Temporal Analysis of the BOLD response using high temporal resolution Echo Volumar Imaging

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Introduction

The BOLD hemodynamic response to any kind of stimulus typically evolves with a temporal resolution of a few seconds. Nevertheless, since the introduction of event-related fMRI studies (1,2), it has been shown that improving the temporal resolution of activation detection could give us new insights into the brain's physiology. We describe the first fMRI results obtained with a new acquisition method which allows high scanning rates (200ms/vol) on isotropic brain volumes, at standard spatial resolutions.

Methods

Experiments were performed on a 1,5 T GEHC scanner (40 mT/m, 150T/m/s slew rate gradient, 8 channel head coil array). The healthy subjects gave their written consent and this study was approved by a local ethical committee for biomedical research. For detection purposes, the reconstructed time series were processed with SPM2 (Statistical Parametric Mapping software).

We used a single shot 3D acquisition sequence (EVI), with outer volume saturation pulses and 2D SENSE reconstruction up to a reduction factor of 4 (3). The sequence and the reconstruction technique have been already described, (see (4)). The advantages of this method are numerous. First, single shot 3D acquisition allows us to acquire the whole volume at the same moment which makes slice timing corrections unnecessary. Second, due to 3D reconstruction, the resulting SNR is higher than for EPI. Finally, zoomed acquisition permits to reach actual fMRI spatial resolutions.

An experimental study about the relationship between accoustic noise and the imaging parameters provided guidance to reduce the noise level from 115 to 100 dB, thus making Echo Volumar Imaging no louder than other fMRI sequences (5).

We implemented two different paradigms for testing and validating our method: a classical block design visual paradigm where we alternated activation and rest periods of the same duration (19.5 s) and a slow event-related visual paradigm with activation periods of 80 ms followed by rests periods of 20 s. The stimuli was a contrast-reversing checkerboard in both cases.

The acquisition parameters were sets as follows: sagittal plane, TE/TR = 57/195 ms (first paradigm), 57/200 ms (second), BW = 62,5 kHz, FOV = 80x80x120 mm^3, matrix acquired = 24x12x12, 24x24x24 effective matrix size after reconstruction.

Results

Block-designed visual paradigm: Figure 1 shows the 10 central slices of the statistical activation map of a subject subtmitted to this stimulus (Student t-test). The map is superimposed on the spatially smoothed EVI images. A robust activation was detected in the posterior visual area ($p < 0.0001$). Figure 2 shows the averaged time course of the 20 most activated voxels, which displays a 9.2 % signal change.

Slow event-related visual paradigm: Figure 3 shows the 8 central slices of the statistical activation map (Student t-test), superimposed on the EVI images. Activations are decreased in size and intensity compared to the first experiment because of the slow event-related design. Nevertheless, the posterior visual area is also significantly activated ($p < 0.001$). Examination of the time course for a single run of the experiment (Figure 3) reveals that the signal change could be observed in many of the individual trials. The single-trial time course (HRF) has been estimated on the most activated cluster using an unsupervised non-parametric approach (HRF toolbox (6)). As expected, we obtained a time course close to the usual assumed shape (Figure 4, left). Nevertheless, we noticed the presence of a *putative early dip* that should be further investigated using longer inter-stimulus interval. Figure 4 (right) shows the superposition of two time courses computed in the same way, the black one being obtained from the 10 first trials and the red one from the 10 last. Although the two responses have relatively close shapes, the high EVI temporal resolution allows to detect very small differences in early dip (1.4 *vs* 1.6 s respectively) and peak delays (7.0 *vs* 6.6 s) and more significant in peak magnitude (1.6 *vs* 1.92 ie a fluctuation of 20%) and full-width at half maximum (5.4s *vs* 4.6s ie a fluctuation of 16%) .

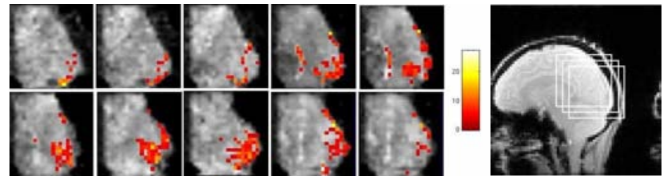

Fig.1. left: 10 central slices of the activation map for the block paradigm (from right to left). $p < 0.0001$ ($T > 3.74$), clusters size > 10 voxels. right: one slice from the sensitivity map (GE), showing the position of the volume of interest and the orientation of the slices.

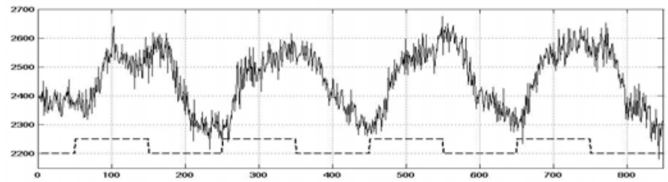

Fig.2. averaged time course of the 20 most activated voxels in the block paradigm (solid line) and the on and off periods of the stimuli (dashed line). The 50 first images have been removed from the statistical analysis as dummies.

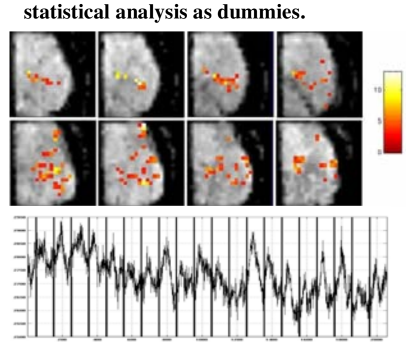

Fig.3. up: 8 central slices of the activation map for the slow event–related paradigm (from right to left). $p < 0.001$ ($T > 3.09$), clusters size > 10 voxels. The volume of interest is positioned as in fig. 1 (two different subjects). down: averaged time course over the 20 most activated voxels and the onsets of the stimulus.

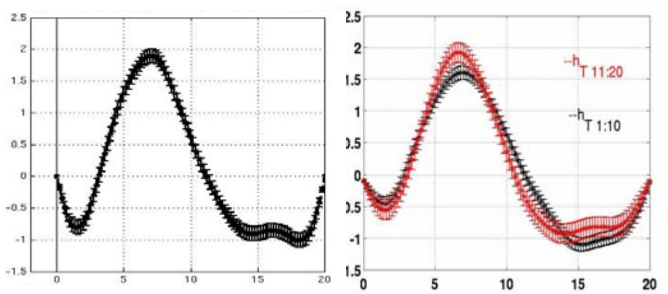

Figure 4 : Estimated time course for single-trial response versus time (seconds). left: estimation on the whole run, right: estimation on each half of the run.

Conclusion

We have demonstrated that robust activation detection can be achieved using zoomed parallel Echo Volumar Imaging both in blocked and event-related trials. Moreover, with the high temporal resolution reached (200ms/volume) and the ability to acquire a large 3D volume in one TR, our method is well adapted to investigate the BOLD signal time features, in particular its nonlinear and nonstationary properties, as well as the presence of an early dip.

References :

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