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Spatial property of visual mental imagery representation: Evidence from ERP P3

Keiko YAMAZAKI* and Jun'ichi KATAYAMA**

*Graduate school of Education, Hokkaido University
**Department of Psychological Science, Kwansei Gakuin University

Abstract: *To investigate if the reaction time effect from an imagery task was due to behavioral control by tacit knowledge, we estimated ERP P3, the peak latency of which reflects stimulus classification speed. Participants visualized the uppercase letter on grids corresponding to a lowercase letter beneath them, and pressed a button only for the infrequent target trials, in which an "X" probe mark in any cell fell on the visualized letter. Half of these target trials were labeled "early" because the probe placed on a segment drawn early in the order to be drawn, and the other half were "late". Not only RT, but P3 latency were modulated by the required stimulus classification speed for the corresponding imagery representation. The result indicates that reaction time for the imagery task reflects cognitive decision based on the spatial property of imagery representation.*

Keywords *Mental imagery generation, Spatial property, ERP P3, Stimulus classification*

1. Introduction

Mental imagery is defined as the perceptual experience in the absence of sensory stimulation. Visual mental imagery plays an important role in our daily life, for example, reasoning, anticipation, and many other cognitive activities. The imagery debate is a famous psychological debate related to the nature of imagery representation.

On one side of the debate (depictive theorist), researchers argue that visual mental imagery has spatial property only as visual perception. This argument is supported by many previous behavioral studies (for review, [1]). For example, Kosslyn et al. (1988) showed that the time taken to scan a visualized map increased based on the distance of scanning [2]. Another finding to verify the spatial property of imagery is mental rotation. People required more time to rotate objects in mental images by greater amounts (e.g., [3]).

On the other side (descriptive theorist), researchers argue that the format of the imagery is the same as other cognitive processing, like language. According to this view, the pictorial aspect of imagery experience is epiphenomenal [4] [5]. They explain the results of previous behavioral studies by implicit "task demand" and the "tacit knowledge" that people have about how things tend to happen in the world. They argue that imagery tasks ask participants to use tacit knowledge to mimic what they think would occur in perception. That is, people do not use cognitive decision by their imagery representation, but by behavioral control to perform the task just like as if they visualized it.

As one resolution of this debate, neuroscientific method has begun to be used for showing similarity between imagery and perception with neuroimaging techniques. For example, PET studies have shown that visual mental imagery engages cortical brain areas for visual perception [6] [7]. One virtue of neuroscientific data is that it is not susceptible to task demands and cannot be explained in terms of tacit knowledge [1].

However, the interpretation of previous behavior-

Kita11 Nishi 7, Kitaku, Sapporo,
Hokkaido 060-0811 Japan
Phone and Fax: +81-11-706-3113
e-mail: keiko115@edu.hokudai.ac.jp

al data by task demand and tacit knowledge is not denied directly. The fact that imagery and perception share the same specific brain areas suggests that visual mental imagery could have spatial property, but does not deny that task demand and tacit knowledge have no effect on behavioral results. Thus, the neuroscientific method, which has sensitivity to the time-course of brain activity, will be needed to show that these data reflect the property of mental imagery per se.

Event-related brain potentials (ERPs) could give some indication for the time-course of brain activity related to visual mental imagery by their high time-resolution. The time-course of brain activity related to visual mental imagery has not been fully examined. One reason for this is that brain imaging methods have coarse time-resolution.

P3 is one of the well-known components of ERP, which has a central-parietal distribution. P3 amplitude decreases with lower external or internal stimulus discriminability [8], and its peak latency reflects stimulus classification speed, but does not reflect behavioral control [9]. Thus, processing speed for imagery representation should be reflected by the P3 peak latency. If people use behavioral control to perform a task by task demand and tacit knowledge, P3 latency would be independent of their reaction time (RT). That is, even if RT shows differences between conditions, P3 latency shows no effect because the time needed for imagery stimulus classification or decision in the brain is the same in any condition. In contrast, if people perform a task based on the spatial properties of visual mental imagery, P3 latency shows the same pattern as RT does.

