The Causal Interaction Within Attention Networks And Emotion Network: A fMRI study

Sicong Liu, Xianxian Kong, Zhenlan Jin, Ling Li*

Abstract—**fMRI studies have suggested that there are two different attention networks: the dorsal attention network (DAN) and the ventral attention network (VAN). The emotion network has also been discovered by some researches. The dorsal attention network controls goal-oriented top-down deployment of attention; the ventral attention network controls stimulus-driven bottom-up deployment of attention; the emotion network will feed back the stimulus especially fearful expressions from the environment. The interaction within these networks has been noticed but few studies have been carried out. The purpose of this study is to explore the interaction within these networks. The regions of interest were acquired by using the GLM analysis after which the granger causality among these ROIs was calculated. Connections among ROIs were considered as causal when their respective granger causality value is greater than the mean value of all granger causalities. According to the results, there is interaction within the three networks, which suggested that the ventral attention network may distract the dorsal attention network and that the emotion network may influence both attention networks.**

I. Introduction

Human visual attention is proven to be controlled by two brain networks, the dorsal attention network and the ventral attention network (Figure.1B) (Wen et al., 2012). Human emotion is also thought to be controlled by brain network (Figure.1C). The dorsal attention network, which comprised of bilateral frontal eye field and bilateral superior parietal lobule or intraparietal sulcus initiates and maintains goal-directed top-down attentional control. (Figure.1A) (Kastner et al., 1999; Shulman et al., 1999, 2003; Corbetta et al., 2000,2005; Hopfinger et al., 2000; Astafive et al., 2003; Giesbrecht et al., 2003). The ventral attention network, a right-lateralized network, is composed of the right ventral frontal cortex and the right temporal-parietal junction. This network makes stimulus-driven bottom-up attentional reorienting possible (Figure.1B) (Shulman et al., 1999; Corbetta et al., 2000; Astafiev et al., 2003; Kincade et al., 2005; Astafiev et al., 2006). The emotion network is composed of both the right and left fusiform gyrus, the inferior temporo-occipital gyri of the bilateral hemisphere (Figure.1C)(Patrik et al., 2001; Kanwisher et al., 1997; Puce et al., 1995) and other relative brain regions such as Thalamus, Cingulate gyrus and hippocampus. Although it is generally considered that the connections between dorsal attention network and ventral attention network underlies the human ability to adapt to complex visual environments and that the interaction within such two brain networks and emotion network may affect both human attention and emotion, the neuronal mechanisms of the interaction within these networks remain unclear. Between dorsal attention network and ventral network, one type of hypothesis is that top-down signals from the dorsal attention network to ventral attention network suppress and filter out unimportant information so that goal-oriented sensorimotor processing can proceed unimpeded, whereas the ventral attention network may shift attention by sending bottom-up signals to the dorsal attention network to disrupt the information processing (Corbetta et al., 2008). Between emotion network and attention network there is a hypothesis that the emotion network may modulate human attention networks. This study mainly focused on the influence of fear emotion on spatial attention.

For the former hypothesis, supporting evidences mainly come from lesion and functional imaging studies. For instance, damage to areas within the ventral attention network or the dorsal attention network, which is either caused by permanent lesion (eg., stroke) or temporary interference (eg.,TMS) may suppress the ability to disengage from an existing attention focus (Meister., 2006). For the latter hypothesis, there are still few direct supporting evidence. Although lesion techniques are very powerful, such techniques require perturbation or even damage to the nervous system. This weakness limits the application of lesion techniques. In naturally occurring lesions such as stroke, the extent of damage is uncontrollable and the damaged tissues not only is distributed at target brain areas but also nontarget brain areas, which confounds precise functional localization (Rorden and Karnath, 2004). Functional MRI is mainly based on noninvasive imaging techniques and owns high spatial resolution. These characteristics make the analysis of different brain areas possible. While resting state fMRI connectivity has revealed correlated BOLD variations in the dorsal and ventral attention networks (Fox et al., 2006), some researches also investigated the interaction between attention network and emotion network (Patrik et al., 2001; Harlan et al., 2004). Though having their advantages, the existing approaches to analyzing temporal correlation cannot delineate the direction of signal propagation. In our study, a mixed block/event-related cued spatial attention-emotion

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Sicong Liu is with the Key Laboratory for NeuroInformation of Ministry of Education, University of Electronic Science and Technology of China, Chengdu, Sichuan 610054 China (e-mail: liusc86@sina.com).

