Brain Activation during the Spot the Differences Game

Eiji Fukuba*, Hajime Kitagaki, Akihiko Wada, Kouji Uchida, Shinji Hara, Takaumi Hayashi, Kazushige Oda, and Nobue Uchida

Department of Radiology, Faculty of Medicine, Shimane University
89-1 Enya-cho, Izumo, Shimane 693–8501, Japan
(Received August 22, 2008; Accepted December 10, 2008)

Spot the Differences is a simple and popular game in which an observer compares a pair of similar pictures to detect the differences between them. Functional activation of the brain while playing this game has not been investigated. We used functional magnetic resonance imaging to investigate the main cortical regions involved in playing this game and compared the sites of cortical activation between a session of playing the game and a session of viewing 2 identical pictures. The right posterior parietal cortex showed more activation during game playing, and cortical activation volume correlated with game-playing accuracy. This cortical region may play an important role in awareness of differences between 2 similar pictures.

Keywords: attention, awareness, detection of change, functional magnetic resonance imaging, posterior parietal cortex

Introduction

Our daily activities are most strongly influenced by visual information among all of the sensory modalities. Humans are very interested in viewing new scenes and changes in visual information. Detecting such changes in what we are viewing is easy under normal circumstances but becomes difficult during transient disruption, such as flicker disturbance. Rensink and colleagues termed this phenomenon change blindness.

The Spot the Differences game, popular worldwide since long before the discovery of change blindness, provides evidence supporting human interest in change detection. Players examine 2 side-by-side pictures that are identical except for a few features with the aim of finding all the differences between them. Detailed comparison of the pictures involves visual attention, i.e., the selection of visual input for detailed processing. Everyone can see the differences, but only some notice them. Noticing the differences involves visual awareness—the subjective experience of seeing a stimulus. A person who detects one difference will start to look for others, whereas someone who has noticed no differences will continue to search for the first one. Thus, the player alternately employs visual attention and visual awareness.

Processing the visual information involves eye movements, primary and secondary visual perception, visual attention, and visual awareness, and collation of the 2 images may require processing of visual memory and should require working and short-term memory. Visual information is perceived initially in the striate cortex and secondarily in the extrastriate cortex. Then the neural activity divides into 2 pathways. The dorsal pathway runs through the parietal region to the dorsal frontal area, and the ventral pathway runs through the lateral occipito-temporal region to the basal frontal region. Higher order visual information processing functions, such as visual attention and visual awareness, were previously associated with the ventral pathway, which was called the object or vision-for-perception pathway and was considered to mediate conscious visual awareness. On the other hand, the dorsal pathway was called the space channel or vision-for-action pathway and was thought to be related to unconscious visual awareness. Although clinical case reports about patients with neglect syndrome and optic ataxia caused by lesions in the right posterior parietal cortex (PPC) have suggested the importance of the dorsal pathway for visual information processing, no experimental data from healthy subjects have been available.
After the discovery of change blindness, the dorsal pathway was noted to have an important role in visual information processing. Using data from functional magnetic resonance imaging (fMRI) from other researchers, Rees suggested that visual attention is processed in the parietal and frontal areas.\(^4\) In an fMRI study of subjects performing a non-spatial task that involved alternating flickering light and fused light, Carmel’s team demonstrated that the frontal and parietal regions are important for visual awareness.\(^{11}\) Beck and associates (2001) demonstrated the importance of the dorsal pathway for visual awareness and visual attention in an fMRI study of change detection and change blindness using human faces as the non-spatial stimulus. Experiments using transcranial magnetic stimulation (TMS) of the right dorsolateral prefrontal region\(^{12}\) and the right posterior parietal region confirmed the importance of the dorsal pathway for visual awareness and attention.\(^{13}\)

We employed fMRI to investigate neural activity related to playing the Spot the Differences game. Experiments on detection of and blindness to change have involved the momentary and sequential presentation of an original image (e.g., a photograph of a face) and a copy. However, in the Spot the Differences game, original and slightly different images are presented continuously and simultaneously. Therefore, we hypothesized that the crucial brain regions for this game would be different from those involved in change detection and change blindness.

