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Creative objects differ from ordinary objects in that they are created by human beings to contain novel, creative information. Previous research has demonstrated that ordinary object processing involves both a perceptual process for analyzing different features of the visual input and a higher-order process for evaluating the relevance of this visual information. However, it is unclear how and when these processes are influenced by the creative information of the object. This study utilized event-related potentials (ERPs) to investigate the time course of creative object processing. Behavioral results revealed that participants spent more time processing creative objects than they did ordinary objects. Analysis of scalp ERPs further revealed that creative objects elicited a more negative ERP deflection between 190 and 340 ms (N190–340) with an anterior scalp distribution. Additionally, creative objects elicited more positive ERP deflection than did ordinary objects between 400 and 700 ms (P400–700) with a right centro–parietal scalp distribution and between 700 and 1000 ms (late positive component) with a right anterior–central scalp distribution. Such results suggest that the processing of creative objects is composed of two distinct stages. The early perceptual stage involves the detection of visual differences exhibited by the creative objects, while the late stage involves the right-lateralized processes of understanding and encoding the creative information.

Creative objects differ from ordinary objects in that they are created by human beings to contain novel, creative information, including original paintings, unconventional object constructions, and inventive devices (Zhang, Liu, & Zhang, 2013). According to the standard definition of creativity (Barron, 1955; Runco & Jaeger, 2012; Stein, 1953), creative objects are characterized by two important attributes: novelty and appropriateness (Rutter et al., 2012; Zhang et al., 2013). Ward, Patterson, Sifonis, Dodds, and Saunders (2002) described how novelty is related to the degree to which creative products deviate from ordinary objects in terms of their basic features. Therefore, novel

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creative objects can be generated by combining features associated with different ordinary objects (Michelon, Snyder, Buckner, McAvoy, & Zacks, 2003). Similarly, the appropriateness of an object refers to the useful or adaptive quality of the novel object in relation to the situation or constraint (Zhang et al., 2013). To obtain stimuli considered both novel and appropriate for the study of creative object processing, both Michelon et al. (2003) and Zhang et al. (2013) combined the features of ordinary objects to create unique species, such as a banana whose skin has been changed to resemble that of a red pepper. This operational approach was also used to manufacture the creative object stimuli in present study.

Previous studies have found that different creative process has featured dissimilar patterns of brain wave activation (Li, Tseng, Tsai, Huang, & Lin, 2016; Martindale & Hasenfus, 1978). Thus, it is reasonable to treat creative object processing as a special process and investigate it separately. Previous research has revealed that ordinary object processing roughly involves two distinct stages: a perceptual processing stage in which information regarding the different visual features of the input is assessed and a higher-order processing stage involving evaluation of the relevance of the information and preparation of an appropriate behavioral response (Romo & Salinas, 1999; Vanrullen & Thorpe, 2001). However, much controversy remains surrounding the mechanisms underlying the processing of creative objects, and investigation of this phenomenon has proven difficult.

Zhang et al. (2013) revealed significant activation in the left precuneus (BA 7) of the dorsal pathway and the right visual cortex (BA 17 and 18) of the ventral pathway when participants were required to process creative objects. This may indicate sensitivity to, and integration of, unusual features exhibited by creative objects. As previously mentioned, the first step involved in object perception is the detection of the visual features of the input. Results obtained from previous studies further indicate that the processing of creative information may occur simultaneously with objection perception, indicating that creativity can be regarded as a property of objects distinguishable in the early stages of visual input perception. However, an imaging study by Michelon et al. (2003) has revealed differential activity for the processing of creative versus ordinary objects, with creative objects activating the bilateral prefrontal cortex, an area closely involved with semantic processing. Such a result indicates that processing of creative object information more likely occurs following object perception and involves some special processing activities such as information representation, evaluation, and so on. This result further emphasized the important role of later higher-level processes for the interpretation of creative information. These two studies together suggest that creative object processing has a close relationship with perceptual activity, however, the temporal relationship between the two requires further investigation.

