ORIGINAL ARTICLE

Effect of Adequate Non-verbal Mnemonic Conflict Management: Comparing Brain Activity during Idea Incubation between Different Creativity Levels

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ABSTRACT

Using electroencephalography, we analyzed differences in the brain activity of designers having different creativity levels for idea conception in design. The 30 designers' conceptual imaginations were measured on the basis of five indicators: Intuition, sensibility, focus, effectiveness, and dialectics. The following results were obtained: (i) Design intuition is driven by verbal memory filtering; (ii) design sensibility mainly results from non-verbal semantic processing; (iii) design focus results from the coactivation of non-verbal communication and cognitive control; (iv) design effectiveness is closely associated with affective and cognitive control; and (v) design dialectic enables the leverage between nonverbal communication and emotional regulation. We differentiated the brain activity between the HC and LC participants for design idea conception which was primarily governed by how effectively non-verbal mnemonic conflict was managed.

Key words: Conceptual Imagination, Creativity, Electroencephalography, Non-verbal Mnemonic Conflict, Visual Designer

INTRODUCTION

Working as a designer typically means that one must develop methods to understand other people's problems, conceive solutions, and express ideas to clients. In other words, designers must sympathize with clients' needs, incubate ideas to resolve clients' problems, and achieve sufficient imaginative capacity to conceive those ideas and transform them into products and services. For successful resolution of a problem, an individual requires time to retrieve relevant information, explore the problem space in the preferential direction, and simultaneously search for new perspectives of the problem.[21,43] How effectively a resolution incubation process proceeds depending on a designer's imaginative capacity, which forms the basis for cultivating creative ideas.[13,26] This incubation process is also known as conceptual imagination, referring to how designers conceive effective ideas and form mental images to resolve design problems.

A designer's conceptual imagination is typically goal directed and involves mentally grasping the core of a phenomenon using intuition and sensibility and formulating effective ideas to achieve a goal by focusing attention and logical dialectics.[23,35] Recent studies have reported that conceptual imagination positively predicts design performance.[1,2] According to Liang and Chia,[3][1] conceptual imagination

1 Based on psychology and creativity research (Kunzendorf, 1982; Liu and Noppe-Brandon, 2009; Taylor, 2013; Vygotsky, 1978), Liang and Chia[3] proposed the imagination capacity (IC) theory, denoted the indicators of IC, and categorised IC into three types: Initiating imagination, conceptual imagination, and transforming imagination. The IC scale and its indicators have been repeatedly tested by measurement invariance across gender, domains (i.e., arts, design, science, and engineering), and contexts (i.e., the United States, Taiwan, Singapore, India, and Pakistan). In 2015, the IC scale was included in the American Psychology Association's PsycTESTS database.

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consists of five indicators: Intuition, sensibility, focus, effectiveness, and dialectics. *Intuition* refers to the ability to generate immediate associations with a goal. Designers consciously and unconsciously use their intuition, acquired through experience, to interpret design problems, and gain a deeper understanding of their creative processes.[4,5] The intuitive process triggers the ventromedial prefrontal cortex, insula, and anterior cingulate cortex (ACC).[6,7]

Sensibility refers to the ability to evoke feelings during the creative process. Niedderer[8] stated that design sensibility involves linking emotional expressions to symbolic meanings, enabling esthetic approaches to a user's emotional reactions and designing through the embodiment of a user's physical movements. Accordingly, the prefrontal, frontal, parietal, and temporal cortices are simultaneously activated when people process particular emotions.[9,10] Focus refers to the ability to formulate ideas through focusing attention. Folkmann[11] described the mental setting of designers for problem solving as a flow of focusing (idea generation) and defocusing (remote association). A conceptually determined focus is associated with a goal-oriented process that is close to a client's requirements. Neurocognitive studies have demonstrated that the interaction between the posterior cingulate cortex (PCC) and the frontoparietal lobe influences individual actions requiring focusing attention.[12,14]

Effectiveness refers to the ability to generate effective ideas to achieve a goal. Lin *et al*.[2] indicated that visual designers must effectively sympathize with users' needs and incorporate their possible activities into design strategies. The goal-directed planning of novel resolutions requires rational thinking and is controlled top-down by working memory in the medial prefrontal cortex and by the left dorsolateral prefrontal cortex (DLPFC).[15,16] Dialectics refer to the ability to seek improvements by recurrently analyzing ideas. Designers often shift between different modalities of arguments, pertaining to contradictory opinions at the time they are being generated.[17,18] Performing dialectics also requires the ability to flexibly regulate psychological states through interactions with other people and with oneself,[19] and the right prefrontal cortex is fundamentally involved in empathy and in regulating emotional responses.[20,22]

Evidence for conceptual imagination in design problem solving is increasing, but the relevant research is insufficient, partially because of the lack of reliable research tools. Due to the availability of new techniques for detecting brain activity, numerous studies have investigated design cognition in the brain.[15,24,25] To address these research gaps, the present study applied a neurological approach based on the identified indicators of conceptual imagination possessed by visual designers. Electroencephalography (EEG) was used to analyze differences in the brain activity of designers having different levels of creativity for idea conception in design. We wish to know: (i) The differences in brain activations and cognitive implications for the five indicators of conceptual imagination, namely, intuition, sensibility, focus, effectiveness, and dialectics, when designers engage in experimental tasks, and (ii) the differences in the brain activations of HC and LC participants while they engage in the experimental tasks involved in conceptual imagination.