**Materials and Methods**

**Subjects**

We recruited 8 healthy right-handed volunteers (6 men, 2 women; aged 23 to 46 years, mean 29 years) with no history of neurological or psychiatric disorders or substance abuse and obtained written informed consent before acquiring fMRI data.

**Paradigm**

Subjects were presented with 3 sets of visual stimuli: a set of 2 identical stars located centrally, a set of 2 similar illustrations, and a set of 2 identical illustrations (Fig. 1). Each individual presentation of these stimuli was done for a 30-s block of a block-design paradigm. The visual stimuli were projected on a magnetically shielded display monitor during fMRI sessions.

Baseline condition. A set of 2 identical stars was presented as the baseline condition and subjects were asked to look at the stars on the monitor (Fig.

---

**Fig. 1.** Target and control task sessions. We presented baseline and game conditions alternately 3 times during the target task session and baseline and same-picture conditions alternately 3 times during the control task session. Each condition is one 30-s block of a block-design paradigm. The subjects performed both task sessions during functional magnetic resonance imaging (fMRI) data acquisition but were not informed which session was first.
Game condition. Three sets of 2 similar illustrations were displayed in turn. The first image was 9 colored apples, the second, a yacht sailing across the sea, and the third, a little boy playing with a Frisbee and a dog in a green field (Fig. 1). Each pair of illustrations had 5 or 7 differences, and subjects were asked to identify all differences.

Same pictures condition. Three sets of 2 identical illustrations were shown as a control task by presenting a pair of each original illustration used for the game (Fig. 1). Subjects were instructed to compare the pictures without being informed that each pair was identical.

Before exposure to the visual stimuli, fMRI images from the first 12 s were discarded because the signal was not stable.

The target task session consisted of the baseline and game conditions presented alternately 3 times, and the control task session, the baseline and same picture conditions presented alternately 3 times.

We informed the subjects that they would perform target and control task sessions but did not tell them the order of the tasks. After acquiring fMRI data, we asked the subjects the number and location of the differences between images in the game condition and calculated their accuracy in detecting these differences.

Data acquisition

fMRI was performed with a 1.5-tesla superconducting unit (Signa CVI, General Electric Medical Systems, Milwaukee, WI, USA). First, we acquired T1-weighted axial images (repetition time/echo time [TR/TE], 500/8 ms; field of vision [FOV], 20 cm; matrix, 64 × 64; slice thickness, 5 mm; slice interval, 2 mm) for anatomical information. To acquire functional data, we obtained 60 sequential images per slice (1,200 total images) during each baseline and task condition using a gradient-echo, echo planar imaging sequence that was sensitive to the blood oxygen level-dependent (BOLD) signal (TR/TE, 3000/50 ms; FOV, 20 cm; matrix, 64 × 64; 20 slices; slice thickness, 5 mm; slice interval, 2 mm; pixel size, 3.125 mm).

Data analysis

We analyzed fMRI data on an Octane workstation (Silicon Graphics) using statistical mapping software (SPM99, Wellcome Department of Cognitive Neurology, London, UK). First, we realigned fMRI images, then coregistered and normalized the images into the Montreal Neurological Institute template. After normalization, we applied 3-dimensional spatial smoothing with a 9 × 9 × 9-mm Gaussian kernel to each volume. We used a high-pass filter to remove subject-specific drifts in signal and low-frequency artifacts due to heart beat and other cyclical components.

We submitted fMRI data from all subjects to a fixed-effect analysis to identify areas of the brain where activity consistently related to playing Spot the Differences game or comparing 2 identical illustrations. We detected significant activation of voxels with the general linear model approach for time-series data. Condition effects were modeled by convolving a boxcar function with a standard hemodynamic response function.

We used group analysis of the data (one-sample t-test) to explore regional activation during target or control task sessions. Statistical significance was set at $P < 0.001$ (without correction for multiple comparisons, height threshold: $T = 4.79$).

We assessed differences of activation during target and control task sessions by 2-sample $t$-test. Statistical significance was set at $P < 0.001$ (without correction for multiple comparisons, height threshold: $T = 3.79$).

To detect the critical region of game performance, we examined the relation between sites of cortical activation and accuracy of each subject in detecting differences. Because cortical activation comprises 2 factors, amplitude and extent, changes in signal intensity and extent in individual subjects were determined as follows.

