Distinguishing Robust Brain Activations Using Consistency Maps

E. Bagarinao[1], K. Matsuo[2], T. Nakai[2], Y. Tanaka[1]

[1]National Institute of Advanced Industrial Science and Technology, Tsukuba City, Ibaraki, Japan, [2]National Center for Geriatrics and Gerontology, Obu, Aichi, Japan

Introduction

Real-time functional magnetic resonance imaging (fMRI) [1-2] is an emerging tool for the assessment of the dynamic and robust changes in brain activations. It employs incremental analysis, a technique in which each image is incorporated into the analysis one after the other, and the activation map is continuously updated until all the images are processed. By utilizing the sequence of activation maps produced during incremental analysis, a map indicating how consistently a given voxel is active throughout the analysis can be constructed. This map, referred to as “consistency map”, could be used to assess the robustness of a given activation. It could also be used to discriminate artifactual activations that could occur any time during the scan. Here, the method to construct consistency maps is introduced. We also investigate its potential in reducing the number of false positives by imposing a consistency constraint that is based on the minimum number of times a particular voxel is consecutively active throughout the analysis.

Methods

Numerical studies were performed using simulated fMRI data sets created by adding activation time courses to a series of 100 echo planar images acquired from a subject in resting condition (no task with eyes closed). The imaging parameters were: TR = 3 s, FOV = 220 mm, slice thickness = 3 mm with 1 mm inter-slice gap, and matrix dimension is 64 x 64 x 30. At the designated active regions, which followed the spatial layout of the regions activated by a simple finger-tapping task, simulated fMRI responses emulating a block design with alternating rest and task blocks (10 scans per block) were added to the baseline data. Five data sets were created corresponding to different activation contrast levels (ACL) [3] ranging from 1% to 5%. For each simulated data set, we performed an incremental GLM [2] analysis. From the series of generated activation maps, consistency maps were constructed as follows. At time n, we checked if a particular voxel is active or not. If not, the consistency map’s value at that voxel is set to 0; otherwise, its previous value is incremented by one. This process was repeated until all the activation maps of a given data set were processed. Thus, instead of encoding the statistical significance of a given activation, consistency map gives the number of times a particular voxel has been consecutively active throughout the analysis. The detection power of both the constraint and unconstraint consistency maps was examined using the receiver operator characteristic (ROC) method [4].

Results and Discussion

Figure 1 shows the activation (left panel) and consistency (right panel) maps of a representative slice from a simulated data set (ACL = 0.01). In the activation map, t-values higher than the set threshold are shown in shades of red. In the consistency map, voxels with values greater than 20 are shown in shades of red while those with values less than 20 were plotted in shades of blue. In terms of the location of the detected activations, the two maps give the same information as can be seen in the figure. The advantage of the consistency map becomes evident when distinguishing which of the active voxels are only recently detected (blue-colored) from those that have been active for sometime (red-colored). Voxels that are activated early in the task could also be extracted by searching for those with higher consistency values. By imposing consistency constraints, the false positives were reduced [Fig. 2 (left panel)] the number of which depends on the used threshold w. The plots of the mean of the ROC curves [Fig. 2 (right panel)] within the limited range of false positive fraction (FPF) between 0 and 0.1 also showed that the constraint cases (w = 5, 10, 15, 20) proved to be more effective than the unconstraint case (w = 1) in detecting most of the true activations while minimizing the number of false positives as can be seen from the higher mean values of the constraint cases.

Conclusion

We introduced the concept of consistency maps. Consistency maps could serve as substitutes to activation maps since they encode the same information in terms of the location of detected activations. With a consistency map, robustly active voxels could be easily distinguished from recently activated ones. Voxels activated early in the task could also be extracted. The results of the ROC analysis also showed that the constraint cases proved to be more effective than the unconstraint case in removing false positives while keeping most of the true activations. Finally, consistency maps are particularly useful for single data analysis such as in real-time fMRI and could play an important role in the analysis of data sets from clinical studies.

References

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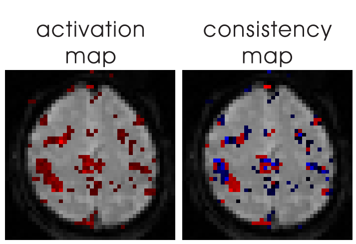

Figure 1

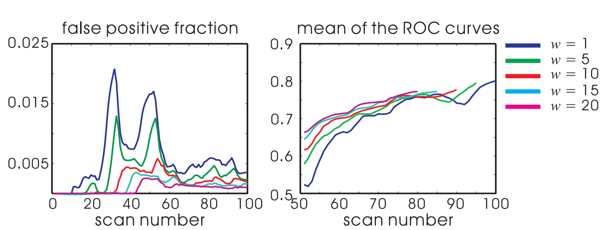

Figure 2

Figure 1. Activation (left) and consistency (right) maps of a representative slice at n = 50 during the incremental analysis of a simulated data set (ACL = 0.01)

Figure 2. Results of the ROC analysis. Left: False positive fraction at different times for different consistency threshold w. Right: Mean of the ROC curves from n = 51 to 100.