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An event-related potential study of semantic style-match judgments of artistic furniture

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ABSTRACT

This study investigates how semantic networks represent different artistic furniture. Event-related potentials (ERPs) were recorded while participants made style-match judgments for table and chair sets. All of the tables were in the Normal style, whereas the chairs were in the Normal, Minimal, ReadyMade, or Deconstruction styles. The Normal and Minimal chairs had the same rates of "match" responses, which were both higher than the rates for the ReadyMade and Deconstruction chairs. Compared with Normal chairs, the ERPs elicited by both ReadyMade chairs and Deconstruction chairs exhibited reliable N400 effects, which suggests that these two design styles were unlike the Normal design style. However, Minimal chairs evoked ERPs that were similar to the ERPs of Normal chairs. Furthermore, the N400 effects elicited by ReadyMade and Deconstruction chairs showed different scalp distributions. These findings reveal that semantic networks represent different design styles for items of the same category.

1. Introduction

Rapid developments in art and design have created an almost limitless number of items in the same category (for example, chairs in the category of furniture) that have a variety of features and different design styles. Scenes of a discordant furniture arrangement in a space are commonplace, for example, a modern floor lamp next to a classic sofa. In design studies, the most popular method of measuring participants' reactions to objects or images is to apply adjectival descriptions of the semantic differences (SD) and to employ a multidimensional scale (MDS). For example, such methods were used in numerous Kansei engineering research projects in Japan (Nagamachi, 1995) and in multidimensional space research (Green and Smith, 1989; Hsiao and Chen, 1997). The studies use questionnaires with a Likert scale, mostly based on the semantics analysis developed by Osgood in 1957, to acquire the participant's subjective responses to stimuli. Different bipolar adjectives (e.g., simple–complicated, plain–luxurious) are tested according to the stimuli and context, in the semantic differential measurement. Although fruitful results have been achieved (Lin and Fang, 2007; Lin et al., 2011), criticism regarding this method of measurement has arisen for several reasons: 1) a concern that the participants' response may be misguided due to the questionnaire design, 2) insufficient reliability and accuracy, and 3) a concern that participants will not answer all of the questions with sufficient care. As the process of acquiring the raw data is not well controlled, the subsequent data analysis may be invalid. Recently, Hung and Chen (2010) found that the SD method could not be used to measure contradictory semantics in the same product, such as "retro car", which displays nostalgia by borrowing characteristics from classical cars but at the same time exhibits modern characteristics. These findings revealed that some traditional methods may not be suitable for artistic design research.

Through recent developments in science and technology, objective psychological responses can be measured using event-related potentials (ERPs). The temporal resolution of ERPs is on the same order of magnitude as the temporal resolution of cognitive processes proposed on the basis of purely behavioral experiments (response time, match percentages, etc.). Hence, the ERP could be used as a new tool for design assessment. In the context of incongruent furniture combinations, the N400 waveform component of the ERP is a widely distributed, negative-going potential peaking at approximately 400 ms after the onset of any meaningful stimuli. This N400 waveform represents the semantic relationship between the current stimulus and the preceding context. Several studies of the N400 waveform were undertaken to index semantic integration processes, using the final word of a sentence as the stimulus (Andrews et al., 1993; Kutas and Hillyard, 1980; McCarley et al., 1991; Mitchell et al., 1991), picture–words (Greenham et al., 2003; Mathalon et al., 2002), pairs of words (Grillon et al., 1991; Koyama et al., 1994; Khateb et al., 2007; Núñez-Peña and Honrubia-Serrano, 2005; Pritchard et al., 1991; Weisbrod et al., 1998), pairs of pictures (Barrett and Rugg,

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1990; Bobes et al., 1996; Ellis and Nelson, 1999; Guerra et al., 2009; Proverbio et al., 2007), and even incongruent human actions (Proverbio and Riva, 2009; Wu and Coulson, 2007) when the presented objects did not fit into any previously established semantic category.

For many years, researchers have examined how classifying objects into categories evokes the N400 effect. In a number of ERP studies using categorization tasks, larger N400 effects were evoked during between-category comparisons (e.g., books vs. dogs) than during within-category comparisons (e.g., sheepdogs vs. golden retrievers) (Bobes et al., 1996; Mathalon et al., 2010; Guerra et al., 2009; Hamm et al., 2002; Proverbio et al., 2007). In natural within-category identification tasks, several studies of lexical categorization have demonstrated that the non-prototypical categories (e.g., shar-peis) elicited greater negative N400 effects than did the prototypical categories (e.g., golden retrievers) (Pritchard et al., 1991; Stuss et al., 1988). Most of these experiments dealt with natural categories (e.g., plants, animals, fruits) rather than artificial categories (e.g., tools, furniture, bicycles) (Paz-Caballero et al., 2006; Proverbio et al., 2007). It is possible that the artificial objects may be much more difficult to identify than natural objects because natural stimuli usually share similar or common elements and are more perceptual (e.g., heads, eyes and legs) and semantic (e.g., move, eat, breathe, and make noise) (Proverbio et al., 2007). In addition, as new objects are produced every day, not only are the representative objects changeable but the distinctions between object categories for design or art pieces are also often blurred; thus, occasionally, it is too difficult to classify objects due to tremendous variations in style. Hence, artificial categorical and semantic processing using ERP is a worthy topic for further investigation in design research.