1) Changes in signal intensity. In the brain region identified by group comparison of target and control task sessions, changes in signal intensity during the target versus control sessions were calculated for individual subjects with the following formula:

$$\frac{(SI_g \text{ or } SI_s) - SI_b}{SI_b \times 100 \%},$$

where $SI_g$ is the mean signal intensity during the game condition, $SI_s$ is the mean signal intensity during the same pictures condition, and $SI_b$ is the mean signal intensity during the baseline condition. Signal intensity was measured at the peak activated voxel identified by the group comparison between task and control task sessions. Mean signal intensity was the average value at the peak voxel during each 30-s condition.

2) Changes in the extent of activation. During each session, we used SPM 99 software to detect the coordinates of peak activation for each subject nearest to those obtained by group comparison between the target and control task sessions. We then obtained the extent of activation during each session by substituting the coordinates in the Cube Range Option of the Talairach Daemon client (Research Imaging Center, University of Texas).
Results

Behavioral data

Accuracy (number of detections/total number of differences) of playing the game ranged from 41% to 76% for the 8 subjects (mean accuracy, 57%). There was no correlation between age or sex and the accuracy of performance. The average accuracy for all 8 subjects was 85% (range, 60 to 100%) for the first set of images, 62.5% (60 to 80%) for the second set, and 31.4% (14.3 to 57.1%) for the third set.

Results of fMRI

Figure 2 shows the results obtained by analysis of group data from the target and control task sessions, and Table 1 lists the Montreal Neurological Institute (MNI) coordinates for each brain region.

During the target task session, significant activation was detected in the left middle occipital gyrus, the right superior parietal lobule, and the precuneus. Moderate activation was observed in the right middle and medial frontal gyri and the right cerebellar hemisphere. During the control task session, there was significant activation in the bilateral lingual gyrus, whereas moderate activation was observed in the right superior occipital gyrus, the superior parietal lobule, the middle occipital gyrus, the left precuneus, and the bilateral cerebellar hemispheres.

Comparison between the task and control sessions revealed significant activation in the right
Fig. 2. Results of group analysis of data from the target and control task sessions. Superior and posterior T₁-weighted images of an anatomical template brain upon which are superimposed the loci where activity was greater during the game than baseline condition (a) or during same-picture rather than baseline condition (b) (one-sample t-test, \( P < 0.001 \), without correction for multiple comparisons, height threshold: \( T = 4.79 \)). Arrows indicate the activated regions. LG, lingual gyrus; Mid FG, middle frontal gyrus; Med FG, medial frontal gyrus; MOG, middle occipital gyrus; Pcu, precuneus; SOG, superior occipital gyrus; SPL, superior parietal lobule.

Fig. 3. Site of activation revealed by group comparison. Sagittal, coronal, and axial T₁-weighted images of an anatomical template brain upon which are superimposed the location of significantly greater activation during the target compared with control task session (2-sample t-test, \( P < 0.001 \), uncorrected for multiple comparisons, height threshold: \( T = 3.79 \)).
Table 2. Site of significant activation shown by group analysis. Montreal Neurological Institute (MNI) coordinates of the region that showed significantly greater activation during the target than control task sessions.

<table>
<thead>
<tr>
<th>Hemisphere</th>
<th>Brain region</th>
<th>MNI coordinates (mm)</th>
<th>t value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right</td>
<td>Posterior parietal cortex</td>
<td>30 -68 42</td>
<td>4.03</td>
</tr>
</tbody>
</table>

Fig. 4. Correlation between the % signal change* in the right posterior parietal cortex (PPC) during the task versus control session for each subject and accuracy of performing the game. There was no significant correlation between the % signal change and accuracy. *% signal change = (SI g (or SI s) - SI b) / SI b x 100 (%), where SI g is the mean signal intensity during the game condition, SI s is the mean signal intensity during the same-picture condition, and SI b is the mean signal intensity during the baseline condition.

Fig. 5. Activation volume and game accuracy. Activation volumes in the right posterior parietal cortex (PPC) during the target and control task sessions are shown for each subject. Note that the activation volume is larger during the target task session in the subjects with a high accuracy of game performance. On the other hand, the activation volume is larger during the control task session in the subjects with low game accuracy.

posterior parietal cortex (PPC) during the task session only (Fig. 3, Table 2). This region is located superior to the parieto-occipital sulcus and adjacent to Brodmann Area 7. When the percentage of change of BOLD signals in the right PPC between the task and control sessions was calculated for each subject, no significant correlation was found with game-playing accuracy (Fig. 4).

