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Authors

Terai, Hitoshi
Miwa, Kazuhisa
Mizuno, Syunsuke

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Development of a Design Database and Experimental Discussion of Brain Activations for Creativity Assessment

Hitoshi Terai (terai@is.nagoya-u.ac.jp)

Kazuhisa Miwa (miwa@is.nagoya-u.ac.jp)

Syunsuke Mizuno (mizuno@cog.human.nagoya-u.ac.jp)

Graduate School of Information Science, Nagoya University, Furo-cho, Chikusa-ku
Nagoya, 464-8601 Japan

Abstract

This study proposed a design database consisting of creative and noncreative designs for creative research and discussed the correlation between creative assessment and brain activities using fMRI. We answered the following two research questions: which brain areas are activated when assessing creative designs in contrast to noncreative designs and does social evaluation influence creativity assessment based on subjective criteria. The left inferior and middle temporal gyri (BA 37) were activated when assessing creative designs in contrast to noncreative designs. These activations suggest that an inference process to understand meanings underlying creative designs is important in creativity assessment. The left superior temporal gyrus (BA 38) was more activated when assessing creative designs with inconsistent social evaluations than without social evaluations; whereas, the decision behavior for creativity assessment was robust. This result suggests that the participants might consider the intentions of evaluation of others when inconsistent social evaluations are presented.

Keywords: Creativity; Assessment; fMRI; Social evaluation.

Introduction

The manner of assessing creative products is one of the central issues when assessing creative ability, evaluating creative process, and validating the effectiveness of creative education (Plucker & Makel, 2010). Finke (1990) proposed a definition of creativity rating along two dimensions: practicality and originality. Creative inventions were defined as practical inventions that were rated as original (Finke, 1990; Finke et al., 1992).

On the other hand, it has been pointed out that such definitions affect the validity of creativity which people feel intuitively to products (Amabile, 1982; Amabile et al., 1996). Amabile (1982) hypothesized that “a product or response is creative to the extent that appropriate observers independently agree it creative” and proposed the Consensual Assessment Technique (CAT) (Plucker & Makel, 2010). The CAT requires judging products’ creativity based on the criteria of one who has competence in related regions.

Cognitive Neuroscience Approach to Creativity Assessment

Measuring a product’s creativity is among the most important aspects in studies of creative cognition; several aspects have been developed as mentioned above. On the other hand, it might be possible to reconsider creativity assessment from the viewpoint of brain activities. In recent years, brain mechanisms underlying higher-order cognition including creative

cognition have been revealed with the development of brain imaging techniques (Dietrich & Kanso, 2010; Fink et al., 2007; Sawyer, 2011).

For example, Kowatari et al. (2009) discussed generative processes of creative designs using fMRI (functional Magnetic Resonance Imaging). They introduced an artistic task, i.e., designing a new pen, and discussed correlations between the creativity of products evaluated by indices of originality and brain activities of generative processes. They confirmed the hypothesis that training increases creativity via reorganized intercortical interactions.

Ellamil et al. (2012) also tried to distinguish between two components of creative cognition, generation and evaluation processes, at the neural level using fMRI. Participants were required to design book cover illustrations while alternating between the generation and evaluation of ideas using an fMRI-compatible drawing tablet. Their findings suggest that the medial temporal lobe may be central to the generation of novel ideas, and creative evaluation may extend beyond deliberate analytical processes supported by executive brain regions to include more spontaneous affective and viscerosensitive evaluative processes supported by default and limbic regions.

Creative research with a cognitive neuroscience approach has examined both generation and evaluation processes in creative cognition. However, most of the cognitive neuroscience research of creative cognition has focused on evaluation processes within generative processes; products for evaluation were self-generated. However, there is little literature discussing correlations between creativity assessment and brain activity. To conduct experiments focusing on creativity assessment, controlled stimulation is necessary.

Therefore, this study proposed a design database consisting of both creative and noncreative designs for use in creativity assessment research. Moreover, we discussed differences in brain activities between assessing creative and noncreative designs.

