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An fMRI study of the brain area that involves suppression of mental imagery generation

H. Motoyama, S. Hishitani

Department of Psychology, Hokkaido University, Sapporo, JAPAN
Correspondence: H. Motoyama, Department of Psychology, Hokkaido University, N10 W7, Kita-ku, Sapporo, JAPAN, 0600810
E-mail: motoyama.hiro@let.hokudai.ac.jp, phone +81 11 706 3047, fax +81 11 706 3047

Abstract. Hishitani [1993, 1995] proposed a mechanism that suppresses information retrieved from long-term memory during mental imagery (hereafter, it is called the "Suppressor"). One way to prove its existence is to identify the brain regions that function as the Suppressor. Hishitani [1993] hypothesized that activation of the Suppressor would increase during negative imagery as compared to positive imagery and during visual perception as compared to pure imagination. Motoyama, Matsumura, and Hishitani [2010] conducted an experiment to examine the first condition. Their results showed that part of the left posterior cingulate gyrus functions as the Suppressor. The present experiment examines the second condition by comparing brain activation during visual perception to that during pure imagination. Results showed some significant activation areas in the visual perception versus imagination condition. Although none of these areas are located in the posterior cingulate gyrus, the activation of two areas of them negatively correlated with vividness ratings of visual imagery. These correlations imply that increased activation of these areas decreases imagery vividness. In addition, one of these areas was the closest area to that which was regarded as the Suppressor in Motoyama et al. [2010]. Therefore, the posterior cingulate gyrus and its neighboring area might be involved in the Suppressor.

Keywords: mental imagery, visual perception, vividness of mental imagery, suppression, posterior cingulate gyrus, precuneus

1. Introduction

The Vividness of Visual Imagery Questionnaire [VVIQ: Marks, 1973], which measures the subjective vividness of visual imagery, has high reliability based on the test-retest method [e.g., Mckelvie, 1995]. This suggests that, as long as the same object is imagined, the vividness of the imagery must be generally stable. However, several previous studies have implied that the vividness of mental imagery varies depending on its attributes. For example, some studies showed that negative imagery was less vivid than positive imagery [e.g., Bywaters, Andrade, and Turpin, 2004; Motoyama, Matsumura, and Hishitani, 2010]. These studies suggest that mental imagery vividness varies systematically with the emotional value of the imagery in each individual. Consequently, intra-individual variability of vividness is not produced randomly and is likely caused by a mechanism that controls mental imagery vividness. The present study was conducted to find the neural correlates of this mechanism.

As mentioned above, some studies have suggested that the vividness of mental imagery depends on its emotional value. The question of how the emotional value of imagery is related to imagery vividness is one of the fundamental problems of imagery research, which is aimed at understanding what determines the vividness of mental imagery. Previous studies have suggested that vividness is determined by the amount of visual information included in imagery [e.g., Baddeley and Andrade, 2000; Hishitani and Murakami, 1992]. On the basis of these findings, we conjecture that negative imagery contains less information than both neutral and positive imagery, so the former is dimmer than the latter. The question of why more visual information is contained in positive than negative imagery also arises. Two explanations for this question are considered here. One explanation is that there are differences in the amount of information stored in long-term memory (LTM) between positive and negative imagery. Another explanation is that some mechanisms that control the amount of information included in mental imagery recruit more information to generate positive imagery than negative imagery, which creates a difference in vividness.