Thus, the purpose of this study is to investigate whether the effects on performance in the imagery task is due to tacit knowledge or not. If P3 latency results show the same pattern as that of RT, these results support the depictive view of mental imagery. In contrast, if only RT, but not P3 latency, shows the effect, the results support the descriptive view.

2. Methods

Participants:

Twelve adults (6 men, 6 women; age range = 21-36 years, M = 25.7 years) participated in the experiment. All participants were right-handed and had normal or corrected-to-normal vision. Written informed consent was obtained from all participants before the experiment began.

Stimulus:

The stimulus consisted of 5 x 5 grids with an "X" mark probe in one cell and a lowercase letter beneath them (Fig. 1). The size of the grids was 5.8 cm x 5.8 cm, and the bottom lines of the grids were placed 11.5 cm from the top of the screen, while the left and right lines were placed 13.4 cm from each side of the screen. A lowercase letter was presented in the range of a 3 cm x 3 cm box (no line) directly beneath the grid. Each stimulus was presented on a computer screen in front of the participants (view distance was 60 cm). A lowercase letter was either a: "c", "g", "h", "i", "l", "t", "s", or "u".

Procedure:

Participants memorized which cells were filled by the block letter corresponding to the lowercase letter.

In the experiment, the stimuli were presented during 500 ms in random order, once every 2 s. Participants visualized the corresponding uppercase letter on the grids and pressed a button only when the "X" mark fell on the visualized letter -- as quickly as possible. In 25% of the trials, the probe fell on the letter (Target), half of which were "early trials" as the probes placed on a segment drawn early in the order (if they would be drawn on paper), and the other half

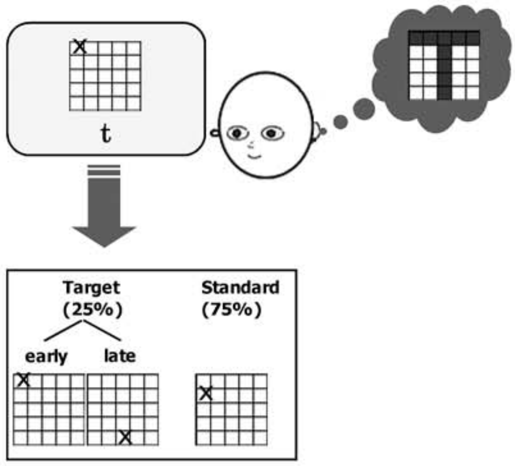

Fig. 1: Imagery task and example of stimulus. In this trial, participants visualized the block letter "T" indicated by the small letter "t" beneath the grid. The position of the probe mark "X" was changed among each trial.

were "late trials". In the Standard trials (75%), the probe fell on one cell out of the visualized letter at random. After all the trials, it was confirmed that all participants drew the uppercase letters corresponding to the lowercase letters in the same writing order.

Recording and Analysis:

We recorded electroencephalogram (EEG) from 25 scalp sites (the extended 10-20 system) by referring to averaged earlobes. Horizontal and vertical EOG (electrooculogram) were measured using bipolar recordings from electrodes placed on the outer canthi of both eyes and from Fp1 and an electrode placed approximately 1 cm below the participant's left eye. All data was digitized at 200 Hz, and a 0.05-30 Hz band-pass filter was applied. Waveforms were averaged off-line for 1600 ms with a 100-ms prestimulus baseline, such that trials with a response error or those on which the EEG or EOG exceeded ±75 µV were rejected automatically.

The P3 component was defined as the largest positive-going peak occurring within the 300-1200 ms time window after the stimulus.

3. Results

Behavior:

The left panel of Fig. 2 shows RT results. RT for the early trial was shorter than that for the late trials (t (11) = 4.4, $p < .05$). The right panel of Fig. 2 shows that the hit rate was higher in the early trials than in the late trials (t (11) = 2.8, $p < .05$), although they were above 90% for both trial types. There was no speed-accuracy trade-off.