Xianxian Kong is with the Key Laboratory for NeuroInformation of Ministry of Education, University of Electronic Science and Technology of China, Chengdu, Sichuan 610054 China (e-mail: kongxian2007@163.com).

Zhenlan Jin is with the Key Laboratory for NeuroInformation of Ministry of Education, University of Electronic Science and Technology of China, Chengdu, Sichuan 610054 China (e-mail: jinzl@uestc.edu.cn).

Ling Li is with Key Laboratory for NeuroInformation of Ministry of Education, University of Electronic Science and Technology of China, Chengdu, Sichuan 610054 China (Corresponding Phone: 86-28-83203371; e-mail: liling@uestc.edu.cn).

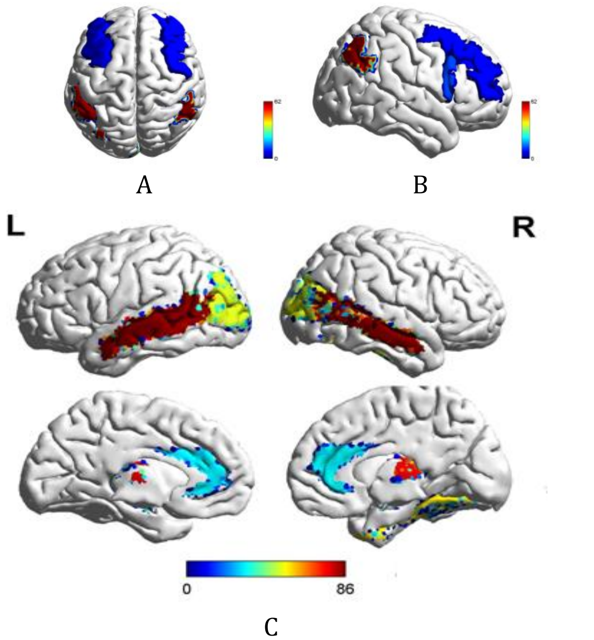


Figure 1. *Attention network and emotion network*. A. Dorsal attention network: bilateral frontal eye field and bilateral superior parietal lobule or intraparietal sulcus. B. Ventral attention network: right ventral frontal cortex and right temporal-parietal. C.Emotion network: the left and the right fusiform gyrus, the inferior temporo-occipital gyri of the bilateral hemisphere and relative areas: Thalamus, Cingulate gyrus and hippocampus.

paradigm where subjects were asked to perform a trial-by-trial experiment was used.

First, the GLM algorithm (generalized linear modeling) was used to locate the regions of interest (ROIs). Direct interaction within ROIs of three networks were then calculated by Granger causality analysis.

II. Materials and Methods

A. Participants

11 healthy adults (right-handed, aged 20-26, three females, eight males) without past neurological or psychiatric history participated in the imaging study. A structural MRI scan was taken during the first session of functional MRI scanning to exclude subjects with structural misalignment.

B. Task

A mixed block/event-related design was used. For each subject, there was 4 experimental sessions that each contains 3 blocks. The experimental timeline is schematically illustrated in Figure 2. On each block, subjects performed a trial-by-trial cued spatial-emotion attention/unattention task. Before performing the task, a cue would first be displayed to indicate the subject whether pay attention to the target or not and which side should be noticed. There are different emotional expressions in each block (Fear, Normal, Happy).

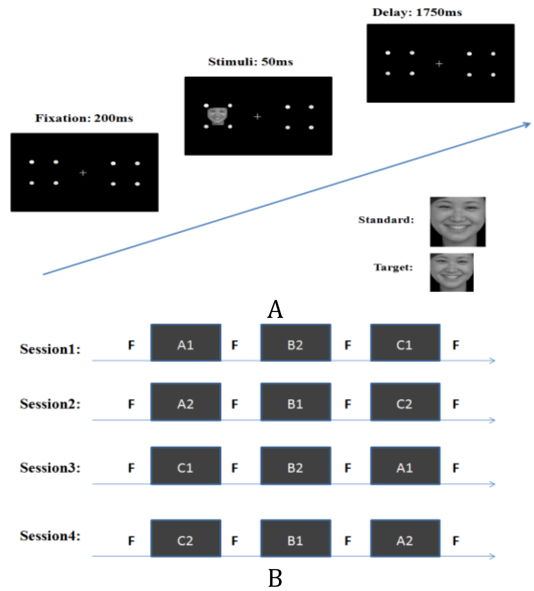


Figure 2. *A mixed block/event-related paradigm was used.* In a single trial, a cue indicating which side should be looked would be presented following a 200ms fixation across. A stimulus would then display for 50ms after which there is a 1750ms delay.

