Neuroscience and Medicine, 2025, 16(1), 1-9
https://www.scirp.org/journal/nm
ISSN Online: 2158-2947
ISSN Print: 2158-2912

Differences in Word- and Picture-Based Visual Memory Affect Memory Performance

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How to cite this paper: Matsuo, M., Takahara, R., Suyama, H., Ichibakase, T. and Higuchi, T. (2025) Differences in Word- and Picture-Based Visual Memory Affect Memory Performance. *Neuroscience and Medicine*, **16**, 1-9.
https://doi.org/10.4236/nm.2025.161001

Received: December 9, 2024
Accepted: January 7, 2025
Published: January 10, 2025

Abstract

Background/Objectives: Word- and picture-based visual memory are negatively correlated: improving one reduces the other. Pictures are supposedly easier to remember than words because visual objects and scenes can capture attention more effectively, resulting in highly detailed memory representations. However, the mechanisms underlying this phenomenon remain unclear, and the trade-off between these two memory types is not fully understood. Therefore, this study investigated the influence of differences in visual recognition by focusing on word and picture stimuli. **Methods:** Electroencephalography (EEG) activity in 21 healthy young adults (9 women and 12 men, aged 20.1 ± 1.30 years) during memory tasks involving four conditions—pictures, hiragana, katakana, and kanji—was assessed. **Results:** The picture condition exhibited the highest EEG activity, followed by the kanji, hiragana, and katakana conditions. Further analysis revealed a tendency for significantly lower R-temporal α, R-occipital β, and R-occipital high-γ waves during picture memorization compared to the other conditions, and significantly higher central low-γ waves. However, no significant differences were observed during the recall process under any condition. **Conclusions:** EEG power levels, particularly R-temporal lower α, R-occipital lower β, and high-γ waves, served as indicators of memory performance. Picture presentation streamlined brain activity and can thus potentially enhance memory performance. Our findings may inform the development of targeted management strategies for individuals with dementia.

Keywords

Visual Perception, Memory, Electroencephalography, Brain Function, Neuroimaging

1. Introduction

Previous research on visual perception and memory has demonstrated a negative correlation between memory tasks involving word- and picture-based visual information; as word memory improves, picture memory decreases, and vice versa [1]. Pictures are supposedly easier to remember than words because visual objects and scenes can capture more attention more effectively, resulting in highly detailed memory representations [2]. Long-term memory for pictures is fundamentally different from that for words because the processing of visual stimuli differs from that of verbal stimuli in that visual stimuli are processed across a wider range of expertise [3]. The suggested neuroscientific mechanism states that sentence memory and picture identification activate different working memory areas in the human brain [4]. Picture encoding involves greater activity in the bilateral visual and medial temporal cortices than word encoding. In contrast, word encoding is associated with increased activity in the prefrontal cortex, brain region linked to language functions, and temporal region [5].

However, many aspects of this mechanism remain unclear, and the negative correlation between word- and picture-based memory task performance has not been elucidated. A previous review article highlighted the need for further research to delineate whether and how different neural mechanisms are causally involved in specific neurocognitive functions [6]. Therefore, in this study, we aimed to clarify the influence of differences in visual recognition by focusing on word and picture memories using electroencephalography (EEG) to measure brain activity during memory tasks. We believe the results of this research can contribute to the effective management of individuals with dementia.

2. Materials and Methods

2.1. Participants

This study was approved by the Ethics Committee of Nishikyushu University (Approval No. 23GYA17; July 19, 2023) and conformed to the principles outlined in the Declaration of Helsinki [7] and its later amendments. All prospective participants were provided with a comprehensive explanation of the study's safety protocols and assured that their personally identifiable information would remain confidential. Subsequently, they provided written informed consent for participation. Additional informed consent was obtained from all participants whose identifiable information was included in this study.

Twenty-one healthy young adults (9 women and 12 men, aged 20.1 ± 1.30 years) participated in this study. All the participants did not have a history of major physical disorders, including neurological or psychiatric illnesses, or brain injuries. And none of them were excluded.

2.2. Tasks

The memory tasks comprised four conditions: picture (black and white) and three different kinds of Japanese letters: hiragana (あめ), katakana (アメ), and kanji

(飴). The task content was selected from the Rivermead Behavioral Memory Test (Chiba Test Center Co., Ltd., Tokyo, Japan) to ensure consistency in the task difficulty levels. Participants were given 10 s to memorize the text or picture shown on paper and then immediately asked to recall the paper content within 30 s.

