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Examination of the Relationship Between Metaphor Generation for Abstract Images and Creativity Using Electroencephalography (EEG)

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Abstract

This study examined electroencephalographic (EEG) activity in the upper alpha band during the generation of descriptions of abstract images to clarify the relationship between metaphor generation and creativity. Shape-based descriptions predominantly involved metaphorical expressions, indicating engagement of metaphor generation processes, whereas color-based descriptions were largely literal. Upper alpha activity during metaphor generation was compared with that during literal expression. Results showed reduced upper alpha power, particularly in posterior regions, during metaphor generation relative to literal expression. These findings suggest that metaphor generation for abstract images recruits enhanced visual and figural processing, reflecting activation of visual cognitive mechanisms underlying creative thinking.

Keywords: metaphor generation; creativity; electroencephalography (EEG)

Introduction

Conceptual blending has been proposed as a core mechanism in creative cognition, enabling the reorganization and integration of previously acquired knowledge into novel representations (Fauconnier and Turner, 2002). This framework explains how combining multiple concepts produces emergent meanings and new ideas. Accordingly, diverse creative activities, including artistic expression and scientific discovery, can be interpreted through conceptual blending. Metaphor represents a linguistic manifestation of this process. Although commonly treated as a rhetorical device, conceptual metaphor theory (Lakoff and Johnson, 1980) posits that metaphor extends beyond language, shaping thought, action, and everyday practices, and playing a central role in conceptual organization.

Metaphor processing relies on detecting similarities across distinct concepts (Bowdle and Gentner, 2005). Developmental evidence indicates that young children preferentially attend to perceptual features such as color and shape, whereas maturation shifts attention toward functional and structural relations (Rattermann and Gentner, 1998). Analogical and metaphorical cues grounded in structural similarity facilitate insight and problem solving. However, even when such cues are available, individuals often fail to apply them unless explicitly prompted, underscoring the difficulty of spontaneous analogical transfer (Gick and Holyoak, 1980). In creativity research, perceptual similarity may initiate exploration of deeper semantic relationships (Indurkhya and Ogawa, 2012). Despite these findings, the link between visually elicited metaphor generation and creativity remains unclear. This study addresses this gap by examining metaphor generation from abstract images using a neuroscientific approach.

Electroencephalography (EEG) studies have investigated the neural correlates of creativity, with particular emphasis on alpha-band activity (approximately 8-13 Hz). Increased alpha power, especially in the upper alpha range, has been associated with creative cognition and appears sensitive to task demands (Fink and Benedek, 2014). Divergent thinking, which supports original idea generation, is linked to higher task-related alpha power than convergent thinking in tasks such as the alternate uses task and word association task (Jauk et al., 2012). During creative ideation, individuals with higher creativity exhibit increased upper alpha power following stimulus onset and before response completion, producing a U-shaped temporal pattern (Rominger et al., 2019).

In contrast, visual creativity has been associated with decreased alpha power relative to baseline (Pidgeon et al., 2016). During the picture completion task of the Torrance Test of Creative Thinking (TTCT; Torrance, 1966), creative ideation is characterized by upper alpha desynchronization over parietal and occipital regions, reflecting elevated visual and figural processing demands (Rominger et al., 2018).

An EEG study of metaphor generation for scientific concepts reported that metaphor novelty correlates with early-stage alpha synchronization followed by later-stage alpha desynchronization (Yu et al., 2025). However, the neural basis of metaphor generation in response to visual stimuli remains insufficiently examined. The present study therefore investigates alpha-band activity during metaphor generation to clarify its relationship with creativity. Prior findings suggest that shape features are more influential than color features in metaphor generation for abstract images (Yamamura et al., 2024). Accordingly, shape-based descriptions are expected to be predominantly metaphorical, whereas color-based descriptions are expected to be largely literal. Based on this framework, this study examines upper alpha activity during the generation of shape- and color-based descriptions of abstract images to evaluate the association between metaphor generation and creativity.

[1]The first and second authors conducted this study while they were students at Future University Hakodate. The present affiliation of the first author is Japan Business Systems, Inc. and that of the second author is Persol Cross Technology Co., LTD

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Experiments

This study comprised two experiments. Experiment 1 consisted of a single session. To improve result stability by increasing trial numbers, Experiment 2 included two sessions. The first session of Experiment 2 replicated Experiment 1. Accordingly, two analyses were conducted. Analysis 1 combined data from Experiment 1 and the first session of Experiment 2, whereas Analysis 2 used data from both sessions of Experiment 2 to increase trials per participant.

