Brain activation pattern and functional connectivity network during classification on the living organisms

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Abstract: The purpose of this study was to investigate brain activation pattern and functional connectivity network during classification on the biological phenomena. Twenty six right-handed healthy science teachers volunteered to be in the present study. To investigate participants' brain activities during the tasks, 3.0T fMRI system with the block experimental-design was used to measure BOLD signals of their brain. According to the analyzed data, superior, middle and inferior frontal gyrus, superior and inferior parietal lobule, fusiform gyrus, lingual gyrus, and bilateral cerebellum were significantly activated during participants' carrying-out classification. The network model was consisting of six nodes (ROIs) and its fourteen connections. These results suggested the notion that the activation and connections of these regions mean that classification is consist of two sub-network systems (top-down and bottom-up related) and it functioning reciprocally. These results enable the examination of the scientific classification process from the cognitive neuroscience perspective, and may be used as basic materials for developing a teaching-learning program for scientific classification such as brain-based science education curriculum in the science classrooms.

Key words: Classification; brain activation pattern; Functional connectivity network, fMRI

I. Introduction

Classification has been considered as a inductive process of scientific knowledge generation and regarded as one of the basic scientific inquiry skill (Kwon *et al.*, 2003). In addition, classification schemes aid communication among biologists (Margulis, 1981; Honey & Paxman, 1986), provide a framework for all biological knowledge, and are tools for doing science (Margulis, 1981). Therefore, a process of the classification is the most important skill in understanding the complex and diverse nature (Jiang *et al.*, 2007; Seger, 2008). Many previous studies of the science education showed that classification plays an important role in the scientific inquiry (Honey & Paxman, 1986; Jo *et al.*, 2005; Kwon *et al.*, 2003).

Kwon et al. (2003) investigated to the scientific thinking type and process of classification by college students. In this study, they suggested that thinking process of classification is consist of two sub-steps. First step is 'searching criteria for classifying' and second step is 'selecting criteria for classifying'. It correspondence with study of Goel & Dolan (2000) - rule-induction and rule-application. However, almost all of previous studies based upon indirect research methods such as paper and pencil test, interview, and questionnaire (Ansari & Coch, 2006). Therefore actual brain activation pattern in intact brain was still remains unclear.

Recently, brain imaging technology has enables us to understand directly the function of the living brain. These brain imaging methods help us to analyze the relationships between specific areas of the brain and the functions they serve. Particularly, blood oxygen level dependent (BOLD) functional magnetic resonance imaging (fMRI) is an imaging technique that makes it possible to dynamically and non-invasively follow metabolic and hemodynamic consequences of whole-brain neural activity (Huettel *et al.*, 2004).

Recently, Goel and Dolan (2000) reported to activation patterns during the inductive inference task. They suggested that inductive inference such as classification is different from deductive

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**Received on 31 August 2009, Accepted on 20 October 2009

inference and anatomical segregation was shown to thinking style of classification (rule-induction and rule-application). Also, Jiang *et al.* (2007) investigated the training effects of classification skills. In this study, they suggested that classification (or categorization) training improves discrimination performance on the trained stimuli. In this study, they reported that LOC (lateral occipital complex), FFA (fusiform face area) and rLPFC (right lateral prefrontal cortex) was play an crucial roles in the classification.

Despite these findings, however, no study has yet explored any neural network patterns of classification in the context of science education. Therefore, in this study, we used functional magnetic resonance imaging (fMRI) to investigate the neural responses associated with the classification process at the aspects of not only regional activation pattern but also functional connectivity network.

Ⅱ. Methods and Procedure

1. Participants

Twenty six right-handed (12 males and 14 females), healthy science teachers volunteered to be participants in the fMRI experiment (age 27.57 ±3.72). All participants of this experiment had normal or corrected-to-normal visual acuity, no history of neurological, psychiatric or major medical illness, and were right-handed according to the Edinburgh handedness inventory (Oldfield, 1971). Each participant gave their informed consent prior to their inclusion in the experiment in accordance with the Declaration of Helsinki. The study was approved by the Ethics Committee of KNUE (Korea National University of Education).