Previous research has revealed that early ERPs, specifically the anterior N2 are sensitive to novel information in early stages of visual input perception (Daffner, Alperin, Mott, Tusch, & Holcomb, 2015; Ferrari, Bradley, Codispoti, & Lang, 2010; Tarbi, Sun, Holcomb, & Daffner, 2011). For example, studies involving oddball paradigms that define novel stimuli as ordinary objects with a low probability of presentation (Daffner et al., 2015; Ferrari et al., 2010; Folstein & Van Petten, 2008; Tarbi et al., 2011), have revealed that novel stimuli elicit greater N2 amplitudes than ordinary ones. In contrast, late ERPs such as the P3b and late positive component (LPC) are strongly modulated by stimulus tasks (De Grauwe, Swain, Holcomb, Ditman, & Kuperberg, 2010). Moreover, these late ERPs are related to the processing that underlies the representation of mental stimuli by updating the context with respect to working memory (Linden, 2005; Polich, 2007). Such processes are further associated with the understanding and evaluation of the content of stimuli following object perception (Ruchkin, Munson, & Sutton, 1982).

This study utilized ERPs to elucidate the time course of creative object processing. To fully examine all stages of creative object processing, participants were not only asked to view the stimuli, but also to judge whether the presented stimuli were creative based on their own comprehension. If creative object information is processed in the early stages of visual input perception, more creative objects would elicit a more negative N2. In contrast, if the creative information is processed after object perception and relies on higher-order activities, creative objects would elicit more positive P3b and LPC. If the processing of creative objects involves both stages simultaneously, the differences in ERP waves would appear both early and late in the time course.

MATERIALS AND METHODS

Participants

Twenty-six healthy students (14 women, mean age 21, ages ranging from 19 to 22 years) were recruited for paid participation in this study. All participants had normal or corrected-to-normal vision, with no history of neurological or psychiatric disorders. According to the adapted Edinburgh Inventory of Handedness (Oldfield, 1971), all participants were right-handed. Two participants were excluded from data analyses due to excessive drifts in their EEG data. The experimental standards of the studies were approved by the local Review Board for Human Participant Research. Written informed consent was obtained from all participants prior to participation.

Stimuli and Procedure

Stimuli

Stimuli included pictures of 60 stimuli classified as creative objects in addition to 60 pictures classified as ordinary objects,

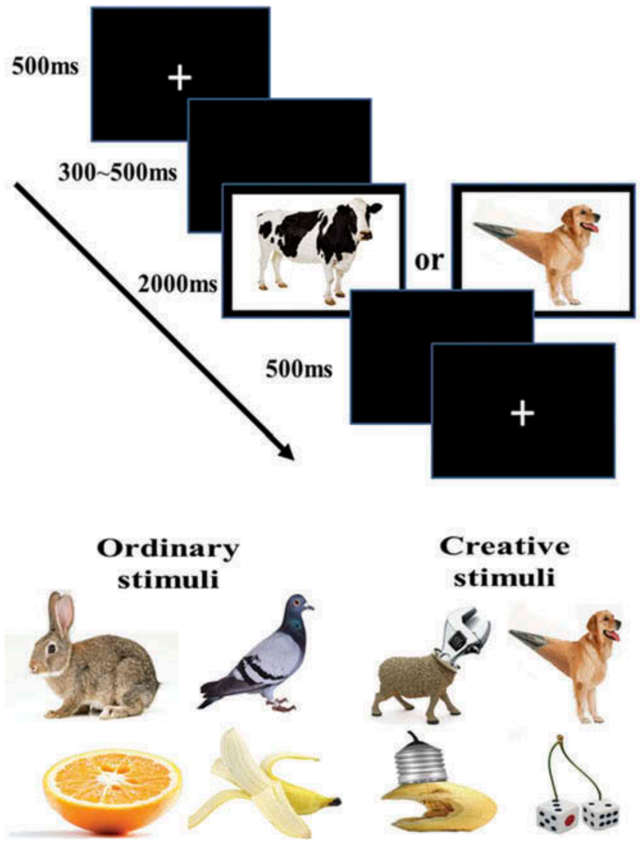

FIGURE 1. Illustration of an experimental run and examples of experimental materials. Four examples are shown for each type.