Method

All participants were native Japanese speakers, right-handed, nonmedicated, and without visual or auditory impairments. Written informed consent was obtained before participation. Eleven male participants (mean age = 20.9, SD = 1.51) completed Experiment 1, and ten different male participants (mean age = 21.3, SD = 0.82) completed Experiment 2. The study was approved by the Ethics Committee of Future University Hakodate.

Participants viewed abstract images and generated descriptions focusing on either color or shape. Experiment 1 used 16 colored inkblot images in a single session. Experiment 2 used 32 images: the 16 images from Experiment 1 in the first session and 16 additional images in the second session. As shown in Fig.1, each trial began with a fixation cross for 10 s (baseline). A Japanese cue was then presented for 5 s (preparation phase): "color" instructed participants to prepare a color-based description (color condition), whereas "shape" indicated a shape-based description (shape condition). During the description phase, an abstract image was presented on a black background for 30 s, during which participants silently generated responses. When the background changed to gray, participants provided verbal responses. The image remained on a gray background for 15 s. Each session included 16 trials (8 color, 8 shape). Image–condition pairings and trial order were randomized.

EEG data were recorded using a 32-channel Biosemi ActiveTwo system, with electrodes placed according to the international 10/20 system. Reference electrodes were positioned on the auricles, and impedance was maintained below 10 $k\Omega$. Signals were sampled at 2,048 Hz. Participants were instructed to remain still and minimize movement during recording.

Classification of descriptions

The generated descriptions were classified as either literal descriptions or metaphorical descriptions by two experimenters. Descriptions that included expressions likening other objects (e.g., "This image looks like a butterfly.") were categorized as metaphorical descriptions and descriptions without such expressions were categorized as literal descriptions. There was no disagreement between them in the classification.

EEG data analysis

EEGLAB (Delorme and Makeig, 2004) in MATLAB was used for preprocessing and analysis. EEG signals were bandpass filtered (0.1 to 100 Hz), and line noise was removed. Independent component analysis was applied to eliminate artifacts. The baseline interval was defined as 1 s after fixation onset to 1 s before fixation offset. The activation interval was defined as 1 s after stimulus onset to 2 s before stimulus offset during image presentation on a black background (Fig.1). Time–frequency analysis computed event-related spectral perturbations (ERSPs) (Makeig, 1993) in the alpha band (7–13 Hz). ERSPs quantify event-related brain dynamics; negative values indicate decreased alpha power relative to baseline, whereas positive values indicate increased power. ERSPs were calculated using a short-time Fourier transform with a 1,000 ms window. Power in the upper alpha band (10.5-12.5 Hz) was extracted.

For statistical analysis, electrodes were grouped by region: left anteriofrontal (AF: Fp1, AF3), left frontal (F: F7, F3), left frontcentral (FC: FC1, FC5), left centrotemporal (CT: T7, C3), left centroparietal (CP: CP1, CP5), left parietotemporal (PT: P7, P3), and left parietooccipital (PO: PO3, O1), with corresponding right-hemisphere regions. Midline electrodes (Fz, Cz, Pz, Oz) were excluded. To calculate the time-course of ERSP, activation interval was divided into three equal time segments (early, middle, late). Median ERSP values were computed for each segment across hemispheres and regions.

Results

Responses

Table1 summarizes the classification of descriptions from Experiments 1 and 2. Trials were categorized as "Other" when invalid (e.g., no response or incorrect timing). In the color condition of the second session of Experiment 2, some metaphorical descriptions were observed, contrary to the initial assumption. Overall, however, metaphorical descriptions predominated in the shape condition, whereas literal descriptions predominated in the color condition, indicating that the task functioned as intended. Trials inconsistent with task demands were excluded from both conditions. In these excluded trials, color-condition responses were often impression-based, whereas shape-condition responses frequently focused on limited image features; both were deemed inappropriate. Subsequent analyses included only metaphorical descriptions in the shape condition (metaphor generation) and literal descriptions in the color condition (literal expression). In the second session of Experiment 2, one participant produced metaphorical descriptions in 5 of 8 trials >50%) in the color condition; this participant was excluded from Analysis 2, and only first-session data were retained for Analysis 1.

