Effect of musical stimuli on design thinking: Differences between expert and student designers

Chaoyun Liang and Yu-Cheng Liu

Abstract: Neuroscientific studies on the influence of musical stimulation have increased recently; however, whether music is associated with changes in the design thinking of designers remains unclear. In this study, 10 expert and 10 student designers were invited to participate in an electroencephalography experiment to examine how musical stimuli affect designers during design thinking. Four musical genre tasks were used to distinguish the effects on the brain activations of designers with different levels of expertise. During the experiment, designers were requested to silently respond to the questions: “What aspect of this music can you use in the project just mentioned?” and “How would you incorporate these aspects into this project?” We found that (i) in both country-folk and classical music tasks, the left prefrontal and right temporal regions of the expert designers were more activated than those of the student designers; (ii) in the rock and roll task, the right temporal region of the experts was more activated than that of the students, whereas the middle prefrontal region of the students was more activated than that of the experts; and (iii) the middle parieto-occipital, left temporal, and right temporal regions of the experts were more activated than those of the students during the soul music task. In conclusion, the brain activations of designers mainly increased in the middle frontoparietal and right temporal regions during the

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PUBLIC INTEREST STATEMENT

Principals of many design firms believe in the power of music to unlock creativity. To them, music is more than just ear candy. It can be used to activate, stimulate and relax a designer’s mind and body. However, how to maximise the power of music? The key is finding the right kind of music to stimulate designer creativity. This neurocognitive study highlights that different musical genres could result in different effects on designers’ thinking. The country-folk genre could substantially arouse emotions in expert designers. The rock and roll genre could assist expert designers in focusing on binding the features of various nonverbal cues with the design target. The soul music genre could benefit designers, particularly experts, in internally focused tasks of nonverbal memory retrieval. Finally, the classical music genre could assist expert designers in consciously filtering out irrelevant semantic information and creating links to facilitate design efficiency.
musical stimulation tasks. Different musical genres could result in different effects on designers’ thinking.

Subjects: Behavioral Sciences; Education; Arts

Keywords: design thinking; electroencephalography; musical stimulation; visual designer

1. Introduction

Designing is a dynamic process that involves the coordination between the hands, eyes, and mind (Seitamaa-Hakkarainen, Huotilainen, Mäkelä, Groth, & Hakkarainen, 2014). Understanding these cognitive processes of creative practices such as design thinking is essential to design and neuroscience research. However, to date, few studies have reported on the neurological basis of design, and they have omitted the recognition or characterisation of design as a distinct cognitive phenomenon (Alexiou, Zamenopoulos, Johnson, & Gilbert, 2009; Yao, Lin, King, Liu, & Liang, 2017). Liang et al. (2017) warned that overlooking the scientific evidence of cognitive reactions can engender erroneous conclusions regarding the relationships between inspiration activities and design creativity and those between external stimuli and spontaneous associations.

The central responsibility of a designer is to present information in a manner that is accessible and memorable. Therefore, designers must comprehend the sociocultural norms of their clients and audiences to develop visual solutions that are seen as relevant, effective, and creative (Liang et al., 2017). Designers are typically sensitive to environmental stimuli and seek a diverse range of external references during product creation (Goldschmidt & Smolkov, 2006). Nonetheless, few studies have elucidated the influence of external references other than pictures and objects. Neuroscientific studies on the influence of musical stimulation have increased over the past two decades, particularly for regulating moods and promoting physical and psychological well-being in clinical settings (Limb, 2006; Stewart, von Kriegstein, Warren, & Griffiths, 2006). Although these studies appear very relevant, they do not specifically attempt to determine the neural correlates of design cognition (Alexiou et al., 2009) or assess designers at different expertise levels to distinguish between their professional performances. Moreover, whether music is associated with changes in the design thinking remains unclear. Design thinking is the study of working designer practices (Cross, 2011) and refers to creative strategies used by designers during the design process (Visser, 2006).

