Improving Sensitivity in Low SNR Diffusion Imaging Using Optimal SNR Coil Combinations

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Introduction Multi-channel coils are ubiquitously used for neuroimaging due to their higher signal-to-noise ratio (SNR) compared to volume coils as well as the potential to reduce distortions and decrease acquisition time through the use of accelerated parallel imaging. Root sum-of-squares (SoS)[1,2] is the standard method for combining the reconstructed image data from multi-channel coils including both unaccelerated and generalized auto calibrating partially parallel acquisitions (GRAPPA). SoS coil combination implicitly assumes that the pixel intensity is a reasonable estimate of the coil sensitivity profile at that location and that the noise in the channels is uncorrelated[1,2]. While this may hold true for acquisitions with high SNR and ideal arrays, acquisitions such as those obtained for high b-value and/or high spatial resolution diffusion tensor imaging (DTI), q-ball and diffusion spectrum imaging (DSI) produce intermediate images with very low SNR and then combine many of these to produce higher SNR estimates of the diffusion environment. In this work we demonstrate improved sensitivity to diffusion anisotropy measures by using simple coil sensitivity estimates based on the high SNR b ≈ 0 images as well as a quick determination of the noise covariance to improve the channel combination for diffusion-weighted images (DWIs). These robust methods add minimally to the scan time but can significantly impact diffusion measurements.

Methods DTI data were acquired on a 25 year old, female with no known pathology using a 32-channel receive coil on a Siemens 3T Tim Trio. The acquisition consisted of 2D DW-SE-EPI with TE/TR=105/10210 ms, b=1000 s/mm^2, 12 diffusion-encoding orientations, BW = 1920 Hz/pixel, resolution = 1 mm x 1 mm x 2 mm, 8 averages. Coil images were combined in two ways: 1) using SoS[1] 2) using optimal SNR (optSNR) coil combination which takes into account the noise-covariance between coils and weights the coil combination according to coil sensitivity profiles[1]. The noise covariance matrix was estimated from a 20 second noise-only acquisition (i.e., without RF excitation), which was corrected for the effective noise bandwidth of the receivers[2]. Coil sensitivity profiles were derived from a b ≈ 0 image that was filtered using a Gaussian 15x15 kernel with standard deviation = 5 pixels. FA values were generated from a standard tensor fit. Bedpostx (www.fmrib.ox.ac.uk/fsl/) was used to generate probability density distribution of principal diffusion orientation (V1) that was then used to estimate the 95% uncertainty angle. Q-ball data were acquired on a 32 year old male with no known pathology using a custom-built 32-channel receive coil and G_{max}=80mT/m AC88 head insert gradients on a Siemens 3T Tim Trio. The acquisition consisted of 2D DW-SE-EPI with TE/TR=70/3500 ms, b = 3000 s/mm^2, 80 diffusion-encoding orientations, BW = 1906 Hz/pixel, resolution = 1.5 mm isotropic. Diffusion orientation distribution functions (dODFs) were generated at each voxel using the spherical harmonic basis[3].

Results FA estimates were on average 30% higher when using optSNR coil combination compared to SoS. The optSNR combination also yielded an 8% decrease in the average 95% uncertainty of V1 and detected 60% more crossing fibers (749 versus 469 for slice shown in Fig.1). The q-ball data (Fig. 2) yields markedly improved SNR for the each raw DWI and much more slender and coherent dODFs.