2.3. Experimental Protocol

The participants were seated in a quiet room on a chair with a backrest. They were instructed to perform the tasks without any additional movements, such as head movements, and to maintain the same posture throughout the experiment. EEG measurements were recorded during the experiment, including memorization and recall periods, using a Polymate Pro MP6100 (Miyuki Giken, Tokyo, Japan).

Before electrode placement, the skin was prepared with alcohol and the electrodes were affixed to an elastic cap using a holder. Based on the international 10 - 20 EEG electrode placement system, 19 gold-coated active EEG electrodes were placed at specific cortical locations: Fp1 (left frontal pole), Fp2 (right frontal pole), F3 (left frontal), Fz (middle frontal), F4 (right frontal), F7 (left inferior frontal), F8 (right inferior frontal), C3 (left central), Cz (middle central), C4 (right central), P3 (left parietal), Pz (middle parietal), P4 (right parietal), O1 (left occipital), O2 (right occipital), T3 (left mid temporal), T4 (right mid temporal), T5 (left posterior temporal), and T6 (right posterior temporal) (**Figure 1**). The EEG recorded at the scalp level represented the aggregate currents of the electrical fields generated by neural activity in the cortical neural circuits [8].

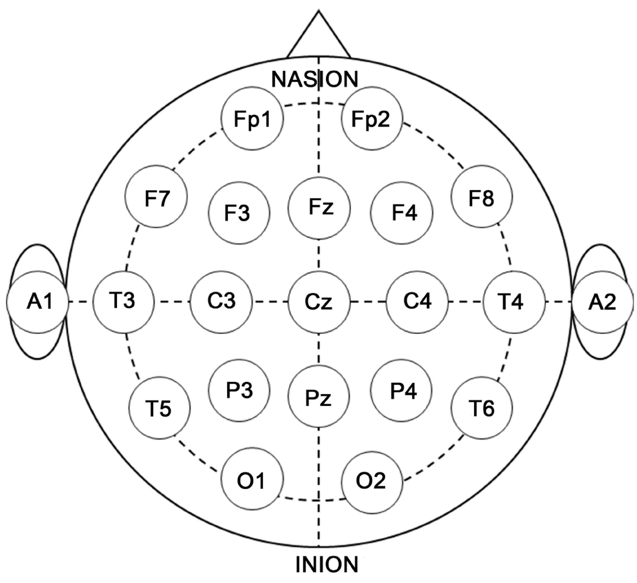

Figure 1. EEG electrode placements. The electrodes were placed according to the international 10 - 20 EEG placement method. EEG, electroencephalography; Fp1, left frontal pole; Fp2, right frontal pole; F3, left frontal; Fz, middle frontal; F4, right frontal; F7, left inferior frontal; F8, right inferior frontal; C3, left central; Cz, middle central; C4, right central; P3, left parietal; Pz, middle parietal; P4, right parietal; O1, left occipital; O2, right occipital; T3, left mid temporal; T4, right mid temporal; T5, left posterior temporal; T6, right posterior temporal.

2.4. Data Analyses

EEG data were sampled at a rate of 1000 Hz and filtered within the 1 - 60 Hz range using a bandpass filter. Artefacts such as eye blinking or muscle movements were excluded. The power spectrum analysis was conducted using an electromagnetic source estimation data editor (Cortech Solutions, Wilmington, NC, USA). The nine regions of interest were set as L-frontal (Fp1, F3, F7, and Fz), R-frontal (Fp2, F4, F8, and Fz), L-temporal (T3 and T5), R-temporal (T4 and T6), central (C3, C4, and Cz), L-parietal (P3 and Pz), R-parietal (P4 and Pz), L-occipital (O1), and R-occipital (O2). EEG rhythms were categorized into six wave bands according to their frequency ranges: δ (0 - 4 Hz), θ (5 - 8 Hz), α (9 - 13 Hz), β (14 - 30 Hz), low-γ waves (31 - 50 Hz), and high-γ waves (51 - 70 Hz) based on previous studies [9] [10]. The mean power level of each waveband was calculated for each task.

