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The neural basis of object recognition for between- and within-category levels -an fMRI study

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The present experiments were designed to examine hemispheric differences for between- basic category and within-category levels of object recognition. In experiment 1, participants indicated whether sequentially presented objects were from the same category or from the different categories (between-category task) or whether objects were identical or not (within-category task). Stimuli were briefly presented either in the right or left visual field. The results indicated a non-significant right visual field (left hemisphere) advantage for the between-category task and a significant left visual field (right hemisphere) advantage for the within-category task. In experiment 2, fMRI was used to investigate cortical activation during between- and within-category object recognition. During the between-category task, left inferior parietal lobule was more activated than the right. For the within-category task, left FFA (fusiform face area) and bilateral inferior parietal lobule were activated. Furthermore, the right superior occipital gyrus (SOG) and precuneus was more activated than the left during the between-category task whereas this asymmetry was reversed during the within-category task. The present results suggest that a hemispheric asymmetry that is parallel to spatial relation processing exists for recognition of objects.

Keywords : object recognition, hemispheric asymmetry, fMRI,

Introduction

An object can be recognized in different category levels. At a basic category level, a chair can be distinguished from a table. For such a basic category recognition, qualitative, categorical information of an object should be encoded (Biederman, 2000). On the other hand, at a within-category member level, *my* chair can be distinguished from other chairs. For such a member level recognition, quantitative, metric information of an object should be encoded. Face recognition is a representative case of such a within-category member discrimination in which one must encode quantitative coordinate relation of facial features (Cooper and Wojan, 2000).

Recent studies suggested that the left hemisphere has processing advantage for categorical quantitative spatial relation while the right hemisphere has processing advantage for coordinate, metrical spatial relation (Kosslyn, 1994; Helegi and Michimata, 1989). Furthermore, the left hemisphere has advantage for classifying different objects for abstract category while the right hemisphere has advantage for specific member level object discrimination (Marsolek, 1999). In the present study, we will examine whether between- and within- category object recognition would show such hemispheric differences.

Experiment 1

In Experiment 1, it was predicted that the left hemisphere has advantage for between-category object recognition and the right hemisphere has advantage for within-category object recognition

Method

Participants Nineteen right-handed undergraduate and graduate students (11 males and 8 females, mean age=19.5)

Design Task (Between-category discrimination task / Within-category member discrimination task) x Visual Field (RVF / LVF).

Stimulus Stimuli were gray-scale pictures of everyday objects. They consisted of 5 basic categories and 5 members for each category (Fig.1). All stimuli were 4^{o} x 4^{o} visual angle in size

Task & Procedure In the between-basic category task, participants judged whether sequentialy presented stimuli were from the same category, ignoring member difference. In the within-category member discrimination task, participants decided whether the two objects were identical. Stimuli were presented on a 19-inch monitor connected to a PowerMacG4 (Apple) computer running Matlab5

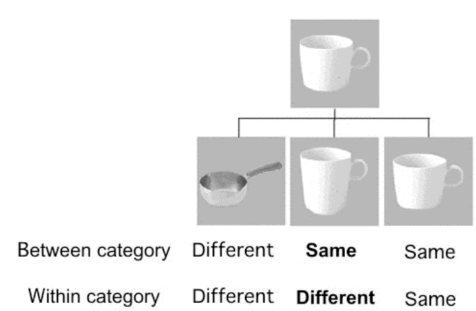


Figure 1. Example of stimuli used in both experiment 1 and experiment 2.