EEG data

Analysis 1 Analysis 1 used combined data from Experiment 1 and the first session of Experiment 2 (Fig.2). A four-way analysis of variance (ANOVA) was conducted with

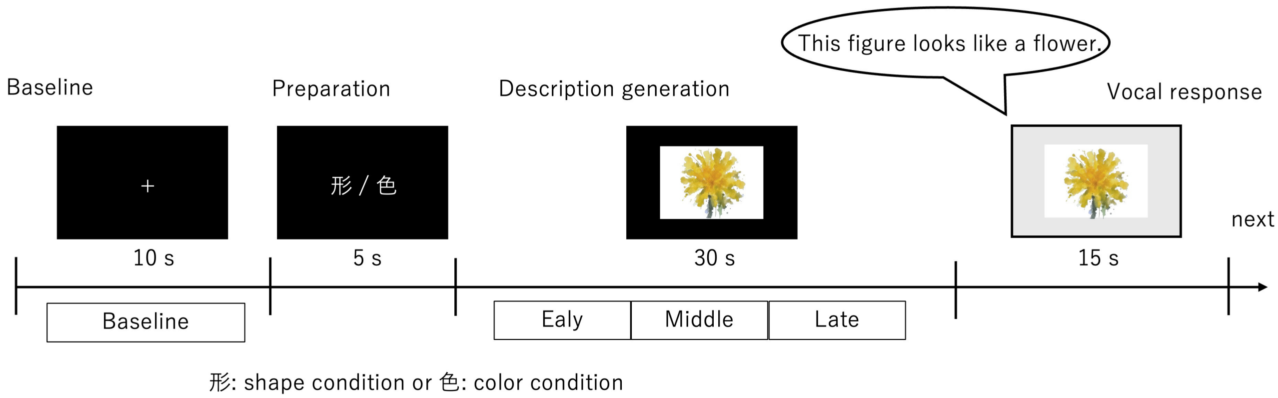

Figure 1: Time course of the experimental task. An 8 s interval within the 10 s fixation period (excluding the first and last seconds) was used as the baseline. The activation interval extended from 1 s after image onset to 2 s before the background color change and was divided into three phases: early, middle, and late. (A similar example abstract image is shown due to copyright.)

Table 1: Classification results of the descriptions. Metaphor: metaphorical descriptions, Literal: literal descriptions, Other: No responses etc.

(a) Experiment 1

		Condition	
		Figure	Color
Descriptions	Metaphor	88	2
	Literal	0	87
	Other	1	0

(b) Experiment 2 (Session 1)

		Condition	
		Figure	Color
Descriptions	Metaphor	77	4
	Literal	3	75
	Other	0	1

(c) Experiment 2 (Session 2)

		Condition	
		Figure	Color
Descriptions	Metaphor	78	11
	Literal	1	68
	Other	1	1

condition (metaphor, literal), laterality (left, right), area, and time (early, middle, late) as factors. Post hoc comparisons were performed using the Holm method with a significance level of 5%. The results showed main effect of area ($F(6, 120) = 23.98, p < .01, \eta^2 = .14$: PO<{AF, F, FC, CT, CP}, PT<{F, FC, CT, CP}, CT>FC), interaction between area and time ($F(12, 240) = 2.30$, $p < .01, \eta^2 = .0006$: early: PO<{AF, F, FC, CT, CP}, PT<{F, FC, CT, CP}, CT>{AF, F, FC}, middle: PO<{AF, F, FC, CT, CP}, PT<{F, FC, CT, CP}, late: PO<{AF, F, FC, CT, CP, PT}, PT<{F, FC, CT, CP}, CT>FC), and interaction among condition, area and time ($F(12, 240) = 1.97$, $p < .05$, $\eta^2 = .0003$). The multiple comparisons for the interaction among condition, area and time revealed that interaction between area and time was observed in metaphor generation ($F(12, 240) = 3.16$, $p < .01$, $\eta^2 = .001$: early: PO<{AF, F, FC, CT, CP}, PT<{F, FC, CT, CP}, CT>{AF, F, FC}, middle: PO<{AF, F, FC, CT, CP, PT}, PT<{F, FC, CT, CP}, CT>FC, late: PO<{AF, F, FC, CT, CP, PT}, PT<{F, FC, CT, CP}, CT>FC) but not in the literal condition. Furthermore, significant trend of condition was observed ($F(1, 20) = 3.52$, $p < .1$, $\eta^2 = 0.005$: metaphor < literal).

Analysis 2 Analysis 2 included data from both sessions of Experiment 2 to increase trials per participant (Fig.3). Similarly, a four-way ANOVA and multiple comparisons were conducted. Results showed a main effect of condition ($F(1, 8) = 6.67$, $p < .05$, $\eta^2 = .02$, metaphor<literal), main effect of laterality ($F(1, 8) = 5.65$, $p < .05$, $\eta^2 = .001$: left<right), main effect of area ($F(6, 48) = 12.92$, $p < .01$, $\eta^2 = .10$: PO<{AF, F, FC, CT, CP}, PT<{CT, CP}) and interaction between area and time ($F(12, 96) = 2.34$, $p < .05$, $\eta^2 = .001$, early: PO<{AF, F, FC, CT, CP}, PT<{CT, CP}, middle: PO<{AF, F, FC, CP}, PT<CP, late: PO<{AF, F, FC, CT, CP}, PT<{CT, CP}).