MATERIALS AND METHODS

Participants

In this study, 42 visual designers (19 women and 23 men) whose ages ranged from 22 to 41 years were invited to participate in an EEG experiment. The inclusion criteria were (i) having worked in visual design for more than 5 years, (ii) being a renowned freelancer or having directed design teams, (iii) having received awards in domestic or international design competitions, (iv) having no history of cardiovascular or vestibular disorders and no history of drug or alcohol abuse, and (v) not taking any medication and having normal or corrected-to-normal vision. These inclusion criteria allowed for various levels of design experience.

Before the experiment began, the participants were guided to complete two creativity assessment tools, namely the creative personality scale (CPS; Gough, 1979)[26] and the imagination capacity scale (ICS; Liang and Chia, 2014).[3] Lower CPS total scores determine lower creativity. Therefore, the top-bottom fourths of the participants (8 women and 12 men) whose ages ranged from 24 to 37 years were subsequently divided into HC and LC groups for brainwave comparison analyses.

Materials and equipment

Pictorial representations evidently affect designer imagination, and abstract images arouse design creativity. [27-30] The stimuli used in the present study were Joan Miró's artworks. The use of these artworks is restricted to academic research without any commercial involvement. Three researchers first nominated 15 of Miró's representative artworks and then compared the selections to ensure that the same work did not appear twice. The remaining artworks were then compared for the characteristics of perceptual fluency, such as clarification, composition, repetition, perceptual priming, and contrast.[31] A final list of 8 artworks was produced; all the 8 artworks were determined to have a similar level of perceptual fluency. They were then randomly presented during the experiment.

In the present study, the 32-channel wireless EEG cap BR32S system was used. It features a sampling rate of 250 Hz and 16-bit quantization, with 2 dry foam-based EEG sensors that are used only for Fp1 and Fp2 sites on the forehead in the international 10–20 system. This headset features spring-loaded dry electrodes and a soft cap, rendering it convenient and precise. The dry electrodes are resilient and can be used repetitively on hairy sites without a conductive gel. EEG data are wirelessly received through the Bluetooth protocol without external devices or cables.

Experimental protocol

The present study was approved by the Research Ethics Office of National Taiwan University. After the participants arrived at the laboratory, a letter of informed consent was read to them, and the experiment began when the headset was worn and the EEG signals were received steadily. The participants' brainwaves during resting periods were recorded to serve as baseline, enabling meaningful statistical comparisons of brain activity when the participants were exposed to visual stimuli. After the resting data were collected, each participant verbally described an ongoing design project for 2 min, including the design problem, purpose, and imagined outcomes. The eight artworks selected for this study were randomly displayed on a slideshow on the computer monitor, and each participant was asked to answer questions related to the indicators of conceptual imagination (i.e., intuition, sensibility, focus, effectiveness, and dialectics).

Regarding the intuition indicator, each participant responded to the following question: "Please answer the following question immediately off the top of your head. How would this image inspire you to change your originally planned project outcome, and explain how the outcome would change?" The participant was asked to remain silent, and their brainwave signals were recorded for 30 s. Thereafter, the participant was asked to verbalize for approximately 90 s; thus, this phase lasted 2 min. The 90-s narration task was designed to acquire narrative information and was simultaneously treated as an intertrial interval to avoid recording overlapping brain responses. The same image was displayed on the monitor, and the researchers then posed the subsequent questions to the participant.

Regarding the sensibility indicator, the participant answered the following questions: "How would this image improve your mood? How would you change your originally planned project outcome if these feelings were embedded in the project?" Regarding the focus indicator, the participant answered the following questions: "Which elements or details would attract you? How would you change your originally planned project outcome if these elements or details were embedded in the project?" Regarding the effectiveness indicator, the participant answered the following questions: "Which parts of this image do you think your client would appreciate? How would you change the originally imagined outcome if you wanted to incorporate your client's preference?" Regarding the dialectics indicator, the participant answered the following questions: "Which parts of this image do you appreciate the most? Explain how the outcome would change if the balance between the client's preference and your own appreciation was maintained." The procedures of the following four phases were identical to that of the first phase.

The researchers then repeated the procedure identically for the remaining seven artworks to ensure the quality of this experiment. Each artwork was used for the five indicators of conceptual imagination, and each indicator (phase) lasted 2 min; thus, each artwork experiment lasted 10 min, and the total EEG experiment lasted 80 min. Each participant remained in the laboratory for 90–120 min, including for the experiment explanation, project description, and EEG headset testing. The researchers then analyzed the recorded brainwave signals.

Data analyses

EEG data collected from the experiments were exported in ASCII (.txt) format and split into 1.6-s signals for further analysis.[32] A low-pass finite impulse response (FIR) filter with a cut-off frequency of 50 Hz and a high-pass FIR filter with a cut-off frequency of 1 Hz were applied to all 1.6-s data sets to remove line noises and direct current drifts. Any channel exhibiting abnormal waveforms was manually removed, and the removed channels were replaced by averaging the data. The filtered signals were decomposed through independent component analysis (ICA) implemented in the EEGLAB toolbox.[33] Each data set was decomposed into 32 independent components considered brainwave sources.[34] All components were regrouped in several clusters according to the similar outcome using the k-means clustering method. Components that were three standard deviations away from the cluster center were treated as outliers.