Prior research has determined that sound, including music, is processed in the auditory cortex. The human primary auditory cortex (PAC) is located at the medial part of the Heschl gyrus (HG) in the superior temporal plane. Secondary auditory cortical areas are lateral to the PAC in the HG (Stewart et al., 2006). To date, substantial evidence has been accumulated regarding the frontotemporal brain mechanisms underlying the perceptual and cognitive musical processes and about the limbic and paralimbic structures, including the amygdala, hippocampus, parahippocampal gyrus, insula, temporal poles, ventral striatum, and orbitofrontal and cingulate cortices, responsible for the musical affective processes (Brattico & Pearce, 2013; Chanda & Levitin, 2013; Kreutz & Lotze, 2008; Limb, 2006). Rogenmoser, Zollinger, Elmer, and Jäncke (2016) indicated that the frontal region is involved in modulating valenced experiences, whereas the right parietotemporal region contributes to emotional arousal. In addition, Boccia, Piccardi, Palermo, Nori, and Palmiero (2015) determined that musical creativity produces activations in the bilateral medial frontal, left cingulate, and middle frontal gyri; inferior parietal lobule; and right postcentral and fusiform gyri.

Music and words are intertwined in songs. Gordon, Schön, Magne, Astésano, and Besson (2010) examined the influence of the attentive processing of words and melodies in songs and found that different word targets elicited an N400 component, and different melodies elicited an N400 component followed by a late positive component. N400 is a well-established marker of semantic
processing, typically of maximum amplitude over right centroparietal regions (Gordon et al., 2010; Kutas, Van Petten, & Besson, 1988). Li et al. (2015) identified that an area-wise distribution is involved in audiovisual semantic integration. Through feature-selective attention, the human brain may selectively integrate audiovisual semantic information from attended features by enhancing functional connectivity, thus regulating information flows from heteromodal areas to brain areas encoding attended features. Li, Chen, and Tsai (2015) studied the neural correlates of song reward processing and revealed that reward gain and reward loss were associated with left- and right-biased temporoparietal junction activation, respectively. The bilateral temporoparietal junctions were active during reward anticipation. In addition, the left-biased lateral orbitofrontal cortex was activated during reward anticipation, whereas the medial orbitofrontal cortex was activated during reward gain.

On the basis of the aforementioned studies, electroencephalography (EEG) was used in the present study to investigate the brain activations of graphic designers at different expertise levels in response to several musical genres during design thinking. Because studies on music's influence on design thinking are rare and not solid enough to form research hypotheses, we propose the following three research questions: (i) Which brain regions are relatively active when graphic designers engage in design thinking with musical stimuli? (ii) What are the differences in brain activations caused by distinct genres of musical stimuli? (iii) What are the differences in brain activations between expert and student designers when they engage in the experimental tasks?

2. Methods

2.1. Participants
In this study, 10 expert and 10 student graphic designers were invited to participate in the EEG experiment of musical stimulation. The inclusion criteria for expert designers (four women and six men; age, 31–39 years) are listed as follows: (i) design-related work experience of more than 10 years; (ii) experience in leading design teams specialising in visual design; and (iii) willing to participate in the experiment. The inclusion criteria for student designers (six women and four men; age, 21–24 years) are listed as follows: (i) junior or senior design major university students; (ii) students achieving creative performance by following the recommendations of course instructors; and (iii) willing to participate in the experiment. These criteria allowed for a degree of diversity in both groups, enabling the exploration of two distinct ranges of designer experience. All participants had no history of cardiovascular disorders or drug or alcohol abuse and had a normal or corrected-to-normal vision.

2.2. Equipment and materials
A 32-channel wireless BR32S EEG headset (Brain Rhythm Inc., Taiwan) was used in the experiment. Scalp markers were placed according to the international 10–20 system in line with the underlying cerebral structures. A reference electrode was located behind the ear, and the electrode impedance was maintained under 5 KΩ. Brainwave data were acquired using Bluetooth and converted to ASCII (.txt) format for future analysis.