No research has directly examined which explanation is better. From some studies, however, it is suggested that the first explanation may be unlikely. For example, Clark and Paivio [2004] found that frequency of nouns does not have a relationship to emotional value. Noun frequency is defined by how often we use a noun. Therefore, this attribute of noun can be good indexes to show how much information about the referent of noun is stored in LTM. As stated above, this index is not related with emotional value of a noun. This implies that there is no relationship between the amount of information stored in LTM and emotional value. In other words, Clark and Paivio's finding implies that the emotionality of an event may not decide the amount of information about it in LTM. Another study rather suggests that more information may be stored for negative events than positive events. Öhman, Flykt, and Esteves [2001] indicated that negative events have a greater tendency to capture our attention than other kinds of emotional events. They showed that fear-relevant pictures were found more quickly than fear-irrelevant ones. They interpreted this result to mean that threatening stimuli, which are of evolutionary relevance, are effective in capturing attention. Quickly acquiring a large amount of information about negative events and storing it in LTM must be a very important survival strategy. Therefore, more information may be stored in LTM about negative events than about other emotional events. Nevertheless, negative imagery is not vivid in comparison to positive imagery. It is conceivable that vividness may not be influenced only by the amount of information in LTM, but it is controlled by the mechanism, which adjusts the amount of information included in mental imagery according to its emotional value.

Hishitani [1993, 1995] suggested a mechanism that controls the amount of perceptual information included in mental imagery called the Suppressor. He hypothesized that the emotional valence of mental imagery is calculated at an early stage of imagery processing and that the amount of information used to generate imagery is reduced if the degree of negativity is high. Therefore, negative imagery is vaguer than positive or neutral imagery. Recently, Motoyama et al. [2010] conducted an fMRI experiment to search for the brain region that functions as the Suppressor. According to the previous discussion, the Suppressor should function more actively in the generation of negative imagery than in positive imagery. Thus, Motoyama et al. focused on areas in which a stronger blood oxygenation level dependent (BOLD) signal has been observed for negative imagery than for positive imagery. It is expected that the region functioning as the Suppressor exists within such an area. Motoyama et al. found that activation of a portion of the left posterior cingulate gyrus was significantly greater in the negative imagery condition than in the positive imagery condition. They also examined the correlation between activation of the region and the subjective vividness of mental imagery. That analysis revealed a significant negative correlation between activation of the area and the vividness of mental imagery in the negative imagery condition. These results clearly suggest that an increase in activation of the left posterior cingulate gyrus leads to a reduction of subjective vividness of negative imagery. Therefore, it can be concluded that this brain region plays the role of the Suppressor.

If the posterior cingulate gyrus functions as the Suppressor, the activation of that area would be seen in conditions where the Suppressor is expected to work in addition to what Motoyama et al. [2010] found. Hishitani [1993] suggested that the Suppressor shows greater activation during direct observation of a visual perceptual figure than purely imagining that same figure. The reason, according to Hishitani, is to prevent confusion about the source of formed images. Mental images can be formed through either a direct observation (i.e., visually perceived) or by pure imagination. To prevent confusion about the source of a formed image, the Suppressor must be activated to suppress the formation of mental imagery based on pure imagination during direct observation. We suggested that the posterior cingulate gyrus should be more highly activated during direct observation of visual figures than during pure imagination, if that area is the neural basis of the Suppressor. Thus, we examined whether activation of the posterior cingulate gyrus is greater when an image is visually perceived as compared to when it is imagined. This result would provide additional evidence to support the findings that the left posterior cingulate gyrus functions as the Suppressor.

2. Material and Methods

This experiment examined whether the left posterior cingulate gyrus was more highly activated during direct observation of visually perceived images without imagination (direct observation condition) than during generation of positive imagery (positive imagery condition).

2.1. Participants

Twelve healthy volunteers, 10 men and two women, participated in this study (mean age of 25.3 years, SD = 2.4). All participants were right-handed.

2.2. Stimuli

A total of 16 nouns were used (Appendix). Eight were used in the direct observation condition as cues of picture stimuli; the other eight were used in the positive imagery condition as cues of imagery. Nouns were counterbalanced across participants. Pictures corresponding to the nouns were selected from Art Explosion 750,000 for Macintosh and were used as the picture stimuli.