The spatial filters can be plotted as the scalp topography of the independent component. Scalp topographies demonstrate the relative strength of the activity of brain parts. With the EEGLAB DIPFIT plugin, the scalp topography of each independent component can be used to plot the three-dimensional (3D) location of an equivalent dipole or dipoles on the basis of a 4-shell spherical head model. Components with similar scalp topographies and dipole locations from a participant can be grouped into component clusters. Clusters that have scalp topographies with a uniform display and a dipole plot with concentrated locations were recognized as robust clusters.[34] In the present study, we transformed time domain data into frequency domain data using fast Fourier transform. We also separated the EEG spectra into five frequency bands based on previous studies,[35-37] namely delta (0.5–3.5 Hz), theta (3.5–8 Hz), alpha (8–13 Hz: Low, 8–9 Hz; middle, 9–11 Hz; and high, 11–13 Hz), beta (13–30 Hz: Low, 13–16 Hz; middle, 16–20 Hz; and high, 20–30 Hz), and gamma (30–100 Hz: Low, 30–60 Hz; typical, 40 Hz; and high, >60 Hz).

RESULTS

The differences of the HC and LC designers were examined and compared for the following five indicators of conceptual imagination: Intuition, sensibility, focus, effectiveness, and dialectics. Regarding the intuition indicator, according to Figure 1, the participants exhibited comparatively high brain activity in the right frontal and middle prefrontal cortices when they involved in the experimental task. The scalp topographies and 3D dipole plots displayed in Figure 1a-c indicate that this brain activation was separated into three components: The left prefrontal, right frontal, and left temporal cortices. Table 1 lists the correlations among these components, in which a positive association was observed between the left temporal and left prefrontal cortices.

Since the component spectra cannot be assumed to be normally distributed and the sample size was small, a paired-sample Wilcoxon signed-rank test was applied to differentiate the brain activities in spectra between the HC and LC participants. As shown in Figure 2a, the LC designers had higher spectral power levels than did the HC designers in the left prefrontal cluster in all frequencies above 9 Hz. The largest differences occurred in the gamma band (40 Hz, $P = 0.0013$) and the beta band (24 Hz, $P = 0.0020$; 23 Hz, $P = 0.0025$). No significant differences were detected in the right frontal and left temporal clusters [Figure 2b and c]. The significance of the null hypothesis related to different frequencies is shown as red stars in the spectra.

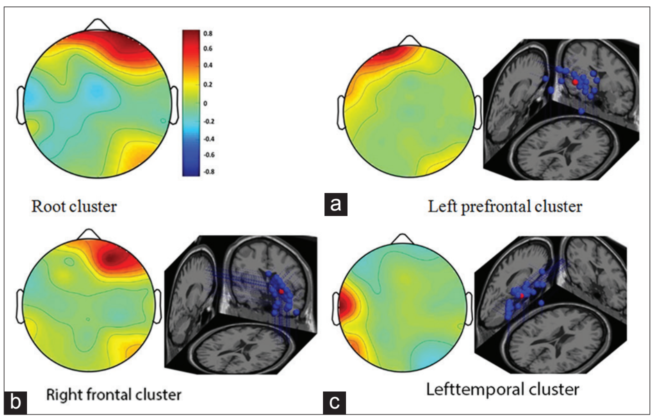

Figure 1: Scalp topographies and three-dimensional (3D) dipole plots associated with the intuition indicator (1: Root cluster; 1a-1c: Scalp topographies and the 3D dipole source locations for the component clusters)

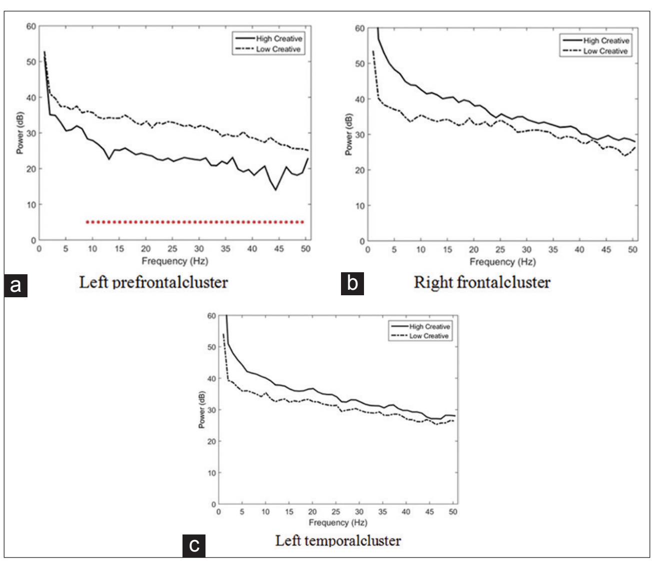

Figure 2: Wilcoxon signed-rank test results for the intuition indicator, (a) left prefrontal cluster, (b) right frontal cluster, (c) left temporal cluster

Regarding the sensibility indicator, the participants exhibited high activations in the prefrontal and frontal cortices when they involved in the task [Figure 3]. The scalp topographies and 3D dipole plots [Figure 3a-c] indicate that the brain activations were separated into three components: The right temporal, left lateral frontal, and right lateral frontal cortices. Table 2 lists the correlations among these major component clusters.