Regarding the experimental materials, based on Tagg's axiomatic triangle of popular music (1982) and after consulting three music and neuroscience experts, four musical genres were used: country-folk, rock and roll, soul, and classical. Most country-folk artists follow the mode of folk artists, and their musical work has a mellower and gentler feel than most country music. In this experiment, “Take me home, country roads,” a country-folk song written by Bill Danoff, Taffy Nivert, and John Denver, was used. A rock and roll song typically uses a verse–chorus structure and has three chords and a strong and catchy melody. A rock and roll song essentially has a blues rhythm with an accentuated backbeat, which is almost always provided by a snare drum. The rock and roll song used was “Billie Jean” by Michael Jackson.

Soul music originated from the black experience in America through the transmutation of gospels and rhythm and blues into a form of funky, secular testament. Soul music is characterised by a slower
tempo, with emphasis on instrumentation and vocal choruses. A song originally performed by Ben King, “Stand by Me,” was used in this study. Classical music typically has clearly defined phrases of melody with two or more contrasting themes. Mostly homophonic, the symphony orchestra of classical music is usually organised into four sections. The piece of classical music used in the study was “Piano Concerto No. 21,” completed in 1785 by Wolfgang Amadeus Mozart. These four musical compositions are well-known worldwide, including in Taiwan. We did not use Taiwanese songs because they may be not comprehensible in other countries, which might limit the generalisability of this study’s results. Notably, the usage of music was restricted to academic research without any commercial involvement. The stimuli were randomly presented to the participants during the experiment.

2.3. Experimental procedure

After obtaining signed consent forms, we recorded designers’ baseline brain responses in a rest period, during which no interference occurred. The participants were then asked to verbalise the design problem, purpose, and desired outcomes of an ongoing design project for approximately 3 min. Next, each of the four musical works were presented randomly to the participants for approximately 90 s ($M = 88.6$, $SD = 3.8$) and their EEG signals were recorded, during which they were requested to silently respond to the same questions: “What aspect of this music can you use in the project just mentioned?” and “How would you incorporate these aspects into this project?”

Subsequently, the participants verbalised their answers for 3 min. Their EEG signals were not recorded during the verbalisation sessions, which were considered intertrial intervals to avoid recording overlapping brain responses. The qualitative narrations obtained from these sessions were collected to assist us in empathising with the designers’ responses, rather than comparing the participants. The experiment was completed in approximately 45 min, including the time required for explaining the experiment, testing the EEG headset, and describing the project. The process was identical for all participants to ensure the consistency of the investigation.

2.4. Data analyses

Low- and high-pass filters with cutoff frequencies of 50 and 1 Hz, respectively, were applied to all signals based on finite-impulse-response filters to remove the line noise, muscle movement contamination, oculomotor activities, and direct-current drift. The 90-s EEG signals of each condition were divided into 1.6-s epochs based on previous studies (Liang, Liu, & Chang, 2018; Liu, Chang, Yang, & Liang, 2018; Wang, Jung, & Lin, 2015). Several epochs were rejected manually due to electrical artefacts. The EEGlab toolbox was used to decompose the filtered EEG signals through independent component analysis with the Infomax algorithm, in which all components except for nonbrain components were grouped into six clusters (K-means clustering) based on relevant studies (Liang et al., 2018; Liu, Yang, & Liang, 2017; Wang et al., 2015).

In this study, all independent brain processes were spatially localised in the brain using a single equivalent current dipole model (Delorme, Palmer, Onton, Oostenveld, & Makeig, 2012) based on the suggestions of dipole fits (Lin et al., 2016). The scalp topography of each independent component was used to plot the three-dimensional location of an equivalent dipole. Each dipole represents the location of an independent component as well as a specific cortex region. The time-invariant correlations between clusters (cortex regions) were obtained by averaging the spectral power of each cluster with correlation coefficients. These correlations suggest the connectivity between the dipoles. Moreover, time-domain data were transformed into frequency-domain data by using the fast Fourier transform function. The differences in the spectra power of brain activity in the participants were evaluated using the paired-sample Wilcoxon signed-rank test.