C. Data acquisition

MRI scanning was performed using a 3-Tesla Magnetom Trio whole-body MRI System (GE) at the University of Electronic Science and Technology of China MRI Center. Structural images were acquired with a T1-weighted sequence and functional images with a gradient echoplanar T2 sequenceusing BOLD (Blood Oxygenation Level Dependency) contrast. A total of 720 functional images were obtained from each subject. Volumes were acquired contiguously with an effective repetition time (TR) of 2s. Each subject would complete a 4-sessions task. Ten dummy volumes at the beginning of every session would be discarded to allow for T1 equilibration effects.

D. GLM analysis and ROI Definition

Before GLM analysis, some preprocessing steps including slicing time, realign, coregister, segment and normalise were performed. (Friston et al., 1995). The SPM8 was used to preprocess and analyze fMRI data (http://fil.ion.ucl.ac.uk). The global scaling was not used due to controversy (Zarahn et al., 1997; Aguirre et al., 1998; Glover et al., 2000; Gavrilescu et al., 2002; Fox et al., 2009). Head motion parameters were not involved in the design matrix to avoid spurious activation (Johnstone et al., 2006). To meet the purpose of this study, the conditions under fear emotion and the baseline were compared to produce the contrast image. These images were computed using a one sample t test to get the activation at group level. The Alphasim correction (Xiao-Wei Song et al., 2011) was used to correct for multiple comparisons after which ROIs for granger causality were selected from activated regions ($p<0.001$, Cluster size=30, Aplhasim-corrected).

TABLE I. CENTER COORDINATES OF THE ROIS

Area Name(ID)	Cluster Size	Peak Value	Coordinates
lFEF(7)	63	20.1327	-24 6 51
rFEF(8)	101	37.3476	27 12 51
lIPS(61)	136	21.0206	-33 -57 42
rLPS(62)	52	13.1144	39 -51 39
raMFG(8)	47	24.0622	33 42 36
rpMFG(12)	27	19.4049	57 18 21
rTPJ(66)	30	9.6181	39 -63 33
lACC(31)	43	26.7043	-3 33 18
rACC(32)	24	23.2328	3 33 18
lHippocampus(37)	23	20.9893	-21 -33 0
rHippocampus(38)	14	19.3958	24 -33 -3
lOccipital_Mid(51)	200	20.0100	-36 -81 27
rOccipital_Mid(52)	132	37.2402	39 -72 33
rFusiform(56)	124	22.4900	30 -54 -3
lThalamus(77)	20	22.6182	-15 -30 6
rThalamus(78)	14	13.3989	15 -27 6
lTemporal_Mid(85)	79	45.2727	-54 -15 -12
rTemporal_Mid(86)	74	31.9135	42 -63 0

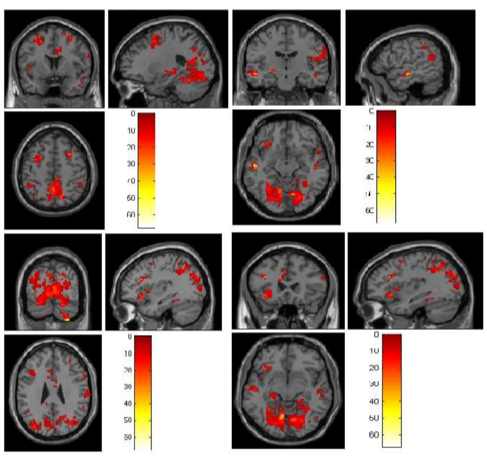


Figure 3. *The activated regions.* The activated regions were overlaid on a template (p<0.001, cluster size=30, alphasim-corrected)