Next, we determined the subtracted activation volume by subtracting voxels significantly activated during the control task session from those activated during the target task session in each cortical region. Figure 5 shows the activation volumes thus obtained in the right PPC during the target and control task sessions. We found that the subtracted activation volumes of the right PPC showed significant positive correlation with accuracy in performing the game (Spearman’s rank correlation coefficient, r = 0.807, P = 0.015, Fig. 6).

Group comparison between the target and control task sessions did not detect significant activation in the prefrontal cortex or the frontal eye field. The sites and intensity of prefrontal cortex activation in the individual subjects varied during the target and control task sessions (Fig. 7), with activation being distributed over the superior, middle, and inferior frontal cortex. Activation of the fron-
Discussion

In the present study, we observed significant activation in the right PPC by comparing group data between the target (Spot the Differences game) and control task sessions (comparison of identical pictures). However, because the key region for performance may differ from the most commonly activated region, it was unclear whether the right PPC was the key brain region for the game or just a region activated in all subjects. Generally, a good performer knows a special technique that may be associated with a specific brain region. Because the key brain region for game performance should be significantly correlated with accuracy, we compared the accuracy of each subject in playing the game with the volume of the activated region in the right PPC. Accuracy ranged from 40 to 70% in our subjects, which was favorable for statistical comparison.

First, we compared the percentage of change of signal in the right PPC with the accuracy of performance for each subject and found no correlation. Then we compared activation volume in the right PPC with performance accuracy for each subject and found significant positive correlation. Thus, the extent rather than intensity of activation in the right PPC is critical for game performance. Generally, activation of primary cortical areas is localized and intense, and activation of higher order areas is broader and less intense. The right PPC is outside the primary sensorimotor region, so a broad and less intense activation pattern is reasonable. Because the Spot the Differences game seems to require higher order visual functions, performance would reasonably depend on the activation of a higher order region.

All 8 subjects showed a larger activation volume in the right PPC during the target rather than control task session. The accuracy of performing the target task and the activation volume of the right PPC showed strong positive correlation. Because the left and right PPC may be important for visual information processing, we examined the relationship between accuracy in performing the game and activation of the left PPC but found no correlation between game performance and the subtracted activation volume in the left PPC. Consequently, the right PPC was shown to be the crucial brain region for the Spot the Differences game.

Game-playing accuracy is directly related to the number of differences detected. Activity increased only in the right PPC in group comparison between the target and control task sessions, although each subject showed some level of activity in other regions that would be expected to have a role in the detection of differences, such as the parietal cortex, the right dorsolateral prefrontal cortex, and the extrastriate visual cortex. Because our experimental design involved 30-s blocks, activation of the right PPC may have resulted from the accumulation of transitory responses related to change detection. Simple motor actions like finger opposition have to be performed more than once per second to generate significant activity that is detectable by fMRI. Accordingly, 30 s is a short time to detect 5 to 7...
changes, and so, transient activity probably would not lead to significant activation. Change detection is instantaneous activity of selecting things transformed from a previous state. On the other hand, visual awareness of changes is a persistent cognitive state after the change detection. Therefore, the right PPC may be involved in a continuous process that is critical for visual awareness of changes.

Because performing the Spot the Differences game requires processing of visual information, eye movements, primary and secondary visual perception, visual attention, and visual awareness are all involved. Because visual memory processing may be necessary for collating the features of the 2 images, playing the game should also require both working and short-term memory.

Among those neural functions, visual attention and visual awareness are continuous activities that could be responsible for activation of the right PPC, and these functions are good candidates as critical neural correlates for visual awareness of changes. The process of visual attention, especially selective visual attention, is recognized as having an association with the frontoparietal network. In addition, visual attention is thought to play a vital role in the detection of change, as demonstrated by many studies on the phenomenon of change blindness. Although visual attention will necessarily precede the detection of changes, a change will not be detected very often when Spot the Differences is played. Accordingly, the correlation between accuracy and visual attention is not expected to be very strong. Therefore, activation of the right PPC was probably not related to visual attention.