Effects of Social Evaluation for Creativity Assessment

Creativity assessment based on one’s own criteria might be influenced by various cognitive biases because it is not possible to refer to objective criteria. Moreover, there are two different types of creative, p-creativity (psychological creativ-

Table 1: List of 18 categories implemented in the design database

<i>Cup</i>	<i>Seesaw</i>	<i>Table lamp</i>	<i>Table</i>	<i>Hair dryer</i>	<i>Swing</i>
<i>Penholder</i>	<i>Boat</i>	<i>Glasses</i>	<i>Chair</i>	<i>Vase</i>	<i>Flashlight</i>
<i>Chute</i>	<i>Bag</i>	<i>Umbrella</i>	<i>Clock</i>	<i>Cleaner</i>	<i>Shelf</i>

ity), and h-creativity (historical creativity); they are sometimes confused (Boden, 2003). Therefore, the perspective of social evaluation might bias creativity assessment as p-creativity.

There are many experimental studies in social psychology about the influence of social evaluation on attitudes, beliefs, and decision-making. Especially, conformity, which is the act of matching attitudes, beliefs, and decision-making to group norms, was confirmed through many social psychological studies (Asch, 1955). Thus, creativity assessment based on one’s own naïve criteria might be influenced by social evaluations.

Therefore, this study discusses influences of social evaluation on assessing creative designs.

Purpose

This study aimed to develop a design database consisting of both creative and noncreative designs to be used in creativity research. In addition to developing the database, we tried to reveal the relationship between brain activities and creativity assessment. The following two research questions (RQs) were addressed:

RQ1: Which brain areas are activated when assessing creative designs in contrast to noncreative designs?

RQ2: Does social evaluation influence creativity assessment based on subjective criteria?

Design Database

The design database consists of 18 design categories, which are items from daily life, and do not require specific knowledge to assess their creativity. Table 1 shows the list of items.

Each design was generated based on the procedure of the design task introduced by Finke et al. (1992) known as one of the typical design tasks in the study of creativity. As shown in Figure 1, each category consists of four designs: three creative designs and one noncreative design.

Each design was gathered and refined by the following three steps. First, twenty one undergraduates majoring in design were recruited to sketch objects’ design from the four categories, which were randomly assigned to them. Second, the authors sorted out these rough designs and refined them based on previous criteria by mutual agreement. Finally, the selected designs were converted to 3D modeling data to reduce habits of touch and to make them easy to use as experimental materials.

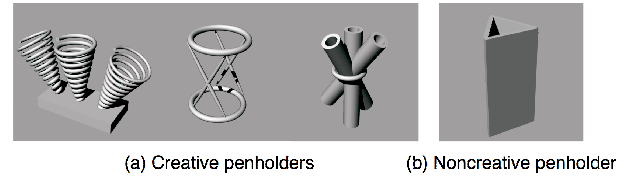


Figure 1: Examples of penholder designs

Experiment 1

In this experiment, we confirmed the validity of our database.

Methods

Participants One hundred and thirty three undergraduates participated in the assessment experiment: 84, 24, and 23 undergraduates were assigned to perform assessment tests about creativity, originality, and practicality of the test items.

Procedure The designs were randomized and presented to the participants sequentially. The designs were rated along three dimensions, using a 7-point scale. In the creativity assessment, the participants were required to assess the creativity of the designs according to each person’s own criteria. On the other hand, in the originality assessment, the participants were required to assess the originality of the items according to the concrete criteria, i.e., “How original is the design from the viewpoint of producing by one’s unique thought?” In the practicality assessment, the participants were also required to evaluate the practicality of the items according to the concrete criteria, i.e., “How practical is the design from the viewpoint of usefulness when it is actually used?”

Moreover, each assessment was repeated a week later to ensure intrapersonal consistency in the creativity assessments in contrast to the originality and practicality assessments.

Results

Two-way between-participants ANOVAs for the design factor (three creative designs and a noncreative design) and the repetition factor (first assessment and second assessment) in each category showed significant main effects of the design factor (creativity: $F_s(3, 249) > 35.12, ps < .001$; originality: $F_s(3, 69) > 51.48, ps < .001$; practicality: $F_s(3, 66) > 13.33, ps < .001$). The multiple comparisons using Ryan’s method showed that the creativity of the creative designs was higher than that of the noncreative designs ($ps < .05$), whereas a few category showed main effects of the repetition factor and interactions. In the results of the originality assessment, the originality of the creative designs was also higher than that of the noncreative designs ($ps < .05$). The results of the practicality assessment showed that the practicality of the noncreative designs was higher than those of the creative designs ($ps < .05$), whereas a few category showed main effects of the repetition factor and interactions.