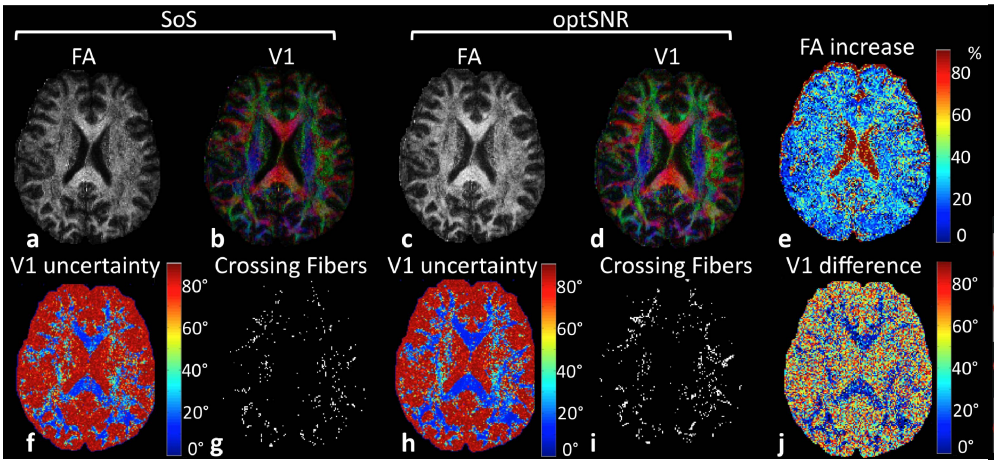

Figure 1: Diffusion tensor imaging and probabilistic tractography measurements using SoS and optSNR coil combination methods. For SoS: a) FA b) directionally encoded colour (DEC) map of principal diffusion orientation (V1), f) 95% uncertainty on V1, g) map of detected crossing fibers. For optSNR: c) FA, d) DEC of V1. The percent increase in FA for optSNR compared to RSS is shown in e). The angular differences between V1 estimated from SoS and optSNR images is shown in j).

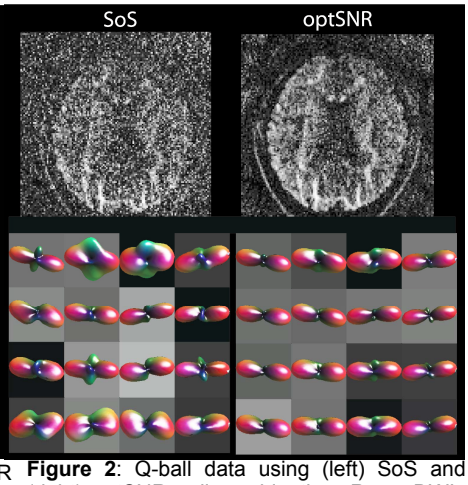

Figure 2: Q-ball data using (left) SoS and (right) optSNR coil combination. Raw DWIs (top) and dODFs from a region in the genu of the corpus callosum (where fibers run putatively left - right without intravoxel crossings) (below) for each method.

Discussion The penalties associated with SoS coil combination increase with the number of receivers[4] and therefore it is only with the recent, more widespread adoption of 32-channel receive coils that the choice of coil combination method has started to seriously impact diffusion measurements. The increase in FA found for optSNR coil combination is in agreement with the previously observed squashing peanut phenomenon[5], which causes an underestimate of indices of diffusion anisotropy when DWI signals are close to the background noise level. Coil combination effects are also most significant for images with signal that is very close to the background noise level such as those with high spatial resolution and/or high diffusion-weighting. Optimal SNR coil combination requires only 20 seconds of additional scan time (for the noise correlation acquisition) and is a very simple and quick image reconstruction. It therefore should be the method of choice for low SNR DWIs acquired with N_{ch}>8 receiver channels[6].

Acknowledgments/References Funding for this work was provided by a CIHR Fellowship and NIH grants P41RR014075 and R01EB006847. The authors acknowledge helpful discussions with Dr. Kawin Setsompop and Thomas Witzel. (1) Roemer et. al. *MRM* 16 (1990). (2) Kellman P. et. al. *MRM* 54 (2005). (3) Descoteaux M. *MRM* 58 (2007). (4) Wiggins G. et. al. *MRM* 62 (2009). (5) Jones DK et. al. *MRM* 52 (2004). (6) Wald LL. Wiggins G. Book Chapter 44, *Parallel Imaging in Clinical MR Applications*. Springer. New York (2007).