Shannon entropy method applied to fMRI data series during evoked and resting state activity

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INTRODUCTION AND PURPOSE

The current developments of fMRI data analysis attempt to extract useful information from the time course of identified region of interest. Here we applied Shannon entropy method to fMRI time series obtained during different experimental paradigms, namely evoked or resting state (RS) brain activity. Shannon entropy measures information content of the signal without making a priori assumptions about lags and/or shape of the hemodynamic response function. Variations of the entropy method was previously applied to fMRI in order to evaluate the degree of diversity (i.e., randomness) in values of event-related time series [1] as well as to identify complexity in block-design experiments [2]. In the present work, we set out to produce maps of Shannon entropy of block-design (visual task) experiments and compare them to resting-state (no task) experiments.

METHODS

Five healthy subjects (age 26±5) participated in this preliminary phase of the study. Visual stimulation consisted of hemi field (6 degree off-center) radial (4 degree) annular b/w checkerboard administered in a block design with attention monitoring. Data were acquired using a 3T Siemens Magnetom Allegra scanner. T1-weighted images were acquired for anatomical reference. Three multi-echo GE-EPI sequence were acquired for functional localizer and RS-Eyes Open (EO) and Eyes Closed (EC) runs (TR=4500 ms, TE=39 ms, FOV 192x192 mm^2). Run order was randomized across subjects. Timing of physiological cycles were recorded and RS data were physiological motion corrected (RETROICOR). Functional and RS data were analyzed (realign, slice-timing, high-pass filter, smoothing) and co-registered in the same space using SPM software.

Prior to any calculation, data was de-trended for linear and constant components, and images were masked to contain only voxels inside the brain (based on signal overage). Shannon entropy H was calculated in each voxel independently (i.e. using the voxel probability distribution obtained by standard histogram method) as $H = -\sum_k p_k \log_2 p_k$ with k being the k-th volume.

RESULTS AND DISCUSSION

First, standard general linear model (GLM) was applied to the data. Figure 1A shows the 30 more active voxels in contralateral visual cortex during the stimulation. Our calculations shows that Shannon entropy is normally distributed in a very narrow range (Figure 1B), which indicates that almost all voxels span the same interval of signal values. Figure 1C show the voxels exhibiting highest entropy values (p<0.01). There is a striking match between the high-entropy and "activated" voxels. Contrarily, resting-state data did not reveal any cluster of high-entropy values (not shown). The distribution of Shannon entropy of RS data was nearly indistinguishable from that of functional data. No significant difference was found in the maps of the upper tail of the entropy distribution between EO and EC stimulation protocols.

CONCLUSION

We have applied entropy method to the analysis of evoked and resting state brain activity. The analysis proved successful in determining the active voxels in a functional activation paradigm, while nothing was detected in subsequent resting-state experiment. Our results suggests that specific regions exhibits complex pattern of activity during evoked but not RS condition. This result indicates that RS activity cannot be extracted using a code (i.e., probability distribution) at the voxel-level. Future work will examine different approaches to determine the code underlying RS activity.

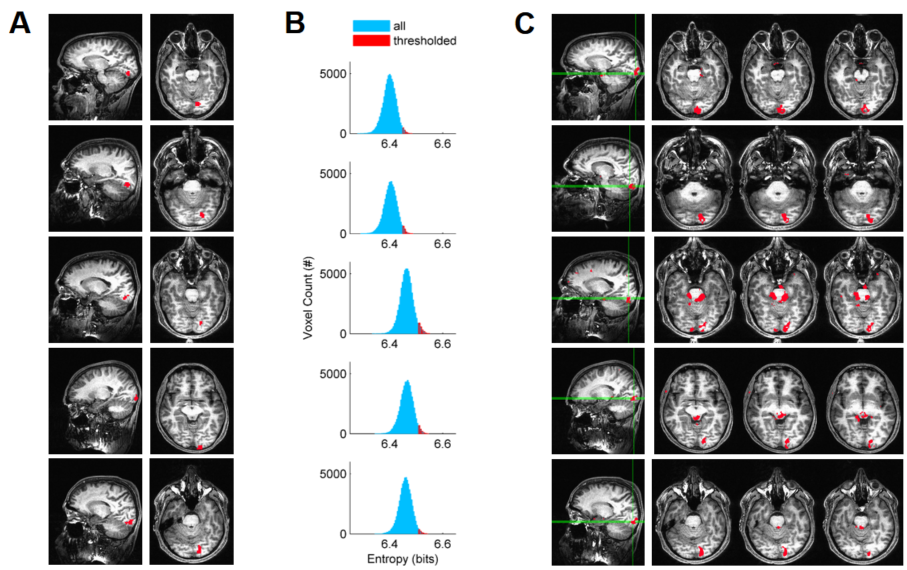

Figure 1. (A) 30 more active voxels as revealed by standard GLM analysis. (B) Histograms of Shannon entropy for all brain voxels (blue). The highest entropy values (red) give rise in the maps shown in (C). The activation in occipital cortex contralateral to the stimulated hemifield is clearly visible. In some subjects, there is also high-entropy (i.e. information content) in the thalamus. Note that the actual amount in bits depends on the number of bins chosen to calculate histogram and relative probability distribution, but have otherwise minor effects on the distribution of data.

REFERENCES

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