2. fMRI experimental task

In this study, the development procedure of fMRI experimental tasks follow Lee *et al.* (2009) in their step. The experimental paradigm was consisting of 9 tasks (Fig. 1). Each task started with a blank slide for dummy phase (12s) followed by notice slide (6s). The notice slide, we have announced the task name (e.g. 'classification') to participants. When the main task was stated, the text slide (12s) was presented before the experimental design slide ('Please, classify the following organisms'). This slide containing the messages for the participants. Finally, picture of the living organisms were presented to participants (24s). The main slide of classification task was consists of nine small pictures. During this phase, participants should have classify the presented living organisms such as animal, plants and microorganisms to generate classification knowledge. End of the trial the white crisscross fixation was presented for 12s. The participants were instructed to keep their eye open at all times and to fixate the central cross to minimize eye movements. Schematic diagram was showing exemplars of the stimulus display and the timings used in this study (Fig. 1).

3. fMRI data analysis

Anatomic T1 and functional T2*-weighted MR images were acquired with a same condition and methods of Lee *et al.* (2009). Structural and functional images were analyzed using SPM2 (the Wellcome Department of Cognitive Neurology, UK). SPM2 was used for realignment, normalization, co-registration, smoothing and statistical analysis to create statistical parametric maps of significant relative regional BOLD response changes. A mean functional image volume was constructed for each subject from the realigned images. The realigned data set was then transformed into Talairach space. Random-effects analyses were performed to examine the effect of numerical distance on the BOLD response. Statistical analysis was carried out using one sample t-test to determine significant activation at group level. Voxels were considered to be significantly activated when they passed a statistical threshold of $p<0.05$, corrected for

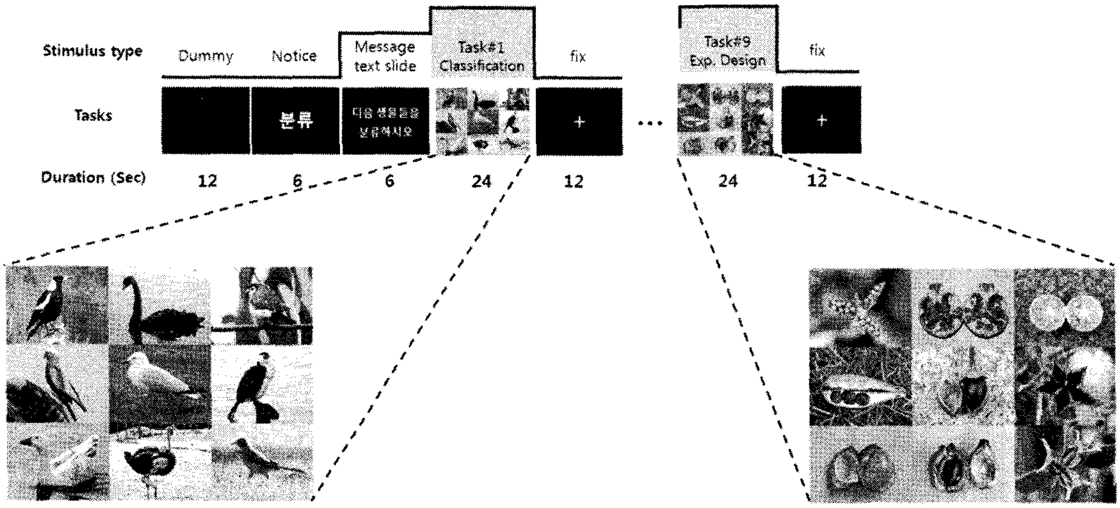

Fig. 1 *Schematic representation of fMRI experimental design. The experimental paradigm was consisting of 9 tasks. In this figure, a representative trial was presented. See the text for explanation.*

multiple comparison.

'Functional connectivity' is defined as the "temporal correlations between spatially remote neurophysiologic events" (Friston *et al.*, 1993). To compute the measure of functional connectivity, BOLD signals of activated voxels were extracted from the selected-ROIs. For each participant, a mean time-course was computed across activated voxels in each ROI. A correlation coefficient was then calculated between the time-courses of pairs of ROIs. Finally, the significant functional connectivity networks among selected ROIs for classification processes were constructed. We regarded the correlation's P value less than 0.05 ($P < 0.05$) as the significant correlation in this study.

Ⅲ. Results and Discussion

1. In-depth interview result

After fMRI scanning, all of participants reported their actual thinking of each task through an in-depth interview. In in-depth interview, all of participants who participated in this study was performed the tasks well. They were all generated their own classification knowledge successfully. Therefore we have regarded them as a significant subject in this study.