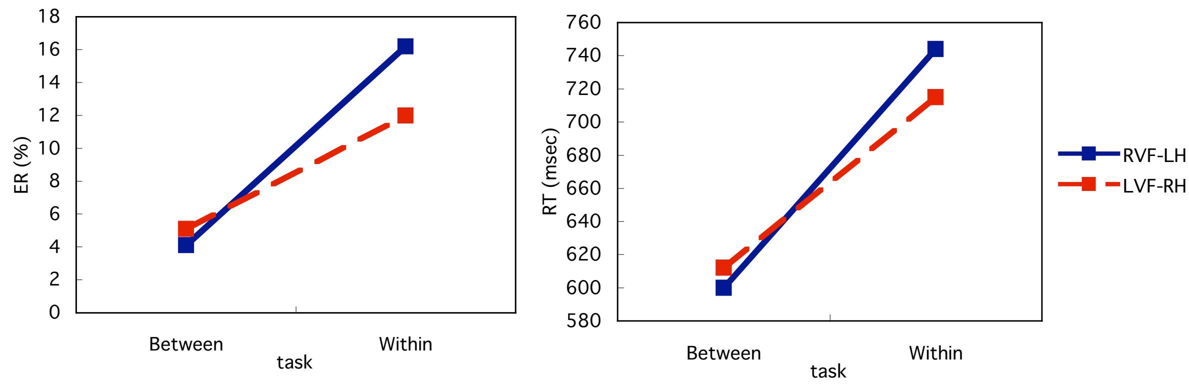


Figure 2. Left : Mean error rate for between and within task in RVF-LH and LVF-RH in experiment 1. Right : Mean reaction times for each task in each VF in Experiment 1.

(Mathworks) with Psychotoolbox (Braianard, 1997; Pelli, 1997) software. Two tasks were run in a different session. One task consisted of 100 trials.

Each trial, a fixation cross appeared for 700 ms, followed by a 1500 ms presentation of first stimulus on the center of the monitor. After appearing of a fixation cross for 700 ms, the second stimulus was presented on left or right visual field for 30 ms. Participants responded by pressing the designated key as quickly as possible.

Results & Discussion

The data of trials that two objects were identical were used for the analysis. Reaction times (RT) for correct responses and error rates were the dependent variables in separate repeated measures analyses of variance (ANOVA). The independent variables were task (between / within) and VF (RVF / LVF), and both were manipulated within participants.

The between-category task was performed faster than the within-category task, $F(1,18)=25.3$, $p<.01$, and with fewer errors ($F(1,18)=12.90$, $p<.05$). The error data produced a significant task by VF interaction ($F(1,18)=5.81$, $p<.05$)(Fig2, left). That is, for the between-category task the pattern was reversed. For the within-category task, error rate was lower for the LVF-RH presentation (12.0%) than for the RVF-LH presentation (16.2 %). For the between-category task, the pattern was reversed. Similar and approaching significance trend was observed for the RT results ($F(1,18)=4.15$, $p=.06$) (Fig 2, right).

It was suggested that left hemisphere had processing advantage for the categorical, qualitative information that was encoded for between-category object recognition. Whereas, right hemisphere had processing advantage for the coordinate, metrical information that was encoded for within-category object recognition

Experiment 2

In experiment 2, we used fMRI to examine the cortical activation during between- and within- category object recognition. We predicted *a priori* that hemispheric asymmetry would be observed at two specific cortical areas; the fusiform face area(FFA) and the posterior parietal lobe.

Posterior Parietal Lobe Recent neuro-imaging studies suggested that some area in the posterior parietal lobe were involved in the processing of spatial relation information. These studies suggested that the left posterior parietal lobe was more activated in the categorical, qualitative information processing, while the right posterior parietal lobe was more activated in the coordinate, metrical information processing (Baciu. et al., 1999; Trojano et al., 2002). It is reasonably assumed that these information would be necessary for object recognition at different category levels. Thus it was predicted that left and right parietal lobe would be activated during between- and within-category object recognition respectively.

Fusiform Face Area Recent studies have suggested that certain areas of middle fusiform gyrus are specialized for perceiving and recognizing face (Kanwicher et al. ,1997). These areas are called FFA (Fusiform Face Area). On the other hand, Cooper and Wojan (2000) suggested that when a face was recognized at a member level, quantitative, coordinate information among features was necessary. These studies imply that FFA would be responsible for processing quantitative, coordinate information required to discriminate objects at a within-category member level. Furthermore, it was suggested that the right FFA was more activated in face recognition than the left FFA (Kanwisher, 1997). Thus the right FFA would have more of a processing advantage for metrical information of objects.

Method

Participants Fifteen right-handed undergraduate and graduate students (10 males and 5 females, mean age＝23.0).