Discussion

Analysis 2, which included more trials than Analysis 1 despite a limited sample size, demonstrated significantly greater suppression of upper alpha power during metaphor generation than during literal expression generation. Analysis 1 showed a comparable pattern as a significant trend. Overall, metaphor generation was associated with stronger alpha suppression than literal expression generation. This finding is consistent with prior evidence linking reduced alpha ac-

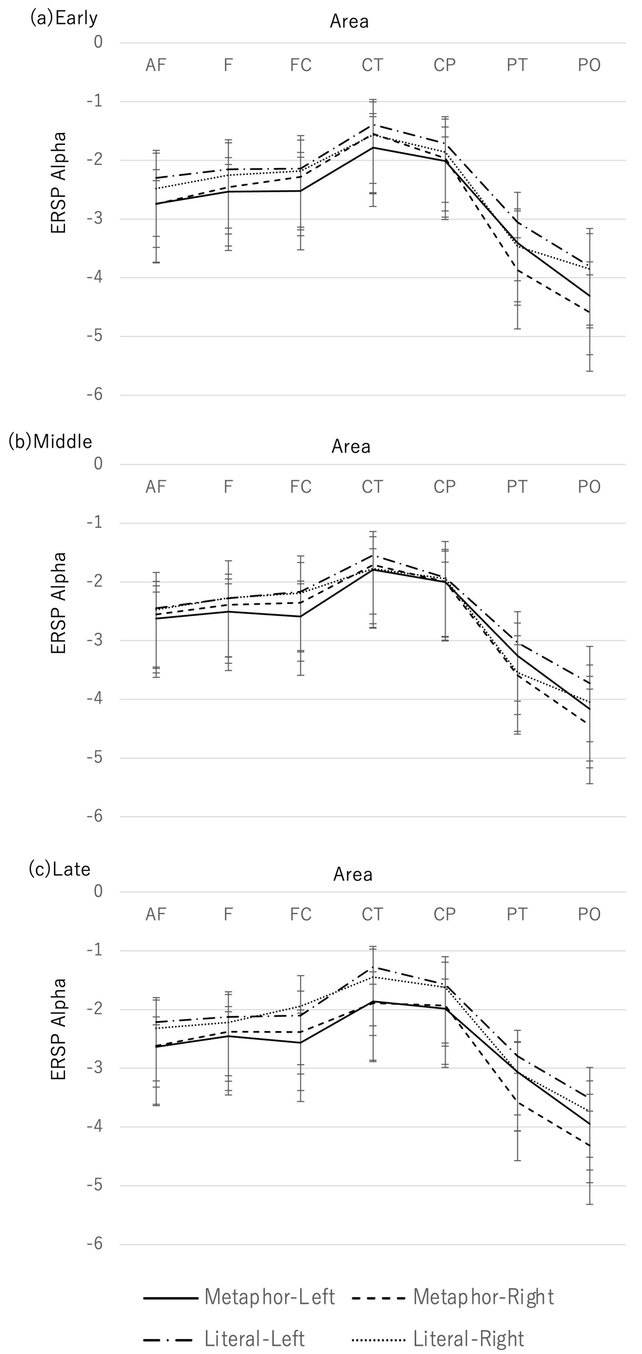

Figure 2: Pattern of ERSPs and error bars (Standard Error) in the upper alpha band (Analysis 1)

