

# Comparing designers' EEG activity characteristics for common association and remote association

Yuan Yin<sup>1</sup>, Pan Wang<sup>2</sup>, Ji Han<sup>3</sup>, Haoyu Zuo<sup>1</sup>, Peter Childs<sup>1\*</sup>

<sup>1</sup>*Imperial College London, UK*

<sup>2</sup>*Hong Kong Polytechnic University, China*

<sup>3</sup>*University of Liverpool, UK*

\*Corresponding author email address: y.yin19@imperial.ac.uk

Design is a principal form of creative output. Understanding creativity can be influential in development aimed at improving the design process. Association, a proxy for creativity, has been studied by neuroscience technology in recent years. However, most of these studies are about which part of the brain or which wave bands are related to the association process. EEG characteristics such as event-related potential (ERP) and EEG signals tendency have not been fully studied. Therefore, this study aims to identify the EEG activities of common association and remote association and compare the differences. The results revealed that the common association was evoked faster than remote association. When common association and remote association processes are evoked, both can lead to a result fast. However, after generating one result, remote association will stop while common association will keep generating more results unconsciously.

**Keywords:** design creativity, design cognition, human behavior, association

## Introduction

Design can be regarded as a process to translate ideas into products or prototypes [1], [2]. Creativity is often defined as the ability to imagine or invent something valuable and novel [3]. Creativity and design have tight associations. As a principal form of creative output, design is a tangible

display of creativity. In addition, creative ideation is a fundamental process of product design [2]. In a design process, designers tend to reformulate problems to identify new knowledge, revise previous solutions and in turn develop an improved solution [4]. After a few iterations of this recursion process, final design ideas are often generated. Creativity has been identified as an important element in this recursion process [4]. In the divergent thinking process of creative design, high creativity levels may also lead to more creative ideas. In addition, researchers have found that the creative ideation process and product design process share some similar brain activity areas such as the left cingulate gyrus [2]. This was an attempt to explain the relations between creativity and design informed from neuroscience perspectives. Therefore, understanding creativity can be influential in development aimed at improving the design process [2].

With the development of neuroscience, applying neuroscience technology (such as functional Magnetic Resonance Imaging (fMRI) and Electroencephalography (EEG)) in creativity areas has been attempted in a number of research studies. Many researchers have found that alpha waves play an important role in creativity [4], [5], [6], [7]. Other band waves such as theta and gamma were also related to the creative idea-generation process [8]. Apart from the band wave, researchers also identified which part of the brain is related to the creative idea-generation process. Frontal and parietal regions were thus promoted to have relations with creative idea-generation processes through fMRI and EEG methods [9].

Association is an important cognitive factor in the creative design process. Also, association is considered an ability that is highly related to creativity because novel association may trigger more creativity [10]. Therefore, to better understand aspects of design, it is important to identify creativity. Association is an important cognitive factor related to creativity and is thus a good starting point. Association is related to alpha waves. When creativity includes association processes, the higher alpha waves will be detected in frontal and parietal regions [11].

Association can be divided into remote association and common association [12]. The ability to associate irrelative concepts is considered remote association. The ability to associate relative concepts is considered common association. In a design idea generation process, remote association is often identified to be related to higher creativity [12], [13], [14], [15], [16]. This is helpful for divergent thinking processes where creative ideas can be generated. Common association, sometimes is considered a barrier to being creative [17].

Considering that the common association and remote association are the core constituents of association, some researchers have tried to identify the differences between common association and remote association in

creative processes through neuroscience technologies. With the help of fMRI, researchers found that remote association tasks included more creative responses compared to common association tasks ( $t[101] = 6.58, p < .001$ ) [12]. Also, remote association has higher brain activation than common association. However, fMRI is a method that measures brain activity by detecting blood flow. It cannot reflect the wave-band results. To identify the wave band, EEG method has been applied. The results from EEG studies reveals that alpha power is lower in common association compared to remote association [5], [18], [19]. This result is also supported by fMRI studies [20].

Although researchers may agree on alpha waves being related to remote association in creative processes, researchers have not agreed on which part of the brain is related to remote association. A few possible brain areas have been promoted such as the left frontal lobe [20], [21], the left temporal lobe [18], and the right temporal lobe [22].

Although existing studies have identified and compared the neurophysiological characteristics between remote association and common association, the results were mainly focused on the characteristics of remote association [18], which part of the brain was active in association processes, or which band waves were related to association processes. The existing studies have not fully identified other EEG activities such as Event-related potentials (ERPS; a measure that can quantitatively reflect the brain temporal response to a specific cognitive event [4], [8], [23]) and EEG signals tendency on remote association and common association.