E. Granger causality analysis

This study has chosen the granger causality to analyze the interaction among the three networks,. Such decision is based on the data-driven nature of the granger causality (Ding et al., 2006; Bollimunta et al., 2008, 2011; Xiao-tong Wen et al., 2012). The steps of the granger causality analysis is as follows: 1) the time series were extracted from fMRI images and global effects were removed (Smith et al., 1999); 2) the percentage BOLD signal was calculated 3) the temporal mean for a given residual time series was computed and removed to meet the requirements of the autoregressive (AR) model (Ding et al., 2000, 2006). The order of the AR model was chosen to be 1 based on the Bayesian information criterion (Roebroeck et al., 2005; Bressler et al., 2008; Hamilton et al., 2011; Xiao-tong Wen et al., 2012)

III. RESULTS

A. Regions of interest

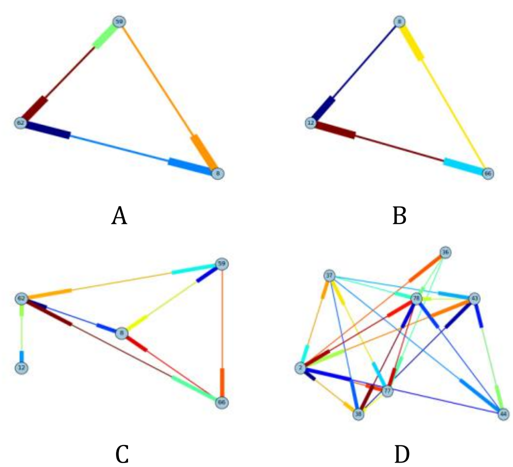
The conditions under fear emotion were contrasted against the baseline to get the activated brain areas by visual spatial attention and fear emotion. Figure 3 shows the activated regions (p<0.001,Cluster size=30, Alphasim-corrected). The areas of activation include 1) the dorsal attention network which contain the bilateral frontal eye field (FEF) and bilateral intraparietal sulcus (LPS); 2) the ventral attention network which includes rTPJ, right anterior middle frontal gyrus (raMFG) , right posterior middle frontal gyrus (rpMFG) and 3) the emotion network which is composed of both the left and right fusiform gyrus, inferior temporo-occipital gyri of the bilateral hemisphere and other relative brain regions such as Thalamus, Cingulate gyrus and hippocampus. In the meantime, the Angular gyrus, bilateral Precentrals, bilateral Lingual gyrus and some cerebellum areas were also activated. Since our study aims at investigating the interaction between the attention network and emotion network, unrelated regions were not included in the analysis. The cluster size, peak value (F value), and MNI coordinates of ROIs were illustrated in table 1.

B. Granger causality analysis and data visualization

The values of granger causality were computed for all ROI pairs. Values less than the mean value of all granger causalities were discarded. Weights were then calculated between the remaining ROI pairs. The following formula can be used:

$$w = (GC_{ij} - mean(GCs)) / mean(GCs) \quad (1)$$

Results between each ROI pairs were shown in Figure 6. The granger causality within different networks and across all networks were also computed. The values were used as the connection value between ROI pairs. Finally, all connected ROI regions were used as the nodes of the whole brain network. The whole brain network was generated using Networkx (http://networkx.lanl.gov/index.html)



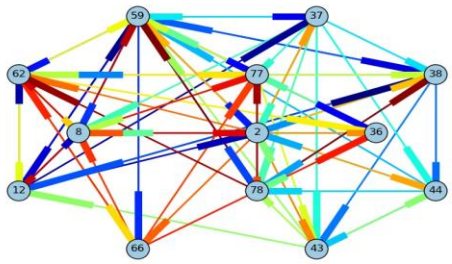


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Figure 4. *Granger causality connection.* A. Within the DAN network, granger causality connections exist among rFEF, llps, and rlps. B. Within the VAN network, granger causality connections exist among all ROIs. C. The interaction between the DAN and VAN network; interference can be found between the connections among the DAN and VAN network . D. Interactions among emotion network nodes exist within the emotion network. E. Interactions among all nodes: There are interactions among all nodes.

IV. Discussion

A. Interaction within networks

The results of this study supported the former hypothesis stated in the introduction that the interaction between the DAN network and VAN network would interfere each other. In our study, the granger causality values of the DAN network, the VAN network and emotion network were calculated respectively. Within the DAN network, we have found interaction between each network node pair. Also, within the VAN network there is interaction between each node pair. But if we compute the granger causality values of the DAN network and VAN network as a whole, we could find that the connections within VAN network had been depressed. This result provided evidence for the former hypothesis. Furthermore, if we put all three networks together and calculate the values of granger causality, we could find that there are communications within the DAN network, the VAN network and the emotion network .

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