# Improving the Resolution of Functional Maps on the Cortical Surface

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**Abstract**. Accurate mapping of functional magnetic resonance imaging (fMRI) data to human cortical anatomy is critical for understanding human cortical function. In the widely used functional space analysis (FSA) method, functional images are realigned and resampled to a functional reference image and processed in functional space. Both simulated and experimental data show that the activation maps from FSA have lower resolution and poor reproducibility when displayed on the maps of cortical surface. Here, we describe a new method, anatomical space analysis (ASA), whereby low-resolution functional images are co-registered and resampled directly into high-resolution anatomical space with subsequent data processing performed in high-resolution space. One major advantage of ASA is that minor head movements which are generally assumed to reduce spatial resolution can actually increase spatial resolution by providing multiple samples of the relationship between functional and anatomical space. Both simulations and analyses of real fMRI data show that ASA improves the precision, objectivity and reproducibility of functional brain image mapping.

**Introduction.** In recent years, functional magnetic resonance imaging (fMRI) has become the tool of choice for localizing cognitive and perceptual operations in the cerebral cortex. Accurate, high-resolution functional maps have provided increasingly detailed insights into the functional organization of visual and auditory cortex. Mapping techniques are critical for the accurate visualization of functional activations on the cortical surface. In the commonly used functional space analysis (FSA) approach, all functional data processing (motion correction, re-slicing, smoothing, computing means and differences, time-series analysis, and statistical testing) is done in low-resolution functional space. We demonstrate here that FSA analysis discards the high-resolution information that can be obtained by the appropriate combination of multiple, lower-resolution samples, significantly reducing the replicability of results when comparing data across successive experiments. As an alternative to FSA, we introduce anatomical space analysis (ASA) , where the first step involves resampling each functional image into the high-resolution anatomical image. In ASA, each functional image is considered as an individual stochastic sample, co-registered to the anatomical image and independently resampled into anatomical space. Further functional data processing is done in high-resolution anatomical space. Experimental data and simulations show that ASA preserves high-resolution information that disappears within FSA.

**Methods.** fMRI experiments were performed on a 1.5T Philips Eclipse. To test the functional reproducibility, four complete experiments were performed on the same scanner on four separate days spaced over a 6-week interval. Anatomical images were first re-sliced to images with a voxel size of 1x1x1 mm, and then inflated to the cortical surface using FreeSurfer[1]. Local maps of human auditory cortex were cut and flattened from the inflated surfaces. Functional activations were generated by FSA and ASA. In FSA, functional images were aligned and resampled to a reference functional image space. Then the reference image was co-registered to the anatomical image in order to map functional data into anatomical space. In ASA, each functional image was co-registered and resampled into anatomical image space. Then, average functional data were computed in anatomical space. All the calculations for realignment and co-registration for both methods were performed using b-spline interpolation in SPM2[2]. To simulate the effects of the two methods, simulated data in the form of a checkerboard pattern was projected onto the average map of auditory cortex of 10 subjects obtained in a previous study. The activated voxels from the cortical surface of each subject were then retransformed into 3D space, displaced according to the actual head movements that the subject had produced during the experiment, analyzed using FSA or ASA, and averaged over subjects. Finally, the two-dimensional correlation coefficient was calculated between the original checkerboard activation and the computed average activation patterns for each subject produced using FSA or ASA.

**Results.**

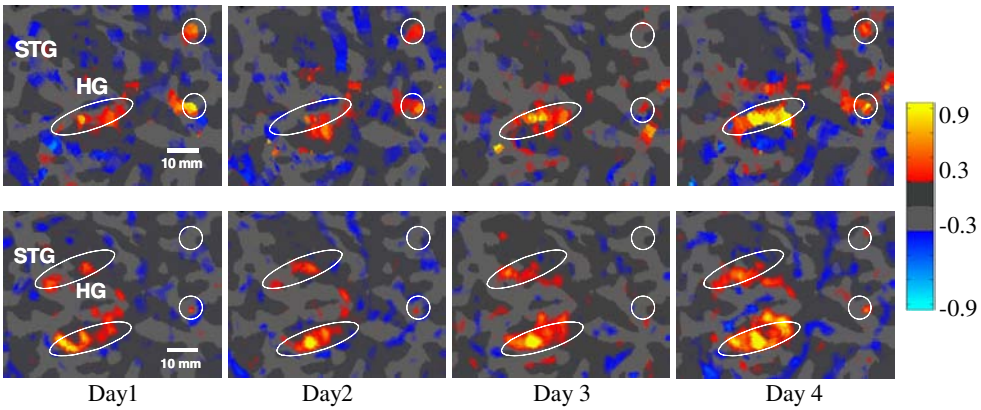


Figure 1. Functional activation maps of core auditory cortex for an fMRI experiment repeated four times in the same subject over a period of six weeks. Light gray = gyri, dark gray = sulci in the background. HG = Heschl's gyrus, STG = superior temporal gyrus. Functional activations are the difference between the presence and absence of auditory stimuli during a visual discrimination task. Top row: FSA. Bottom row: ASA. Activations encircled by the ellipses show much better replicability by ASA than FSA. The smeared activation noise in the two circles is greatly reduced in ASA compared with FSA.

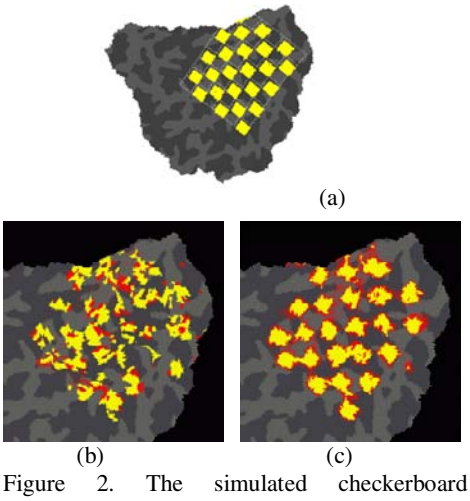


Figure 2. The simulated checkerboard activation pattern (a), the simulated activation maps (b) for FSA and (c) for ASA. Averaged 2D correlation coefficients between the initial checkerboard activation and the ASA activation maps were 0.76 and 0.78 for left and right hemispheres, respectively. In contrast, averaged FSA correlation coefficients were 0.52 and 0.60

**Conclusions**. ASA improves the replicability and the precision of fMRI data analysis particularly when activations are mapped to the cortical surface. The advantages of ASA are particularly evident when examining the replicability of sensory activations in independent experiments. Simulations confirmed the improved spatial precision of ASA, suggesting that it can improve the spatial resolution of functional brain imaging.

**References**

1. Dale, A. M, *et al. Neuroimage* 1999; **9**(2): 179-94.
2. Friston, KJ, *et al. Hum Brain Mapp* 1995; **2,** 165-89.

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