Regularized Localized Parallel EVI: application to the study of habituation effects in fMRI.

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Introduction

2D SENSE imaging and field-of-view (FOV) reduction make Localized Parallel EVI a powerful 3D single-shot acquisition method, which allows the acquisition of isotropic brain volumes at very high scanning rates (1). The benefits offered by this method have already been demonstrated in visual fMRI experiments (2, 3). Nevertheless, these first data were obtained at relatively low SNR, mainly because of the high geometry factors arising from parallel reconstruction of small volumes. In the present work, all imaging parameters have been optimized in order to improve SNR. The optimized setting has then been used to study habituation in a language comprehension slow event-related fMRI paradigm.

Methods

Experiments were performed on a 1.5 T GEHC scanner (40 mT / m, 150 T / m / s slew rate gradient, 8-channel head coil array by MRI Devices). The healthy subjects gave their written informed consent.
First, in order to maximize the SNR and improve the brain coverage, the FOV has been increased compared to previous studies. The spatial resolution has also been degraded to 6 x 6 x 6 mm^3. This spatial scale is commonly used in fMRI group studies involving brain normalization and smoothing.
Second, the optimal acquisition bandwidth has been computed in order to minimize the echo train duration (ETD) and improve image quality. Indeed, when ramp-sampling is not used, an optimal bandwidth can be estimated from the numbers of samples and FOV along the read and phase directions.
Third, as pioneered in (4, 5), parallel reconstruction has been regularized in order to avoid noise amplification and improve activation detection. Minimum norm quadratic Tikhonov regularization has been applied, as proposed in (6). The relative importance of the regularization term was modulated using a regularization parameter, λ^2, manually set.
Acquisition parameters were set as follows: sagittal orientation, TE / TR = 40 / 200 ms, flip angle = 35°, BW = 100 kHz, 3D-FOV = 120 x 120 x 140 mm^3, acquired matrix = 20 x 10 x 12, effective matrix size after SENSE reconstruction = 20 x 20 x 24, ETD = 58 ms.
The stimulation consisted of a slow-event presentation of short auditory sentences every 14.4 s. The 12 different sentences have been repeated four times successively to introduce habituation effects (7).
The post-processing and statistical analyses of the EVI temporal series have been conducted using SPM2 (www.fil.ion.ucl.ac.uk) and Brainvisa (http://brainvisa.info). As in (8), a numerical band-rejection filter has been applied to reduce cardiac and respiratory artifacts. A 10-mm Gaussian spatial smoothing has also been applied. A generalized linear model has been generated by defining 4 variables, corresponding to the 4 sentence presentations (P1 to P4), convolved with the standard hemodynamic response function (HRF) and its first temporal derivative. The significativity of the detected activations has been assessed using a Student test corrected for multiple comparisons (FWE).

Results

In the two subjects, activation in response to the first presentation of the sentences (P1) was detected along both the superior temporal gyri and sulci, for all settings of λ^2. In all cases, cluster-level p-values were inferior to 10^{-4}. For subject 1, a representative activation map is displayed in Fig.1.
For increasing values of the regularization parameter, median t-scores were computed from the 200 most activated voxels in response to P1. Results are given in Tab.1. Median t-scores increase when λ^2 is increased, the same effect has been also observed for temporal SNR (data not shown). Nevertheless, this improvement slows down at high regularization levels. Moreover, at high λ^2, reconstructed EVI volumes display important reconstruction artifacts, as illustrated in Fig.2. These observations demonstrate the necessity of finding the optimal reconstruction parameter, in order to maximise the sensibility of activation detection, as well as the accuracy of the reconstruction.
At the optimal value of λ^2 (empirically chosen equal to 0.1 here), single-voxel HRF could be estimated through selective averaging. As illustrated in Fig.3, habituation effects can be observed in some voxels located inside the temporal lobe, and several timing properties can be estimated: time-to-peak, magnitude of the signal change associated to the BOLD effect and initial slope of the HRF.