Visual awareness is another essential process in detecting change. Studies of patients with neglect and Bálint syndrome have provided clear evidence that the parietal cortex has a role in visual awareness. In healthy subjects, fMRI studies have suggested that both the ventral and dorsal pathways play roles in visual awareness. Moreover, a number of reports suggest that the parietal cortex may play a general role in visual awareness. Because of the strong correlation between the accuracy of game performance and the extent of PPC activation, the parietal activity detected in the present study seems to be related to the visual awareness of change. The positive correlation between game accuracy and this activity is evidence against the belief that conscious awareness is dominantly mediated by the ventral stream, but it is in accordance with the results of recent experimental studies. In an event-related fMRI study and using TMS, Beck and colleagues demonstrated that the right PPC is a critical region in detection of changes.

The activation of the right PPC noted by Beck’s team was slightly anterior to our region of activation, which suggests a close anatomical relationship between the regions involved in visual awareness of change and detection of change. Beck and colleagues performed TMS of the right PPC at the coordinates obtained during their earlier fMRI study on change detection. Because of the relatively broad influence of TMS, they could have stimulated the core region for the visual awareness of change as well as that for change detection. They suggested that the increased response time was related to interruption of the detection of change, but we think that the reduced accuracy they noted may have reflected interruption of the visual awareness of change.

Our present results indicated that eye movements, primary and secondary visual perception, working memory, and short-term memory were not critical in the Spot the Differences game. Eye movements (both saccadic and smooth pursuit) are necessary for visual comparison of 2 images arranged side by side. The major type of eye movement involved in this game is saccadic and controlled by the frontal eye fields (FEF) and other regions, such as the occipital lobe, the superior colliculus, and the PPC. Our inability to detect activation in the FEF is supported by a report of an fMRI study in which such activation was only detected when the frequency of movement exceeded once per second. Rather than rapid eye movements, visual recognition seems to be critical for finding differences between 2 images arranged side by side. Visual information is transmitted from the parietal region to the dorsolateral prefrontal cortex (DLPFC) for short-term spatial memory (from 300 to 25 s) and from the parietal eye fields (PEF) to the FEF for active fixation. Active fixation involves holding fixation while ignoring peripheral stimuli, so comparing 2 static images requires more involvement of short-term memory than active fixation, which is another reason that no activity was detected in the FEF. On the other hand, the DLPFC showed activation during the game and control tasks according to the analysis of individual data, but not the group comparison between the target and control task sessions. This indicates that short-term memory was moderately recruited during the experiment and suggests that the strategy employed for the game varied among subjects. Variation of prefrontal activation is supported by a recent study showing that the efficiency of task performance determines which prefrontal region undergoes activation.
The extrastriate cortex showed no significant activation in the group comparison of task-control data. However, areas of significant activation were found by group comparison between the target and control task sessions. Secondary visual perception involves perceiving aspects of visual information such as light-dark contrast, direction of movement, color, shape, and line. Subjects were asked to compare 2 pictures even in the control session, so the extrastriate cortex may have been fully activated during both the task and control sessions. This may help explain why no increase of activation in the extrastriate cortex was detected by the group comparison between the target and control task sessions.

The ventral pathway was previously thought to be overwhelmingly important for conscious awareness. However, Beck and colleagues reported that the role of the ventral pathway was category specific. We did not find any activation of the ventral pathway by either group comparison between the target and control task sessions or the analysis of individual data. This lack of ventral activation can be explained by the images utilized in this study. We did not use photographs of human faces, which are typically employed to detect “What”-type visual information processing. The ventral pathway handles such information in contrast to the “Where”-type information that is considered to be processed via the dorsal pathway. The images that we used were illustrations of familiar things, such as 9 apples, a yacht, the sea, and a park. We instructed the subjects to detect and describe the differences between each pair of images. These factors could have led to a lack of activity in the ventral pathway.

Conclusion

In conclusion, this study revealed the right posterior parietal cortex as the site of brain activation related to visual awareness of changes after detection of the differences between 2 similar pictures.

References

1. Rensink RA, O’Regan JK, Clark JJ. To see or not to see: the need for attention to perceive changes in scenes. Psychol Sci 1997; 8:368–373.