2.3. Procedure

The experiment consisted of eight positive imagery trials and eight direct observation trials (Fig. 1). The aim of this experiment was to compare the brain activation of the direct observation condition to that of the positive imagery condition directly. Therefore, a rest condition was not set in this experiment. During the experiment, participants opened their eyes. One positive noun appeared on the display for 5 s, and subsequently, the word "Imagery" or "Picture" was presented for 2 s. When the word of "Imagery" appeared, participants had to form and maintain a mental image of the word within 20 s and to rate their mental imagery vividness on a 4-point scale by pressing one of four buttons (with 4 indicating very vague and 1 indicating very vivid). When the word of "Picture" appeared, participants had to observe the presented picture for 20 s and to subsequently answer questions relevant to the previously presented picture on a 4-point scale by pressing one of the four buttons; the questions acted as a motivation for the participant to observe the picture. The next trial started when a button was pressed.

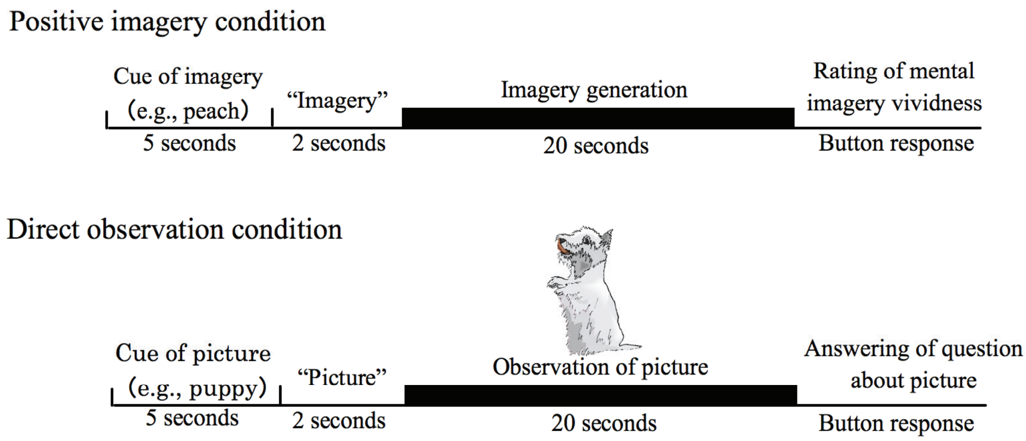

Figure 1. *The procedure of this experiment. Positive imagery and direct observation conditions were conducted in random order.*

A whole-body 1.5T Signa Echo-Speed scanner (General Electric, Inc.) was used to acquire high-resolution T1-weighted anatomical images and gradient echo echo-planar T2*-weighted images with a BOLD contrast of 20 axial slices. The parameters of the sequence were set as follows: TR = 3000 ms, TE = 40 ms, flip angle = 90°, FOV = 240 x 240 mm, matrix = 64 x 64, slice thickness = 4 mm, and slice gap = 0.8 mm. Data were analyzed by statistical parametric mapping (SPM2, Wellcome Department of Cognitive Neurology, London, UK) and general linear model was used.

We expected that the Suppressor would be more highly activated in the direct observation condition than in the positive imagery condition. Firstly, on the basis of this expectation, we tried to identify the brain regions where activation in the direct observation condition was significantly greater than activation in the positive imagery condition. Significant level of this study was equal to that used of Motoyama et al. [2010]: $p < 0.0005$ uncorrected, with clusters of 30 or more contiguous voxels. Secondly, we examined the correlation between subjective vividness of mental imagery and activation of the regions that had been obtained in the previous analysis. If these regions involve the Suppressor, their increased activation might indicate a stronger suppression of mental imagery formation, thus reducing mental imagery vividness. In particular, we predicted that the activation of these regions would negatively correlate with ratings of mental imagery vividness[1].