In the design field, artificial objects are judged based on their functions and beautiful appearance. However, designers apply their creativity to produce new designs and react to social issues; thus, the definitions of design streams and design styles differ for different generations. For example, in addition to Modernism, Fischer (1989) divided the style of mainstream products in the 1980s into six design categories. Two of them, Minimalism and Archetype, have currently taken over the position of modernism, and new design challenges, such as ReadyMade, Deconstruction and New Art Deco, have gradually become fashionable. For this study, we chose four types of design: Archetype, Minimal, ReadyMade, and Deconstruction as the testing design styles because of their popularity, potential for development, and diversity. According to Fischer (1989), the Archetype design style aims to define the basic "primary" form of an object, as opposed to producing individual arbitrary interpretations and encouraging a rapid change in fashion. Normal, vulgar and anonymous objects are references for this style and are intelligently transformed into new designs (Lin and Cheng, 2004). Lin (2003) appears to be closely related to shapes found in traditional rural cultures but have been "upgraded" by the use of high-quality materials and distorted proportions. Minimal designs are characterized by a reduction in expressive media, a rediscovery of the value of empty space, extreme simplicity, and formal cleanliness (Bhaskaran, 2005). Many well-designed contemporary products tend to have simple shapes, such as the Apple iPhone and iPad. This style is based on the ultimate, most reduced structure to achieve a "pure" and minimized form (Rashid, 2004). Works in the Deconstruction style, much like art pieces, usually make use of broken and jagged forms, warped and overlapped planes, and, at times, disturbing shapes, in sharp contrast to logic and order (Bhaskaran, 2005). The Deconstruction style was derived from literary criticism that aimed to extract the meaninglessness of the text by destabilizing its rationality and logicality (Culler, 2008). The Guggenheim Museum, designed by Frank Gehry, is a typical example of Deconstruction in architecture: with the distorted shape of the building, Gehry challenges the ideal of rational order and offers us another alternative. In ReadyMade works, the combination of unrelated found objects in a new context is close to a kind of art that leads viewers to be puzzled by the familiar yet unfamiliar appearance. In Fig. 1, the guitar chair appears to be bizarre as a whole, despite the fact that the box and the guitar are common objects individually. ReadyMade style was most often associated with Dadaism (Richter, 1997; Short, 1994); Marcel Duchamp who was a highly influential Dadaist subverted conventional art based on everyday found objects such as dubbing a "urinal art" and naming it "Fountain" (Scanlan, 2003). Additionally, this style also deals with environmental issues such as green design. Based on their respective ideals, these four styles exhibit their own unique visual features.

Our interest lies in the style and artistry of artificial objects, which should be easier to identify than natural objects in the within-category (e.g., sheepdogs vs. golden retrievers). Thus, the comparison of style within the within-category in this study should be similar to "prototypical categories" and "non-prototypical categories". Several art criticism studies on ReadyMade works included interpreted meanings that were ambiguous (Goldsmith, 1983; Molesworth, 1998), disordered (Goldsmith, 1983; Scanlan, 2003), contradictory (Smuts, 1997) and puzzling (Moffitt, 2001). Moreover, Deconstruction works are exemplified by free-form structures (Iyengar et al., 2006; Schober et al., 2010), organic shapes (Giovannini, 2004), and even montages of fragmented forms (Hartoonian, 2002). Gerlach et al. (2004) reported that such distorted structures for the identification of objects may activate areas in the posterior region of the brain; this phenomenon most likely reflects the use of the structural description system in models of object recognition. We expected that artificial objects with a bizarre style (e.g., Deconstruction and ReadyMade) would evoke larger N400 amplitudes than those of a more conventional style (e.g., Normal). Additionally, we were interested to find out whether Minimal and Normal styles could be distinguished by manipulating their combinations. If the N400 effect could serve as indicator of the degree of perceived similarity on within-category identification tasks of artificial objects, we believe that the ERP could become a new tool to help designers better understand design recognition. This study could also provide new information for physiologists about the N400 response not only in the context of "pure" semantics but also in the perception of artificial designs. Hence, the results of this study could be a good starting point for further research in other fields.

2. Method

2.1. Participants

Eighteen undergraduate students (10 male, 8 female; mean age = 22 years) from National Central University were paid 500 New Taiwan Dollars to participate in the experiment. All of the participants were right-handed, native Chinese speakers with normal or corrected-to-normal vision. Written consent was obtained from all participants.

2.2. Materials

The stimuli included 8 gray-scale pictures of tables and 32 gray-scale pictures of chairs (see Fig. 1) on a white background. All of the selected pictures were acquired via the Internet and depicted works by famous designers such as Philippe Starck, Jasper Morrison, Emmanuelle Moureaux, Tom Dixon, Philippe Bestenheider, Tejo Remy, Fernando and Humberto Campana, and Max McMurdo. Each picture was approximately 6 cm high and 4 cm wide. These pictures were displayed at a subtended vertical and horizontal visual angle of approximately 45° for better viewing. The 32 chairs were divided into 4 groups of 8 chairs each. Each group corresponded to one of the following design styles: Normal, Minimal, Deconstruction, and ReadyMade. The categorization was performed by 6 design experts. All 8 tables, however, were in the Normal design style. A total of 256 trials were generated by pairing each of the 8 tables to each of the 32 chairs. This