To address the gaps, this study aims to identify the ERPS and EEG signals tendency of common association and remote association and compare the differences between them.

## Methodology

To achieve the study goals, the study attempts to use the Alternative Uses Task (AUT) and the Object Characteristics Task (OCT), respectively, to identify remote association and common association EEG signals of industrial and product designers.

## Participants

The study recruited 30 right-hand Chinese participants [5]. One participant had to be excluded from all data analysis because of technical problems during EEG recording, resulting in a final sample of 29 participants (14

female, 15 male; aged 20-25). All of the 29 participants were industrial design or product design background students, who had experience in designing products and using hand-drawing to express their ideas in the past year.

### **Tasks**

AUT was used to measure the designers' remote association ability in creative processes [5], [21], [24], [25]. Participants were asked to find a remotely related use for each object (such as Umbrella - boat for animals). Considering that remote association may be an unfamiliar expression for participants, participants were asked to "think of a concept for which only a few people would think of" to replace "remote association" [12].

OCT was used to measure the common association ability in creative processes [5], [21]. Participants were asked to find a high-related characteristic for each object (such as Shoes - paired). Considering that common association may be an unfamiliar expression for participants, participants were asked to "report the first characteristic that comes to mind to most people" and use this expression to represent "common association" [12].

Each task included 30 trials. In both tasks, participants were presented with 15 everyday object words and 15 everyday object graphics. In this case, the EEG characteristics which were generated from different thinking forms (images or words) can be removed. Each word or graphic was presented once in each task. The order of the presentation was random. The words and graphics used in AUT and OCT were different.

The words and the description of graphics were collected from Stevens Jr and Zabelina (2020) [5]. The corresponding graphics were collected from BaiduImage searching (<https://image.baidu.com/>) which is a common Image searching method in China. The image which can reflect the described object accurately was selected. The size of the graphics was resized to 500x500 pixels.

### **Procedure**

Before the study, participants were given an information sheet and they could ask any questions they have. If there were no questions, they were asked to sign a consent form.

An introduction was then delivered to participants. The introduction included how many trials are included in this study, what the participants need to do, and an example.

Each trial for the AUT task began with a fixation period, presenting a black fixation cross on light grey background jittered between 2 and

5s. Then, the word or graphic was displayed and remained on the screen for up to 8s. During the period, participants were asked “based on the word or graphic, think of a concept that only a few people would think of” but not verbalize this. If they found a solution before the timeout, they can hit the “Space” key on the computer keyboard to progress to the next fixation interface. If the 8s run out, the interface will jump to the next fixation interface automatically.

After the AUT, participants can have a 5-minute rest. Then, the OCT started. Each trail of OCT began with a fixation period, presenting a black fixation cross on light grey background jittered between 2 and 5s. The word or graphic is displayed and remained on the screen for up to 8s. During the period participants were asked to “based on the word or graphic, report the first characteristic that comes to mind to most people” but not verbalize this. If they found a solution before the timeout, they can hit the “Space” key on the computer keyboard to progress to the next response interface. If the 8s run out, the interface will jump to the next response interface automatically.

The order of AUT and OCT was random in the study. The whole study took about 15 minutes to complete. This study was approved by the local ethics committee of the first author institute.

### **EEG recording and equipment**

EEG signals were collected using a Neurofax EEG-9200 system with 16 scalp and 2 mastoid Ag/AgCl electrodes mounted according to the 10/20 system. An EEG measurement system, Amplifier, and EEG results viewing software are all included in the system. Impedances of all EEG channels were below 5 k $\Omega$ . The data were sampled at 1000 Hz.

Previous studies have found that the activated brain areas of remote association and common association may be the frontopolar cortex [26] or temporal lobe [27]. The 16 channels can cover most of those areas and thus more channels may be not necessary. To be specific, Fp1/Fp2/F7/F8/F3/F4 can report signals in the frontal lobe; T3/T4/T5/T6 can report signals in the temporal lobe. Considering the study is also interested in potential hemispheric differences, the midline electrodes such as FZ, CZ, PZ were not included [24].

The EEG tasks were generated with the help of E-Prime 3.0. All tasks were presented on a computer screen (35.89 x 24.71cm with a resolution of 2560 x 1600). The data were collected and stored in the Neurofax EEG-9200 system.