3. Results

According to the scalp map for the root cluster, when the expert and student designers engaged in the country music task, they had relatively low brain activation in the occipital cortex and high activations in the frontal and temporal cortices (Figure 1(a)). The scalp maps
and 3D dipole plots displayed in Figure 1(b–e) reveal that these brain activations could be divided into four major component clusters, namely the left prefrontal, middle frontoparietal, right temporal, and right prefrontal cortices. The colours represent the brainwave energy distribution; the blue point represents the estimated dipole position, and the red point represents the geometric centre of the dipoles in the cluster. Noticeably, the right prefrontal cortex was deactivated during the task.

To determine the associations among activated brain regions, an averaged compositional relationship between each pair of clusters was computed. The relationship between clusters was not independent because the cluster components were formed from multiple subjects. The correlations among these major component clusters are listed in Table 1. Accordingly, the associations were notably high for the left prefrontal and right prefrontal, middle frontoparietal and right temporal, and middle frontoparietal and right prefrontal cortices.

The results indicated that the differences in spectral power between all designers and their averaged baselines are noteworthy. The results also reveal that the spectral power of expert designers is generally higher than that of student designers. As depicted in Figure 2(a) (the left prefrontal cluster), the largest differences appeared in the alpha band at 12 Hz ($p = 0.000$) and 11 Hz ($p = 0.000$). In the middle frontoparietal cluster (Figure 2(b)), the largest differences appeared in the theta band at 4 Hz ($p = 0.001$), 6 Hz ($p = 0.005$), and 7 Hz ($p = 0.012$). In the

Table 1. Correlations among the major component clusters in the country music stimulation task

| Component                        | IPF | mFP | rT  | rPF |
|----------------------------------|-----|-----|-----|-----|
| Left prefrontal cluster (IPF)    | 1   | .24*** | .26*** | .50*** |
| Middle frontoparietal cluster (mFP) | 1   | .50*** | .67*** |
| Right temporal (rT)              |     |     | 1   | .36*** |
| Right prefrontal (rPF)           |     |     |     | 1   |

*p < .05. **p < .01. ***p < .001.
right temporal cluster (Figure 2(c)), the largest differences appeared in the alpha band at 11 Hz ($p = 0.000$), the delta band at 2 Hz ($p = 0.000$), and the theta band at 5 Hz ($p = 0.000$). In the right prefrontal cluster (Figure 2(d)), the largest differences appeared in the alpha band at 13 Hz ($p = 0.000$) and 12 Hz ($p = 0.000$).

The expert and student designers exhibited high brain activation in the prefrontal cortex when they engaged in the rock and roll task (Figure 3(a)). The scalp maps and 3D dipole plots depicted in Figure 3(b–e) reveal that these brain activations could be separated into four major component clusters: the left frontal, right temporal, middle frontoparietal, and middle prefrontal cortices. According to Table 2, the associations were particularly high for the left frontal and middle prefrontal cortices.

The results also indicate that the differences in spectral power between designers and their baselines were observable, and the spectral power of expert designers is generally higher than that of student designers. As depicted in Figure 4(a) (the left frontal cluster), the largest difference appeared in the theta band at 7 Hz ($p = 0.006$). In the right temporal cluster (Figure 4(b)), the largest difference appeared in the beta band at 16 Hz ($p = 0.007$). In the middle frontoparietal cluster (Figure 4(c)), the largest differences appeared in the delta band at 3 Hz ($p = 0.000$) and the theta band at 4 Hz ($p = 0.000$) and 7 Hz ($p = 0.001$). Finally, in the middle prefrontal cluster (Figure 4(d)), the largest differences appeared in the low gamma band at 42 Hz ($p = 0.002$) and 50 Hz ($p = 0.002$).