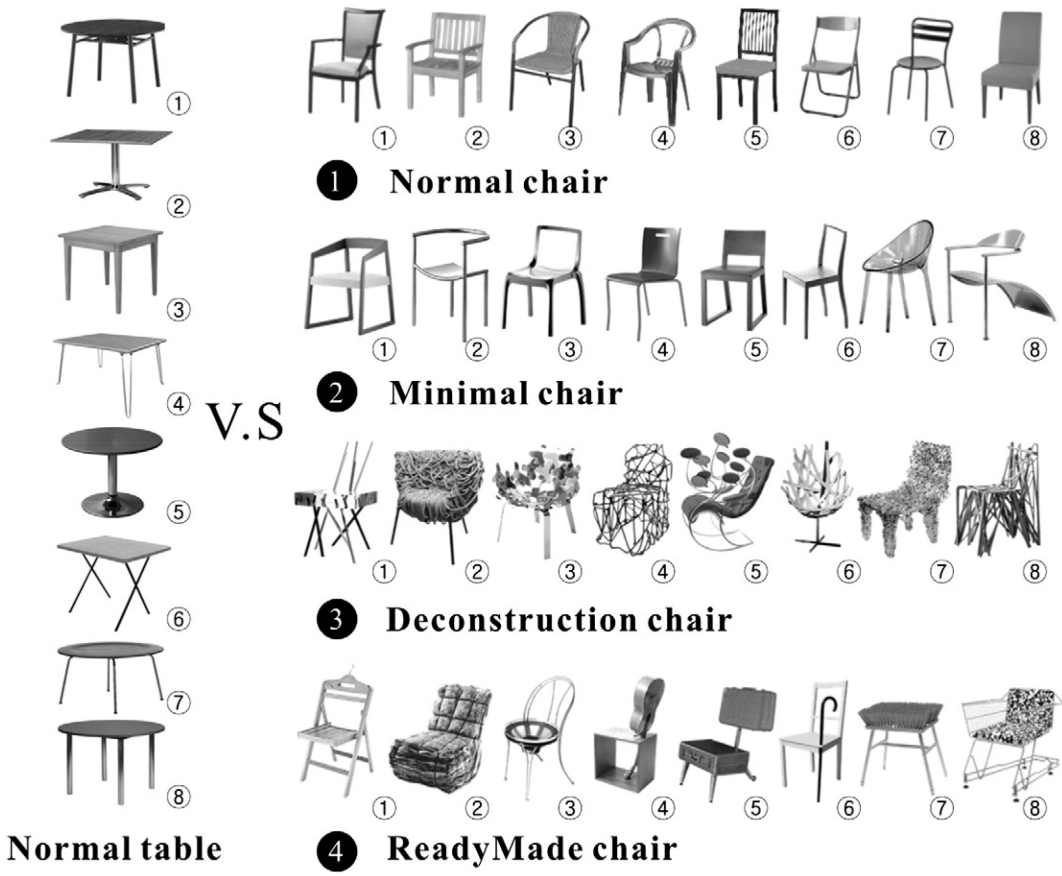

Fig. 1. Stimuli included four types of table–chair pairs (Normal-Normal, Normal-Minimal, Normal-Deconstruction, and Normal-ReadyMade).

pairing produced four types of table–chair combinations, with 64 pairs in each combination. The semantic relationship between the table and chair was match in Normal–Normal pairs but not in the other three types of table–chair pairs.

2.3. Procedure

Participants were fitted with an elastic electrode cap and then seated in an electrically isolated chamber. The participants were asked to sit at a distance of approximately 70 cm from the screen. During the experiment, the participants made style judgments on 256 table and chair pairs that were presented sequentially. Each trial began by showing a fixation point at the center of the screen for 1000 ms. After the fixation point disappeared, the prime image (i.e., one of the eight Normal style tables) was presented for 1000 ms, followed by a blank screen presented for 500 ms. The target (i.e., a chair of ReadyMade, Deconstruction, Minimal, or Normal style) then appeared and remained on the screen for 1000 ms. There was no repetition of either the prime or target stimuli on any two consecutive trials. During this brief period, the participants judged whether the chair matched the preceding table in terms of structure and appearance. The screen then went blank for 1000 ms, and then, the next trial started. There was a short break after 128 trials. After the break the participants were again instructed to judge whether the chair matched or did not match the preceding table in terms of structure and appearance. Participants were told to press a button with the index finger of one hand to register a response match, and to register non-matches with the index finger of the opposite hand. To avoid their dominant hand influencing the match/mismatch response times, the assignment of the fingers to the response categories was counterbalanced across participants: half of the participants used their right index finger to input "match", and the other participants used it to input "mismatch".