Task&Design A functional run consisted of 18 task blocks interleaved with 18 rest blocks. Task blocks

Table 1. Regions demonstraiting greater activation for each conditions

Side	Area (Broadman's area)	x	y	z	Z-score
Between>Control					
Left	Precuneus(7)	-20	-63	39	5.79
Left	Inferior Parietal Lobule(40)	-40	-38	29	5.21
Left	Fusiform Gyrus(37)	-41	-56	-15	4.82
Rught	Fusiform Gyrus(37)	33	-58	-31	4.55
Rught	Parahippocampal(36)	3	-75	-24	4.45
Rught	Middole Frontal Gyrus(6)	33	-3	47	4.37
Left	Middole Frontal Gyrus(6)	-29	-3	49	4.33
WIthin>Control					
Left	Middle Occipital Gyrus(19)-Fusiform Gyrus(37)	-41	-60	-4	5.54
Left	Middole Frontal Gyrus(6)	-29	-2	47	5.47
Left	Inferior Parietal Lobule(40)-Supramarginal Gyrus(40)	-38	-48	34	5.45
Right	Cingulate Gyrus(32)	1	12	41	5.17
Right	Precuneus(7)-Inferior Parietal Lobule(40)	27	-65	33	5.16
Right	Superior Occipital Gyrus(19)-Precuneus(7)	26	-71	31	4.95
Rifht	Fusiform Gyrus(37)-Uncus(20)	38	-62	-30	4.78
Right	Middole Frontal Gyrus(6)	24	1	44	4.65
Within>Between					
Right	Cingulate Gyrus(32)	4	20	39	4.19
Right	Insula(13)	27	20	0	4.12
Right	Inferior Frontal Gyrus(49)	40	37	10	3.81
Right	Precuneus(7)-Inferior Parietal Lobule(40)	43	-48	43	3.8
Right	Superior Occipital Gyrus(19)	29	-75	24	3.7

Codninate are in Talairach coordinate of the center of mass of supra-threchold clusters ($p < .001$, uncorrected)

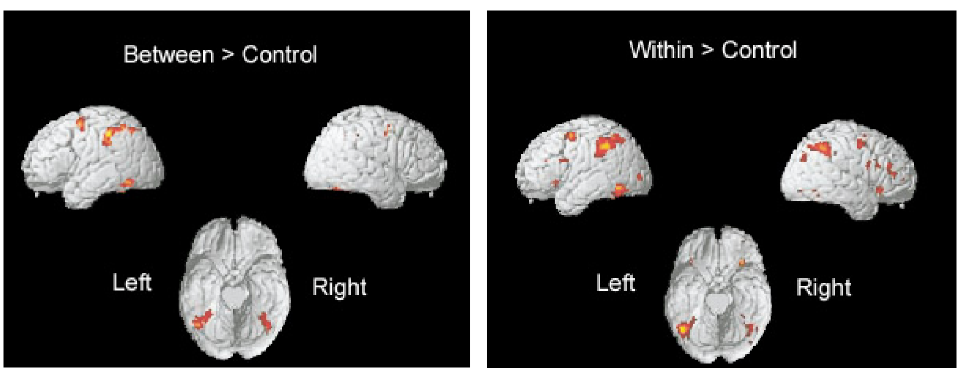
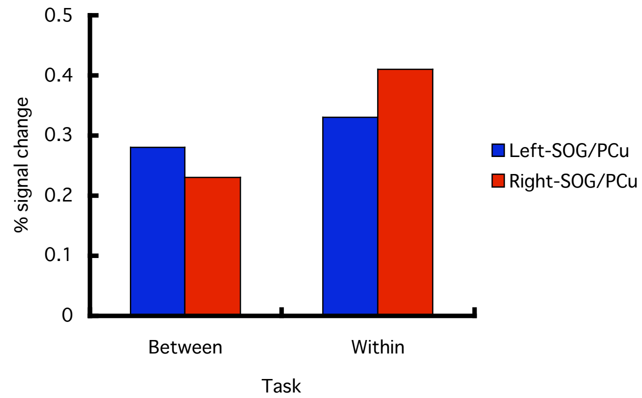