ERP:

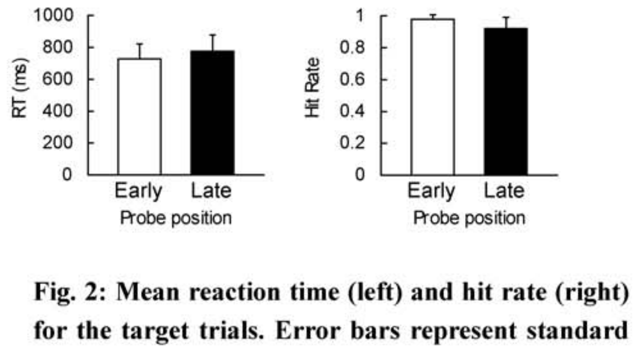

Fig. 2: Mean reaction time (left) and hit rate (right) for the target trials. Error bars represent standard deviation.

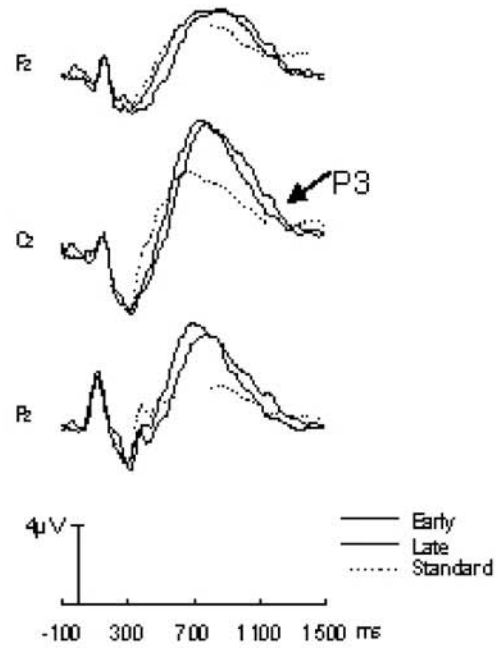

Fig. 3: Grand averaged ERPs for the early, late targets and standard trials. A 13-point moving average filter was applied for presentation.

Fig. 3 shows the grand averaged ERPs for three midline electrodes; frontal (Fz), central (Cz), and parietal (Pz). P3 was observed in the target trials compared to the standard trials.

Fig. 4 illustrates the mean P3 peak latencies for target trials at the Pz. P3 peak latency in the early trials was shorter than that in the late trials (t (11) = 3.1, p <.05). This result was consistent with the RT results.

Fig. 5 illustrates P3 peak amplitudes for the target trials. A 2-factor (2 probe positions X 3 electrodes) analysis of variance found that the interaction was significant, F (2, 22) = 4.09, $p < 0.05$. Post hoc comparisons using the Tukey method indicated the effect of probe position was significant only at the Pz electrode site (p <.05).

4. Discussion

Behavior:

RT was shorter for the early trials than for the late trials. In the early trials, the probe mark fell on the early position, and in the late trials, the probe mark fell on the late position in the writing order. The result supports the notion that the participants visualized letters in the spatial certain order, which is consistent with the previous studies [10]. This result suggests that

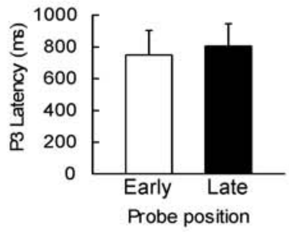

Fig. 4: Mean P3 Peak latency for the Pz. Error bars represent standard deviation.

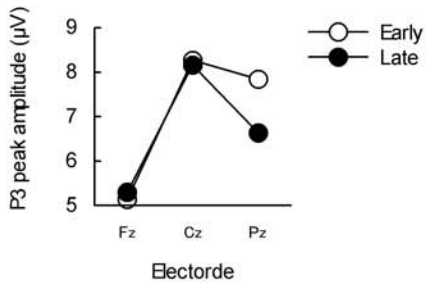

Fig. 5: Mean P3 peak amplitudes for the midline electrodes.

the participants performed the task based on the spatial property of the mental imagery representation. However, there is a possibility that they used tacit knowledge for implicit task demand, as described above.

