Power Calculation for fMRI Data Analysis with Non-Central Random Field Theory

S. Hayasaka[1,2], A. Peiffer[2], C. Hugenschmidt[2,3], and P. Laurienti[2]

[1]Biostatistical Sciences, Wake Forest University School of Medicine, Winston-Salem, North Carolina, United States, [2]Radiology, Wake Forest University School of Medicine, Winston-Salem, North Carolina, United States, [3]Neuroscience, Wake Forest University School of Medicine, Winston-Salem, North Carolina, United States

Introduction: Determining power and sample sizes in fMRI studies is a difficult task because of massive multiple comparisons among tens of thousands of correlated voxels. Although there have been some attempts to calculate power for fMRI studies [1-3], to date, there are no effective power calculation methods which can account for the family-wise error (FWE) rate in fMRI data analyses. To address this issue, we propose a power analysis method for fMRI data based on non-central random field theory (RFT).

Methods: Power can be determined by comparing the distribution of the test statistic under H_0 (no activation) and under H_A (activations in some areas), as seen in Fig 1. The distribution under H_0 has been found for various statistic images [4]. To describe the distribution under H_A, we model the statistic image as a non-central random field with a non-centrality parameter δ describing the effect size. This distribution can be derived via the Euler characteristic based on the gradient and Hessian of the non-central random field [5].

To calculate power, we focus on a small neighborhood around each voxel, since activations are often detected as a collection of voxels in fMRI experiments. The neighborhood is defined as a sphere of radius=FWHM (image smoothness) centered at each voxel. Within this neighborhood, the effect size is estimated in terms of δ and power is calculated locally by non-central RFT. This process results in a power map as well as a sample size map [3] in terms of DF (degrees of freedom).

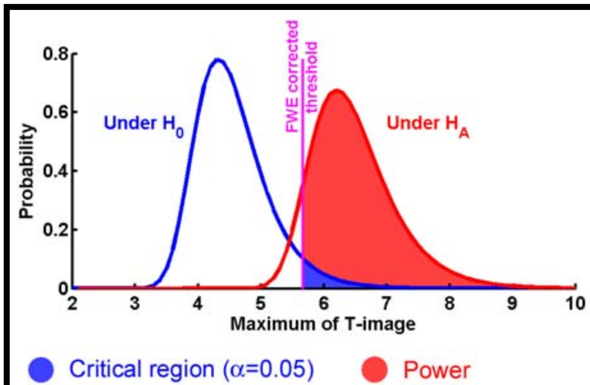

Fig 1: A schematic of power calculation. Power (red shaded area) is calculated as the distribution under H_A (red curve) is compared to the FWE corrected threshold (pink line), determined from the distribution under H_0 (blue curve).

Application: 43 adult volunteers were scanned during a BOLD fMRI auditory experiment. EPI images were acquired by a 1.5T GE scanner (TR/TE/FA = 2500ms/50ms/90) while auditory stimuli (white noise) were presented in four 30s epochs (4s on, 4s off). For each subject, acquired images were pre-processed (realignment, normalization, and smoothing) and analyzed to produce a contrast image for activations during white noise. From the 43 resulting contrast images, 5 images were randomly selected and analyzed by a one-sample T-test as a mock-pilot study with low DF. The effect size was estimated from this mock-pilot study at each neighborhood in terms of δ. Based on the effect size, we generated a power map and a DF map (with α=0.05 FWE-corrected) to determine the adequate sample size for a subsequent study. As a demonstration, we re-ran the same analysis with as many subjects as determined necessary by the DF map.

Results: In the mock-pilot data analysis, activations were found in the auditory cortices of each subject, but not in the group analysis due to low DF (Fig 2). The resulting power map indicated possible activations in the auditory cortices (Fig 3, left), and the corresponding DF map indicated that DF=19 or 20 subjects were needed to detect activations (Fig 3, center). A follow-up analysis with 20 subjects revealed activations in the bilateral auditory cortices, as predicted (Fig 3, right).

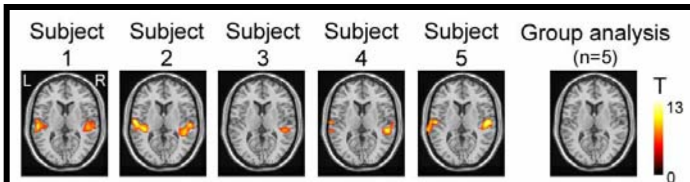

Fig 2: The mock-pilot study analysis results. Activations were observed in the auditory cortices in each intra-subject analysis, but not in the group analysis due to low DF. All the analysis results are FWE-corrected with p<0.05.

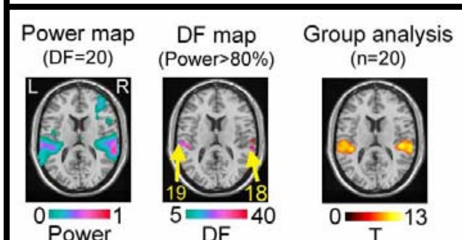

Fig 3: The power map (left) and the DF map (center) from the mock-pilot study. A group analysis with n=20 (right) found activations predicted by these maps.

Conclusion: We were able to calculate power while controlling for multiple comparisons, and to generate power and DF maps with a small sample size typical in fMRI pilot studies. Such power and sample size maps can be useful in study planning, not only in fMRI, but also in a variety of other MRI modalities.

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References: [1] Desmond & Glover, J Neurosci Meth 118: 115-128 (2002). [2] Murphy & Garavan, NeuroImage 22: 879-885 (2004). [3] Van Horn et al., NeuroImage 7: 97-107 (1998). [4] Worsley et al., Hum Brain Map 4: 58-79 (1996). [5] Worsley, Adv App Prob 26: 13-42 (1994).