2.4. ERP recording and analysis

EEG signals were recorded from 64 Ag/AgCl electrodes, 62 of which were embedded in an elastic cap. The remaining two electrodes were placed on the mastoids. Data were acquired from 27 electrode sites (F7, F5, F3, F1, Fz, F2, F4, F6, F8, T7, C5, C3, C1, Cz, C2, C4, C6, T8, P7, P5, P3, P1, Pz, P2, P4, P6, and P8). All channels were referenced to an electrode located between Fz and FCz and were re-referenced off-line to the average of the two mastoid electrodes (Luck, 2005). Vertical and horizontal EEG signals were recorded from the bipolar electrodes that were placed above and below the left eye and on the outer canthus of each eye. Data were continuously recorded and sampled at 250 Hz. All of the channels were amplified with a bandpass filter of 0.05–70 Hz (3 dB points). Linear regression was used to correct the contribution of blink artifacts to the EEG signals (Semlitsch et al., 1986). Data were low-pass filtered at 30 Hz (12 dB/octave). Trials with non-blink eye movements or with a baseline drift exceeding 70 μV in any channel were rejected. ERPs were calculated for epochs of 1020 ms relative to the onset of the pictures of chairs, with a 100 ms pre-stimulus interval as a baseline.

3. Results

Repeated measures ANOVA tests were used to analyze both the behavioral and ERP data. The Greenhouse–Geisser correction for non-sphericity was applied as appropriate. Post-hoc comparisons employed Bonferroni corrections.

3.1. Behavioral data

Table 1 displays the percentages of "match" responses and reaction times (RTs) for the style judgments of all four types of chairs.

Table 1
Behavioral results for four chair styles in the semantic match/mismatch judgment tasks (standard deviation of mean in parentheses).

Prime-target	Match response (%)	Reaction time (ms)	
Normal table vs. Normal chair	54 (22)	Match	920 (290)
		Mismatch	925 (459)
Normal table vs. Minimal chair	44 (13)	Match	959 (477)
		Mismatch	923 (284)
Normal table vs. Deconstruction chair	20 (15)	Match	895 (649)
		Mismatch	874 (404)
Normal table vs. ReadyMade chair	21 (11)	Match	993 (538)
		Mismatch	869 (315)

Almost half of the Normal chairs elicited an “unmatch” response. These findings may indicate a lack of fit to the participants' table-chair prototype.

Table 2 displays the mean percentages of match responses for each “Normal table–Normal chair” pair. The 7th table–5th chair pair (M = 17) in which the table and chair differ (i.e., a low table with a rectangular top surface vs. a rounded chair seat) was associated with the lowest “match” response compared with other pairs, as were the 7th table–8th chair pair and the 8th table–1st chair pair (both M = 28). These findings indicate that the normal table–chair pairs exhibited combinations of varied features that decreased the match responses.

A repeated measures ANOVA applied to the rates of match responses revealed a significant main effect of chair type ($F[3, 51] = 19.76$, $p < .001$, $\varepsilon = .48$). Post-hoc comparisons indicated that the rates of match responses were statistically equivalent for Normal chairs and Minimal chairs; both were higher than the proportions for ReadyMade chairs (both $p < .001$) and Deconstruction chairs ($p < .005$ and $p < .001$, respectively). There were no differences between the rates of match responses for ReadyMade chairs and Deconstruction chairs.

A two-way repeated measures ANOVA applied to the RT data revealed that neither of the main effects of chair type and response type (match vs. mismatch) were statistically significant ($p = .208$ and $p = .501$, respectively) nor was their interaction ($p = .492$). These findings may be due to the absence of priming effects in the RT data. A paired-sample *T* test was used to compare the match responses to Normal chairs and mismatch responses to Minimal, Deconstruction, or ReadyMade chairs. There were no significant differences for any of the “mismatch” conditions ($p = .928$, $p = .263$, and $p = .113$, respectively), which suggested that negative priming was not a factor in the mismatch responses, whereas their mean RT values were smaller than the mean RT values in the match responses.

3.2. ERP data

ERPs were time-locked to the onset of chair stimuli and were based on the responses of each participant, including the match responses to Normal chairs and the mismatch responses to Normal, Minimal, Deconstruction, and ReadyMade chairs. The discussion below uses the following nomenclature to label the five conditions: Normal-Match, Normal-Mismatch, Minimal-Mismatch, Deconstruction-Mismatch, and ReadyMade-Mismatch. The mean trial numbers (and range) for the five conditions were as follows: 27 (16–60), 31(16–58), 28 (17–43), 41 (16–63), and 41 (23–60), respectively.

The five conditions were divided into two groups to illustrate the averages of ERPs associated with the prototypical and non-prototypical categories. Fig. 2 shows a comparison between the Normal-Match and Normal-Mismatch conditions that reflects the prototypical ERP effects. Fig. 3 shows non-prototypical ERP effects in the mismatch responses in the Minimal, Deconstruction, and ReadyMade conditions, compared with the Normal-Match condition. The waveforms diverged approximately 200 ms after stimulus onset, with the Deconstruction-Mismatch and ReadyMade-Mismatch waveforms becoming more negative than the Normal-Match and Minimal-Mismatch waveforms 300–500 ms after stimulus onset. The ERPs were quantified by measuring the mean amplitudes over the 300–500 ms time period after stimulus onset. Several previous N400 studies (Eddy and Holcomb, 2009; Mathalon et al., 2010) also informed the selection of the N400 measurement interval. The measurement interval was chosen based on visual inspection and preliminary analyses of consecutive 100 ms latency intervals to show maximal differences between the waveforms. Data were included from the left anterior (F7, F5, F3), medial anterior (F1, Fz, F2), right anterior (F4, F6, F8), left central (T7, C5, C3), medial central (C1, Cz, C2), right central (C4, C6, T8), left posterior (P7, P5, P3), medial posterior (P1, Pz, P2), and right posterior (P4, P6, P8) electrode sites. An ANOVA was first conducted for the condition (Normal-Match, Normal-Mismatch, Minimal-Mismatch, Deconstruction-Mismatch, and ReadyMade-Mismatch), the left–right scalp region (left, medial, and right), and the anterior–posterior caudality (anterior, central and posterior) of the scalp electrode locations. Secondary ANOVAs for pairwise comparisons were conducted to check for any significant effects of the condition factor.

