Squashing the g-factor: Ultra high scan acceleration factors in reduced Field of Excitation imaging

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Motivation Parallel imaging using SENSE (1) is routinely used to shorten MR scans. Separately, efforts have been made to reduce the Field of Excitation (rFOX) to the desired region of interest to facilitate reduced Field of View (rFOV) imaging (for faster scanning) (2,3) and/or to avoid artifacts from nearby moving tissue (4). In this work, we explore the combination of both methods, in part suggested by Coristine et al (5). We show that the unfolding capabilities of SENSE can be improved in scans where spin excitation is reduced along two directions.

Theory In SENSE imaging, the acquisition time is shortened by undersampling the k-space. The resulting folded images are unfolded using the spatial sensitivity distributions of the receive coils. Voxels outside the imaged object, with insignificant signal contribution, are usually excluded from the reconstruction (6). This reduces the local degree of aliasing and, as a result, the reduced system matrix used for the unfolding step has a lower condition number. The unfolded image will show a lower noise level. The noise perturbation from the unfolding is quantified by the g-factor, which relates to the SNR of the image as $SNR(R)=SNR^{full}/[g(R)\sqrt{R}]$. R is the acceleration factor, SNR^{full} is the SNR without SENSE acceleration and $\sqrt{R}$ is the signal loss inherent to acquiring fewer data points. In rFOX scans, many more voxels can be excluded from the unfolding process if their locations are known, leading to a far better posed inversion problem, lower g-factor and thus even lower noise in the obtained image compared to a full FOX image.

Experiments SENSE acceleration factors of 3x3 and 5x5 (APxRL) were used to scan a healthy volunteer on a 7 T MR scanner (Philips) using a 32 channel receive coil (Nova Medical). The FOX was limited in the transverse plane by using a 2D SSE RF pulse that was designed to excite an elliptical shape with axis lengths of 1/3rd the dimensions of the head. Several 3D FFE scans were acquired in sagittal orientation, covering the complete head, with TR/TE: 75/25ms, FA: 15˚, EPI factor: 9, resolution: 0.5 mm isotropic. Also, an rFOV image was acquired with the FOV matching the excitation profile. SENSE reference maps were acquired with regular RF excitation pulses (full FOX, scan time: 1m6s) and with the 2D SSE RF pulse scaled to 1˚FA (rFOX, scan time: 2m28s). Raw data was reconstructed offline using the ReconFrame platform (Gyrotools, Zurich, Switzerland) in MATLAB (The MathWorks, Inc., Natick, Massachusetts, United States). G-factor maps for a number of acceleration factors were calculated based on the SENSE reference maps. Their mean values over the rFOX were used to estimate the SNR.

