

SNR Optimization of MION fMRI in the anaesthetized monkey using an 8-channel PA-coil and accelerated imaging

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Introduction: Noninvasive imaging tools such as fMRI are very useful for studying sensory and cognitive processing in macaque monkeys. The use of the contrast agent MION (monocrystalline iron oxide nanoparticle) improves the CNR and spatial sensitivity of the MR signal changes [1], [2]. Contrary to BOLD contrast for which the maximum CNR is typically found at TE values of 30ms at 3T, maximum CNR for MION contrast is found at very low TE values below 15ms but can be optimized for a given TE by adjusting the injected dose. The minimal attainable TE, however, is limited by the sequence and the resolution, and typical scan parameters using a single loop coil in a 3T scanner are found at TR/TE=4000ms/24ms at 1.25mm isotropic resolution [3]. Furthermore, for a given TE value the optimum CNR is found at MION concentrations, which decrease the MR signal by 50% [1] further restricting optimization of the data acquisition. In this work we will demonstrate that improvements can be made using a multichannel phased array receive coil with smaller coils and accelerated data acquisition, which allows us to significantly lower TE below the value given for non-accelerated data acquisition. The improvement can be characterized by a figure of merit, FOM, which, for optimized CNR levels, can be written as a function of SNR and TR for a fixed MION concentration and spatial resolution: $FOM = SNR/\sqrt{TR \cdot S}$. Here, the SNR depends on TE (T_2^* -relaxation) and on the g-factor for a given acceleration rate R. The factor $1/\sqrt{TR}$ reflects the increase in statistical power due to a shorter minimum repetition time TR at increasing acceleration factors. The factor S is a sensitivity factor and reflects the SNR related to the number and size of coils used. This study will focus on the gain in SNR, which can be achieved by optimizing TE and TR through use of accelerated imaging.

Methods: We have developed a single loop (d=12cm) and an 8-channel phased array coil (d=3.5cm), which fits tightly on the head of anaesthetized juvenile male rhesus monkeys [4], and carried out measurements for both coils using a Trio 3T clinical scanner (Siemens Medical Solutions, Erlangen Germany). Data for SNR measurements have been collected with transmitter power on and off using a proton density weighted 3D-GRE sequence (TR/TE=5ms/2ms, 1.25mm isotropic resolution, 160mm FOV, 128x128 and 56 slices). These GRE images were used as sensitivity maps to simulate g-factor maps by a 1D-SENSE simulator [8]. Non-regularized as well as regularized ($\lambda=0.5$) g-factors were calculated [5]. For the optimization of SNR at different TE and different acceleration rates, EPI data with transmit power on and off were collected at fixed 1.25mm isotropic resolution, TR=2800ms, and flip angle of 86° for a MION concentration of 10mg/kg. The raw data were obtained and reconstructed offline using a SENSE reconstruction algorithm [6] at a fixed TE of 28ms (R=1-3) as well as at the minimum TE for a given acceleration rate R (R=2: TE_{opt}=20ms; R=3: TE_{opt}=17ms). The SNR was calculated from a signal map and the corresponding noise map, the latter was measured with the transmitter off. After reorganizing the volumes in small cubes (4x4x4 voxels) local statistics were used to calculate the noise standard deviation [7]. The noise maps of the single loop and the individual 8-channel coils were scaled to same magnitude and the same scale factors applied to the signal maps. SNR profiles were computed based on a simulation of the B1-field for comparison with the experimental data (fig.1) [8].

Results: Figure 1 shows a comparison of the calculated and measured SNR profiles in a monkey brain (right to left). There is an increase in SNR for the 8-channel coil compared to a single loop coil at the peripheral sides of the brain (on average 50% gain in cortex) while at the center the SNR levels are similar. We find good agreement between the measured profiles and the simulated intensity curves (fig.1: green lines). This gain reflects a gain in sensitivity S of the multi-channel coil over the single loop coil. Figure 2A shows a U-shaped ROI along the cortex of the brain, for which we calculated FOM_{Mr}=FOM/FOM(R=1) as a relative measure used for the optimization of parameters TE and TR. Figure 2B-D shows the noise maps obtained for different acceleration rates (R=1, 2 and 3). The mean g-factor for 2- and 3-fold acceleration in this ROI is 1.09 and 1.32, respectively. The effect of the g-factor on the noise maps due to the offline SENSE reconstruction becomes visible as the acceleration rate increases, leading to an associated rise in noise. Without any optimization of TE or TR (fig.3: green curve) this leads to a decrease in SNR (and thus also in the FOM_{Mr}) if accelerated imaging is used. Using regularized SENSE reconstruction the values of FOM_{Mr} are found above the values expected from theory [2]. When scanning at the minimum TE the $1/(g \cdot \sqrt{R})$ loss in SNR due to acceleration is largely compensated for (fig.3: red curve). Further optimizing TR we find a significant enhancement of FOM_{Mr} if the minimal achievable TR is used (R=1: TR_{opt}=2770ms; R=2: TR_{opt}=1710ms; R=3: TR_{opt}=1350ms, fig.4: light-blue curve), leading to an overall gain of 60% compared to the non-accelerated case for two and threefold acceleration.

Discussion: Our results confirm that the use of multi-channel coil technology for accelerated EPI offers significant improvements for fMRI data acquisition at high resolution. Here we have demonstrated that accelerated imaging in combination with a contrast agent such as MION allows an additional optimization of parameters TE and TR, resulting in a further increase of FOM_{Mr} (60%) on top of the 50% increase in SNR due to the enhanced coil sensitivity of the 8-channel coil. This leads to a combined gain factor of almost 2.4 averaged over cortex and can be used to obtain higher resolutions. On a standard Siemens Tim Trio we reached values of TR/TE=2000ms/19ms, 1mm³ using a standard sequence and 3-fold acceleration, which sufficiently suppresses in-plane distortions and improves image quality for awake monkey fMRI.

References and acknowledgements:

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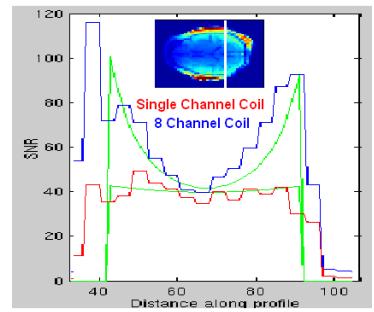


Fig.1: SNR profiles from 2 coil designs, no acceleration.

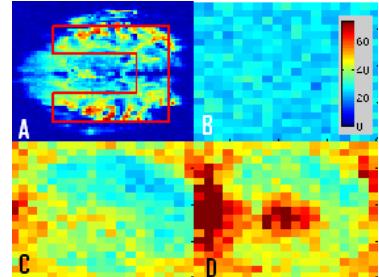


Fig.2: A: EPI image with ROI indicated, B-D: SENSE reconstructed noise maps for acceleration rate: 1, 2 and 3 at optimal TE.

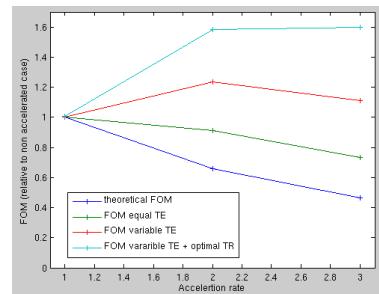


Fig. 3: FOM_{Mr} as a function of acceleration.