The expert and student designers had relatively low brain activations in the left frontal cortex and bilateral occipital cortices, as well as high activations in the middle frontal and left temporal cortices when they engaged in the soul music task (Figure 5(a)). The scalp maps and 3D dipole...
plots displayed in Figure 5(b–e) reveal that these brain activations could be divided into four major component clusters, namely the middle parietooccipital, left temporal, middle frontoparietal, and right temporal cortices. The correlations among these major component clusters are listed in Table 3. Accordingly, the association of left temporal and middle frontoparietal cortices was notably high.

The results indicate that the differences in spectral power between designers and their baselines were discernible, and the spectral power of expert designers is generally higher than that of student designers. As depicted in Figure 6(a) (the middle parietooccipital cluster), the largest differences appeared in the beta band at 16 Hz ($p = 0.000$), 29 Hz ($p = 0.000$) and 15 Hz ($p = 0.000$). In the left temporal cluster (Figure 6(d)), the largest difference appeared in the theta band at 7 Hz ($p = 0.001$). In the middle frontoparietal cluster (Figure 6(d)), the largest difference appeared in the beta band at 17 Hz ($p = 0.002$). In the right temporal cluster (Figure 6(d)), the largest differences appeared in the low gamma band at 43 Hz ($p = 0.000$) and 45 Hz ($p = 0.000$) and the beta band at 23 Hz ($p = 0.000$).

Both the expert and student designers exhibited relatively low brain activations in the prefrontal and middle parietooccipital cortices, as well as high activations in the left frontal and right temporal cortices when they engaged in the classical music task (Figure 7(a)). The scalp maps and 3D dipole plots displayed in Figure 7(b–e) reveal that these brain activations could be divided into four major component clusters, namely the middle frontoparietal, left prefrontal, middle

### Table 2. Correlations among the major component clusters in the rock and roll stimulation task

| Component                        | IF     | rT     | mFP    | mPF    |
|----------------------------------|--------|--------|--------|--------|
| Left frontal cluster (IF)        |        |        |        |        |
| Right temporal cluster (rT)      | 1      | -0.45**| -0.45***| 0.64***|
| Middle frontoparietal cluster (mFP)| 1      | 0.15***|        | -0.32***|
| Middle prefrontal cluster (mPF) |        |        | 1      | -0.35***|

*p < .05. **p < .01. ***p < .001.
parietooccipital, and right temporal cortices. Noticeably, the middle parietooccipital cortex was deactivated during the task. The correlations among these major component clusters are listed in Table 4. Accordingly, the association of left prefrontal and right temporal was notably high.

The results also indicate that the differences in spectral power between designers and their baselines were evident, and the spectral power of expert designers is generally higher than
that of student designers. As depicted in Figure 8(a) (the middle frontoparietal), no significant power difference was observed. In the left prefrontal cluster (Figure 8(b)), the largest differences appeared in the low gamma band at 46 Hz ($p = 0.000$), 31 Hz ($p = 0.000$), and 45 Hz ($p = 0.000$). In the middle parietooccipital cluster (Figure 8(c)), the largest differences appeared in the theta band at 5 Hz ($p = 0.002$) and 4 Hz ($p = 0.003$). In the right temporal cluster (Figure 8(d)), the largest differences appeared in the low gamma band at 36 Hz ($p = 0.005$) and 35 Hz ($p = 0.01$).

