Network reduction for interpreting large scale brain networks

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Introduction

Although structural equation modeling (SEM) has been applied in an exploratory manner for ascertaining effective functional connectivity in relevant networks, its practical utility is limited by the number of nodes to be considered in a network. In this work, we illustrate the utility of multivariate Granger causality analysis [1] for characterizing large brain networks and introduce a new procedure to for removing unimportant nodes while retaining the important ones in the network. This method was applied to tactile perception fMRI data.

Materials and Methods

Six subjects were scanned on a 3T Siemens Trio using an EPI sequence with scan parameters: TR=2 s, TE=30 ms, FA=90º, 25 slices covering the whole brain with voxel size of 3.44×3.44×5 mm^3. A block design paradigm containing alternating stimulus and rest blocks was employed. Shape and texture stimuli were pseudo randomly presented during the stimulus block. Twenty-five activated regions were identified, consisting of shape-selective, texture-selective and multisensory areas [2]. The mean time series from each ROI was extracted, normalized, concatenated subject wise and input into a multivariate Granger model [1] to obtain a causal network. The resulting network was thresholded using surrogate data [1,3] and further reduced by removing ROIs which did not significantly reduce the overall network connectivity upon elimination. The reduction procedure was as follows. Let the connectivity matrix of the original R ROIs be A. Upon removal of an ROI, a connectivity matrix B was determined using the remaining R-1 ROIs. The overall connectivity of A and B, designated as S_A and S_B, respectively, are given below where $N_R=R(R-1)$ are the total number of possible connections.

$$S_A = \frac{1}{N_R}\sum_{i=1}^{R}\sum_{j=1;\, i\neq j}^{R} A(i,j) \qquad S_B = \frac{1}{N_{R-1}}\sum_{i=1}^{R-1}\sum_{j=1;\, i\neq j}^{R-1} B(i,j)$$

The cost function for dropping the given ROI is given by $\eta = S_A - S_B$. If η was statistically insignificant, the ROI under consideration was considered not to have a significant contribution to the network and dropped. To determine the statistical significance of η, surrogate data [3] was employed. The above procedure was started with R=25 ROIs and successively repeated by dropping the least significant ROI at each stage where in the network was recalculated with the remaining ROIs. The procedure was terminated when all the ROIs in the residual network were significant.

Results and Discussion

The network reduction process yielded 16 significant ROIs. The ones eliminated were mostly contralateral homologs, indicating redundancy in bilateral brain regions (Fig.1). The role of R LOC, a visual area, in tactile perception may be either top-down when driven by frontal/parietal areas (visual imagery representation) or bottom-up when driven by somatosensory areas (multisensory representation) [2]. This is not evident from the 25 ROI network. However, from the 16-ROI network there is evidence for bottom-up sensory inputs from PCS and insula as well as top-down inputs from PMv and IPS driving R LOC. Hence, both top-down and bottom-up mechanisms are present in tactile perception. This finding is in agreement with a previous SEM-based study using only 5 ROIs [4].

Conclusions

We have demonstrated the utility of multivariate Granger causality for characterizing large brain networks without *a priori* assumptions about the model. We have also illustrated the efficacy of our network reduction procedure for obtaining meaningful insights by eliminating redundancies in networks. This approach demonstrated the co-existence of top-down and bottom-up mechanisms in tactile perception. Our approach is likely to be of value for exploratory neuroscientific studies of large brain networks.

References

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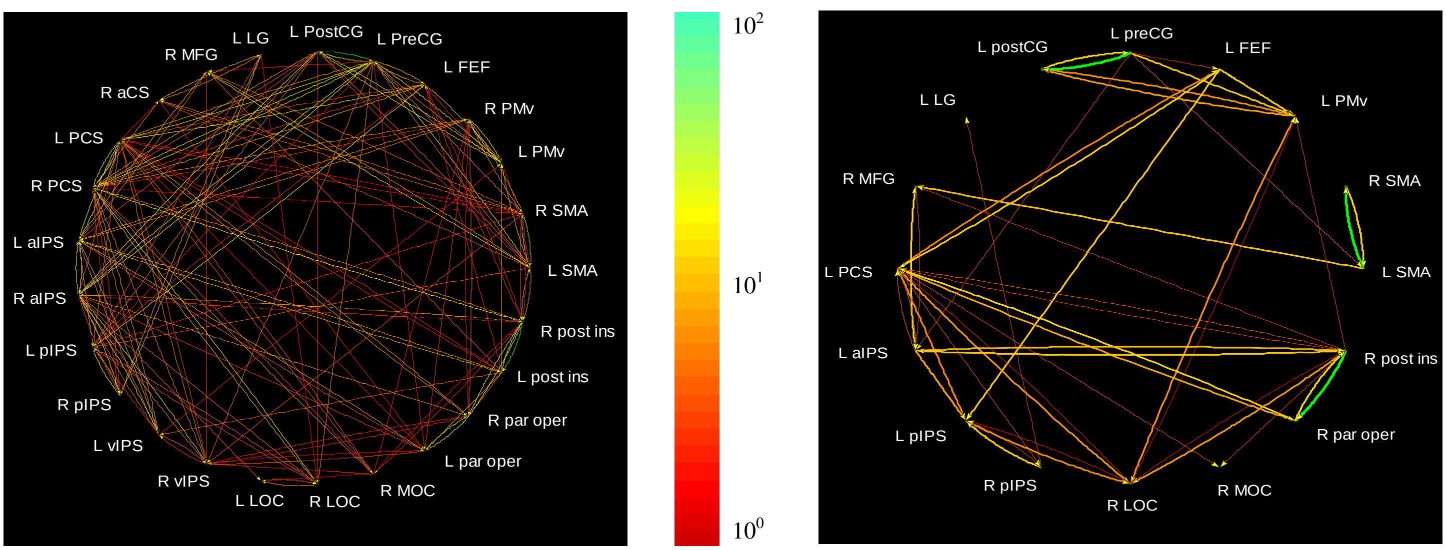

Figure 1 Granger causality networks thresholded at p=0.05. Left: 25 ROI network. Right: Reduced 16-ROI network. Abbreviations- L: left, R: right, a: anterior, p: posterior, v: ventral, SMA: supplementary motor area, PM: premotor, FEF: frontal eye fields, CG: central gyrus, LG: lingual gyrus, MFG: middle frontal gyrus, CS: cingulate sulcus, PCS: postcentral sulcus, IPS: intraparietal sulcus, LOC: lateral occipital complex, par oper: parietal operculum, post ins: posterior insula