Theoretical framework for determining the required SNR in event-related fMRI

T. Parrish[1]

[1]Radiology, Northwestern University, Chicago, IL, United States

Introduction

Neuroscience research has driven new developments in experimental designs in fMRI. A major step towards typical neuropsychological testing was made when fast, overlapping trials were introduced in the form of event-related fMRI [1, 2]. This development allowed investigators to use multiple stimuli types in a more natural testing condition. Furthermore, this design allowed for the comparison of "correct" versus "incorrect" states of the brain. However, little attention has been paid to exactly how the signal to noise ratio (SNR) impacts the development of the functional maps. The goal of this paper is to derive the minimum signal to noise ratio required to generate a reliable functional map for an event-related design and estimate the requirements when considering analysis of correct versus incorrect responses.

Methods

Theoretical development

Based on previous work to determine the minimum SNR required for a block design experiment [3], a modified formulation of SNR was created for a multi-stimuli event-related design. The model assumed that each trial type (including rest) had the same number of trials. The total number of volumes acquired was N, which is the product of the number of trial types and volumes per trial. The newly derived minimum SNR for a multi-stimuli experiment was found to be SNR= t*SQRT(2*x) / ΔS / SQRT(N), where t=t-test threshold and ΔS is the BOLD signal change. The difference form the result derived in ref #3 is the additional term of (SQRT(2*x)), where x is the number of stimuli types including rest. As the number of stimuli types increases, the minimum SNR required increases for fixed values of N (see Table 1).

Investigation of correct versus incorrect trials

This type of investigation often uses only a single trial type such as words or pictures the subject was told to remember. This trial type is then further divided into a correct or incorrect category. The level of correctness can be written as α ($0<\alpha<1$) for inclusion in the SNR model. An additional factor which accounts for the level of correctness, SQRT($(1/\alpha) + (1/(1-\alpha))$) is included in the model above. This factor has a minimum value of 2 when α =.5, chance response. As α increases, the factor rapidly rises to values greater than 4 when α approaches 95% correct.

Computer simulations

A computer simulation was implemented using MATLAB. The simulation investigated the effects of noise on the detection and power characteristics of the t-test. To model the response of the brain to the stimuli, a hemodynamic response was convolved with stimuli stick-functions. The hemodynamic response had a true baseline of 1 and a peak signal of (1+ ΔS) associated with the activation. The hemodynamic response had noise added to the time course with a known standard deviation to create a time course with a specified temporal SNR (between 10 and 500). Each functional experiment, consisting of N volumes, was repeated 10,000 times at each noise level. A t score was calculated for each run. The cutoff values for the t-test were determined by choosing an alpha of 1% ($p < 0.01$) and 5% ($p < 0.05$) and the appropriate degrees of freedom based on N.

The number of trials exceeding the significance threshold for each statistic was calculated. The level of detection (beta) was set at 99% or 95%, 9,900 or 9,500 trials. Simulations were run for the different experimental parameters of trial length (N = 160, 320 and 640), and activation-related signal change (0.5%, 1%, 2% and 5%). A minimum SNR value was calculated for the t-test (2 levels).

Results

The minimum SNR values derived from the simulation with N=320 and an expected BOLD signal change of 0.5% are shown in Table 1 for different number of stimuli using a detection rate (power) of β=0.05. The table also shows the impact of investigating correct versus incorrect responses.

Discussion

In this paper, a method for calculating the minimum signal to noise ratio for a given level of statistical confidence was developed for use with fast, overlapping event-related designs which employ multiple trial types. Furthermore, the model was extended to conditions where correct responses or comparisons between correct and incorrect responses were investigated. The model demonstrated that there is a significant penalty in the required SNR, if the number of trial types is increased for a fixed number of volumes or for a fixed amount of imaging time. The penalty is further increased if one wishes to investigate a subset of a particular trial type such as correctly remembered words.

It is important to note that the SNR calculations are independent of field strength, coil type or sequence used. This analysis uses a simple t-test statistic as a method for putting an upper bound on the SNR required for detections. It does not consider more sophisticated statistical methods or issues such as multiple comparisons. Therefore, any steps taken by the investigator to lower the threshold of the statistic including modeling or region of interest analysis can be implemented in this framework by altering the t value used. Using the minimum SNR value calculated from the time series data, a mask can be generated and applied to the functional maps to show only those activations that meet the statistical <u>and</u> SNR threshold required. The application of this mask will improve the quality of the maps and the confidence in the conclusions made about them.

References: 1. Boynton, GM, Engle SA, Glover GH, Heeger DJ. J Neurosci. 16, 4207-4221, 1996. 2. Dale A, Buckner RL. Hum Brain Map. 5, 329-340, 1997. 3. Parrish TB, Gitelman DR, LaBar KS, Mesulam MM. MRM 44, 925-932, 2000.

Table 1	α=5%	α=1%
2 stimuli types including rest	80	95
3 stimuli types including rest	98	116
4 stimuli types including rest	113	134
2 stimuli 50% correct only comparison	113	134
2 stimuli 75% correct only comparison	92	110
2 stimuli 90% correct only comparison	84	100
2 stimuli 50% correct vs incorrect comparison	160	190
2 stimuli 75% correct vs incorrect comparison	184	219
2 stimuli 90% correct vs incorrect comparison	266	317