2. fMRI Results

1) Brain activation patterns of the classification

To determine the basic pattern of activation for classification, we used the 'classification versus baseline' contrast to reveal areas showing significantly increased blood oxygenation level dependent (BOLD) signal during conditions in which participants were required to classification compared signals during the control baseline condition. The Talairach-space coordinates and their number of Brodmann's area and their significant Z-value($P < 0.05$, FDR corrected) are listed in Table 2.

The 'classification versus baseline' contrast yielded bilateral activations in the inferior frontal gyrus, (BA 9, 46), the middle frontal gyrus (BA 6, 9), the superior parietal lobule (BA 7), the fusiform gyrus (BA 37), the cuneus (BA 17, 30) and the cerebellum (the culmen and the declive). In addition, the left inferior parietal lobule (BA 40), the right precuneus (BA 7), the right superior occipital gyrus (BA 19), the right middle occipital gyrus (BA 19), the right lingual gyrus (BA 18), the left lingual gyrus (BA

Table 1

Brain regions showing significant activations in contrast classification versus baseline

Region of activation		BA & Side	Z-score	Talairach coordinate		
				x	y	z
Frontal	Inferior Frotal Gyrus	9 L	6.72	−46	7	25
		46 L	4.08	−46	31	6
		9 R	4.62	44	9	24
	Middle Frontal Gyrus	6 L	5.87	−26	−1	52
		9 L	5.37	−50	6	37
		6 R	4.9	26	−1	48
Parietal	Superior Parietal Lobe	7 L	7.83	−26	−60	44
		7 R	6.29	28	−58	43
	Inferior Parietal Lobe	40 L	4.82	−44	−33	38
	Precuneus	7 R	6.33	26	−64	33
Occipital	Superior Occipital Gyrus	19 R	6.6	32	−73	22
	Middle Occipital Gyrus	19 L	6.67	−30	−85	17
	Fusiform Gyrus	19 R	6.78	32	−69	−13
	Lingual Gyrus	18 R	5.41	12	−72	5
	Cuneus	17 L	5.25	−20	−77	8
		30 R	5.65	26	−75	7
Temporal	Fusiform Gyrus	37 L	5.53	−46	−47	−14
		37 R	5.8	44	−47	−11
Limbic	Parahippocampal Gyrus	L	6.58	−24	−29	−4
	Putamen	L	4.56	−18	0	6
	Globus Pallidus	L	4.46	−20	−5	9
		R	4.36	22	−16	−4
Cerebellum	Culmen	R	6.88	38	−52	−21
		L	5.6	−46	−50	−19
	Declive	L	6.86	−32	−67	−19
		R	6.78	32	−59	−14

BA: Brodmann areas, L: left hemisphere, R: right hemisphere

18), the left parahippocampal gyrus and the left putamen were activated in the 'classification versus baseline' condition (Table 2 and Fig. 2). Conducting the classification in this study, the brain activation regions that were shown in the participants all appeared in bilateral hemisphere (Fig. 2, 3).

First, the activation of bilateral occipital regions were revealed in the classification (Fig. 2, 3). For this region, it was connected each other significantly in the occipital regions and it was connected bilateral cerebellum and left parietal region, too (Fig. 3). This parts (lateral occipital complex) postulated to play a key role in human object recognition (Jiang *et al.*, 2007). After recognize organisms, participants extract a number of characters to comparing and grouping, then it projected to both occipito-parietal and occipito-temporal pathway.

The parahippocampal cortex might be an association area, coding information from sensory organs as well as mediating contextual associations and semantic integration to our environment (Yue *et al.* 2007; Bar & Aminoff 2003). Also, this region has been found to be related to the intermediate-term storage and maintenance of individual mental representations (Luo *et al.*, 2003). The activation of this region mans temporary maintaining and association of spatial information about organisms (e.g. the location of bill and the ramification patterns of leaf vein structure etc.) which is received to where pathway (occipito-temporal pathway) (Poirier *et al.*, 2006) during the classification. If more information is required for classification, they increase the amount of information by observing the phenomena in detail, which is considered a cause of this activation of fusiform gyrus.