The results of the present study indicated that participants' brain activations increased in the middle frontoparietal and right temporal regions under musical stimulation, and the spectral power of expert designers was generally higher than that of student designers. The brain activations of expert and student designers varied with musical genres.
4. Discussion

4.1. Brain activations during the country-folk song task

The EEG results indicated that the occipital region was deactivated and the frontal and temporal regions were activated during the country-folk song task. In particular, the activation of the left prefrontal, middle frontoparietal, and right temporal regions as well as the deactivation of the right prefrontal region were prominent. The deactivation of the occipital cortex concurred with prior research (Boccia et al., 2015; Gougoux et al., 2004), indicating that the occipital region plays a critical role in visual processing rather than auditory perception. The left prefrontal cortex is involved in semantic processing (Mayseless & Shamay-Tsoory, 2015). Its activation might have allowed the participants to focus on integrating musical stimuli into design thinking. In addition, the HG is situated in the middle frontoparietal region, and the right temporal cortex is responsible for nonverbal memory (Rogenmoser et al., 2016; Wisniewski, Wendling, Manning, & Steinhoff, 2012). These findings may demonstrate the designers’ corresponding reactions to the stimuli. Furthermore, the right prefrontal cortex was fundamentally involved in the regulation of emotional provocation (Gallup & Platek, 2002), and its deactivation suggests that the country-folk stimulus provoked participants’ affective responses.

Table 4. Correlations among the major component clusters in the classical music stimulation task

| Component                                      | mFP  | lPF  | mPO  | rT  |
|------------------------------------------------|------|------|------|-----|
| Middle frontoparietal cluster (mFP)            | 1    | 0.35*** | 0.25*** | 017*** |
| Left prefrontal cluster (lPF)                  | 1    | -0.35*** | -0.50*** |       |
| Middle parietooccipital cluster (mPO)          | 1    |     | -0.23*** |       |
| Right temporal cluster (rT)                    |     |     |       | 1   |

*p < .05. **p < .01. ***p < .001.
The correlations among the major components reveal the complicated functional connectivity of these brain regions during the country-folk song stimulation task. The activation of the middle frontoparietal region was strongly associated with that of the right temporal cortex and with the deactivation of the right prefrontal cortex. The results imply that country-folk song stimulation might provoke participants’ nonverbal memory with evident emotional reactions. In addition, the activation of the left prefrontal cortex was strongly associated with the deactivation of the right prefrontal cortex, possibly suggesting that designers might experience emotional stimulation which enhances the efficiency of design tasks during country-folk song stimulation.

The highest power differences (experts > students) in the left prefrontal cortex were observed in the alpha band, supporting previous findings that the left prefrontal alpha power increases with the generation of creative ideas (Benedek et al., 2014) and engagement in word encoding and retrieval tasks (Casasanto, 2003). This finding may indicate that by devoting more cognitive resources, expert designers could optimise creative idea generation under country-folk song stimulation more effectively than student designers can. The highest power differences (experts > students) in the right temporal cortex were observed in the theta and alpha bands. An increase in the theta and alpha power in the right temporal cortex can be perceived as an indicator of unconscious attention to nonverbal information processing (Wisniewski et al., 2012). This finding implied that this particular country-folk song may serve as an idea facilitator. Moreover, the highest power differences (experts > students) in the right prefrontal cortex were observed in the theta and alpha bands. This result implied that expert designers might spend more cognitive energy in regulating emotional responses (Gallup & Platek, 2002) than student designers during the task.

4.2. Brain activations during the rock and roll song task

Our results demonstrated that the prefrontal and middle frontoparietal regions were activated during the rock and roll song task. In particular, the activation of the left frontal, right temporal, middle frontoparietal, and middle prefrontal regions was noticeable. These results revealed the typical reactions to selected musical stimuli and further identified the critical role of the middle...
prefrontal cortex in responses to rock and roll song stimulation, supporting the neural architecture of music-evoked autobiographical memories suggested by Janata (2009). Moreover, this song stimulus triggered vivid past memories for the participants.

Regarding the correlations among the major components during the rock and roll song task, the activation of the left frontal cortex was strongly associated with that of the middle prefrontal cortex. The left frontal cortex is involved in brain correlates of analogical reasoning, which is critical for deriving inferences and adapting to novelty (Aichelburg et al., 2016; Li et al., 2015). This strong association may imply that the rock and roll song stimulation evoked participants’ autobiographical memories and simultaneously helped them incorporate these inferences into design thinking.