3.3. N400 (300–500 ms)

Table 3 displays the N400 amplitude means for the Normal-Match, Normal-Mismatch, Minimal-Mismatch, Deconstruction-Mismatch, and ReadyMade-Mismatch conditions across 9 scalp regions. The N400 amplitude means for the five conditions were 4.34, 3.64, 4.04, 3.62, and 2.99, respectively. Both the Deconstruction-Mismatch and Ready Made-Mismatch conditions exhibited more negative N400 amplitudes over the anterior region compared with the Normal-Match condition.

The global ANOVA showed that the main effect of the condition was significant ($F[4,68] = 3.35$, $p = .05$, $\varepsilon = .8$). The interaction between condition and anterior–posterior location was also significant ($F[8,136] = 9.85$, $p < .001$, $\varepsilon = .39$), which suggested that different conditions (art style pairings) resulted in activation of different brain areas.

Table 2
Behavioral results for the “match” responses for Normal table–chair pairs (standard deviation of the mean in parentheses).

Table/chair	Match response for Normal table–chair pairs (%)								
	1st	2nd	3rd	4th	5th	6th	7th	8th	Mean
1st	33 (49)	72 (46)	61 (50)	72 (46)	39 (50)	61 (50)	72 (46)	61 (50)	59 (48)
2nd	50 (51)	61 (50)	39 (50)	67 (49)	39 (50)	39 (50)	61 (50)	44 (51)	50 (50)
3rd	61 (50)	78 (43)	44 (51)	67 (49)	78 (43)	61 (50)	61 (50)	50 (51)	63 (48)
4th	61 (50)	44 (51)	44 (51)	50 (51)	33 (49)	33 (49)	44 (51)	33 (49)	43 (50)
5th	33 (49)	78 (43)	67 (49)	61 (50)	33 (49)	56 (51)	61 (50)	61 (50)	56 (49)
6th	67 (49)	67 (49)	33 (49)	72 (46)	50 (51)	28 (46)	72 (46)	33 (49)	53 (48)
7th	50 (51)	56 (51)	72 (46)	44 (51)	17 (38)	33 (49)	67 (49)	28 (46)	46 (48)
8th	28 (46)	89 (32)	61 (50)	72 (46)	39 (50)	56 (51)	67 (49)	50 (51)	58 (47)

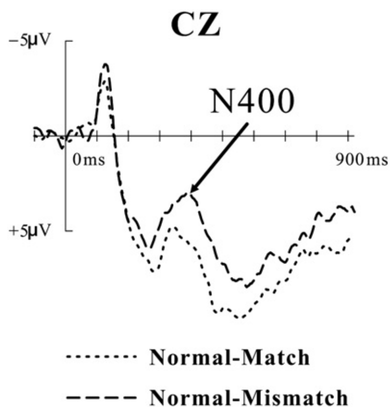

Fig. 2. Grand average ERP waveforms showed N400 effects in Normal-Match and Normal-Mismatch conditions (N400: 300–500 ms).

3.3.1. Prototypical category

Fig. 2 shows the averages of the ERPs associated with the Normal-Match and Normal-Mismatch conditions. To reflect the effects of prototypicality in the Normal style, the Normal-Match condition was used to provide a baseline for comparison. We predicted that the Normal-Mismatch condition would evoke the N400 effect; thus, Normal-Mismatch condition could not be subjected to further ERP analysis.

A comparison between the Normal-Mismatch and Normal-Match conditions showed a significant interaction between the condition and the left–right location ($F[2,34]=5.55$, $p<.01$, $\varepsilon=.93$). There was a greater N400 effect for the Normal-Mismatch condition than for the Normal-Match condition at the left, medial and right scalp locations ($F[1,17]=5.77$, $p<.05$; $F[1,17]=10.49$, $p<.01$; and $F[1,17]=8.58$, $p<.01$, respectively), which suggested that the N400 effect in the Normal-Mismatch condition may have led to a distortion of the distribution of voltage over the scalp, thereby reducing the observable changes in ERPs.

3.3.2. Non-prototypical category

Fig. 3 shows the ERP averages in the Normal-Match, Minimal-Mismatch, Deconstruction-Mismatch, and ReadyMade-Mismatch conditions. Secondary analyses of ERP data from Normal-Match vs. ReadyMade-Mismatch conditions showed that both the main effect of condition and its interaction with anterior–posterior location were significant ($F[1,17]=6.14$, $p<.05$ and $F[2,34]=10.26$, $p<.01$,