In addition, we found significant activations of basal ganglia (putamen and globus pallidus), a number of studies have suggested that the basal ganglia are also involved in human category learning (Ashy & Spiering, 2004). One important neural system involved in categorization and classification is the corticostriatal system connecting cortex and basal ganglia. Almost all regions of cortex send projections to the input structures of the basal ganglia, which include the striatum and subthalamic nucleus (Seger, 2008).

Classification is a repetitive process of rule-generation and rule-selection. Therefore, when we classifying the diverse organisms, our brain generate a number of rules and select suitable rules (criterion for classification) among the prior generated (Goel & Dolan, 2000). In this process, not a few tentative and intermediate abstract rules were represented. In some ways, it is an uncertain situations. According to recent studies, the cerebellum plays an important role in inferring and decision making under uncertain circumstances (Blackwood *et al.*, 2004). Additionally, we found bilateral prefrontal activations during classification (Table 2 and Fig. 2). The activation of right prefrontal cortex was related to rule-generation and left prefrontal cortex (especially, IFG) was related to rule-selection (Goel & Dolan, 2000; Koenig *et al.*, 2005). That is the reason why bilateral prefrontal cortex and cerebellum was shown in the classification.

The activation of bilateral parietal regions (superior and inferior parietal gyrus) were revealed in this study (Table 2, Fig 2). According to previous studies, working as a visuo-spatial working memory buffer, these regions are known as a temporary storage for basic visuo-spatial information that is acquired for participants to perceive (Smith & Joindes 1997; Tomasi *et al.* 2007). Also, if it activated with frontal region, it was working on the fronto-parietal system. The fronto-parietal system play an important role in the top-down attentional control on visual cortex that enable recognition. It is known to modulate visual cortical activity during perception in a context-dependent manner and retrieval of visual stimulus representations from stored memory is mediated by fronto-parietal attentional mechanisms (Itoh *et al.*, 2008).

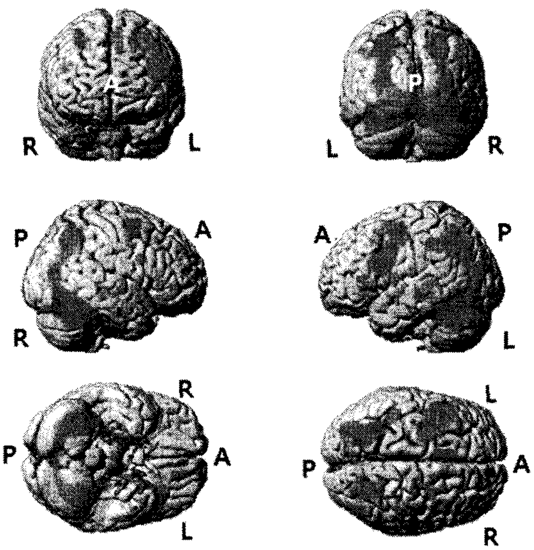

Fig. 2 *Brain activation pattern during classification on the living organisms (P < 0.05, FDR corrected). L; Left hemisphere, R; Right hemisphere, A; Anterior, P; Posterior.*

2) Brain functional connectivity network of the classification

In order to examine the neural correlation network among the involved regions, we then calculated percent signal changes of the activated regions (time-series of BOLD signals) in classification process for each participant and calculated the Pearson's correlation coefficient among all the regions detected from the prior analysis: selected-ROIs. Several previous neuroimaging studies have indicated the possibility of the functional connectivity or associations using correlation analyses among regions (Tsukiura *et al.*, 2001). Significant correlation network in analysis is shown in Fig. 3.

In our functional connectivity network model of the classification, all of their correlation's P value