for a total of 120 objects. To ensure that the creative objects were sufficiently novel and appropriate, one creative stimulus was composed from two ordinary images belonging to different conceptual categories (for instance, dog in animal category and pen in stationery category, see Figure 1) using Photoshop CS6 software (Adobe Systems Inc., California, United States). Ordinary stimuli were comprised of plant and animal pictures from everyday life. All stimuli were pretested prior to the formal experiment with 40 participants. The average rating for the degree of creativity for stimuli was 5.89 ($SD = 0.44$) and average rating for creativity degree for ordinary stimuli was 2.01 (SD = 0.47) on a 7-point rating scale ranging from 1 (*very common*) to 7 (*very creative*). The paired t-test revealed significant differences in creativity between the two classes of objects, $t(39) = 38.71$, $p < .001$, Cohen's $d = 8.01$. See Figure 1.

Procedure

During the experiment, participants were seated comfortably about 80 cm in front of an LCD screen in an electrically shielded room. They were instructed to judge whether the presented pictures were creative or not as quickly as possible. If they believed the stimulus to be congruous with daily life or ordinary, they were instructed to press the *F* button using their left index finger. If they found that the presented stimulus was incongruous with daily life or creative, they were instructed to press the *J* button using their right index finger. In addition, the number of creative stimuli presented to each subject was equal to the number of ordinary stimuli. On each trial, a fixation sign (+) was presented at the center of the screen for 500 ms. A picture was then presented after a random interval of 300–500 ms. The presentation time for each picture was determined by the latency of the subject's response, within 2,000 ms. The intertrial interval (ITI) was 500 ms (see Figure 1). After 18 practice trials, 120 trials were presented in a pseudo-randomized manner in two blocks (30 creative stimuli and 30 ordinary stimuli for each).

Electroencephalogram Recordings and Data Analysis

The electroencephalogram (EEG) data were recorded continuously using the CURRY 7 system (Compumedics Neuroscan, Texas, USA) with 64 Ag/AgCl electrodes and monitored using the CURRY recorder software. The EEG signal was amplified using a SynAmp amplifier and digitized at a sampling rate of 1000 Hz. The impedance was kept under 5 kΩ. Eye movements were monitored through bipolar electrodes that were placed above and below the right eye, as well as at the left and right canthi. Data were recorded using an on-line M1 reference. EEG data were analyzed using the SCAN 4.5 software. Data were filtered with a 0.01-Hz high-pass and a 30-Hz low-pass filter. Ocular correction to remove eye movement artifacts was computed based on the method described by Gratton, Coles, and Donchin (1983). Data were further segmented into epochs of 1200 ms duration, starting at 200 ms prior to stimulus presentation. Segments were then baseline corrected using this 200-ms time window. Artifacts with amplitudes exceeding ±75 μV were removed from the data set. Grand averages for each condition were used to derive the temporal intervals for the ERP waves. A negative-going wave starting at about 190 ms with a peak at 340 ms was observed; then the mean amplitude for the time interval from 400 ms to 700 ms after onset of the picture was computed (P400–700). In order to investigate possible late ERP waves, the mean amplitude for the time interval of 700–1000 ms after onset of the critical word was also calculated (LPC).

RESULTS

Behavioral Results

Results of the paired t-test revealed that participants took significantly longer to respond when presented with creative stimuli ($M = 857.03$, $SD = 119.61$) compared to ordinary stimuli ($M = 793.79$, $SD = 118.65$), $t(23) = 3.41$, $p < .05$, Cohen's $d = .54$. With respect to accuracy rates, there was no significant difference between creative ($M = .96$, $SD = .03$) and ordinary stimuli ($M = .95$, $SD = .04$), $t(23) = 1.42$, $p > .05$.