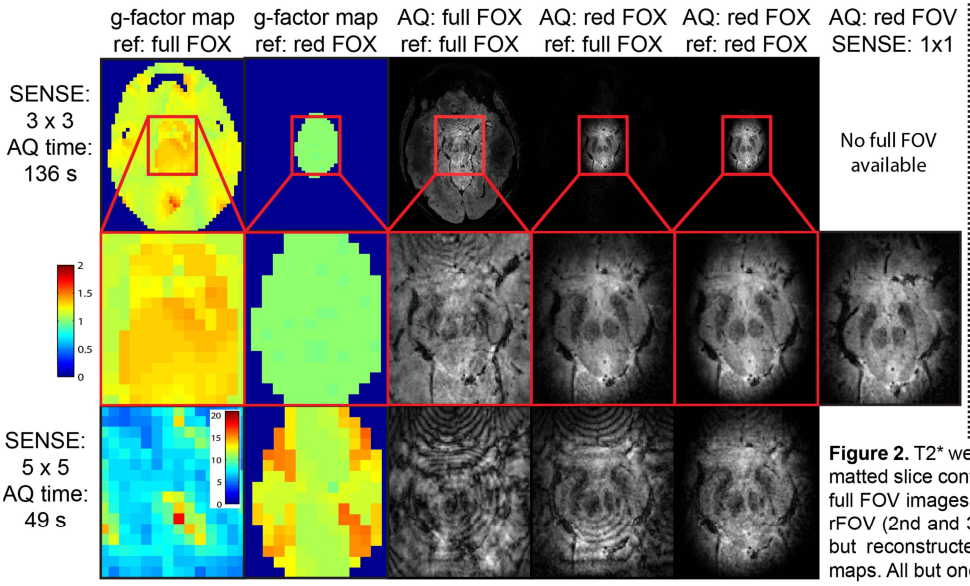

Figure 2. T2* weighted images and g-factor maps of a transverse reformatted slice containing the substantia nigra and the nucleus ruber. The full FOV images (1st row) are cropped around the rFOX, similar to the rFOV (2nd and 3rd rows). The rFOX acquisitions were scanned once, but reconstructed both using the fullFOX and the rFOX sensitivity maps. All but one of the g-factormaps are color coded from 0 to 2.

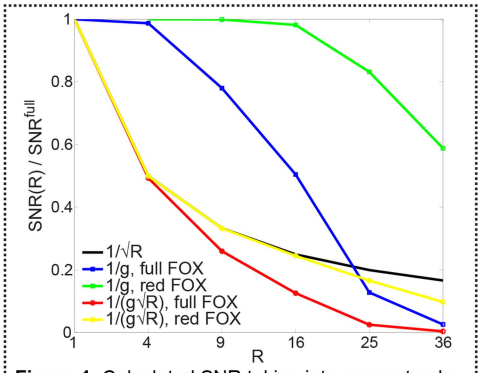

Figure 1. Calculated SNR taking into account only √R or g, and their combined contribution to the SNR, for reference maps with full and reduced FOX.

Results Fig.1 shows that the SNR of the rFOX reconstruction (yellow line) stays close to the 1/√R-line of theoretical maximum SNR. The red line for the full FOX reconstruction decreases much more rapidly. Fig. 2 shows the same: the g-factor remains below 2 even at a 25-fold acceleration combined with rFOX, compared to ~10 at full FOX. Thus, a significant gain in SNR can be expected at high acceleration factors. This is reflected in the T2* images: those acquired using rFOX at SENSE 3x3 show a much better image quality than the full FOX SENSE accelerated images. Even greater improvements are observed at SENSE 5x5, in the images that are reconstructed using the reference map acquired using rFOX. As expected, the rFOV image is of similar quality as the SENSE accelerated scan of the same acquisition time.

Discussion Highly accelerated scans benefit from rFOX inclusion in the SENSE image reconstruction. In practice, the usefulness shall depend on the specific geometries that are excited, also with respect to the spatial distribution of the receive coils. Also, the SNR of the unaccelerated scan should be high enough to support the inherent 1/√R-loss in SNR. Without g-factor penalty, the SNR of a SENSE accelerated acquisition is the same as a scan in which the FOV is reduced by the same factor. If the signal suppression outside the rFOV is not perfect, it will fold back into the image. We expect the selective SENSE approach to be able to unfold this unwanted signal to its spatial origin, at the cost of a slight g-factor penalty in SNR, making it preferential over the rFOV approach. The scan time of the reference map was increased as result of the longer RF excitation pulse, this might be avoided by masking the full coil sensitivity data with a predicted rFOX. We reduced the FOX by using 2D SSE, but in theory the extended voxel exclusion technique is also applicable to any other scan in which the FOX is limited, for instance by spatial saturation.

Conclusion Including the rFOX in the SENSE reconstruction results in a substantial reduction of the g-factor penalty in SNR and enables highly accelerated scans. Images of good quality were obtained at a 25-fold acceleration, using a 32-channel receive coil.

References **1**. Pruessmann KP *et al.* Magn. Reson. Med. 1999;42:952–62, **2**. Schneider JT *et al.* Magn. Reson. Med. 2013;69:1367–78, **3**. Abd-Elmoniem KZ *et al.* Magn. Reson. Med. 2012;68:822–9, **4**. Edelman RR *et al.* Radiology 1988;166:231–6, **5**. Coristine AJ *et al.* Magn. Reson. Med. 2014, **6**. Weiger M *et al.* MAGMA 2002;14:10–19.