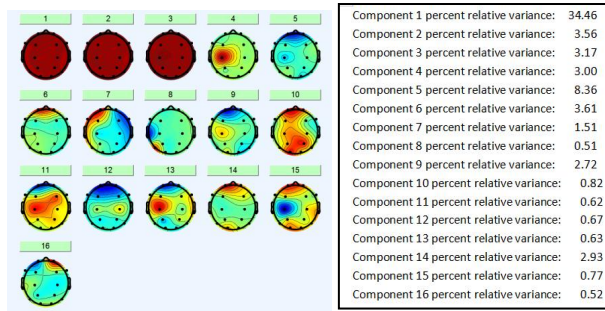
## EEG Data analysis

All EEG signals processing was based on MATLAB R2018b (The MathWorks, Inc., Natick, Massachusetts, United States) using EEGLAB. A 50 Hz notch filter has been applied to remove the electrical mains contamination. Then, the signals were passed through a band-pass filter with a pass-band of 0.1–100 Hz [24]. The reference electrodes were placed on the left and right mastoid processes.

Remote association and common association events were marked and extracted from EEG signals. For each event, blink artifacts were removed with the help of ICA. The ERP results for each event were represented by the averaged results of all participants and all event-related-task trials.

## Results

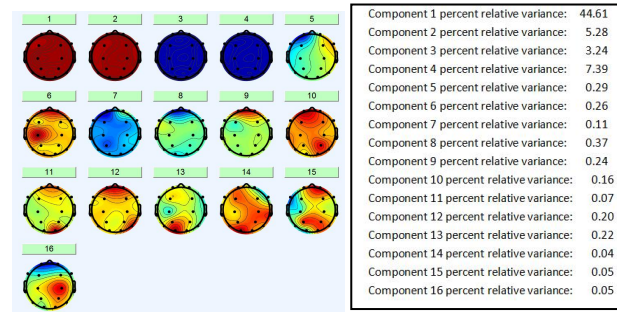
### Spectral analysis



**Fig. 1** The EEG analysis results of remote association. Left figure: The ICA results after removing blink and artifacts. Right figure: The component percent variance results from spectral analysis. The Component number on component percent variances is consistent with the ICA component number.

For each event, spectral analysis was conducted and the component percent variance was accounted for. The top-five component percent variances were selected and used as the cue to identify which brain areas were activated in the event. The Component number on component percent variances is consistent with the ICA component number. The results showed that for remote association (Fig.1), Components 1, 5, 6, 2, 3 were top-five component percent variances. For common association (Fig.2), Components 1, 4, 2, 3, 8 were top-five component percent variances. From the correlated ICA component of remote association and common association, it could be seen that both remote association and common

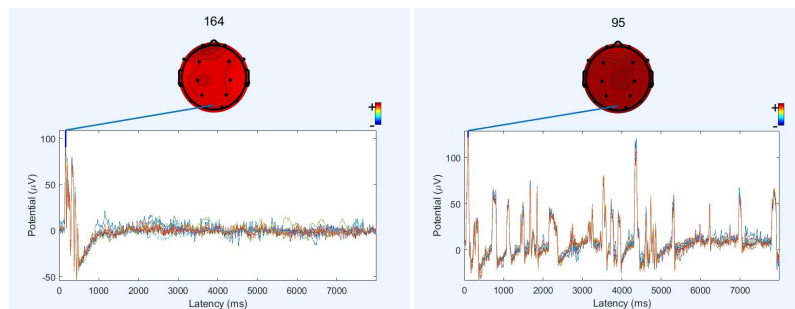
association mainly relate to Fp1 and Fp2 channels areas which is the frontal lobe area.



**Fig. 2** The EEG analysis results of common association. Left figure: The ICA results after removing blink and artifacts. Right figure: The component percent variance results from spectral analysis. The Component number on component percent variances is consistent with the ICA component number.

### ERPS results

After identifying the activated brain areas, the study further analysed the ERPS results of each event. The ERPS results were analysed based on the related activated-brain-area EEG channels (Fp1/Fp2). The remote association's highest ERP was generated at 164ms while the common association's highest ERP was generated at 95ms (Fig.3).

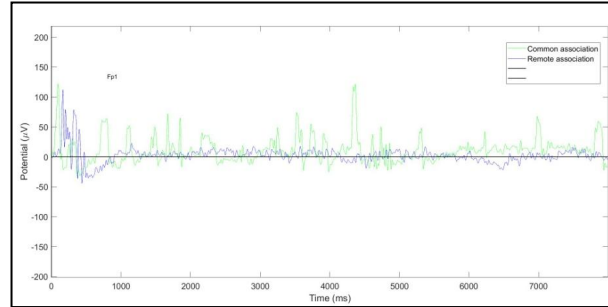


**Fig. 3** Left figure: The highest ERP result of remote association on Fp1 channel. Right figure: The highest ERP result of common association on Fp1 channel.

### EEG signals tendency results

The EEG signals tendency between remote association and common association were compared. The results are shown in Fig.4. From comparison of the two association types' EEG signals, it can be seen that after the highest ERPS, the common association's ERPS generated

discontinuously during the whole 8000ms while the remote association's ERPS generated continuously for a short period.