The data that we were able to obtain from scanning directly were relative MRI signal. However, the MRI signal declines consistently over time due to several factors, including participants' habituation to the experiment. Thus, the MRI signal change, which compares each scan of the positive imagery condition to the first scan of the positive imagery condition, was used as the index. If a brain area functions as the Suppressor, the activation of the area starts to decreases when the participant starts to form mental imagery. Therefore, the activation of the area would decrease compared to the starting point of the positive imagery trial. Using Marsbar[2], we calculated the MRI signal change of each area of interest. One trial lasted for 20 seconds in the positive imagery condition. Moreover, the TR duration was 3 seconds. Thus, the MRI signal data was recorded six or seven times during positive imagery

[1] In this experiment, ratings of mental imagery vividness ranged from 1 (very vivid) to 4 (very vague). If vividness ratings negatively correlate with activation of the area of interest, a positive correlation coefficient would result.
[2] http://marsbar.sourceforge.net/

condition. Data from only six scans, from the beginning to the end of the positive imagery condition, were analyzed. The first of these six scans was regarded as the base and the MRI signal change was calculated for the following five scans. These signal change values were averaged and used as the data of the correlation analysis.

3. Results

In the contrast of the direct observation condition versus the positive imagery condition, significant activation was found in nine areas (see Table 1 and Fig. 2).

We examined the correlation between activation of these regions and subjective vividness of mental imagery. For the correlation analyses, the mean MRI signal change and mean vividness rating (both from the positive imagery condition) were calculated for each participant. A marginally significant positive correlation was found in [-14, -68, 38: precuneus] and [30, -72, -1: lingual gyrus], $r = 0.51$, $p < .10$, $r = 0.51$, $p < .10$ (Fig. 3). These correlations suggest that increases in the activation of the areas of interest decrease imagery vividness. In addition, although [-14, -68, 38] is not located in the posterior cingulate gyrus, the area of interest was the closest brain area regarded as the Suppressor in Motoyama et al. [2010] [-14, -53, 25].

Table 1. *Areas of significant activation during observation of a figure versus generation of positive imagery, and correlation coefficients between MRI signal change rate and vividness of positive imagery and the distance from [-14, -53, 25] that was obtained in Motoyama et al. [2010] are shown.*

Brain area	Number of voxels in cluster	Cluster-level P value (uncorrected)	T value at local maximum	Tarairach coordinates x	y	z	correlation coefficient	the distance from [-14,-53,25] (mm)
Direct observation - Positive imagery								
Middle Occipital Gyrus	396	0	15.38	-30	-91	10	0.07 (n.s.)	43.9
Middle Occipital Gyrus	917	0	12.75	40	-87	6	-0.06 (n.s.)	66.6
Precuneus	67	0.001	9.32	-30	-52	52	-0.10 (n.s.)	31.4
Superior Parietal Lobule	434	0	8.01	26	-63	53	0.43 (n.s.)	49.8
Lingual Gyrus	54	0.002	7.63	30	-72	-1	0.51(p < .10)	54.5
Precuneus	270	0	7.28	-14	-68	38	0.51(p < .10)	19.8
Precuneus	153	0	7.17	4	-57	62	-0.05 (n.s.)	41.3
Superior Frontal Gyrus	35	0.009	6.75	24	66	6	0.15 (n.s.)	126.4
Precentral Gyrus	72	0	5.71	38	-6	41	0.49 (n.s.)	71.9

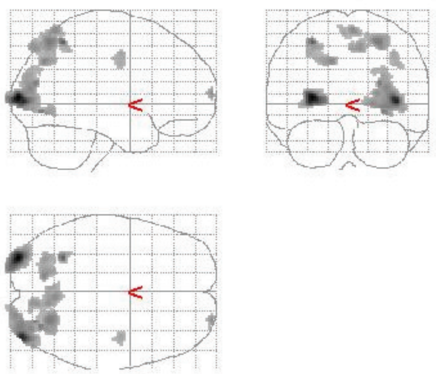

Figure 2. *Areas significantly activated by the observation of visual perception compared to the generation of positive imagery.*