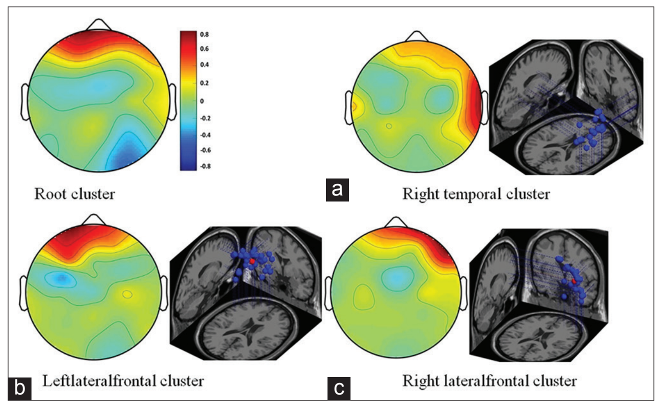

Figure 3: Scalp topographies and three-dimensional dipole plots associated with the sensibility indicator (1 - root cluster, (a) right temporal cluster, (b) left lateral frontal cluster, (c) right lateral frontal cluster)

Table 1: Correlations among the components for the intuition indicator

Component	LPF	RF	LT
LPF	1	0.25***	0.43***
RF		1	0.25***
LT			1

*P<0.05. **P<0.01. ***P<0.001. LPF: Left prefrontal, RF: Right frontal, LT: Left temporal

Table 2: Correlations among the components for the sensibility indicator

Component	RT	LLF	RLT
RT	1	0.27***	0.31***
LLF		1	0.23***
RLF			1

*P<0.05. **P<0.01. ***P<0.001. RT: Right temporal, LLF: Left lateral frontal, RLF: Right lateral frontal

Accordingly, the positive association between the right lateral frontal and right temporal cortices was comparatively strong.

The results indicated that the spectral power of the LC participants was generally lower than that of the HC participants in the right temporal cluster [Figure 4a]. The largest differences occurred in the delta band at 1 Hz ($P = 0.0007$) and the theta band at 7 Hz ($P = 0.0083$) and 6 Hz ($P = 0.0094$). In the left lateral frontal cluster, only one significant difference appeared in the beta band at 16 Hz] $P = 0.0365$; Figure 4b]. No significant difference appeared in spectral power in the right lateral frontal cluster [Figure 4c].

Regarding the focus indicator, the participants exhibited relatively high brain activations in the left frontal cortex [Figure 5]. Figure 5a-c indicates that the activations could be separated into three components: The left lateral frontal, middle parieto-occipital, and right temporal cortices. A positive association was observed between the left lateral frontal and right temporal cortices [Table 3]. In addition, a negative association was observed between the middle parieto-occipital and left lateral frontal cortices and between the right temporal and middle parieto-occipital cortices.

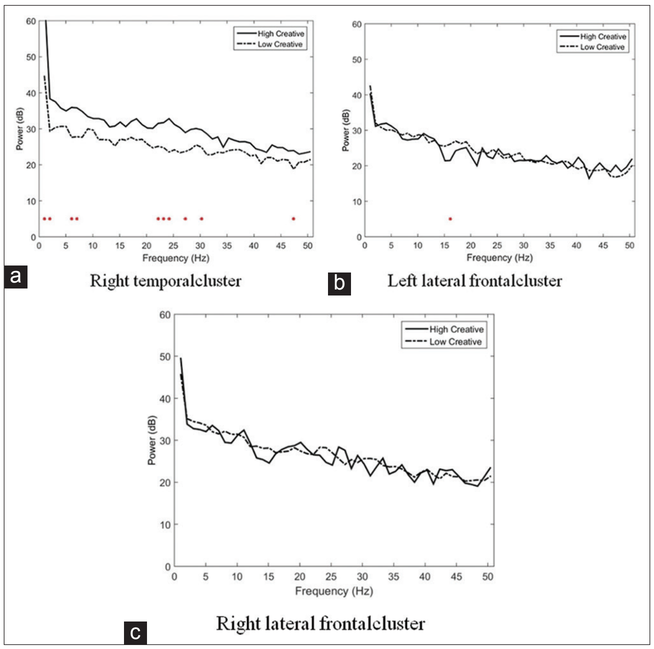

Figure 4: Wilcoxon signed-rank test results for the sensibility indicator, (a) right temporal cluster, (b) left lateral frontal cluster, (c) right lateral frontal cluster