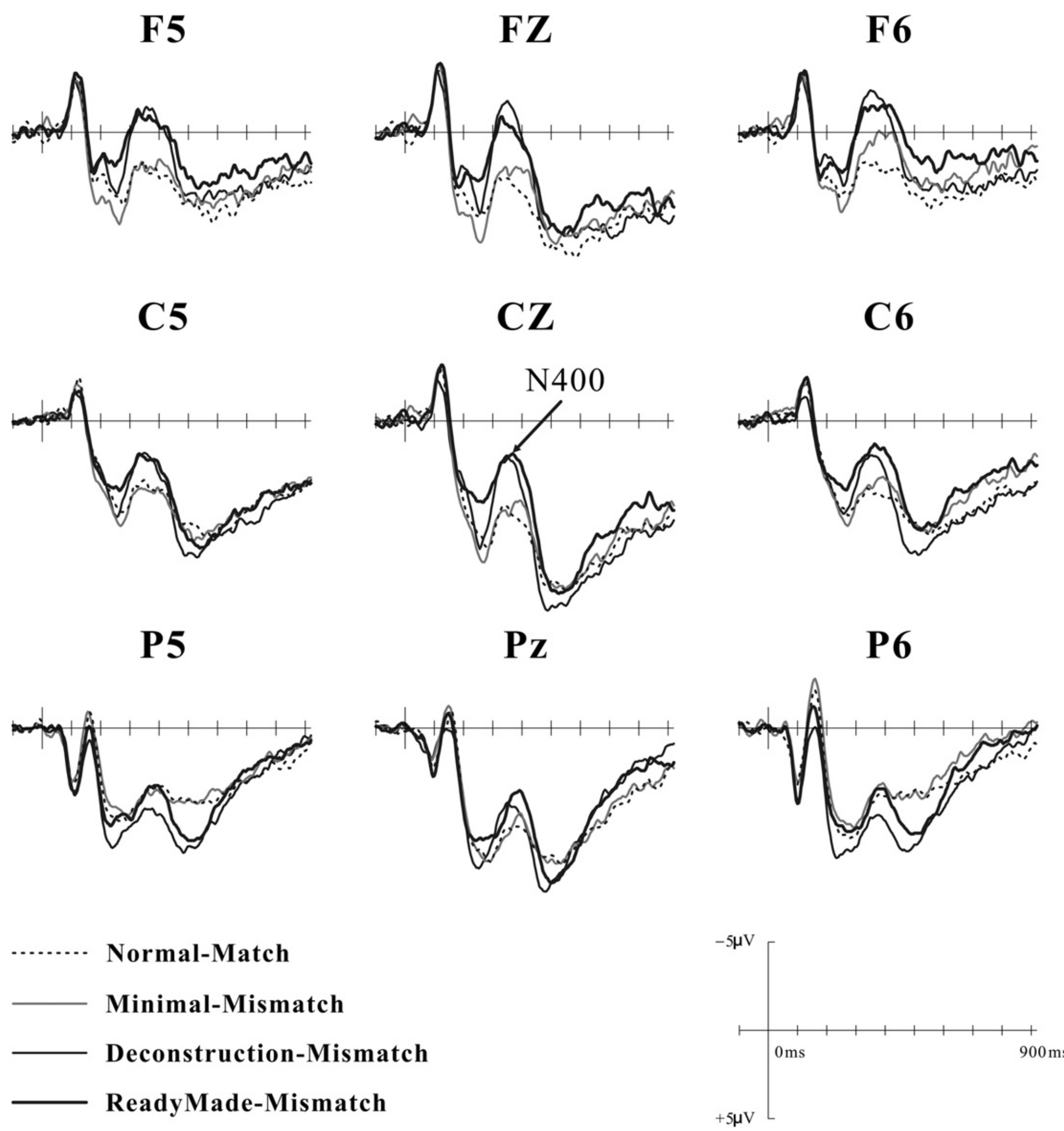

Fig. 3. Grand average ERP waveforms showed N400 effects for the Normal-Match, Minimal-Mismatch, Deconstruction-Mismatch, and ReadyMade-Mismatch conditions (N400: 300–500 ms).

Table 3
Group mean N400 amplitudes of the responses to Normal-Match, Normal-Mismatch, Minimal-Mismatch, Deconstruction-Mismatch, and ReadyMade-Mismatch conditions that were recorded from 27 electrodes over 9 regions of the scalp: left anterior (F7, F5, F3), medial anterior (F1, Fz, F2), right anterior (F4, F6, F8), left central (T7, C5, C3), medial–central (C1, Cz, C2), right central (C4, C6, T8), left posterior (P7, P5, P3), medial–posterior (P1, Pz, P2), and right posterior (P4, P7, P8).

Condition	Left anterior	Middle anterior	Right anterior	Left central	Middle central	Right central	Left posterior	Middle posterior	Right posterior
Normal-Match	2.70 (4.85)	3.97 (6.83)	2.45 (5.02)	4.54 (4.76)	6.53 (6.84)	4.72 (4.76)	3.71 (2.77)	6.21 (4.00)	4.22 (3.10)
Normal-Mismatch	1.67 (3.98)	1.92 (4.77)	0.82 (3.70)	3.39 (3.90)	4.36 (5.19)	3.48 (3.69)	3.08 (3.31)	4.47 (3.78)	3.30 (2.79)
Minimal-Mismatch	2.71 (5.10)	3.46 (6.00)	1.49 (4.44)	4.63 (4.61)	6.11 (5.64)	4.42 (4.15)	3.67 (3.44)	5.91 (3.84)	3.96 (2.73)
Deconstruction-Mismatch	0.58 (4.72)	1.23 (5.50)	−0.22 (4.79)	3.86 (4.63)	5.38 (6.08)	4.02 (4.81)	5.04 (3.82)	6.66 (4.91)	5.99 (3.40)
ReadyMade-Mismatch	0.46 (4.75)	1.35 (5.20)	−0.28 (4.64)	3.33 (4.26)	4.31 (5.29)	2.82 (3.99)	4.35 (2.96)	5.77 (3.72)	4.78 (2.54)

