A Potential Application of Incremental Analysis in Offline Processing of Functional MRI Data

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Introduction

A commonly used method in real-time functional MRI, incremental analysis refers to the technique in which each image volume is incorporated into the analysis one after the other and the activation map is continuously updated until the last image is processed. With incremental analysis, the contribution of the newly added image volume in the final activation map can be assessed and effects of events that are localized in time, such as sudden head movement, but which can strongly influence the final activation map can also be detected. Using this method in offline processing, changes in the activation map that are localized in time due to sudden head movements are investigated. The effectiveness of realignment in removing these local effects is also assessed.

Methods

An fMRI data set acquired using a gradient recalled EPI technique (TR = 3s, FOV = 220mm, slice thickness = 3mm, gap 1mm, matrix dimension is 64 x 64, 30 slices per volume) was analyzed. The experiment was designed in a block manner with 13 task blocks. In the task blocks, the subject performed a finger-tapping task with a frequency of 1 Hz in synchrony with a flashing visual cue (2^{nd}, 6^{th}, and 10^{th} blocks) or an auditory cue (4^{th}, 8^{th}, and 12^{th} blocks). The general linear model (GLM) was used in the analysis. Its incremental implementation is carried out using our newly developed algorithm[1], a recursive technique that facilitates the efficient revision of the estimates of GLM coefficients when new observations become available. For the analysis without realignment, the data set was first smoothed by convolving it with a 3D Gaussian operator (FWHM = 2voxel dimension). For the analysis with motion correction, all image volumes were first realigned relative to the first volume before smoothing. Both realignment and smoothing were performed using SPM99[2]. A scalar quantity θ defined as the number of voxels with *t*-statistics value exceeding the set threshold was used to track the changes in the activation map as more volumes are included in the analysis.

Results

Figure 1 shows a sharp increase in the detected total number of active voxels θ_T at n = 50, 60, and 110 due to the presence of sudden head movements (not shown) at n = 40 and 100. Although the maximum estimated translation is less than a third of the voxel's dimension, its effect in the obtained activation map is significant as evident in Fig. 1. More surprisingly is that even after realignment, the same behavior was observed (plot drawn in asterisks). Except for a slight decrease in the number of active voxels, the process of realigning the images for motion correction did not eliminate the observed peaks showing that a relatively small amount of movement could still generate significant number of false positives even after motion correction. Contrary to the behavior of θ_T, which exhibited no significant changes after realignment, the behavior of the local (slice-by-slice) detected number of active voxels θ_i is quite different. Without realignment, slice 21 and neighboring slices turned out to be the primary source of false positives at n = 110 as shown in Fig. 2A. With realignment, two sources of false positives can now be found as shown in Fig. 2B, one cluster coming from slice 21 and neighboring slices and the other from slice 11 and neighboring slices. Rather than minimizing motion artifacts, in this case, realignment only redistributes or spreads the sources of false positives.

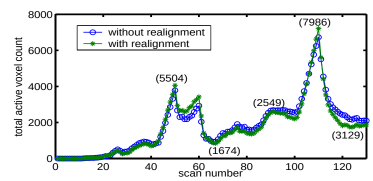

Fig. 1. Total number of detected 'active' voxels as a function of the number of image volumes included in the analysis. The numbers enclosed in parenthesis are the number of active voxels obtained using SPM99 for n = 50, 70, 90, 110, and 120.

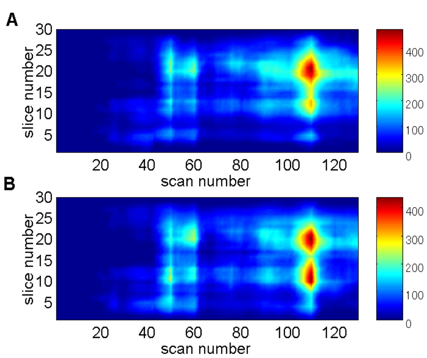

Fig. 2. Comparison of the slice-by-slice behavior of the activation map with (B) and without (A) realignment. The figure shows the number of active voxels (color values) for each slice (y-axis) as a function of the number of image volumes (x-axis) included in the analysis.

Discussion

The effectiveness of realignment in removing motion artifacts was observed to vary from one data set to another. In some cases, realignment does remove false positives and increase detection of active voxels (data not shown). In others, realignment has negligible contribution such as illustrated in Fig. 1. At times, it can even increase the number of false positives in a given slice as in Fig. 2B. The effectiveness of realignment is therefore difficult to predict. Assessing its effectiveness in the analysis of any fMRI data is therefore necessary. One promising approach is incremental analysis as illustrated in the above results. Incremental analysis can provide deeper insights into the estimation process. Since the data is incorporated volume-by-volume into the analysis, the contribution of each new volume in the activation map can be easily assessed. It also promises several potential applications. One of these is in the selection of the number of data to be included in the analysis. This is particularly useful in clinical studies with uncooperative patients where the acquired data sets are usually characterized by sudden and large head movements that the localization and detection of their effects in the final activation map are important. Since it is very difficult, if not impossible, to remove motion artifacts in the final activation map, choosing the appropriate number of volumes to be included in the analysis is critical.

References

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