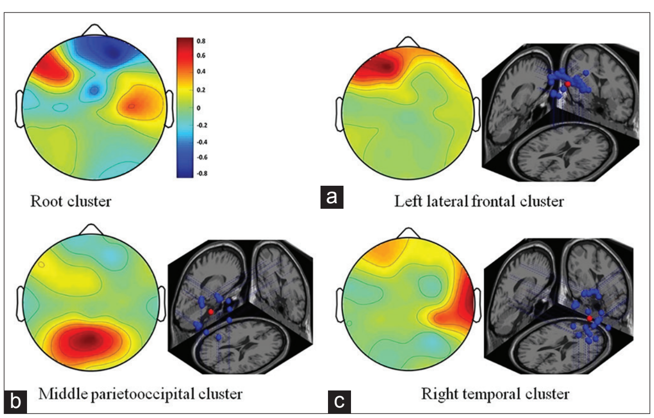

Figure 5: Scalp topographies and three-dimensional dipole plots associated with the focus indicator (5 - root cluster, (a left lateral frontal cluster, (b) middle parietooccipital cluster, (c)right temporal cluster)

Other than possible measurement errors, no significant differences appeared in the left lateral frontal and middle parieto-occipital clusters [Figure 6a and b]. In addition, significant differences appeared at most frequencies in the right temporal cluster [Figure 6c]. The largest differences were observed in the beta band at 25 Hz ($P = 0.0001$) and the low gamma band at 40 Hz ($P = 0.0002$).

Regarding the effectiveness indicator, the participants exhibited high activations in the middle prefrontal and frontal cortices when they involved in the experiment [Figure 7]. The scalp topographies and 3D dipole plots [Figure 7a-c] indicate that these activations were separated into three components: The left frontal, right temporal, and right prefrontal cortices.

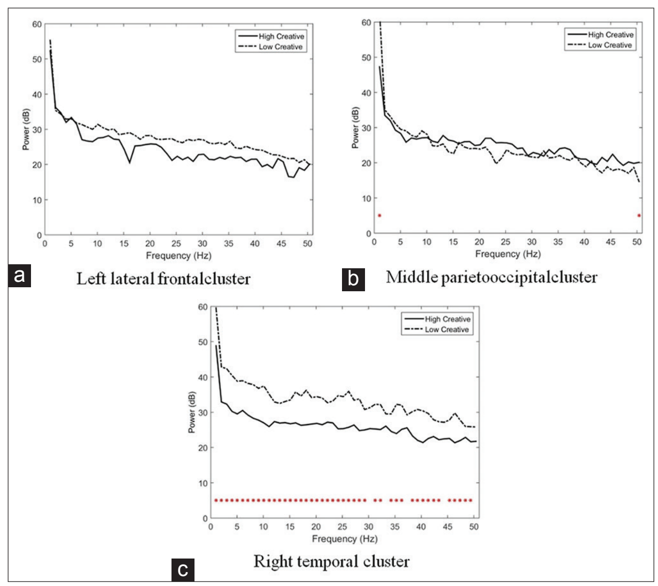

Figure 6: Wilcoxon signed-rank test results for the focus indicator, (a) left lateral frontal cluster, (b) middle parietooccipital cluster, (c) right temporal cluster

Table 3: Correlations among the components for the focus indicator

Component	LLF	MPO	RT
LLF	1	−0.56***	0.69***
MPO		1	−0.38***
RT			1

*$P<0.05$. **$P<0.01$. ***$P<0.001$. LLF: Left lateral frontal, MPO: Middle parietooccipital, RT: Right temporal

A positive association was observed between the right temporal and left frontal cortices as well as between the right prefrontal and right temporal cortices [Table 4].

According to Figure 8a, there was significant power differences appeared at all frequencies. The largest differences occurred in the low gamma band at 32 Hz (P = 0.0000) and 38 Hz (P = 0.000), and the beta band at 27 Hz (P = 0.0000). There was no significant power difference appeared in the right temporal cluster [Figure 8b]. In addition, significant differences were observed at distributed frequencies in the right prefrontal cluster [Figure 8c]. The largest differences were observed in the alpha band at 8 Hz (P = 0.0090), beta band at 15 Hz (P = 0.0091), and theta band at 5 Hz (P = 0.0225).

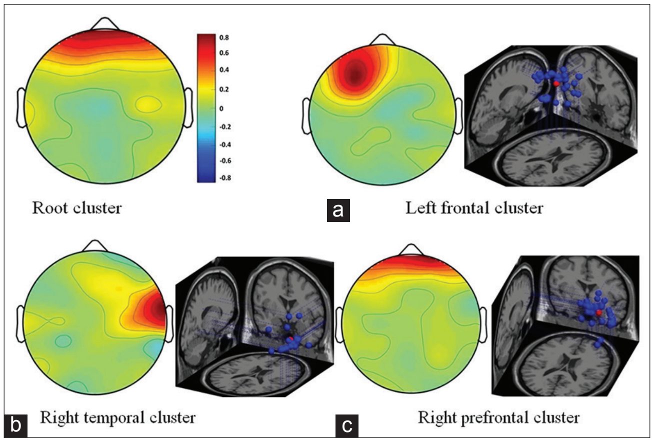

Figure 7: Scalp topographies and three-dimensional dipole plots associated with the effectiveness indicator (7 - root cluster, (a) left frontal cluster, (b) right temporal cluster, (c) right prefrontal cluster)

