1 relaxation. To overcome this limitation, we use a single-shot EPI read-out. Moreover, due to the long T_R (5 s) of the sequence, this ultra-fast read-out allows a multi-slice scan to be performed with no slice gap such that the entire brain is covered (33 axial slices, 5 mm thickness) without increasing total scan duration. This RF map scan used the same geometry as the ΔB_0 data along with flip angles of 10° to 210° in 20° steps for a total of 11 dynamics. Total scan time is 65 s. Given the B_0 variations in the brain at 7 T, dramatic distortions result from the use of single-shot EPI; however, the ΔB_0 map acquired with identical static field shimming can readily be used to make the necessary EPI distortion corrections [3]. This post processing step and the least-squares fitting are performed in Matlab (The MathWorks, Natick, MA) and take approximately 60 s for a total scan + processing time of ~2.5 minutes. For comparison/validation, we perform RF mapping utilizing multi-shot EPI (EPI factor = 3, scan time = 19.5 min.) during the same scan session.

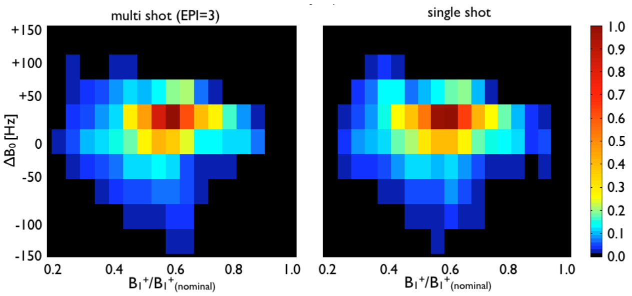

Fig. 2: Relative number of voxels of the 3D B_1^+- ΔB_0 in-vivo data, acquired with multi-shot (left) and single-shot (right) EPI read-out.

Results and Conclusions

A sample of axial slices from all field maps is presented in Fig. 1. Values of ΔB_0 largely fall in the ±150 Hz range with the largest deviations occurring near the frontal sinuses and the ear canals. Single-shot EPI B_1^+ maps are qualitatively similar to those acquired with the low EPI factor; however, small-scale variations are apparent in regions of maximum ΔB_0 and reflect imperfections in the EPI distortion correction. Measurements of ρB_1^- differ more noticeably between the single- and multi-shot scans, but, again, variations occur mostly on a small spatial scale. The highly localized nature of these differences suggests that single-shot RF field maps may benefit from the application of a 2D low-pass filter. Overall, the estimated geometry of both B_1^+ and ρB_1^- maps is preserved under single-shot acceleration despite a ~20-fold reduction in scan time. This fact is reflected in the 2D voxel histograms of Fig. 2 which show the distributions of ΔB_0 and B_1^+ throughout the brain to be quite similar. The combination of techniques presented here thus appears to be a practical tool given the existing demands for fast and accurate field mapping.

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References: [1] K. Setsompop et al., JMR 195: 76 (2008); [2] M. Jankiewicz, et al., JMR 203:294 (2010); [3] Jezzard, P. et al.: MRM 34: 65 (1995).