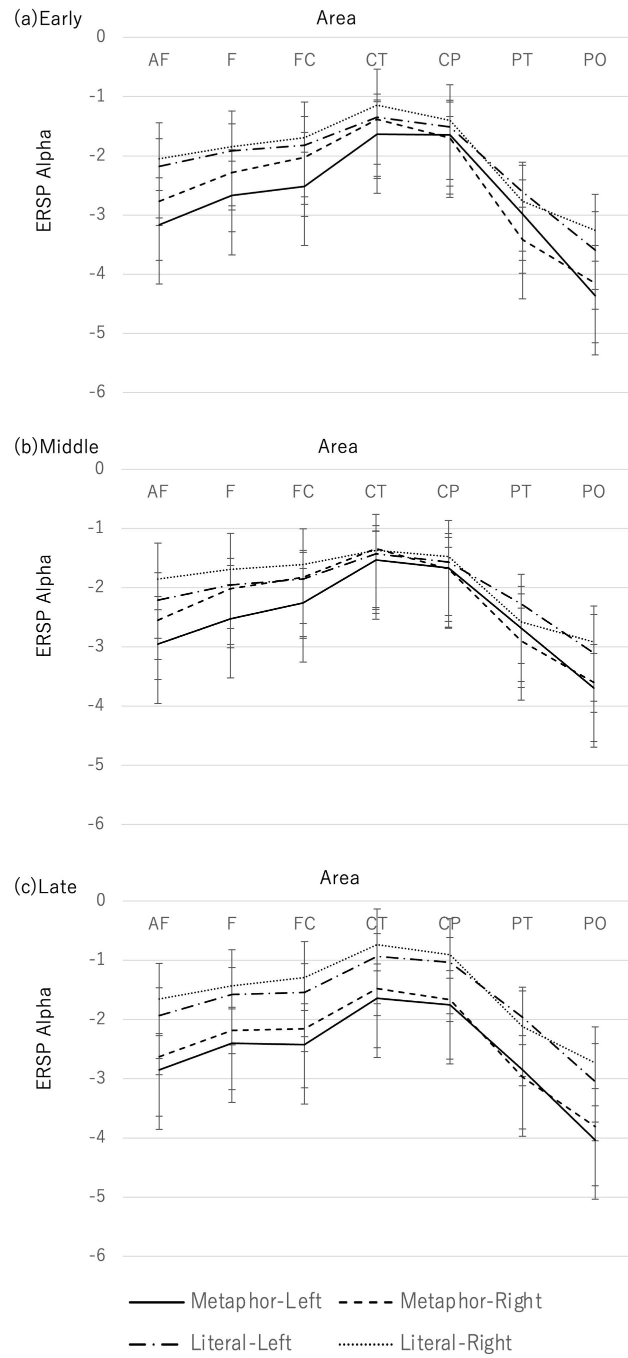

Figure 3: Pattern of ERSPs and error bars (Standard Error) in the upper alpha band (Analysis 2)

tivity to figural creativity. Significant regional differences were identified in both analyses. Alpha suppression was more pronounced in posterior regions than in anterior or central regions, suggesting greater involvement of visual and figural processing during description generation for abstract images. Prior work has shown that creative ideation in the figural domain is associated with upper alpha desynchronization over parietal and occipital regions, reflecting increased visual processing demands (Rominger et al., 2018). Accordingly, the present findings indicate that metaphor generation for abstract images engages cognitive processes related to enhanced allocation of attentional resources to internal or external visual representations during creative thinking.

Interactions between region and time were observed in both analyses, indicating that alpha suppression varied across regions over the course of description generation. Previous research (Rominger et al., 2018) reported that idea elaboration in the figural domain is associated with relatively increased upper alpha power in occipital and parietal regions compared with idea generation. The present findings may therefore reflect distinct phases of description generation, including a generation phase and an elaboration (or evaluation) phase. In Analysis 1, post hoc comparisons of the significant condition × region × time interaction showed a region–time interaction during metaphor generation but not during literal expression generation. This pattern suggests that metaphor generation may involve additional elaboration (or evaluation) processes beyond those required for literal expression generation. However, no increase in alpha activity was observed in later stages, indicating that further investigation is necessary.

Conclusion

This study examined the relationship between metaphor generation and creativity by analyzing EEG upper alpha activity during description generation of abstract image features. Metaphorical descriptions were predominantly produced in the shape condition, whereas literal descriptions were primarily produced in the color condition, indicating that the experimental manipulation functioned as intended. Compared with literal expression generation, metaphor generation was associated with stronger suppression of upper alpha activity, particularly in posterior regions. These findings suggest that metaphor generation for abstract images involves enhanced visual and figural processing, reflecting increased engagement of visual cognitive mechanisms in creative thinking.

A stronger region–time interaction was also observed during metaphor generation than during literal expression generation, suggesting that metaphor generation may involve additional elaboration (or evaluation) processes. However, the study did not clearly distinguish between generation and elaboration phases, and future studies using alternative experimental designs are required to verify this interpretation.

Finally, metaphor generation was operationalized using participants' descriptions of abstract images, with shape-based descriptions classified as metaphorical and color-based descriptions classified as literal. This design introduces a potential confound, as effects attributed to metaphor generation may instead reflect differences in cognitive demands between shape and color processing. Future research should directly compare metaphorical and literal expression generation within the same task to isolate the specific contribution of metaphor generation.

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