Electrophysiological Results

According to the ERP waves and topographic maps (Figure 2), three ERP time windows were analyzed: N190–340 (190–340 ms), P400–700 (400–700 ms), and LPC (700–1000 ms).The Greenhouse-Geisser correction was applied to the *p*-values associated with multiple *df* comparisons when tests violated assumptions of *sphericity*.

N190–340

Repeated measures analysis of variance (ANOVA) according to type of stimulus (creative, ordinary) and electrode (F1, Fz, F2, FC3, FC1, FCz, FC2, FC4, and Cz) of the averaged amplitudes from 190 to 340 ms revealed main effects of stimulus type [$F(1, 23) = 9.12$, $p < .05$, $\eta_p^2 = .28$] electrode position [$F(8, 184) = 13.17$, $p < .001$, $\eta_p^2 = .36$]. Compared to ordinary stimuli, the creative stimuli elicited larger average N190–340 amplitudes. In addition, the Bonferroni post hoc test of electrode position indicated that FC3, FC1, FCz, FC2, FC4, and Cz had larger average N190–340 amplitudes than the other electrodes. However, no interaction was found between stimulus type and electrode position, $F(8, 184) = 1.26$, $p > .05$, $\eta_p^2 = .05$.

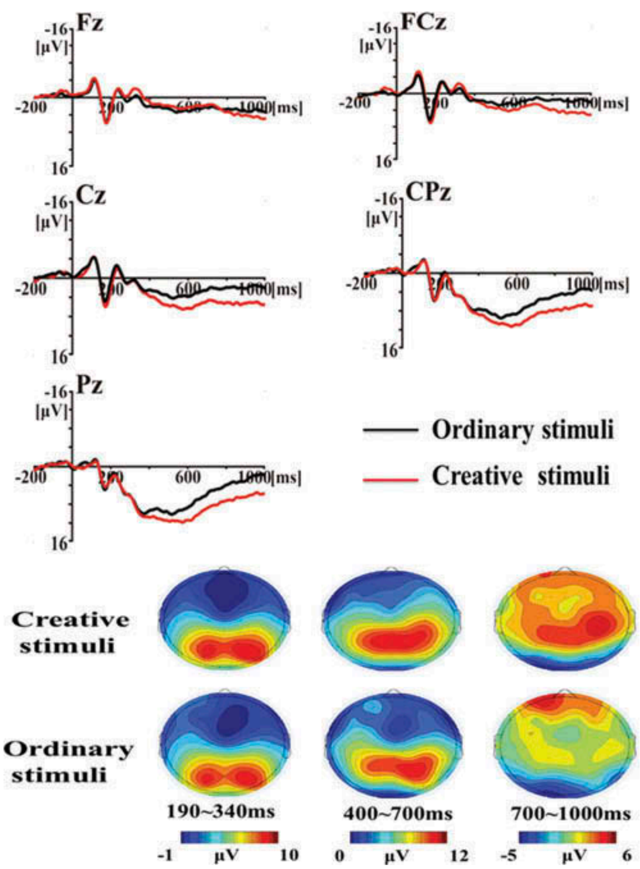

FIGURE 2. Grand average of the event-related potentials (ERPs) at FZ, FCZ, CZ, CPZ, and PZ sites and topographies of the ERPs activity of the two kinds of stimulus presented in the experimental task. The topographies of N190-340 (190–340 ms), P400-700 (400–700 ms) and LPC (700–1000 ms) are illustrated.

P400–700

Analyses were conducted using 2 (stimuli types: creative, ordinary) × 4 (region: FC, C, CP, P) × 3 (line: 3, z, 4) repeated-measures ANOVA to examine the effect of creativity and determine if this effect varied over the time course of P400–700 and LPC in different brain regions.