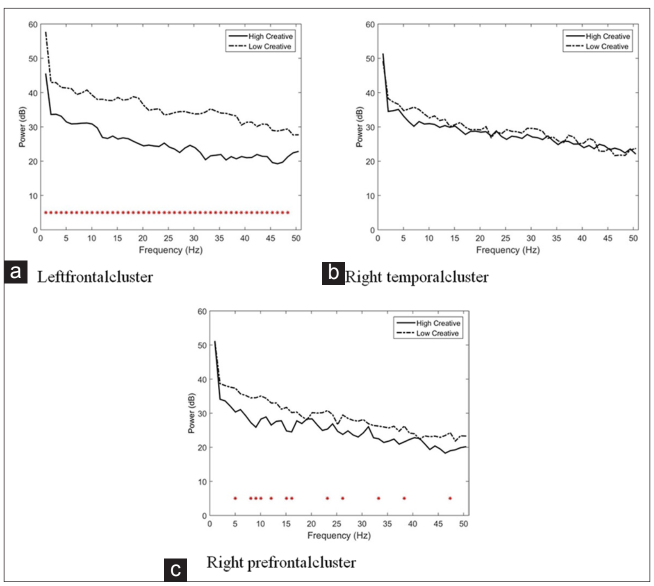

Figure 8: Wilcoxon signed-rank test results for the effectiveness indicator, (a) left frontal cluster, (b) right temporal cluster, (c) right prefrontal cluster

Table 4: Correlations among the components for the effectiveness of indicator

Component	LF	RT	RPF
LF	1	0.42***	0.09*
RT		1	0.48***
RPF			1

*P<0.05. **P<0.01. ***P<0.001. LF: Left frontal, RT: Right temporal, RPF: Right prefrontal

Regarding the dialectics indicator, the participants exhibited high activations in the middle prefrontal and frontal regions when they involved in the task [Figure 9]. The scalp topographies and 3D dipole plots [Figure 9a-d] indicate that these activations were separated into four components: The left temporal, left prefrontal, right temporal, and right prefrontal cortices. Accordingly, a negative association was observed between the right prefrontal and right temporal cortices [Table 5]. Our results revealed that, in the left temporal cortex [Figure 10a], significant differences were observed at lower frequencies. The largest differences appeared in the delta band at 1 Hz (P = 0.0033) and the alpha band at 13 Hz (P = 0.0234) and 8 Hz (P = 0.0239).

DISCUSSION

Brain activity regarding the intuition indicator

In this study, intuition refers to a designer's ability to generate immediate associations with a design goal. Our results indicated that the left prefrontal, right frontal, and left temporal cortices of the visual designers were activated when they engaged in the intuition stimulation task. The left prefrontal cortex can filter unrelated information to warrant efficiency in daily works.[38,39] The frontal cortex is where the ACC is located, and the right ACC is critical to the types of divergent semantic processing involved in artistic creativity.[40,41] The left temporal cortex generally controls verbal memory. This finding is in agreement with those of the previous studies[6,7] and suggests that design intuition is closely related to rational thinking and semantic processing.

The result also revealed a correlation between the left prefrontal and left temporal cortices, further indicating that

Table 5: Correlations among the components for the dialectics of indicator

Component	LT	LPF	RT	RPF
LT	1	0.30***	−0.23***	0.11*
LPF		1	−0.10*	−0.30***
RT			1	−0.75***
RPF				1

*P<0.05. **P<0.01. ***P<0.001. LT: Left temporal, LPF: Left prefrontal, RT: Right temporal, RPF: Right prefrontal