2.5. Statistical Analyses

A Friedman test was conducted to compare task performance (number of items recalled correctly) and EEG power levels during memorization and recall tasks. Wilcoxon's signed-rank test was performed as a post-hoc test for significantly different results, and P levels were adjusted using Bonferroni's multiple comparison test. EZR software for medical statistics [11] was used for the statistical analyses. Statistical significance was set at $P < 0.05$.

3. Results

The integrated EEG topographic maps for each task are displayed in **Figure 2**. Comparison of task performance between conditions revealed that the picture condition correlated with significantly highest performance (7.0 ± 1.9), followed by kanji (5.9 ± 1.5), hiragana (5.3 ± 1.0), and katakana (4.5 ± 1.2) ($P < 0.05$) (**Figure 3**).

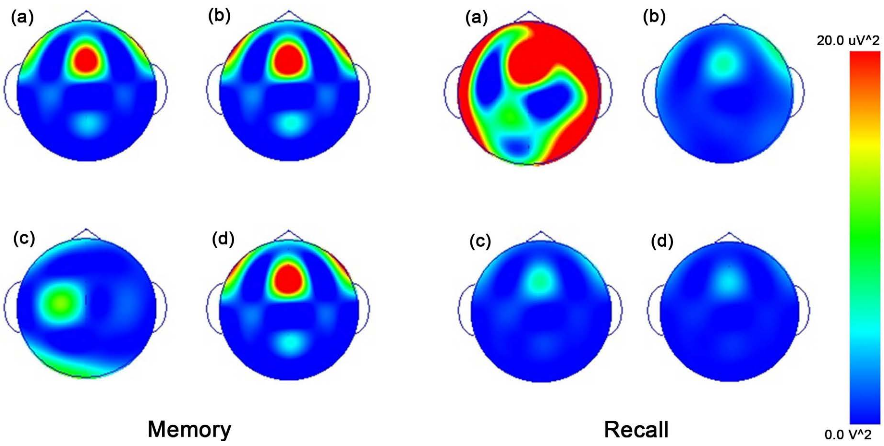

Figure 2. Representative EEG topographic maps during memorization and recall tasks for each condition: (a) picture, (b) hiragana, (c) katakana, and (d) kanji. Hotter and cooler spots indicate higher and lower EEG power levels, respectively. The maps were plotted using an EEG wave band ranging from 0 to 70 Hz.

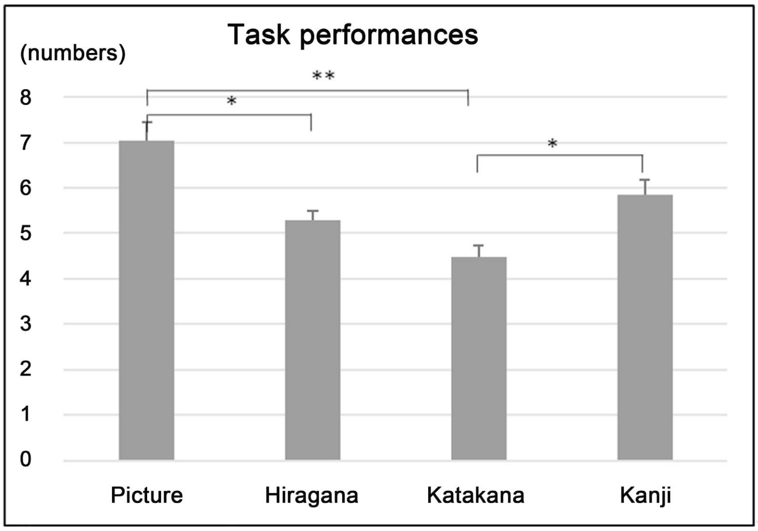

Figure 3. Comparison of the average task performance of all participants (vertical bars) for each condition: picture, hiragana, katakana, and kanji. Post-hoc tests confirmed significant differences between the picture condition and each of the other three conditions ($P < 0.05$). **$P < 0.01$, *$P < 0.05$ as determined using the Bonferroni multiple comparison test.

Further analysis of the EEG power levels revealed a tendency for significantly lower R-temporal α waves, R-occipital β waves, and R-occipital high-γ waves during the picture memorization process compared to other conditions, although significantly higher low-γ waves ($P < 0.1$) (**Table 1**). However, no significant differences were observed in the EEG power levels during the recall process between all the conditions ($P > 0.05$).

Table 1. Comparison of EEG power levels across the task conditions.

