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3.2.2: Brain Imaging

Detection of Periodic Signals in Brain Echo-Planar Functional Images

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Abstract

In this paper, we propose to use signal autocorrelation values at specially selected delays in order to construct brain periodic activity images. Comparatively to usual approaches, our method requires very few a priori information about the real signal. We applied this method on a well-known vision paradigm. The images thus obtained revealed that the autocorrelation peak method discriminates better expected activated areas from background than the classical method based on correlation with an artificial waveform [1, 2] which may induce false detection.

1. Introduction

Functional mapping of the human brain using MRI has been a great success for last years. Indeed, functional MRI and especially EPI sequences [2], provide such a temporal resolution that we can follow the hemodynamic response to stimulation through time-series. Most of MRI experiments present the same pattern of paradigm. The subjects are instructed to perform alternatively an activation and a reference task. In these conditions, the expected response of activated areas is periodic. In this paper, we propose a simple method to detect regions where temporal signal has the same period as the paradigm.

2. Methods

In this section we expose first a trend correction step, then we describe our activation detection method. It should be noted that time-series from MRI data are of small length (about 80 samples). Therefore, in both steps, we include corrections or specific processing to minimize side-effect that may corrupt part of the data, and bias induced by calculating autocorrelation on data of different lengths.

2.1. Trend correction

We expect an activated voxel time-reponse s(t) to be periodic with the same period T as the stimulus. If we consider these periodic variations as seasonal variations, it is possible to suppress the trend by moving average. We get a smoothed time-serie m(t) by calculating its average on a moving window of length T. We obtain the corrected time-serie by subtracting the raw and smoothed signals. In order to keep globally the same level of signal, we eventually add the mean of the initial time-serie. By doing so with every voxel, we get rid of low frequency variations (see Fig. 1, 2 (left)).

2.2. Detection of activations

A classical method to obtain brain activity images consists in correlating the time-response of each voxel with an artificial signal that simulates the ideal response to the paradigm stimulus. One of the most simple responses to use is a boxcar waveform [1]. Our reference model is created from such a waveform where up and down slopes are replaced by pieces of exponential functions [2]. A major drawback of these methods is that the correlation coefficient depends on parameters

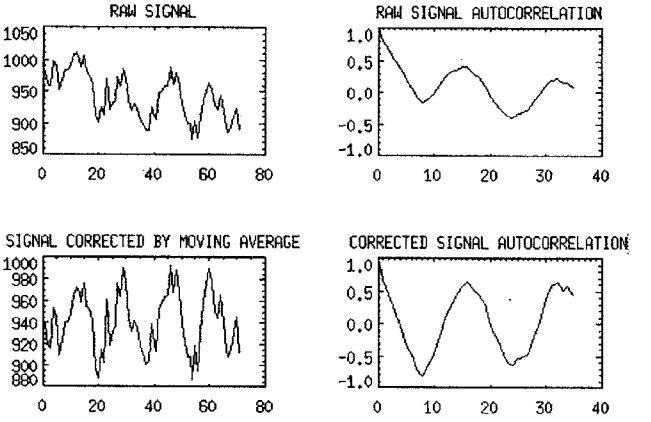

Figure 1. Influence of trend correction: activated voxel

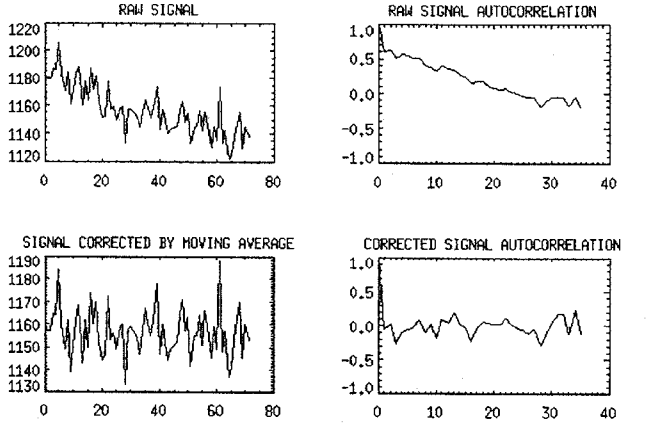

Figure 2. Influence of trend correction: non activated voxel

such as hemodynamic response delay between stimulation and response model onset (see Fig. 3 (bottom right)). Such parameters are difficult to estimate and may vary throughout the brain. Moreover, in some experiments, the real hemodynamic response is far from being exponential-shaped.

In this paper we propose to use the information directly present in the time-serie. The autocorrelation function of a T-periodic function is itself T-periodic. MRI signal cannot be perfectly periodic because of (additive uncorrelated) noise but the value of its autocorrelation function at a delay T, $a(T)$, provides a criterion of confidence on whether it contains an evoked T-periodic response. In the case of symmetrical periodic stimuli like ours (activation and control tasks are of same duration), $-a(T/2)$ provides a supplementary criterion. For our test, we created images of a combined criterion defined as $(a(T)-a(T/2))/2$ that we called autocorrelation peak dynamics. As we warned before, data of functional MRI are rather