Next, we calculated intrapersonal assessment consistencies between the first and second assessment results using

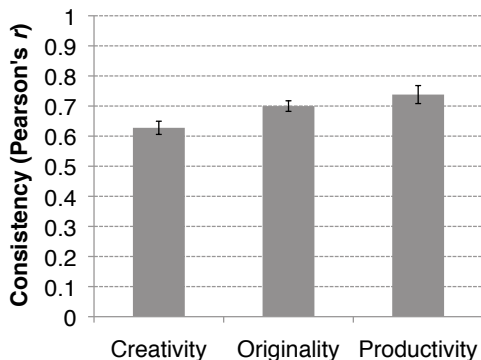


Figure 2: Intrapersonal consistencies of assessment tests

Note. Error bars indicate standard errors.

Pearson's product-moment correlation coefficient. Figure 2 shows the average of intrapersonal assessment consistencies in each assessment test. The result of the interpersonal consistency of the creativity assessment shows moderate correlation as well as both the originality and productivity assessments, although a one-way ANOVA for these intrapersonal assessment consistencies showed significant main effects ($F(2, 128) = 4.21, p < .05, \eta^2 = .06$) and significant difference between the creativity and productivity assessments (Ryan's method, $p < .05$).

The results are summarized as follows: First, there are distinct differences in each assessment between the three creative designs and the noncreative design in each category. Second, we confirmed the intrapersonal consistencies of creativity assessment according to subjective criteria similar to originality and practicality assessments based on objectively-defined criteria.

Experiment 2

Next, we revealed (1) differences in brain activities between when a person was assessing creative and noncreative designs and (2) influences of social evaluations (creative, noncreative, and without evaluations) when assessing creative designs.

Methods

Participants Twenty healthy, right-handed undergraduate students (18 to 21 years old; 9 males and 11 females) participated in this experiment. The participants were native Japanese speakers and their handedness was assessed by a modified Oldfield questionnaire (Oldfield, 1971). The participants provided written informed consent in accordance with the research ethics committee guidelines of Nagoya University's Research Institute of Environmental Medicine.

Design In the experiment, we focused on four conditions based on two factors: creativity of designs and social evaluations of creative designs. Table 2 shows the matrices and four experimental conditions.

The creativity of design factor included two levels: creative

Table 2: Experimental design

		Design	
		Creative	Noncreative
Social evaluation	None	(B) ← → (A)	
	Consistent	(C)	-
	Inconsistent	(D)	-

↔ Discussion of RQ1
 ↔ Discussion of RQ2

and noncreative designs. The discussion of RQ1 was based on a comparison between Table 2 (A) and (B).

On the other hand, the social evaluations of the creative design factor included three levels. In the consistent condition, a social evaluation as "creative" for the creative designs was presented. In the inconsistent condition, a social evaluation as "ordinary" for the creative designs was also presented. In the none condition, no social evaluations were presented. The discussion of RQ2 was based on comparisons between Table 2 (B) and (C), and (B) and (D).

Procedure Participants were given a practice session using two examples outside the MRI scanner. Following the practice session, they engaged in 72 trials while in the scanner. The trials consisted of evaluating 54 creative designs and 18 noncreative designs.

Figure 3 illustrates the experimental sequence. Following a fixation point and a category name, each design was presented to the participants for up to approximately eight seconds. The participants instructions were as follows: "Some designs had been evaluated on their creativity by approximately a thousand raters. Therefore, if designs had evaluation results, the evaluation results, creative or ordinary, would be presented with the category names." Category names for one-third of 54 creative designs received an added adjective, "creative," as did the results of social evaluation randomly (consistent condition). In the same manner, category names for one-third of the items received the added adjective, "ordinary" (inconsistent condition). The rest of the items were not presented with such social evaluations (none condition).