ROI	EEG wave band	Picture	Hiragana	Katakana	Kanji	P-value
R-temporal	A	0.549	0.602	0.554	0.563	0.082
R-occipital	B	0.189	0.291	0.289	0.305	0.059
Central	Low-γ	0.569	0.308	0.464	0.350	0.080
R-occipital	High-γ	0.125	0.193	0.196	0.207	0.080

Data are expressed as mean EEG power levels (μV^2). All results were $P < 0.1$, as determined using the Friedman test. EEG, electroencephalography, ROI, region of interest.

4. Discussion

Memory is defined as the storage and use of learned information in the brain [12]. The overall memory process comprises three stages: encoding (registration), storage (retention), and retrieval (decoding). The memory tasks used in this study involved instant recall; thus, we focused on the cerebral activity during the encoding and retrieval stages. In this study, we investigated memory task performance using four different types of visual stimuli to elucidate the influence of differences in visual recognition. EEG was used to measure brain activity during the memorization and recall processes. The picture condition yielded significantly better results than the hiragana and katakana conditions, and the kanji condition was significantly better than katakana, which is consistent with a previous study [13]. Picture memory is influenced by multiple factors, including processing depth, familiarity, and visual category [14], and pictures seem to trigger deeper semantic processing of the associated items [13].

Regarding cerebral activity, the R-temporal α, R-occipital β, and R-occipital high-γ waves during picture memorization tended to be significantly lower than in other conditions, whereas the central low-γ wave tended to be significantly higher. These findings suggest that picture presentation is effective for memory encoding, and that memory performance can be predicted using EEG power levels. A correlation has been reported between attentional task performance and EEG power levels [15]. α and β waves are observed in the wakeful state [16], and recent studies have proposed that α waves can regulate the transmission and processing of neural activity, and thus contribute to neural activities in regions including the visual, motor, and prefrontal cortices, as well as the temporal and parietal lobes [17] [18].

Importantly, α-waves can induce periodic inhibitory moments when their amplitudes are high, leading to a periodic decrease in perceptual performance [19]. However, engaging in cognitive task results in a large reduction in α/β power. This decrease in α/β power is considered a proxy for information processing [20]. A previous study observed lower θ, α, and β bands in the right hemisphere in a low-attention group [21]. These reports and the results of the present study suggest that high EEG amplitudes do not always indicate high cognitive performance. Higher β-wave activity may reflect the effect of pupil size on oculomotor activity and/or visual processing; spontaneous pupil dilation or constriction has been shown to correlate positively with the α-band [22]. Therefore, the low β-wave activity in the right occipital lobe, which is a visual hub, may be associated with a smaller pupil size during picture memorization.

Verbal stimuli generally elicit greater power than non-verbal stimuli. Enhanced verbal power was found bilaterally in the θ band, in the frontal and occipital areas in the α and β bands, and centrally in the γ band [23]. Overall, the lower α-wave activity in the right temporal lobe, which is a memory hub, and the lower β and high-γ waves in the right occipital lobe might serve as key predictors of high memory performance. These phenomena indicated low attention levels, suggesting that picture presentation streamlined brain activity and facilitated enhanced memory performance.

This study had a few limitations. First, all participants were healthy young adults; whether our results can be generalized to older patients or to those with neurological disabilities remains unclear. Second, the memory task was limited to an instant recall; whether brain waves during other memory tasks could be comparable to those observed during current tasks remains unclear. Third, the study focuses solely on EEG power levels, overlooking other relevant EEG measures might provide more detailed insights into the temporal dynamics of memory encoding and retrieval. Finally, the study sample size was small. Future studies should be conducted with a larger number of participants under various conditions, and brainwaves should be investigated during various memory tasks, and analyzed with different techniques.

5. Conclusion

Picture memorization demonstrated the best task performance, followed by kanji, hiragana, and katakana. Significantly lower R-temporal α, R-occipital β, and R-occipital high-γ EEG waves were observed during picture memorization compared to other conditions; these waves can potentially serve as predictors of high memory performance. Picture presentation streamlines brain activity, potentially enhancing memory performance. We believe that these findings expand our understanding of the complex interplay between cerebral activities and memory task performance. Further research is warranted to delve deeper into the neural mechanisms underlying memory performance in relation to EEG frequencies. Our findings may aid in the design of more effective management strategies for individuals with dementia.

Acknowledgements

The authors extend their gratitude to all study participants.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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