Figure 3. Activation during each task contrasted against control condition (group results, uncorrected $p < .0001$)

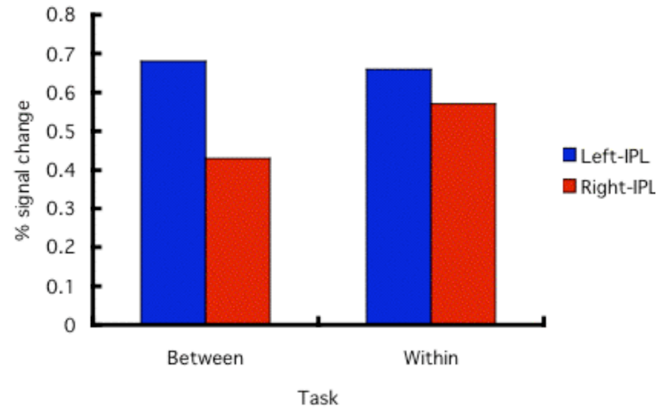
involved between-category task and within-category task, which were basically identical to Experiment 1 except that "*one-back matching*" procedure was employed. A control task, (scrambled pictures were presented d participants pressed the keys alternatively) was introduced. Finally, there were Rest blocks, in which participants focused on a fixation cross presented at the center of the screen. These four blocks were presented in the order of Between-Rest-Control-Rest-Within-Rest. Participants responded by pressing the designated key. Within each task block, 16 randomly ordered stimuli were presented for 500 ms each followed by a fixation cross for 1000 ms. Before the experiment, participants practiced each task, one block, each task outside of the scanner.

Stimulus Stimuli were the same as Experiment 1 except that one more category was added. All stimuli were 4ºx4º in size.

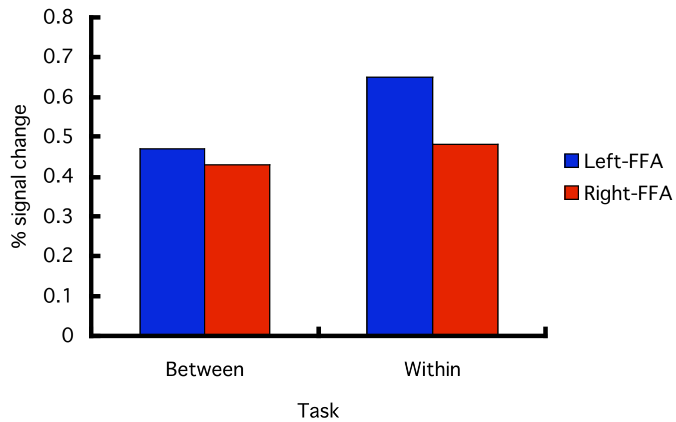
Procedure Stimuli were projected on a screen via an Panasonic TH-P7000 LCD projector connected to a PowerbookG4 (Apple) notebook computer running Matlab5 (Mathworks) with Psychtoolbox software. A mirror attached to the head coil allowed participants to view the projected stimuli. (Braianard,1997; Pelli, 1997)



(1) Superior Occipital Gyrus / Precuneus



(2) Inferior Parietal Lobule



(3)Fusiform Face Area

Fifure 4. Averaged percentage signal change (relative to rest) for between- and within-category task in left and right (1) superior occipital gyrus (SOG) and Precuneus(PCuyu).), (2) inferior parietal lobule (IPL) and (3) fusiform face area (FFA)

Image Acquisition A General Electric 1.5Tesla Signa LX scanner was used to acquire T2*-weighted EPI images. (29-31 axial slices, 4 mm thick, TR=6 s, TE=40 ms, FOV = 24 cm x 24 cm x 18.6 cm).

A General Electric 1.5 Tesla Signa Holizon scanner was used to acquire T1 anatomical images.(124 axial slices, 1.5 mm thick, TR=15 ms, TE=7 ms, FOV = 24 cm x 24 cm x 18.6 cm).