Participants were required to press the corresponding buttons assigned to the index and middle fingers of their right hand when deciding whether presented design was creative. This sequence was repeated 72 times. The experiment consisted of two fMRI runs.

Imaging Data Acquisition Scans of the whole-brain images were acquired by using a gradient echo planar image acquisition on a 3T MRI Scanner (Siemens Verio, Siemens Healthcare, Erlangen, Germany). The functional imaging parameters were TR = 2.5 s, TE = 30 ms, FA = 70°, VoF = 20 cm × 20 cm, and 39 slices. To avoid head movement, the participants wore a neck brace and were asked not to talk or move during the MRI scan. High-resolution anatomical im-

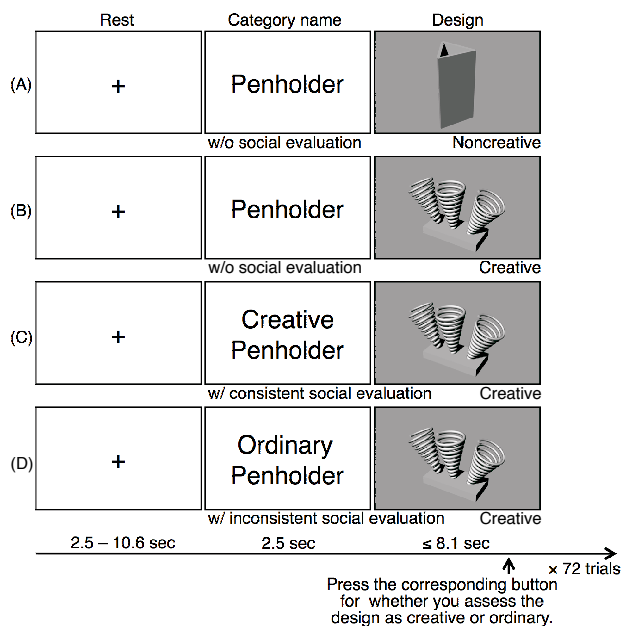


Figure 3: Experimental sequence

Note. (A), (B), (C), and (D) correspond to the experimental conditions in Table 2.

ages (T1) were also acquired by using gradient echo planar image acquisition. We acquired T1 images (TR = 2.5 s, TE = 2.48 ms, FA = 8°) with 192 sagittal slices, each being 1 mm in thickness. Motion correction was also performed in a standard realign process in SPM8.

Imaging Data Analysis The imaging data were analyzed using SPM8. Each participants' imaging data was individually preprocessed (realignment, slice time adjustment, normalization, smoothing) and the spatially preprocessed data was then estimated to establish a random effects model. The statistical threshold was set at $p < .001$, uncorrelated with an extended threshold of 10 contiguous voxels.

Results

Behavioral Results Figure 4 shows the results of the average ratio of assessing the designs as creative. Figure 4 (a) shows the results of the comparison between the noncreative design and the creative design without social evaluation (corresponding to Table 2 (A) and (B)). Figure 4 (b) also shows the results of the comparison among social evaluations: none, consistent, and inconsistent (corresponding to Table 2 (B), (C), and (D)).

A t -test detected a significant difference between the ratio of assessing the designs as noncreative and creative as shown in Figure 4 (a) ($t(19) = 18.69, p < .000, r = 0.97$).

On the other hand, a one-way between-participants ANOVA for the social evaluation conditions (none, consistent, and inconsistent) showed no difference among them ($F(2, 39) = 0.80, p = .46, \eta^2 = .04$).

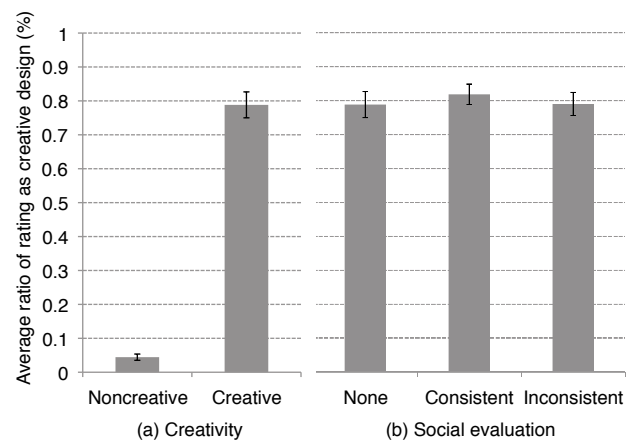


Figure 4: Results of assessment

Imaging Results Next, we compared brain activities in both the design and social evaluation factors.