$\varepsilon = .65$, respectively). There was a greater negativity in the Ready Made-Mismatch condition than in the Normal-Match condition, and this N400 effect was most pronounced at the anterior and central sites ($F[1,17] = 9.68$, $p < .01$; $F[1,17] = 6.70$, $p < .05$). A comparison between the Deconstruction-Mismatch and Normal-Match conditions revealed a significant interaction between condition and anterior–posterior location ($F[2,34] = 16.26$, $p < .001$, $\varepsilon = .62$). Follow-up analyses revealed a greater N400 effect for the Deconstruction-Mismatch condition than for the Normal-Match condition at the anterior sites ($F[1,17] = 9.69$, $p < .01$), but a positivity to Deconstruction-Mismatch over the posterior sites ($F[1,17] = 5.33$, $p < .05$). A comparison between the Minimal-Mismatch and Normal-Match conditions revealed no significant effects of the condition factor.

3.4. Topographic analysis

Because the ReadyMade-Mismatch and Deconstruction-Mismatch conditions produced greater N400 effects than the Normal-Match condition, we examined whether the N400 effect for these two styles of chairs exhibited different scalp distributions. Two different waves were generated by subtracting the Normal-Match waveforms from the ReadyMade-Mismatch and Deconstruction-Mismatch waveforms. The waves from the 62 scalp electrode sites were range-normalized using the max–min method to avoid any confounding effects in the magnitudes of the two effects and the differences in scalp distribution (McCarthy and Wood, 1985). The range-normalized data were then entered as a factor with 62 levels (all of the scalp electrodes) in the topographical analysis (Fig. 4). A secondary ANOVA was performed on the differences between these two conditions and the anterior–posterior caudality (medial anterior, medial central, medial posterior) of the scalp electrode locations.

The global ANOVA showed a significant interaction between condition and recording site ($F[61,1037] = 2.77$, $p < 0.001$, $\varepsilon = 0.08$). Based on the scalp topography (Fig. 4), the ReadyMade chair condition seems to exhibit a more widespread distribution over the anterior region than the Deconstruction chair stimulus. Secondary analyses revealed a significant interaction between the condition and the anterior–posterior location ($F[2,34] = 3.72$, $p < .05$, $\varepsilon = .93$), which suggested that the N400 effects for these two chairs had different topographic distributions over the medial region.

4. Discussion

This study examined how the brain responds to variations in the artifactual prototypicality within the same semantic category. The results indicate that a stronger variation in style elicits stronger N400 effects within the same semantic category. The participants easily recognized conspicuous styles as non-prototypical. The ERP results provided evidence that ReadyMade and Deconstruction styles elicited larger N400 amplitudes. In addition, the N400 effects of these two styles had different topographic distributions, indicating that these styles may have unique characteristics. As a result, the comparison of four "within-category" styles in this study is similar to that of "prototypical categories" and "non-prototypical categories" (Pritchard et al., 1991; Stuss et al., 1988). This observation shows that for natural objects (Paz-Caballero et al., 2006; Proverbio et al., 2007) and artificial objects, the non-prototypical categories elicited a greater negative N400 effect than the prototypical categories. We consider evidence for these conclusions separately in the following sections.

4.1. Semantic style-match judgments

Based on behavioral data (Table 1), the high proportion of match responses to Normal table–chair pairs may indicate a lack of fit with an ideal table–chair prototype. In the current study, however, none of these Normal table–chair pairs was a set (see Fig. 1) in that they were not paired together; thus, they do not match coherently to be considered a furniture set. It is possible that participants responded based on shape differences between the table and chair stimuli (e.g., a table with a rectangular top surface vs. a chair with a rounded seat; a low table vs. a high chair). Another possible reason for the high proportion of match responses is that the participants in this study had varied degrees of agreement with the semantic style-match judgments predetermined by the investigators. Not everyone has the same preferences or finds the same elements to be pleasing.

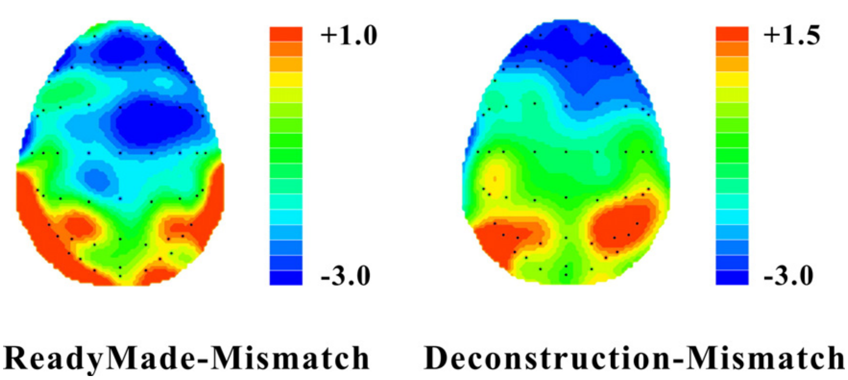

Fig. 4. Voltage spline maps showing that the topographies of N400 effects of the semantic mismatch were different in the ReadyMade-Mismatch and Deconstruction-Mismatch conditions during the 300–500 ms time period.