ERP:

The peak latency of the P3 was shorter in the early trials than in the late trials. Although the RT result might include time for motor control, the peak latency of the P3 only reflects the stimulus classification speed. Therefore, the result showed that the time for stimulus classification was shorter in the early trials than in the late trials. In this experiment, the time for stimulus classification corresponds to the time for the decision whether the trial is the target or not. The tacit knowledge for implicit task demand belongs to the behavioral control, i.e., participants could extend the reaction time as if they saw blocked letters. However, P3 latency, reflecting stimulus classification, does not reflect this behavioral control.

P3 peak amplitude was larger in the early trials than in the late trials at the Pz. This result indicates that stimulus discriminability was higher in the early trials than in the late trials, and is consistent with behavioral results. If participants performed this imagery task only by descriptive representation, it would be difficult to explain this result.

In the long lasting imagery debate, tacit knowledge for task demand was a difficult problem to solve. One resolution has been the neuroscientific measure, in particular, PET and fMRI. These neuroimaging methods have brought not only counterevidence to tacit knowledge in the respect of location similarity between visual imagery and perception, but also the clue to reveal the brain mechanism of imagery processing. In a lot of previous behavioral studies however, there was no direct evidence for not using tacit knowledge for implicit task demand. Our result shows that tacit knowledge for implicit task demand played no role in the imagery task – at least regarding that which we used in this study. This finding is one of convergent evidences for spatial property of visual mental imagery.

The ERP method used in this study has the advantage of shedding light on the time-course of imagery processing, in addition to supporting the findings of previous imaging studies. Although there has been only a limitied number of previous studies of imagery using ERPs, Farah et al. (1988) showed the involvement of the visual cortex using ERP during imagery maintaining [11]. They reported the modulation of visual related potentials, which was triggered to probe stimuli during imagery maintaining after imagery generation. This result showed that it was possible to detect visual activity during imagery by ERP, but the result was not related to imagery generation per se.

Recently, Ganis et al. (2008) showed the equivalence of imagery and perceptual representation using the ERP method [12]. They used the adaptation method to compare ERP to face stimuli during imagery and perception. This study also recorded brain activity after imagery generation, and found the activity of visual related brain area during imagery.

In this study we recorded ERPs triggered by imagery generation cues. It is possible that this method can reveal the time-course of visual mental imagery generation. Imagery generation is a major part of imagery processing, and the mechanism of generation could be a clue to the understanding of imagery property. For example, if the same stimulus elicited different visual ERPs, corresponding to the imagery content, in earlier latency range than P3 elicited, this result would indicate that the visual related activity is necessary for imagery generation. This type of approach is possible by ERP with high time-resolution. Furthermore, Farah et al. (1989) showed slow negative deflection at the occipital electrode site during imagery generation by concrete words to be visualized [13]. The relation between P3 and this negative deflection would also provide new implications for imagery process.

Finally, if we could clarify the brain activity related to imagery, it would be possible to understand spontaneously generated representation. This would thus support knowledge about human thinking or reasoning.

5. Conclusion

P3 latencies, as well as RTs, were modulated by the required stimulus classification speed for the corresponding imagery representation. This result indicates that reaction time during the imagery task was not contaminated by behavioral control by tacit knowledge, but reflects cognitive decision based on the spatial property of imagery representation, and favors the depictive view for visual mental imagery.

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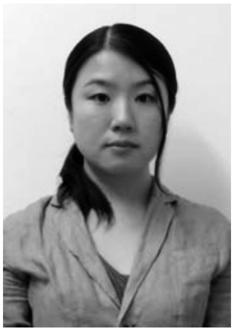
Keiko YAMAZAKI



She received her master degree in education from Hokkaido University in 2002. She is a doctoral student in the Graduate School of Education, Hokkaido University, and Research Fellow of the Japan Society for the Promotion of Science. Her present research interest is the time-course of brain activity during visual mental imagery.

Jun'ichi KATAYAMA

He is a Professor in the Department of Psychological Science and the Director of the Center for Applied Psychological Science (CAPS) at Kwansei Gakuin University. He received his

Ph.D. in experimental psychology from Kwansei Gakuin University, and has taught and conducted research at the Faculty of Education, Hokkaido University. He is a cognitive psychophysiologist and his laboratory studies the human cognitive processes with physiological measures, such as ERPs.