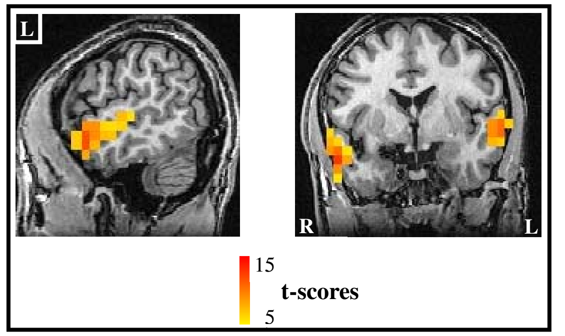

Fig.1: activation maps showing the areas activated by P1 for subject 1 (thresholded at $p < 10^{-4}$, FWE).

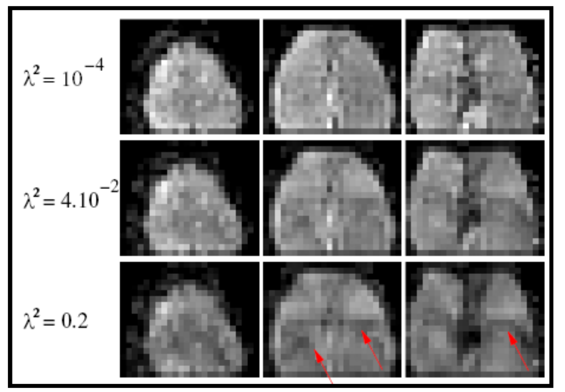

Fig.2: image quality as a function of λ^2, apparition of reconstruction artifacts at high regularization levels.

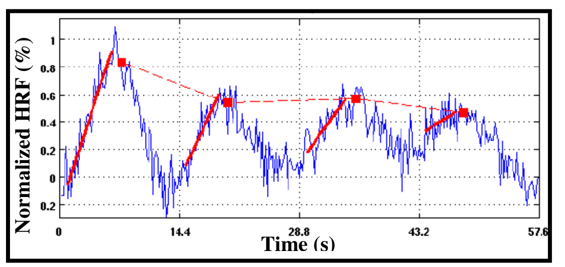

Fig.3: voxel-wise hemodynamic response function to the 4 presentations of a sentence, after suppression of low frequency drifts and selective averaging.

Discussion

The present work demonstrates the high potential of Localized Parallel EVI for advanced fMRI studies. Robust estimation of high temporal resolution single-voxel HRF and statistical studies of their timing properties could improve the understanding of complex neurovascular mechanisms. Future work should include a voxel-specific, automatic, determination of the optimal regularization parameter, as in (4). Moreover, a comparison of Localized Parallel EVI with conventional and parallel EPI would be of interest, especially regarding inflow artifacts which should be reduced in the former. Finally, as in any parallel acquisition method, attention should be paid to the SNR maps, in order to take into account the noise spatial inhomogeneity introduced by parallel imaging in cognitive interpretations.

Tab.1: median t-score as a function of λ^2.

	Median t-score	
λ^2	Subject 1	Subject 2
10^{-4}	7.45	5.18
10^{-2}	8.26	5.42
4.10	8.83	5.91
10^{-1}	8.99	6.20
2.10	9.11	6.16

References: (1). C.Rabrait et al, 2006, Proc.ISMRM 2006, 897. (2). C.Rabrait et al, 2007, Proc.ISMRM 2007, 1948. (3). C.Rabrait et al, 2005, Proc.ESMRMB 2005, 37. (4). F.H. Lin et al, 2005, MRM, 54 :343-353. (5). A.Ribés et al, 2007, Proc.ISMRM 2007, 1757. (6). K.F.King et al, 2001, Proc.ISMRM 2001, 1771. (7). G.Dehaene-Lambertz et al, 2006, HBM, 27 :360-371. (8). van der Zwaag et al, 2006, MRM, 56 :1320-1327.