The highest power differences (experts > students) in the right temporal cortex were observed in the beta and gamma bands. An increase in the beta and gamma power in the right temporal region is an indicator of mindful attention to the perceptual grouping of nonverbal information (Brunet et al., 2015; Herrmann, Fründ, & Lenz, 2010). This result may indicate that expert designers are more focused on binding the features of various nonverbal cues (i.e. melody, words, images, and dancing) with the design target than student designers are. In addition, the highest power differences (experts > students) in the middle frontoparietal region were observed in the delta and theta bands. This result showed that expert designers had more reactions to the song than student designers did. Notably, the spectral power of student designers was generally higher than that of expert designers in the middle prefrontal cortex, which manages music-evoked autobiographical memories (Janata, 2009). This suggests that student designers (of a young generation) might have recalled more individualistic memories when listening to this particular rock and roll song than the expert designers did.

4.3. Brain activations during the soul music task
During the soul music task, the activation of the middle parieto-occipital, left temporal, middle frontoparietal, and right temporal cortices was evident. Activation of the middle frontoparietal and right temporal cortices are typical reactions to musical stimuli. The default mode network (DMN) is situated in the middle parieto-occipital region. Previous studies have suggested that listening to favourite music can stimulate the DMN, which plays a critical role in retrieving autobiographical memories (Uddin, Kelly, Biswal, Xavier Castellanos, & Milham, 2009). This result implies that the song might have facilitated designers to focus internally on recollecting their life experiences. Studies have indicated that semantic-based word retrieval is mediated primarily by the left temporal cortex (Henry & Crawford, 2004), suggesting that the lyrics of “Stand by Me” might stimulate designers to reminisce about their important life events. The negative association between the left temporal and middle frontoparietal cortices demonstrated the different reactions to word and music encoding during the task.

The spectral power of expert designers was noticeably higher than that of student designers in the middle parieto-occipital and right temporal regions. The differences in spectral power between baseline values and expert designers in these two regions are reasonably similar, indicating that expert designers are more engaged in internally focused tasks of nonverbal memory retrieval than student designers. In addition, the spectral power of expert designers is generally higher than that of student designers in the left temporal region. Typically, experts have encountered higher personal and professional hurdles than students. The significance of particular lyrics (semantic-based word retrieval and encoding) may arouse more resonations among expert designers than student designers. Furthermore, the spectral power in the middle frontoparietal region was higher in expert designers than in student designers, suggesting that expert designers were more aroused by the gospel-hymn soul song than student designers.

4.4. Brain activations during the classical music task
During the classical music task, the activation of the middle frontoparietal, left prefrontal, and right temporal cortices as well as the deactivation of the middle parieto-occipital cortex were apparent. The activation of the middle frontoparietal and right temporal cortices are typical reactions to
musical stimuli. Accordingly, the left prefrontal cortex may block creative thoughts (Chrysikou et al., 2013; Mayseless & Shamay-Tsoory, 2015). Furthermore, the activation of the left prefrontal cortex can assist the participants in focusing on transforming the musical stimuli to their design target. The DMN is typically deactivated during tasks requiring externally oriented attention (Uddin et al., 2009), implying that the participants are required to focus on the classical music during the task. The negative association between the left prefrontal and right temporal cortices indicated that inhibiting information screening and enhancing nonverbal communication may facilitate creative idea generation through classical music stimulation.

No differences between expert and student designers were observed in the middle frontoparietal cortex. The highest power differences (experts > students) in the left prefrontal and right temporal cortices were observed in the gamma band. Consistent with related studies (Mayseless & Shamay-Tsoory, 2015; Wisniewski et al., 2012), this result implied that expert designers consciously consumed more energy in screening irrelevant semantic information and optimising their nonverbal memories to facilitate design efficiency than student designers did. In addition, the present study observed that although the DMN was deactivated in most of the participants, the highest power of expert designers was stronger than that of student designers. This result indicated that although the classical song may not be connected to designers’ daily lives, expert designers devoted themselves more to creating imaginative links between their designs and the song than student designers did.