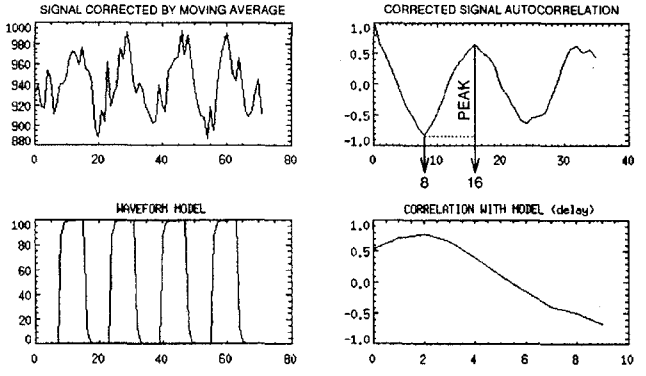

Figure 3. Influence of the delay estimate on the coefficient of correlation (bottom) vs independence of the autocorrelation peak dynamics on this delay (top): activated voxel.

short time-series and the value of autocorrelation varies dramatically with the number of points used for the calculation (depending on the delay). We thus computed an unbiased autocorrelation that takes this number into account.

Activity images display for each voxel a criterion related to activation probability. This criterion stems from temporal information. In order to include spatial information in the final result we use two approaches. The first one consists in applying a 3D hysteresis thresholding combined with a threshold on 3D connected component volumes (see Fig. 4). The second one, relying on a Markovian random field model, consists in applying a contextual regularization using the usual Ising model which introduces a penalization depending on the activation volume/surface ratio.

3. Results

All experiments were performed on a 3T system (Bruker). Functional images were obtained with a T2*-weighted EPI sequence (FOV=256mm, 64x64 pixels, TE=40 ms, TR=305 ms) by sets of 10 contiguous axial slices (thickness=5mm) acquired every 3 seconds. Data consist of time-series of 72 slices-sets/volumes. The first 8 acquisitions correspond to the control task, the following 8 to the activation task (T=16). This alternance is repeated until the end (4 completed periods plus half-period of control task). Visual stimulation consisted in presenting alternatively static and randomly moving points. This paradigm is typically used to display the cortical area MT/V5. A rich literature on the localisation of this area [3, 4] allows us to judge the quality of the results obtained by comparing them to a well-known reference.

In figures 1 and 2, we can observe that trend correction maximises $(a(16) - a(8))/2$ criterion for an activated voxel whereas it is stuck to zero for the non activated one. Figure 4 summarizes the comparison between both activation detection methods. Top left image is a map of correlation-with-a-model coefficient. We can observe in the middle a spot of high correlation level that is detected as activated whereas the signal (middle right) of the region is rather suspicious and does not seem to follow the paradigm. In autocorrelation peak dynamics map (top right) this spot does not appear. Instead, expected activations (e.g. area MT which signal is displayed at bottom right and extrastriate visual areas) flash out much better. These

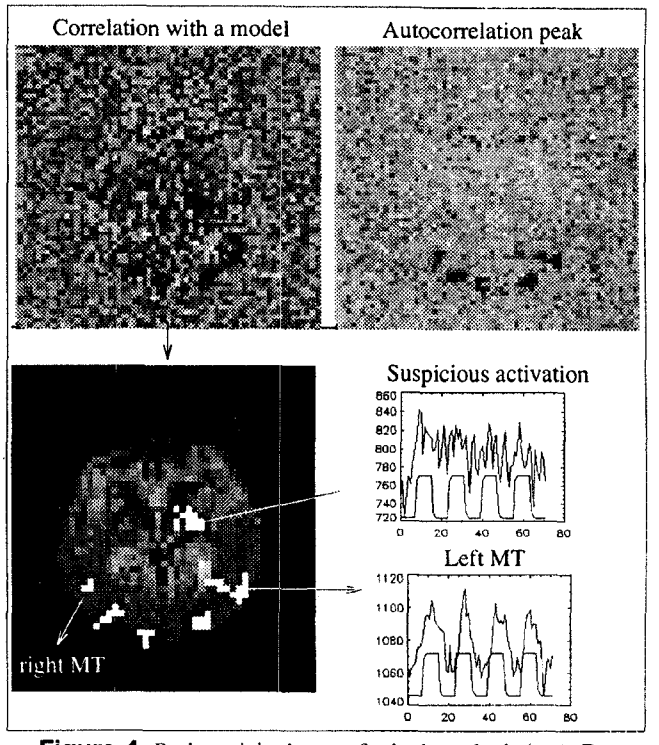

Figure 4. Brain activity images for both methods (top); Detected activation area for correlation criterion superimposed on raw data (bottom).

results are consistent across the four studied volunteer subjects.

4. Discussion

Little is known about hemodynamics. Therefore, it should be noted that, although we systematically corrected the trend of the data, we did not try to interpret it when it may be an important part of the signal signification. Moreover, usual models of response to stimulation are difficult to estimate rigourously. However more work could probably be done using parametric estimation techniques of signal processing. The method we proposed here does not require any a priori model neither for trend correction nor for activation detection, besides the expected signal period. Indeed, this method supposes that the hemodynamic response is the same for each stimulation in the sequence, so that each response pattern is used as a model (area-dependent) for the following one. Practically, this may be sometimes questionable, especially if we consider habituation phenomena that modify signal amplitude, but such difficulty has not been addressed by any detection method up to now.

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