

Spatial Normalization Can Morph RF Coils into Geometries Optimized for fcMRI Studies in Specific Brain Regions

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Target Audience: MR Hardware Engineers

Background and Purpose: With a phased array of radiofrequency (RF) coils placed around a subjects head, the overlap of magnetic fields (B-fields) enables one to sub-sample the spatial information of the brain, generating aliased coil images that are reconstructed with techniques such as SENSitivity Encoding (SENSE)¹. The effective depth of sensitivity for each coil in the array is proportional to the width of the coil, and thus a uniform overall B-field sensitivity profile is achieved using “birdcage” arrays comprised of rectangular coils that have left/right and top/down symmetry. SENSE reconstructed images are known to have a reduced SNR due to both the sub-sampled spatial frequency signal and an amplified noise caused by an overlap of coil B-fields, commonly measured through the geometry factor (*g*-factor). In functional connectivity MRI (fcMRI), brain regions that exhibit a significant correlation in spontaneous low temporal fluctuations of blood oxygenation are deemed functionally connected. However, recent studies have shown that the SENSE unfolding of aliased coil images artificially induces a non-biological correlation between previously aliased voxels that can corrupt the conclusions drawn in fcMRI studies². As both the *g*-factor and SENSE induced correlations (*corr*_{SE}) are greatest in areas with the highest level of aliasing, and many degenerative brain disorders are commonly associated with specific regions of the brain that may reside in those regions, the use of a generic/symmetric coil array may not be optimal for all fcMRI studies. The goal of this study is therefore to morph a conventional birdcage array of rectangular coils into an arrangement that simultaneously minimizes both the *g*-factor and *corr*_{SE} within a region of interest (ROI) using spatial normalization³ with sine and cosine basis functions.

Methods: A 42×42×42 voxel FOV was simulated for a brain phantom in the center of $N_C=8$ rectangular coils in Fig. 1a. The ROIs represented by the three green ellipsoids in Fig. 1b simulate the Default Mode Network (DMN), and were positioned in areas that would be aliased prior to a SENSE reconstruction with a reduction factor of $R=3$. Assuming bilateral symmetry within the brain, and a fixed coil radius of $r=14$ cm, the left half of the coil in Fig. 1a was “unrolled” onto a 2-dimensional Cartesian plane in which the horizontal ϕ -axis has a period of $p_\phi=\pi$, and represents the angle of displacement from the center of the rear coil at $\phi=-3\pi/2$ to the center of the first (red) coil at $\phi=\pi/2$, while the vertical z -axis has a period of $p_z=2r$ and represents the length of the coil. With each coil represented by a collection of 22 connected vertices with initial (ϕ, z) locations⁴, $(J_\phi=5) \times (J_z=5)$ 2D basis functions, $B(\phi, z, j_\phi, j_z) = 2(p_\phi p_z)^{-1} \sin[\pi j_\phi (\phi - \pi/2) p_\phi^{-1}] \cos[\pi (j_z - 1) z p_z^{-1}]$, were used to shift the coordinates of each vertex into new locations through $\phi_{new} = \phi - \sum_{j_z}^{J_z} \sum_{j_\phi}^{J_\phi} T_\phi(j_\phi, j_z) B(\phi, z, j_\phi, j_z)$ and $z_{new} = z - \sum_{j_z}^{J_z} \sum_{j_\phi}^{J_\phi} T_z(j_\phi, j_z) B(\phi, z, j_\phi, j_z)$. Starting with a birdcage array, $T_{\phi/z}=0$, an iterated conditional modes (ICM) algorithm⁵ was used to vary and ultimately determine T_ϕ and T_z for the array that simultaneously optimized the *g*-factor and *corr*_{SE} in the DMN ROIs. Biot-Savart was used to estimate the coil B-fields over the entire volume in each iteration.

Results & Discussion: The array that jointly minimized the *g*-factor and *corr*_{SE} in the ROIs is presented in Figs. 1b and 1c. As the DMN ROIs extends through the regions of greatest aliasing, the optimal deformation in Fig. 1c shifted the rectangular coils into an array with coils that are wider at the top in the anterior and posterior and wider at the bottom on the left and right. Switching from a birdcage array in Fig. 1a to the optimized array in Fig. 1b lowered the overall *corr*_{SE} from 0.46 to 0.35, and when comparing the center plane through the ROI's, the *g*-factor for the optimal array in Fig. 1e was lower on average to birdcage array in Fig. 1d.

Conclusion: Most brain disorders are associated with specific brain regions, creating a natural need for RF coils to be purpose built to optimize the statistical properties of fcMRI data within those regions. As the brain is not fully symmetric, using a generic/symmetric birdcage array for studies with an ROI that is either off-center or in an aliased area will not be optimal. While the proof of concept for using spatial normalization with an ICM optimization algorithm has been demonstrated here for an array of $N_C=8$ coils and an ROI resembling the DMN, this procedure can be used for an arbitrary number of coils and any ROI. Additionally, while Biot-Savart was used in this study, a software package such as HFSS can be used to generate more realistic B-field estimates for higher field strengths.

References: 1. KP Pruessmann et al. MRM 42:952-962, 1999. 2. IP Bruce et al. MRI 30:1143-1166, 2011. 3. J Ashburner, KJ Friston, HBM 7:246-266, 1999. 4. G Chen et al. MRM 186:273-281, 2007. 5. JE Besag, J of Royal Stat Soc, Series B 48(3):259-302, 1986.

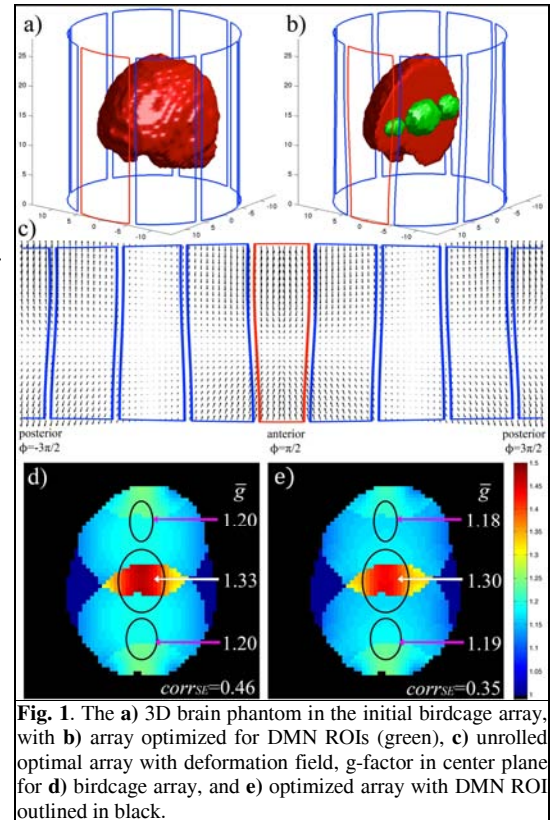


Fig. 1. The a) 3D brain phantom in the initial birdcage array, with b) array optimized for DMN ROIs (green), c) unrolled optimal array with deformation field, *g*-factor in center plane for d) birdcage array, and e) optimized array with DMN ROI outlined in black.