**Fig. 4** The comparison results of EEG signals between remote association and common association on Fp1 channels.

## Discussion

This section compares the findings with existing studies, discusses the comparison results, identifies the limitations of this study, and what is expected for future studies.

### Compare the findings with existing studies

The results of this study indicated that remote association is related to the frontal lobe and the highest ERPS was at 162ms. This location result is related to some existing studies [20], [21]. However, the results is inconsistent with some other studies which support that the remote association is related to the left temporal lobe [18], and the right temporal lobe [22].

One possible explanation for this difference is that semantic memory and episodic memory are related to association [21]. When the brain areas related to remote association were activated, brain areas related to semantic memory and episodic memory may also be activated. Semantic memory is related to the activity of the frontopolar cortex [26] while episodic memory is related to the activity of the temporal lobe [27]. Therefore, the identified active brain areas of remote association may also include the active brain areas of semantic memory and episodic memory. This may be the reason why the active brain areas of remote association are different.



**Comparing the EEG activities for remote association and common association**

From the study, both remote association and common association are related to the frontal lobe area. Apart from the similar results between remote association and common association, there are also some different results. For example, the highest ERPS result on remote association is 162ms while that of common association is 95ms. ERPS can quantitatively reflect the brain response to a specific cognitive event [23]. Therefore, the results revealed that the participants have a faster response to common association tasks than to remote association tasks [5], [11]. This may indicate the reason why common association is more likely to occur than remote association. When a creative person plans to use remote association to image some creative ideas, common association may occur and interrupt the remote association.

From the comparison, it has also revealed that after the highest ERPS, the common association's ERPS generated discontinuously in the whole 8000ms while the remote association's ERPS generated continuously in a short period. This indicates that common association will occur swiftly when participants recognize the word or image and they will have a result quickly. Although remote association was evoked more slowly than common association, as long as it occurs, it will get a result quickly. However, the speed to obtain a remote association result is still slower than that of common association.

After generating one result, remote association will end, while common association will keep generating more results unconsciously. Thus, the ERPS of common association is discontinuous and lasted during the whole task period, while the ERPS of remote association is a one-time event in a short period. This further indicates and helps explain why in a creative design process, designers may have more results from common association than remote association. Also, this result indicated that without deliberate control, designers may be less likely to have remote association. In other words, remote association is a conscious cognitive behavior while common association can be regarded as an unconscious cognitive behavior.

These comparison results can also trigger thinking on how to stimulate remote association in a creative design process from cognitive levels. On the one hand, considering the remote association is a one-time cognitive behavior, the remote association stimulation method should be a continuous action. In this way, the continuous stimulation can maintain remote association actively in design for a period of time. On the other hand, considering the common association can occur repeatedly, if remote

association can be triggered from each common association period, remote association can also occur repeatedly.

### **Limitations and future research**

There are some limitations existing in this study. Firstly, this study only recruited 30 Chinese participants. The participants' culture and age may also affect the EEG results. In the future, more participants from different ages and cultures are expected.

In addition, the study tried to be conducted without any external intervention (such as movement and noise). However, spill-over effects cannot be ruled out completely. In other words, it may be possible that the previous task/trial affected the later task/trial. What the study can do is to limit the spill-over effects by presenting the two tasks in a random order and presenting the trials in each task in a random order. Also, even after denoising, the eyebrows' muscular movement cannot be completely removed from the EEG signals which may bring bias in this study.

Finally, the study was designed to ask participants to think in a remote association or common association way. However, the study cannot identify whether the tasks results of participants were remote association or common association results. Therefore, in the future, the study is expected to add remote association or common association results checking mechanism to further accurately identify whether the participants have a remote association or common association thinking in the related tasks.

### **Conclusion**

Creativity is helpful to generate novel ideas in divergent thinking processes in design. To better understand design, identifying creativity is important. Association as an important cognitive factor related to creativity and is thus a good starting point. An EEG study was designed to identify and compare designers' EEG activities (ERPS and EEG signal tendency) of remote association and common association in creativity.

The results support that the association in creativity is mainly related to the frontal lobe brain area. The comparison results indicated that when common association and remote association processes are evoked in the brain, both of the processes can lead to a result quickly. However, the common association was evoked faster than remote association. Also, after generating one result, remote association will stop while common association will keep generating more results unconsciously. These results

further explain why the common association is more likely to occur than remote association from an ERPS perspective.

The results prompt reconsidering association control and stimulation methods in design. To be specific, to stimulate remote association process, continuous stimulation may be needed. Also, one possible direction for future work that could provide insights could focus on whether remote association can be triggered by common association.

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