The results revealed significant main effects of stimulus type, $F(1, 23) = 10.17$, $p < .05$, $\eta_p^2 = .31$, and region, $F(3, 69) = 36.27$, $p < .01$, $\eta_p^2 = .61$. Meanwhile, significant interactions between stimulus type and line, $F(2, 46) = 12.88$, $p < .0001$, $\eta_p^2 = .36$, and between region and line, $F(6, 138) = 5.98$, $p < .001$, $\eta_p^2 = .21$, were observed. A three-way interaction effect was observed among stimulus type, region, and line, $F(6, 138) = 3.48$, $p < .01$, $\eta_p^2 = .13$. The Bonferroni post hoc test indicated that creative stimuli elicited larger average P400–700 amplitudes in the right posterior regions than they did in the anterior regions (see Figure 3).

LPC (700–1000 ms)

The repeated measures ANOVA according to stimuli types (creative, ordinary), region (FC, C, CP, P) and

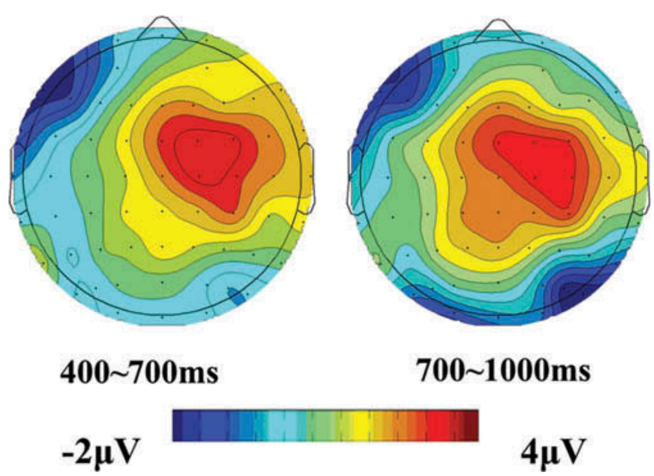

FIGURE 3. Topographies of the different event-related potential (ERP) waves (creative objects minus ordinary objects) of P400–700 (400–700 ms) and late positive component (LPC) (700–1000 ms) in the experimental task.

line (3, z, 4) revealed significant main effects of stimulus type, $F(1, 23) = 36.47$, $p < .001$, $\eta_p^2 = .61$, and region, $F(3, 69) = 5.14$, $p < .05$, $\eta_p^2 = .18$. Significant interactions were observed between stimulus type and line, $F(2, 46) = 9.02$, $p < .001$, $\eta_p^2 = .28$, and between region and line, $F(6, 138) = 7.66$, $p < .001$, $\eta_p^2 = .25$. A three-way interaction effect was observed among stimulus type, region, and line, $F(6, 138) = 9.50$, $p < .01$, $\eta_p^2 = .29$. The Bonferroni post hoc test indicated that creative stimuli elicited larger average LPC amplitudes in the posterior and central-posterior regions of the right hemisphere than they did in the anterior regions (see Figure 3).

DISCUSSION

This study utilized ERPs to investigate the time course of creative object processing. Consistent with the results of several previous studies (Michelon et al., 2003; Riefer, 1998; Rutter et al., 2012; Shibata, Abe, Terao, & Miyamoto, 2007), participants spent more time processing the creative objects than they did ordinary ones, suggesting that the processing of creative objects is more complicated and requires more cognitive resources than ordinary object processing. More importantly, analysis of scalp ERPs revealed that creative stimuli elicited different waves with ordinary objects during the time windows of 190–340 ms, 400–700 ms, and 700–1000 ms. These ERP waves may reflect the different activities involved in the processing of creative objects.