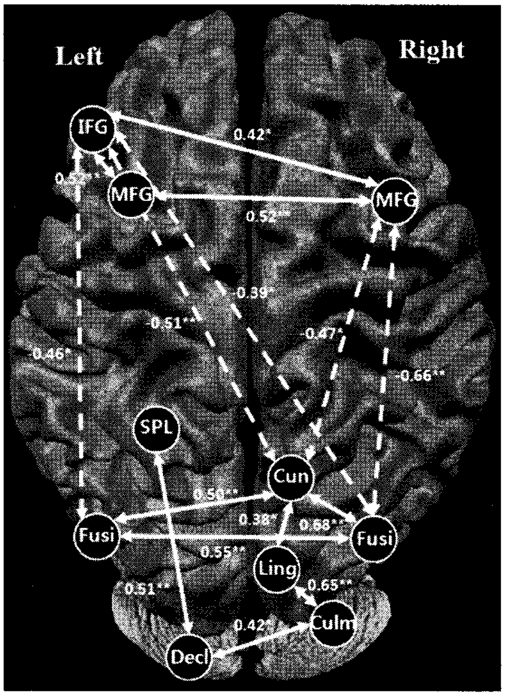

Fig. 3 *The significant functional connectivity networks among selected ROIs for classification processes. This study regarded the correlation's P value less than 0.05 (* P < 0.05, ** P < 0.01) as the significant correlation. The number on the line means the correlation coefficient. The abbreviations of circles mean the anatomical name of ROIs (MFG; Middle frontal gyrus, IFG; Inferior frontal gyrus, SPL; Superior parietal lobe, Ling; Lingual gyrus, Fusi; Fusiform gyrus, Cun; Cuneus, Culm; Culmen, Decl; Declive).*

between ROI pairs less than 0.05 as the significant correlation. The network model was consisting of ten nodes (ROIs) and its fourteen connections. In classification process, the left inferior frontal gyrus (IFG) had the significant correlations with the left middle frontal gyrus (MFG) (r = 0.52), the right cuneus (Cun) (r = −0.51), the right middle frontal gyrus (MFG) (r = 0.42) and the right fusiform gyrus (Fusi) (r = −0.39). Also, right cuneus (Cun) had the significant correlations with the right middle frontal gyrus (MFG) (r = −0.47), the right lingual gyrus (Ling) (r = 0.38), and the left fusiform gyrus (r = 0.50) and right fusiform gyrus (Fusi) (r = 0.68). We also found the significant correlations between the left middle frontal gyrus (MFG) and the right middle frontal gyrus (MFG) (r = 0.52), between the right middle frontal gyrus (MFG) and the right fusiform gyrus (Fusi) (r = −0.66), and between the left superior parietal lobule (SPL) and the left cerebellum (Declive; Decl) (r = 0.51), between the bilateral fusiform gyrus (r = 0.55), between the right lingual gyrus (Ling) and the right cerebellum (Culmen; Culm) (r = 0.65), and between the bilateral cerebellum (Culmen and Declive) (r = 0.42) (Fig. 3).

Classification is a fundamental cognitive ability essential for survival, as exemplified by obvious importance of efficiently distinguishing friend from foe or edible from poisonous objects. It requires combining "bottom-up" stimulus-driven information with "top-down" task-specific information to the complete classification (Jiang *et al.*, 2007).

In this study, the brain activation regions that were shown in the participants all appeared in both hemispheres (Fig. 2, 3) during the classification on the living organisms. Also, significant functional connectivities were found among bilateral prefrontal regions, occipital regions, parietal region, temporal regions and cerebellum during the classification on the living organisms. There are two types of connectivity was found. One is positively correlated neural network and the other is negatively correlated neural network (Fig. 3).

The functional neural network of the classification consists of two major clusters which is correlated to positively themselves. One is prefrontal cluster and the other is cerebero-occipito-parietal or temporal cluster. The former network work on the function of top-down process related to secondary abstract level and the later was related to the function of bottom-up process as a primary imagery formation process from environment (e.g. diverse living organisms) (Freedman *et al.*, 2003; Jiang *et al.*, 2007; Thomas *et al.*, 2001). Therefore the two network systems were functioning reciprocally. That is the reason why negative correlation was shown in the functional neural network of classification.

Ⅳ. Conclusion and Implications

Classification is a kind of complex high-order inferential process (Jiang *et al.*, 2007; Kwon *et al.*, 2003). Therefore, it is more significant when they cooperate as neural correlates or a network than when they work all separately as a single region. In this study, functional connectivity analysis was conducted to search for the brain network which is related to classification. In consequence, this study found that there are fourteen significant functional connectivity pairs in the classification process, which is connecting each region. Taken together, the brain network of the classification is consist of prefrontal cluster (top-down related) and the other is cerebero-occipito-parietal or temporal cluster (bottom-up related). Then, the two network systems were functioning reciprocally.

These results enable the examination of the classification process from the cognitive neuroscience perspective, and may be used as basic materials for developing a teaching-learning program for scientific classification such as brain-based science education curriculum in the science classrooms. In addition, this network model could be applied on the measuring individual differences or learning-related changes of the students' classification ability at the neurological level.

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