Compensating for Field Strength with Coils; Comparison of SNR at 1.5T, 3T and 7T with 12 and 32 Channel Arrays

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Introduction: Sensitivity in MR detection generally comes at considerable expense; either through higher field strength magnets, or through close-fitting highly parallel detection arrays which utilizes additional RF hardware and image reconstruction infrastructure. Despite the considerable costs of both approaches, the tradeoffs between them for increasing sensitivity is little studied. While presumably the most sophisticated close-fitting coil at the highest field strength is always the most sensitive, what are the trade-offs that can be expected for other choices? Can a 1.5T 32ch array improve at least some aspects of sensitivity compared to a 3T magnet with a more modest 12ch array? In this abstract, we evaluate image Signal-to-Noise Ratio (SNR) for anatomical imaging and time-series SNR (tSNR) for fMRI across three field strengths (1.5T, 3T and 7T) as well as channel count (12ch and 32ch) to inform the tradeoff between these two approaches.

Methods: Data from two healthy subjects were acquired using the product 12 and 32 channel head coils on the 3T TIM Trio and 1.5T Avanto system and a 7T system (Siemens Medical Solutions, Erlangen Germany.) The 7T images were acquired with both a band-pass volume birdcage coil (28cm dia. 20cm length) and a home-built 32ch array of similar element layout as the product 32ch coil. Since intrinsic sensitivity was desired (as opposed to contrast changes), image SNR (SNR0) was evaluated in proton density (PD)-weighted GRE images acquired with same parameters at all field strengths; voxel size 1x1x5mm3, TR/TE/flip=100ms/4.4ms/7o and 15 slices. The use of array data requires a more complex analysis to generate an accurate SNR0. SNR0 maps were therefore calculated using the method of Kellman et.al [1,2] to account for the effective noise bandwidth on the noise estimates and the effect on the noise distribution due to the combination of magnitude images collected from multiple channel coils. Array data was combined with the root Sum-of-Squares (rSoS) method and with the optimum combination (which incorporates the noise correlation information.)

To evaluate the SNR relevant to fMRI, fully-relaxed resting state EPI images were collected using a single-shot gradient echo EPI sequence at four in-plane resolutions ($1.5x1.5mm^2$, $2x2mm^2$, $3x3mm^2$, $4x4mm^2$) with TR=5400ms, 60 time points, and 15 slices. To insure practical relevance, the TE was chosen to optimize BOLD contrast at each field strength. Time-course SNR maps were then estimated from the EPI time-series as the ratio of the mean pixel intensity across time points to the temporal standard deviation. A 3D T_1-weighted structural scan was acquired (MPRAGE) to facilitate brain tissue parcellation into gray, white and basal ganglia using FreeSurfer software [3]. SNR_0 and tSNR measurements were evaluated in these ROIs and compared across arrays and field strengths.
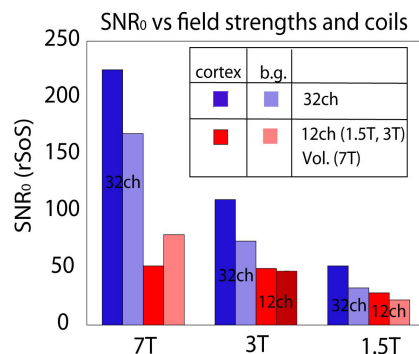

Figure 1:SNR_0 (rSoS combination) for the 3 field strengths and coils.
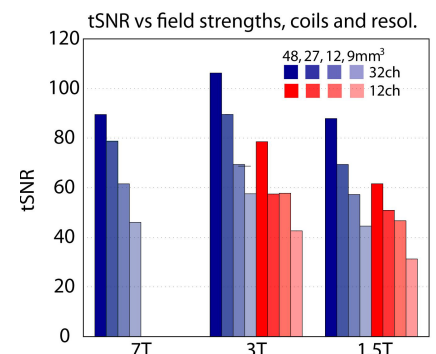

Figure 2:tSNR (rSoS combination) for the 3 field strengths and coils.

Results and Discussion: Figure 1 shows image SNR for the cortical and basal ganglia ROI across coils and field strengths. The data shows the basic linear relationship as a function of field strength (for similar coils) and a sensitivity boost for the higher channel coil at a given field strength for cortical regions. For the basal ganglia measure, the benefit of moving from 12ch to 32ch at 1.5T and 3T was minor, as expected since the center of the head reaches 100% of the ultimate capability of electromagnetic detection in the center at a relatively low number of elements. However, for the cortical ROI, the RF investment (e.g. moving from 12ch to the 32ch) provided a larger sensitivity boost than the field strength approach (moving to a higher field strength). For example, the sensitivity of the 32ch 1.5T array was 1.05 fold higher than the 3T 12ch. Similarly the 3T 32ch was 2.12 fold the sensitivity of the 7T birdcage volume coil. For the basal ganglia measurements, the field strength approach yielded higher sensitivities.

Figure 2 shows the time-series SNR (tSNR) from a resting state functional acquisition of various spatial resolutions across coils and field strengths. When the time series is thermal (image) noise dominated, we expect the same general relationship as for the SNR0 comparisons. However, as SNR0 is improved, physiological noise becomes increasingly important and improvements in image sensitivity from either field strength of RF detector are expected to play a smaller role. Nonetheless, for a given field strength, switching to the 32ch coil improved the tSNR for all of the resolutions. For a given coil, increasing the field strength also improved tSNR, with the exception of the 7T, which had lower tSNR. This results contradicts our previous work comparing field strengths (using single channel coils), where we saw the expected asymptotic behavior, but not a decrease. We are investigating the cause of this discrepancy which might have arisen from a coil instability. For the 1.5T and 3T measurements, while both higher field and more channels increased tSNR, the RF approach provided the larger gain. For example, the 1.5T 32ch array provided 1.12, 1.21 fold higher tSNR than the 3T 12ch array for 48mm3 and 27mm3 resolutions.

In a study such as this one, the ability to compare "apples to apples" is limited. Furthermore, it is therefore important to keep in mind that important contrast changes (many beneficial) occur with higher field and that the close fitting arrays have some drawbacks such as inhomogeneous sensitivity, longer reconstruction times, ease-of-use issues (although well tolerated in patient settings) and reduced space for audio headphones. Highly parallel arrays also have some benefits, not evaluated in this study, such as improved ability to accelerate image encoding.

References: 1)Kellman P.,et al.MRM, 54(6):1439-1447, 2005, 2)Erratum to Kellman et al. MRM, 54(6):1439-1447, 2005 3)Dale A.M., et al. Neuroimage, 9 (2):179–194, 1999 4)Wright PJ.,et al. MAGMA. 2008 Mar;21(1-2):121-30.