Results of this study indicate that both creative and ordinary objects elicit anterior N190–340 in the time window of 190–340 ms with frontal distribution. As anterior N2 is sensitive to differences in the features of visual objects, such a result may suggest that the features of creative objects are processed similarly to those of ordinary objects in the early stages of visual perception. Further, the amplitudes of anterior N190-340 elicited by creative objects were more negative than those of ordinary objects, a result similar to that observed in previous studies (Daffner et al., 2015; Tarbi et al., 2011). This may indicate that, due to the deviation from normal objects, creative objects produce a visual mismatch process and elicit more attention, allowing individuals to distinguish creative objects from ordinary ones in early stages of visual perception. The results of this study support this view that creative information processing occurs simultaneously with objection perception (Zhang et al., 2013).

Though Daffner et al. (2015) reported differences between novel and standard objects only early on in the ERP time course, the results of our study observed some late ERP activity related to creative object processing. Creative objects elicited a more positive P400–700 in the parietal cortex did ordinary objects, possibly indicating that the P400–700 is P3b, which is strongly modulated by the stimulus task and reflects task requirements and responses (Knight & Nakada, 1998). The difference in P400–700 amplitudes elicited by creative and ordinary stimuli in this study suggests that participants can distinguish these two kinds of stimuli. Meanwhile, P3b also reflects the process of representing stimuli in working memory (Donchin & Coles, 1998; Steiner, Barry, & Gonsalvez, 2013). When stimuli were presented, participants were not only required to respond but also to integrate and understand the meanings of the stimuli. The P3b may reflect the process in which the activated hippocampus sends updated visual information to the posterior cortex (Knight, 1996). Thus, the difference in average amplitudes of P400–700 may indicate translation of stimulus meaning and creation of mental representations in working memory with respect to creative and ordinary stimuli. The greater positive P400–700 elicited by creative stimuli may suggest that the representation of creative objects exerts a greater cognitive load on working memory due to the conflict between prior knowledge and novel stimulus information exhibited by creative objects. Consisted with brain imaging results from Zhang et al. (2013), our results indicate that creative object processing involves the integration of objects features as well as the understanding of creative information, which relies on working memory in the late stages of processing.

Creative objects elicited larger LPC waves (700–1000 ms) than did ordinary stimuli, especially in the right central and frontal scalp distribution. Previous studies have revealed that individual differences in memory encoding stimuli can result in a DM effect (ERP differences based on later memory performance), meaning that better encoding and performance with respect to memory elicits larger LPC waves (Paller & Kutas, 1992). The results of this study thus indicate that participants encode creative information more deeply in their memory after they complete the representation of creative objects, potentially explaining the behavioral finding that creative objects are more easily memorized (Riefer, 1998). Topographic maps (Figure 2) further revealed differences between the average amplitudes of LPCs elicited by creative and ordinary objects with respect to central and, centro–frontal scalp distributions, supporting the observation of Michelon et al. (2003) that frontal brain regions are significantly involved in the comprehension and processing of creative objects. In conclusion, the results suggest that late stages of creative object processing involve the representation of creative object information in addition to integration and encoding of features in working memory.

It is interesting to note the lateralization of processing observed in late stages of creative object processing. According to the difference in waves depicted in the topographic maps (Figure 3), creative objects evoked larger LPC in the right hemisphere than in the left, especially in the central and centro-frontal scalp regions, potentially indicated that the right hemisphere is more involved in creative object processing. As creative object processing is an important creativity-related cognitive processes, the results of our study support the notion that mechanisms underlying creativity are primarily right lateralized (Grabner, Fink, & Neubauer, 2007; Martindale, Hines, Mitchell, & Covello, 1984).

This study possesses some limitations with respect to the experimental technique and number of ERPs required for each condition, given that participants were required to make only two types of judgments (creative or non-creative) regarding stimuli. Future research should explore the mechanisms involved in judging stimuli according to varying degrees of creativity to evaluate whether such degrees affect creative object processing. Additionally, although this study examined creative information processing at the perceptual level using pictorial materials, future research should include lexical/literary materials in order to investigate creative information processing at the semantic level.

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