5. Research limitations

EEG is a promising neuroscientific tool that allows designers to assess design cognition in a naturalistic environment. However, its use and experimental design lead to several limitations, which impede broader generalisations. First, because of the limited spatial resolution of EEG, the dipole localisations can be interpreted as brain activation, but they are not equal to fMRI results. Second, the experimental stimuli used in this study were limited to four musical genres; however, a specific song or musical work cannot represent a particular genre. Therefore, additional genres and other combinations should be explored. Other measures of hedonic values, such as reward values, can provide valuable findings and should be evaluated. Third, the present study only focused on graphic designers and was limited to the number of participating designers and the age range between experts and students. Therefore, whether these findings can be applied to a general population of designers of different age groups and levels of expertise remain unknown. Finally, the statistical tests in the present study were not adjusted for multiple comparisons which may result in the problem of cumulative alpha error.

6. Conclusions and reflections

Despite the study limitations, several conclusions can be drawn. First, the brain activations of designers mainly increased in the middle frontoparietal and right temporal regions during the musical stimulation tasks. Second, the spectral power of expert designers was generally higher than that of student designers. Third, compared with student designers, expert designers rated country-folk stimulation as considerably more arousing for the alpha band in the left prefrontal and right temporal regions. Fourth, during the rock and roll task, the beta and gamma powers in the right temporal region of expert designers were higher than those of student designers, and the beta and gamma powers in the middle prefrontal region of student designers were higher than those of expert designers. Fifth, the middle parieto-occipital, left temporal, and right temporal regions of expert designers were more activated than those of student designers during the soul music task. Finally, compared with student designers, expert designers rated classical music stimulation as substantially more arousing for the low gamma band at the left prefrontal and right temporal regions.

Taken together, our results have four implications that can be explored further. First, the country-folk genre can substantially arouse emotions in designers, and expert designers are highly capable of regulating affective responses. Second, the rock and roll genre can assist expert designers in focusing on binding the features of various nonverbal cues with the design target as well as facilitate student designers to focus internally. Third, the soul music genre can benefit
designers, particularly experts, in internally focused tasks of nonverbal memory retrieval. Fourth, the classical music genre may not be connected with designers’ daily life but can assist expert designers in consciously filtering out irrelevant semantic information, enhancing their nonverbal memories, and creating imaginative links to facilitate design efficiency.

The present study highlighted the role of musical stimulation in design thinking. Along with other recent works on song perceptions and responses, the findings supported recent cognitive theories and provided evidence regarding the effects of songs on designing activities. Further research is warranted to thoroughly understand the roles of the identified regions during musical stimulation in design thinking and the relationships among these regions to determine their interaction processes, particularly to elucidate the functional connectivity among the frontoparietal, right temporal, and prefrontal regions. With increasing advancements in neuroaesthetics, future studies may explore these nuanced aspects in detail. Moreover, understanding these relationships would facilitate talent development in creative designers.

Acknowledgements
The current study is part of the research project (Grant number MOST 106-2511-S-002-001-MY3) supported by Taiwan’s Ministry of Science and Technology. The authors would like to extend their gratitude to the insightful suggestions of anonymous Cogent Psychology reviewers.

Funding
This work was supported by the Taiwan’s Ministry of Science and Technology [Grant number MOST 106-2511-S-002-001-MY3]

Competing interests
The authors declare no competing interests.

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Citation information
Cite this article as: Effect of musical stimuli on design thinking: Differences between expert and student designers, Chaoyun Liang & Yu-Cheng Liu, Cogent Psychology (2018), 5: 1510298.

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