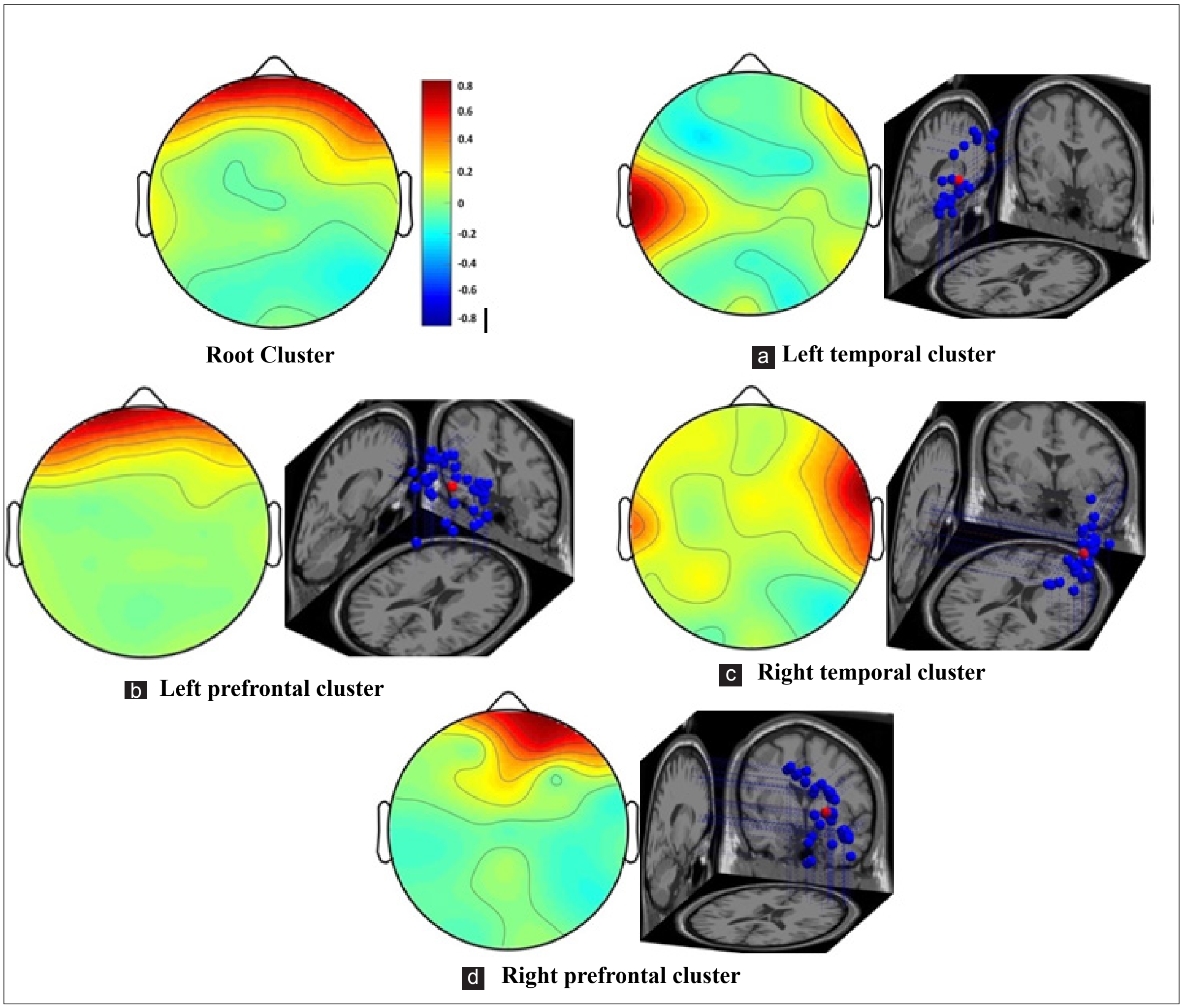

Figure 9: Scalp topographies and three-dimensional dipole plots associated with the dialectics indicator (9 - root cluster, (a) left temporal cluster, (b) left prefrontal cluster, (c) right temporal cluster, (d) right prefrontal cluster)

design intuition is closely associated with verbal memory filtering. Significant differences (LC > HC) were observed in spectral power levels in the left prefrontal cortex when the designers engaged in the intuition stimulation task. As stated earlier, the left prefrontal cortex is associated with filtering irrelevant information that may simultaneously block creative thoughts. This finding implied that the LC designers outperformed the HC designers in verbal memory filtering. In summary, the HC designers used lower energy in cognitive control than did the LC designers, which facilitated divergent semantic processing when engaging in the design intuition task.

Brain activity regarding the sensibility indicator

In this study, sensibility refers to a designer's ability to evoke feelings during the creative process. The EEG results specify that the right temporal, left lateral frontal, and right lateral frontal cortices of the visual designers were activated when they engaged in the sensibility stimulation task. The right temporal cortex handles non-verbal communication and memory.[42] The left frontal cortex manages analogical reasoning and concept formation.[44,45] The right frontal cortex is crucial to divergent semantic processing involved with creativity.[40,41] The ACC, situated in the frontal cortex, is involved in several emotive and cognitive functions, such as error detection, and in assessing the emotive significance of external stimuli.[46] This finding agrees with those of previous research[9,10] and suggests that the ACC has a central role in design sensibility, in which the emotional impact on analogical reasoning and semantic processing is enabled[47] and nonverbal mnemonic conflicts are detected and monitored.[46,48]

The results revealed that the correlation between the right lateral frontal and right temporal cortices was significant, indicating that design sensibility was closely associated with non-verbal semantic processing. Significant differences (HC > LC) were observed in spectral power levels in the right temporal cortex when the designers engaged in the intuition stimulation task, implying that the HC designers outperformed the LC designers in non-verbal semantic processing. In summary, compared with the LC designers, the HC designers were more competent in applying non-verbal memory and mixing with diverse emotional presentations to generate design creativity. The result also implied that the LC designers struggled with non-verbal mnemonic conflicts that hindered them from engaging the DLPFC to resolve such conflicts.

Brain activity regarding the focus indicator

In this study, focus refers to a designer's ability to formulate ideas through focusing attention. Our result revealed that the left lateral frontal, middle parieto-occipital, and right temporal cortices of the visual designers were activated when they engaged in the focus stimulation task, supporting the results of previous studies.[12,14] The middle parieto-occipital region is where the PCC is situated and serves as a critical connector hub of the default mode network (DMN). The PCC and DMN are closely associated with self-referential information processing and self-generated thought. This finding suggests that design focus is heavily involved in the cognitive control and conflict monitoring of self-referential nonverbal memory. This suggestion is supported by the finding of coactivation between the left lateral frontal and right temporal cortices observed in the present study.

