Increasing spatial coverage for high resolution fMRI studies

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Introduction: Although fMRI has been widely used in the study of brain functions, its spatial resolution is typically very low. This is due to tradeoffs between temporal resolution, spatial coverage and spatial resolution. Spatial coverage is traditionally sacrificed in order to achieve high spatial and high temporal resolutions. In this work, a novel technique which combines 3D acquisition with the UNFOLD technique [1] is proposed to increase spatial coverage, as well as maintain high spatial and temporal resolutions, the total scan time and the SNR of images.

Theory: The comparison is based on the assumption that thermal noise dominates the experiment, which is true for high resolution scans [2]. 3D stack-of-spirals trajectory [3] is used for both methods. Fig. 1 shows the data acquisition process (with two interleaves) for the two methods. For a fair comparison, the total scan time $T_{s,\ total}$ is set the same. In general, multi-interleaves are necessary to achieve the in-plane high spatial resolution. The traditional method will use all interleaves to generate aliasing free images. The proposed method, however, generates aliased images from each interleave and removes aliasing artifacts afterwards with the UNFOLD technique. Assume that the number of interleave is N_{int} and the volume scan time is $T_{R,\ vol}$, the number of slices which could fit into $T_{R,\ vol}$ is N_z for the traditional method and N_zN_{int} for the proposed method. Since the spatial resolution is the same for both methods, the relatively SNR is solely determined by the total readout time $T_{r,\ total}$. Since $T_{r,\ total}$ is $N_zN_{int}T_r$ for both methods, where T_r is the readout time for a single spiral, the SNR performance ideally should be the same for both methods, and so does the quality of activation maps. From the above analysis, we can see that all characteristic parameters are the same for the two methods except that the number of slices is N_{int} larger for the proposed method.

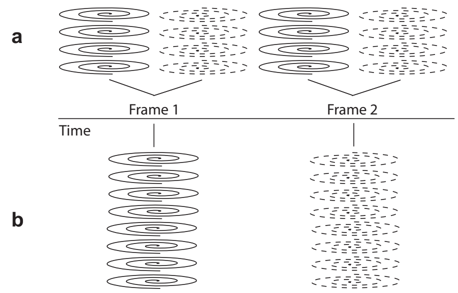

Figure 1: Sequence comparison between the proposed method (a) and the traditional method (b). The first interleave is plotted with solid lines and the second with dashed lines. The volume TR is the same for both methods.

Methods: All experiments were performed on a 3T whole-body scanner (Signa, rev 12M4; GEMS, Milwaukee, WI, USA). The body coil was used for transmission and a homemade 3-inch surface coil was used as a receiver. Three healthy volunteers were involved. Anatomic images were acquired with a T_2-weighted FSE sequence (TE/TR/ETL/FOV/MAT = 68ms/3000ms/8/14cm/128×128, 24 1.1mm contiguous slices). Three high resolution (1.1mm isotropic voxel) functional scans with visual checkerboard stimulus were performed. One used the same prescription as that in the anatomic images (24 1.1mm slices), while for the other two scans, only half number of slices (12 1.1mm slices) were collected as that in the first scan. The centers of the last two scans were offset so that the combination of two scans could provide the same spatial coverage as that in the first scan. The 3D stack-of-spirals sequence [3, 4] was used for all three scans. Each scan lasted 436.32s. TE is 30ms, TR is 90ms and flip angle is 21°. The in-plane FOV is 14cm. Two interleaves were used to cover a 128×128 matrix. A time frame was generated from each interleave for the first scan and from both interleaves for the last two scans so that the volume TR (2.16s) was the same for all scans. The number of time frames collected for each scan was 200. For the first scan, 6% of the spectrum was filtered out to remove aliasing artifacts.

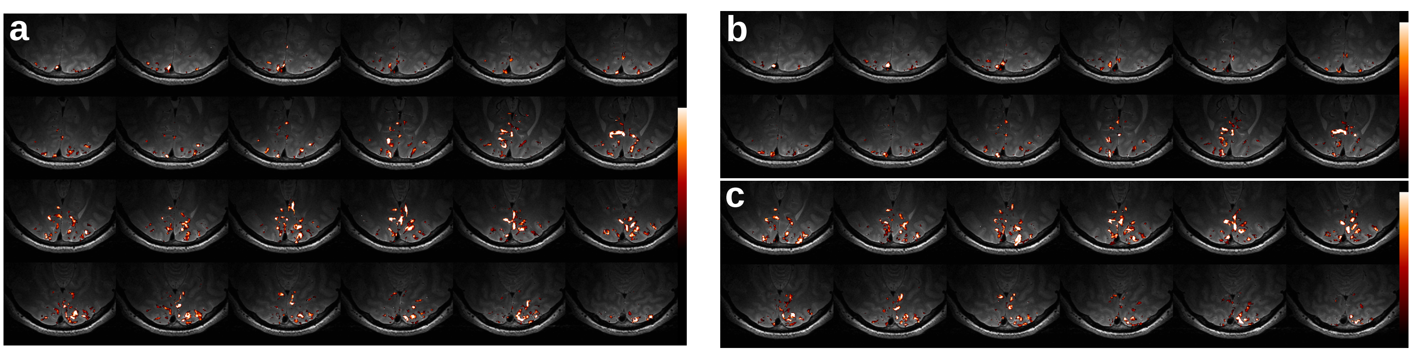

Figure 2: Comparison of activation maps achieved with the proposed method (a) and the traditional method (b and c). All three scans had the same total scan time. The combination of b and c provided exactly the same spatial coverage as that in a.

Results: The activation maps from a representative volunteer are shown in Fig. 2. The display scale of t-scores is from 3.09 to 6.00. The quality of activation maps obtained with the proposed method (a) is similar to those obtained with the traditional method (b & c). All three scans had the same total scan time. If we divide the 24-slice in Fig. 1a into two 12-slice sub-slabs, then a direct comparison of the number of activated voxels ($P<0.001$) can be made between the two methods. The results are listed in Table 1 and 2. Student's t-tests show no difference for the two methods for both sub-slabs. All results confirm that given the same total scan time, the proposed method can be used to increase the spatial coverage without compromising the quality of activation maps.

Subject	Traditional	Proposed
1	1612	1551
2	1398	1402
3	768	820
AVE±STD	1259±439	1258±386
TTEST(p)	0.964	

Table 1: Comparison of the number of activated voxels (sub-slab #1).

Subject	Traditional	Proposed
1	1592	1213
2	2443	2494
3	109	446
AVE±STD	1381±1181	1384±1035
TTEST(p)	0.990	

Table 2: Comparison of the number of activated voxels (sub-slab #2).

Discussion: We have shown that our proposed method can be used to enlarge the spatial coverage without affecting other characteristic parameters such as the volume TR, the total scan time and the quality of activation maps. There is a very minor cost (6%) to the temporal resolution due to the spectrum filtering used in the UNFOLD technique. Parallel imaging, as an alternative, won't increase temporal coherence. However, it suffers from SNR loss caused by the g-factor. The proposed method can also be modified to lower the gradient duty. In this case, we will double the TR between RF excitations rather than the number of slices. When TR is small compared to the T_1, the SNR penalty caused by undersampling could be fully compensated by the increase in steady-state signal due to the longer TR.

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References:

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