However, we believe that future studies could be improved if the Normal control set of stimuli consisted of a more formal match set of tables–chairs to obtain more consistent responses.

The RT data in Table 1 may also suggest the presence of negative priming for some conditions. However, statistical analyses did not support this hypothesis, even though participants took longer to make a judgment for the Normal chairs than for the bizarre Deconstruction and ReadyMade chairs. The more likely explanation is that Normal table–chair pairs rely to a greater degree on similar perceptual dimensions, including shading, texture, color, surface detail, and the spatial arrangement of features (Bruce and Humphreys, 1994; Gerlach et al., 2004; Laws and Neve, 1999; Turnbull and Laws, 2000). However, the bizarre chairs in the Deconstruction and ReadyMade styles have more distinct features that make them easier to identify.

Nevertheless, these findings revealed the inconsistency between ERPs and associated behaviors. Neely (1991) has shown that the semantic priming effect could be subserved by multiple mechanisms, including automatic spreading activation and strategically controlled processes of expectancy priming and semantic matching/integration. The semantic priming effects elicited by the primers may involve non-equivalent mechanisms; it is possible that the measurement of RT was not precise enough to differentiate between these mechanisms (Heil et al., 2004; Neely and Kahan, 2001; Rolke et al., 2001).

4.2. N400 effect

The unrelated components of ReadyMade objects have an important influence on the perception of the whole and produced similar effects on between-category tasks. For instance, participants initially might have confused the guitar chair for a musical instrument (Fig. 1). Similar to the Deconstruction objects, even while maintaining a vague impression of chairs, ReadyMade objects may confuse people (Fig. 1) because their fragmentary and distorted features are too far from the ideal chair type. Evidence supporting this notion comes from studies (Moore and Price, 1999) that found that the processing of multicomponent objects (e.g., animals and vehicles) caused greater activation than the processing of objects with simple shapes (e.g., vegetables and fruit). However, the activation of anterior brain regions with Deconstruction style objects is inconsistent with the previous suggestion that activation of the posterior regions may reflect access of stored integrated perceptual features (Gerlach et al., 2004). We inferred that the participants do not need to identify the style of a stimulus (e.g., Deconstruction) because they already knew what is a chair was before the experiment. Consequently, it is reasonable to suggest that the activation of the anterior regions reflects access to semantic knowledge (Guerra et al., 2009; Bobes et al., 1996).

In addition, it would be interesting to clarify why a match response to Normal chairs and a mismatch response to Minimal chairs evoked similar ERPs. One explanation may be that as Minimal chair designs generally have fewer elements than Normal chairs, they possess the essential form of a chair, which is not much different from the form found for an archetypical chair. Therefore, it would be difficult to discriminate between Normal and Minimal styles based on their appearances and structures. Another possible reason may be that the repetition of stimuli masks N400 amplitudes. Debruille and Renoult (2009) suggested that the semantic processes indexed by the N400 component could be absent for the stimuli that have already been presented multiple times. This possibility raises other questions about the effects of repetition priming on ERP data and may hinder interpretation of the data. However, we believe that our conclusions are still valid for the following reasons. First, the repetition was equivalent for all types of stimulus pairs. Should any influence or effect be caused by the repetition of the stimuli, it should be the same for all conditions. Second, in the experimental design, there was no repetition of stimuli, either of the prime or the target, in two consecutive trials, so the immediate, short-term repetition effect frequently observed in previous studies was avoided in the current study. We predict that the N400 effects would be more robust if we had a sufficient number of stimuli such that none was repeated.

Although the present study offers new insights about the N400 component of the ERP, it has some limitations. The first limitation is that the generalization of the results to other populations with different educational backgrounds may be limited. The sensitivity of semantic recognition may depend on participant expertise. For example, because the participants in this study were not familiar with styling, experts might have been better able to detect the small feature differences between stimuli on the within-category identification task. Professional designers, therefore, would likely exhibit a greater N400 effect than the general public, even when comparing Minimal-Mismatch with Normal-Match chairs. The second limitation is that this study used only Normal table stimuli; as a result, the N400 results in the current study cannot be generalized to these three style designs. Finally, methodological problems in the research design limit the interpretations of the N400 scalp topography associated with ReadyMade chair and Deconstruction chair stimuli. The perception of these two chair styles may involve additional semantic networks. It can only be stated that the topographic distribution of activation in response to the stimuli was different distributions for ReadyMade and Deconstruction chairs over the medial scalp region.

Even though the application of neuroscience and ERPs is rather new in the design field, this experiment has successfully evoked the participants' varied ERP amplitude by presenting chairs with different styles. We suggest that future research should adopt a hierarchical structure of the spectrum of artistic styles. This study has confirmed that the ERP method can aid design research beyond the scope of traditional methods (e.g., the SD method and the MDS method). Additionally, this study could make use of semantic networks to provide greater understanding of the N400 component of the ERP. We acquired valuable experience in employing this new tool, acknowledged the limitations of ERP, and recognized that there is still more knowledge to be uncovered. It is hoped that the current findings will promote the application of the ERP method to design studies.

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