In addition, the negative correlation between the left lateral frontal and middle parieto-occipital cortices was evident in this study. This finding implies that mnemonic conflict detection leverages thought generation, inducing the designer to focus on details. Our results also showed that significant differences (LC > HC) were observed in spectral levels in the right temporal cortex when the designers engaged in the focus stimulation task. As stated earlier, the major function of the right temporal cortex is non-verbal communication and emotional interpretation. On the basis of the coactivation between the right temporal and left lateral frontal cortices observed in this study, these findings suggest that, compared with the HC designers, the LC designers spent more energy on controlling their non-verbal communication cognitively and emotionally. These aspects of control may incur trade-offs with overall creative performance.

Brain activity regarding the effectiveness indicator

In this study, effectiveness refers to a designer's ability to generate effective ideas to achieve a design goal. The results revealed that the left frontal, right temporal, and right prefrontal cortices of the visual designers were activated when they engaged in the effectiveness stimulation task. The right prefrontal cortex is fundamentally involved in empathy and in regulating emotional responses.[20,22] These findings accorded with those of prior neurocognitive research[15,39] and suggest that design effectiveness is driven by goal-directed planning and mnemonic conflict monitoring with high levels of emotional regulation.

Our results revealed coactivations between the right temporal and left frontal cortices as well as between the right prefrontal and right temporal cortices. These findings imply that the effectiveness task facilitates collaboration between conflict detection and non-verbal communication as well as that between non-verbal communication and emotional regulation in a designer. In other words, the design effectiveness is strictly related to both effective and cognitive control of non-verbal memory. The LC designers spent more energy on these collaborations than did the HC designers. In common with the discussion on the focus indicator, these collaborations may hinder the LC designers' creative outcomes. Comparatively, the HC designers appeared to be more capable of activating the DLPFC and reducing conflicts to generate effective resolutions for clients and users.

Brain activities regarding the dialectics indicator

In this study, dialectics refers to a designer's ability to seek improvements by recurrently analyzing design ideas. Our EEG analyses show that the left temporal, left prefrontal, right temporal, and right prefrontal cortices of the visual designers were activated when they engaged in the dialectic stimulation task. These findings demonstrate that dialectic behavior is driven by complicated affective and cognitive controls of verbal and nonverbal memory and communication. This behavior leads the designers to self-correct themselves back and forth according to their design needs. The negative correlation between the right prefrontal and right temporal cortices implies that the designers balanced emotional regulation and non-verbal communication to perform the design dialectics.

Our results reveal that there were significant differences (LC < HC) in the left temporal cortex appeared in the theta and alpha bands. The left temporal cortex controls low-level perception, including comprehension, naming, and verbal memory. Theta and alpha synchronization is regarded as a marker of internally directed attention processing, and such synchronization is observed in different contexts.[49] The finding shows that, compared with the LC designers, the HC designers spent more energy on internally directed attention processing in verbal memory during the dialectics task. In addition to the conflict-reduced behavioral adaptation performed by the DLPFC, understanding the crucial role of verbal information processing and its relationships with self-correcting ability in design dialectics may facilitate the discovery of further insights.

Research limitations

Although this study expands on the findings of previous research, it has some limitations. First, designer imagination is a sophisticated mental activity; thus, creating reliable and valid experimental processes that can be fulfilled and repeated is challenging. Nevertheless, neuroscientific studies have characteristically investigated simple and repeatable cognitive tasks. Second, the low spatial resolution of EEG on the scalp obstructs the tracing of the exact brain point where the cognitive activity is instigated. Third, the stimuli used in the current study were restrained to the paintings of Miró. Additional visual symbols and other forms of stimuli could be employed. Fourth, this study merely focused on the visual designers. Whether the findings can be applied to a general population of designers of different design disciplines, expertise levels, and age groups remains unknown. Finally, we cannot completely exclude the possibility that the participants extended their thoughts from a preceding indicator to the subsequent indicator; thus, the mixed ideas may blur the investigating outcome for a specific indicator, particularly for the subsequent indicators.

Closing remarks

In summary, the following results were obtained in the present study: (i) The intuition task was closely associated with verbal memory filtering; (ii) the designer initiated non-verbal semantic processing during the sensibility task; (iii) the coactivation of non-verbal communication and cognitive control was the crucial attribute when a designer executed the focus task; (iv) the effectiveness task was strictly related to both effective and cognitive control; and (v) a designer balanced both non-verbal communication and emotional regulation during the dialectics task. The differences between the HC and LC designers in brain activity for design idea conception were primarily governed by how adequately non-verbal mnemonic conflict could be detected and resolved. These findings led us to understand how designers conceive the effective ideas and form mental images to resolve design problems. Moreover, the results of the comparison between the HC and LC designers suggest the possible causal contribution of the functional connectivity of the ACC and the DLPFC to the conceptual imagination. The more effectively the non-verbal mnemonic conflicts are managed, the more novel and valuable design resolutions can be successfully conceived, thereby improving overall creative performance.

Although our results extend recent work on creative cognition, additional studies, using fMRI and rTMS, are needed to test hypotheses concerning the functional connectivity of the ACC and how the DLPFC mediates different types of designer imagination. Additional studies must also clarify the specific role of these regions and how they interact when a designer is engaged in different design phases. Future studies should employ more precisely control tasks and continue to explore brain network interactions supporting creative task performance. Such research should provide critical insight into how and when memory systems interact with cognitive and effective controls and with divergent semantic processing to support the generation and practice of unique and feasible ideas.

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