Trial by Trial Detection of Activation using Wavelet Analysis of Event-Related fMRI

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Introduction

Low contrast to noise ratio (CNR) requires fMRI using blood oxygenation level dependant (BOLD) contrast to use signal averaging and statistical processing to produce robust activation maps. Such strategies assume a deterministic model of brain activation (i.e. constant response to a repeated stimulus). Yet brain function may be probabilistic (i.e. variable response to a repeated stimulus). The consistency of individual trial responses is examined with a non-orthogonal, Paul-type wavelet analysis of fMRI with an event-related paradigm. Distinction is suggested between the deterministic and probabilistic models of brain activity.

Methods

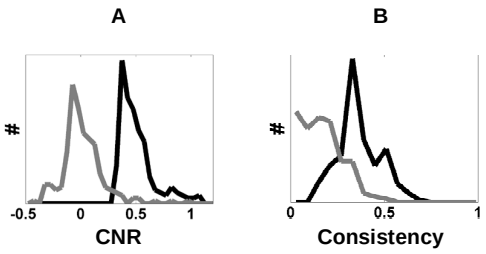
Imaging was performed at 3T using gradient echo, echo-planar imaging (TR=1000ms, TE=30ms, voxel resolution 1.6x1.6x3mm^3, 7 axial slices through the calcarine sulcus). The event-related paradigm consisted of 40 trials of a visual stimulus (3s duration, flashing checkerboard at 10Hz) followed by central fixation (12s, static cross). An activation map was found with a t-test analysis with a false discovery rate (FDR) of $q<0.05$.

A synthetic time course of signal intensities for the fMRI experiment was constructed for a 40 trial event-related paradigm with each BOLD response constructed from two gamma functions and convolved with 40 equally spaced delta functions. White noise was varied to yield a range in CNR from 4.0 to 0.01. A set of 100 such datasets for each CNR was generated. A similar set of time courses was also generated with CNR=0.

The previously described, non-orthogonal wavelet (Von Tscharner & Thulborn, 2001) was convolved with the synthetic time courses to extract the wavelet amplitude threshold and phase window required for detection of BOLD signal in each individual trial. Each wavelet amplitude threshold and phase window was applied to the time courses with and without BOLD signal to determine Types 1 and 2 error rates for each CNR. The wavelet properties were determined for single trial detection at a confidence limit of 95% with equal rates (5%) of Types 1 and 2 errors. The optimized wavelet was then used to measure the consistency of activation (active trials/total trials) in the actual experimental dataset.

Results

The simulation demonstrated that a CNR of 0.474 was required to detect the BOLD response of an individual event using the optimized wavelet (amplitude threshold of 32.5% of the BOLD signal, 3s phase window centered on the synthetic BOLD response). When this analysis was applied to the experimental data, 45% of voxels that activate under a FDR threshold of a t-test have a CNR >0.474. The distributions of CNR and activation consistency in active voxels (black) and non-activating voxels (gray) are markedly different as shown in Figure 1A and 1B, respectively. Of the active voxels, the maximum consistency of 70% well below 100% despite the CNR >0.474 for a large number of active voxels. The distribution of activation is very similar based on all 40 trials and on a consistency of 0.45 (Figure 1C & 1D).



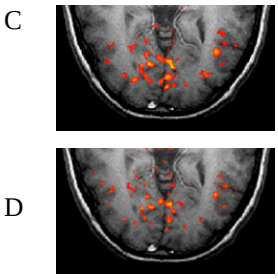


Figure 1: Activating (black) and non-activating (gray) voxels based on an FDR corrected t threshold distributed by CNR (A) and by consistency of wavelet detection (B). Activation maps for t-test with FDR correction for 40 trials (C) and using wavelet consistency of greater than 45% (D).

Discussion

The limits for detection of responses to individual stimuli by the optimized wavelet have been derived from a simulation designed to emulate the actual fMRI experiment. When applied to the actual experiment, 45% of the voxels that are active by the conventional FDR statistical method meet criteria for detection of BOLD responses in individual trials by the wavelet approach. These voxels show activation consistencies of less than 70%. This data further supports the probabilistic model of brain function in that a given area of cortex sampled at this voxel resolution does not respond identically on every stimulus.

Reference Von Tscharner & Thulborn, IEEE-TMI 2001 20:704-714