Data analysis Data were analyzed using statistical parametric mapping software (SPM99) employing a random effects model. Each participant's scans were realigned to the first volume and resliced and normalized to standard template image. The data were smoothed using a 8-mm isotropic Gaussian kernel.

FFA identification session FFA were identified by an extra session after 10 minutes of rest. A functional run consisted of 12 task blocks interleaved with 12 rest blocks. Task blocks consisted of Face viewing task and Object viewing task. In both task participants pressed the key alternatively. Stimuli were gray-scale photographs of the 96 faces (without hair) and the 96 everyday objects. All stimuli were 4^o x 4^o visual angle in size. Within each block, 16 randomly ordered stimuli were presented for 500 ms each followed by a fixation cross for 1000 ms.

Results & Discussion

Overall patterns of activation are presented in figure 3 and table 1. As can be seen from the figure, the between-category task produced predominantly left hemisphere activation, while the within-category task produced more bilateral activation.

For each VOI we used the spherical region of 5-mm radius centered on the maximum voxel of the clusters that survived the threshold criteria (uncorrected $p<0.001$) and were included in a priori areas.

The percentage signal change produced a significant task by hemisphere interaction at the border region between posterior parietal lobe and occipital lobe. ($F\,(1,14)=6.39$, $p<.05$) (Fig. 4(1)). That is, for the between-category task, the left superior occipital gyrus (SOG) and precuneus (PCu : a part of the parietal lobe) were more activated than the right whereas for the within-category task, the inversed pattern was observed.

Furthermore, for the between-category task, the left inferior parietal lobule (IPL) was more activated than the right IPL, whereas in the within-category task, the bilateral IPL activations were not different, (F (1,14) = 5.53, $p<.05$)(Fig4.(2)).

The FFA was defined for each individual as the area within the fusiform gyrus, where was more activated when viewing faces compared to objects (T>2.0, uncorrected for multiple comparisons). In order to compare left and right FFAs, we selected 9 participants who had bilateral FFA activation. We used the spherical region of 5 mm radius. The percentage signal change produced a task by hemisphere interaction ($F(1,14)=3.90$, $p=.08$)(Fig 4(3)). That is, for the within-category task, activation of the left FFA was larger than the right FFA, whether for the between-category task, activation of left and right FFAs were not different

General Discussion

The present study examined the neural basis of the between- and within-category object recognition. In Experiment 1, the between-category task produced a left hemisphere advantage. On the other hand, the within-category task produced a right hemisphere processing advantage. This task x VF interaction is remarkably similar to the one frequently reported in the studies of hemispheric processing of spatial relations (see Jager and Postma, 2003 for a review).

It is likely that processing of categorical, qualitative spatial information of objects (and relation among its parts) would be necessary for between-category object recognition.. Likewise, processing of coordinate, quantitative spatial information of objects would be necessary for within-category object recognition. Therefore, the present results suggest the possibility that the hemispheric asymmetry observed for the two types of object recognition could be a manifestation of more fundamental asymmetry in processing of different types of spatial relation.

This possibility is further supported by the results of Experiment 2. During the between-category task, the left SOG / PCu was more activated than the right. On the other hand, during the within-category task, the right SOG / PCu was more activated than the left. These results were consistent with the results of Experiment 1. Furthermore, it should be noted that the SOG / PCu area is a boundary between occipital lobe and parietal lobe. It has been pointed out that categorical and coordinate spatial relation processing may have neural basis in the left and right posterior parietal lobe respectively (Baciu et. al., 1999; Trojano et. al., 2002).

The left IPL was more activated than the right during the between-category task, and this also supported our prediction. However, patterns of activation in IPL and in FFA were complex and interpretation is not readily available. For example, for the within-category task, IPL produced symmetrical activation and the left FFA was more activated than the right. These results do not support our hypothesis. Apparently, the cortical mechanism involved in object recognition must consist of numerous functional components, many of which are yet to be uncovered.

Conclusion

A behavioral experiment demonstrated that the left and right hemispheres have processing advantage for the between- and within-category level object recognition, respectively. An fMRI experiment indicated that the locus of this hemispheric asymmetry could be in the superior occipital gyrus and precuneus.

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