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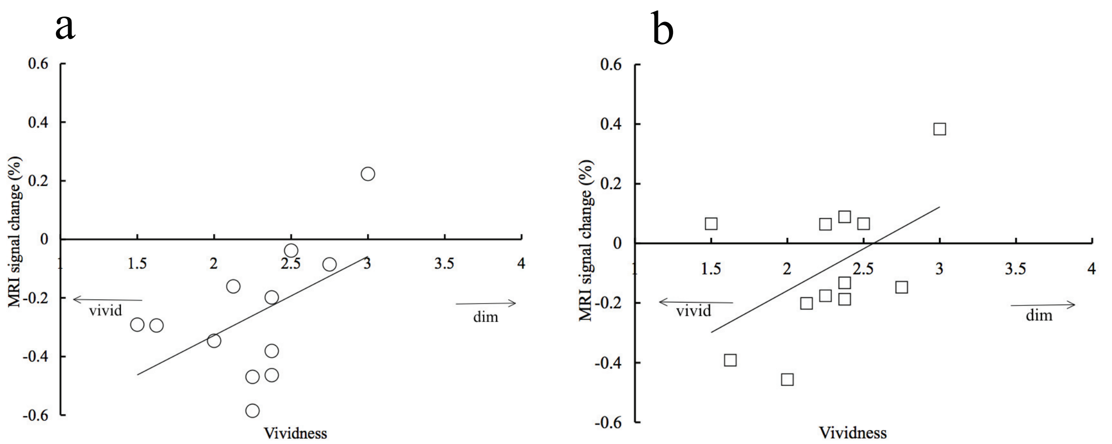

Figure 3. *Scatter diagrams (a) between vividness of positive imagery and MRI signal change in [-14, -68, 38] and (b) between vividness of positive imagery and MRI signal change in [30, -72, -1].*

4. Discussion

Motoyama et al. [2010] suggests that the left posterior cingulate gyrus plays a role in the mechanism of the Suppressor. In this experiment, we examined whether the brain region that was shown in Motoyama et al. also activates in other conditions where the Suppressor is expected to work. The activated brain area of this experiment did not perfectly correspond to that of Motoyama et al. However, results showed a negative correlation between vividness of positive imagery and the activation of the precuneus which is most closely neighboring to the area regarded as the Suppressor in Motoyama et al.'s study. The idea that this area functions as the Suppressor can explain this correlation. The distance between the local maxima of the area of activation found here and that of Motoyama et al. was about 20 mm. If the size of the activated area is calculated as a sphere, the radius of the area of the present experiment was about 8 mm and that of Motoyama et al. was about 4 mm. That is, the distance between both areas was only about 8 mm. Therefore, these results suggest that a particular brain region is activated under conditions where the Suppressor is expected to work, and that the posterior cingulate gyrus and precuneus (which is close to the posterior cingulate gyrus) are included in this region. Although we showed that the posterior cingulate gyrus and its neighboring areas may be involved in the Suppressor, the number of participants was small in this experiment and the obtained correlation coefficient was only marginally significant. To increase the reliance of this finding, further research should be conducted.

In addition, this experiment showed a significant activation of the lingual gyrus and a negative correlation between activation of this area and vividness of mental imagery. The distance between this area and the area shown in Motoyama et al. [2010] was 45.8 mm^3. A previous report showed that activation of the posterior cingulate gyrus and lingual gyrus decreased during generation of mental imagery [e.g., Mellet, Tzourio, Crivello, Joliot, Denis, and Mazoyer, 1996]. Based on the results from the previous and Motoyama et al.'s studies, we can suggest that the function of posterior cingulate gyrus is to suppress the generation of mental imagery; thus, the reduction of activation of the posterior cingulate gyrus was shown during the generation of mental imagery. However, what the function of the lingual gyrus during generation of mental imagery is and why the activation of that area decreases during generation of mental imagery are not clear. Future research should examine whether activation of the lingual gyrus also reflects suppression of the generation of imagery or whether it is irrelevant to such a function.

Appendix

The nouns used in this experiment

Fireplace	Kitten	Windmill	Rainbow	Book	Sun	Coast	Rabbit
Bath	Peach	Harp	Salad	Star	Chocolate	Puppy	Sunset

[3] If the size of the activated area is calculated as a sphere, the radius of activating lingual gyrus could be regard as about 4.7 mm.

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