The results of the contrasts between assessing the noncreative and creative designs are as follows.

Creative > Noncreative

This contrast examined the brain areas that were more activated during assessment for the creative designs than for the noncreative designs. Several peaks of activation were found, including left and right inferior temporal gyri (BA 37), left middle temporal gyrus (left BA 37), right fusiform gyrus (BA 37), right middle occipital gyrus (BA 19), left inferior frontal gyrus (BA 44), left superior frontal gyrus (BA 8), left middle occipital gyrus (BA 18), right superior occipital gyrus (BA 19), and right middle temporal gyrus (BA19) (Table 3 (a)). Figure 5 (a) depicts these areas of activation.

Noncreative > Creative

This contrast examined the brain areas that were more activated during assessment for the noncreative designs than for the creative designs. Several peaks of activation were also found, including left medial frontal gyrus (BA 9), left supramarginal gyrus (BA 40), left inferior temporal gyrus (BA 20), right middle temporal gyrus (BA 21), and right supramarginal gyrus (BA 40) (Table 3 (b)). Figure 5 (b) depicts these areas of activation.

The results of the contrast between assessing the creative designs without social evaluation and with the consistent social evaluation, and without social evaluation and with the inconsistent social evaluation are as follows.

Inconsistent > None

This contrast examined the brain areas that were more activated during evaluation of the creative designs with the inconsistent social evaluation rather than for the creative designs without social evaluation. Several peaks of activation were also found, including left superior temporal gyrus (BA 38) and left parahippocampal gyrus (BA 36) (Table 3 (c)). Figure 5 (c) depicts these areas of activation.

Consistent > None, None > Consistent, None > Inconsistent

Table 3: Activation peaks during creative assessment

(a) Creative > Noncreative									
Cluster	Voxel			MNI coordinates			Region	BA	
	k_E	T	Z	p_{unc}	x	y			
108	5.28	4.09	0.000	-48	-67	-5	Left Inferior Temporal Gyrus	37	
	4.55	3.69	0.000	-57	-52	-14	Left Middle Temporal Gyrus	37	
111	4.95	3.92	0.000	51	-58	-14	Right Middle Occipital Gyrus	19	
	4.61	3.73	0.000	60	-61	-11	Right Inferior Temporal Gyrus	37	
74	4.26	3.52	0.000	42	-64	-11	Right Fusiform Gyrus	37	
	4.74	3.80	0.000	-54	17	22	Left Inferior Frontal Gyrus	44	
17	4.33	3.57	0.000	-3	20	55	Left Superior Frontal Gyrus	8	
13	4.17	3.47	0.000	-39	-94	7	Left Middle Occipital Gyrus	18	
26	3.88	3.29	0.001	33	-76	22	Right Superior Occipital Gyrus	19	
	3.78	3.22	0.001	33	-85	28	Right Superior Occipital Gyrus	19	
	3.75	3.20	0.001	39	-82	22	Right Middle Temporal Gyrus	19	
(b) Noncreative > Creative									
Cluster	Voxel			MNI coordinates			Region	BA	
	k_E	T	Z	p_{unc}	x	y			
29	5.32	4.11	0.000	-6	47	28	Left Medial Frontal Gyrus	9	
31	4.84	3.86	0.000	-60	-58	28	Left Supramarginal Gyrus	40	
	4.09	3.42	0.000	-51	-49	28	Left Supramarginal Gyrus	40	
11	4.82	3.85	0.000	-48	-13	-35	Left Inferior Temporal Gyrus	20	
51	4.66	3.76	0.000	69	-25	-8	Right Middle Temporal Gyrus	21	
	4.17	3.47	0.000	63	-22	-17	Right Middle Temporal Gyrus	21	
11	4.00	3.37	0.000	63	-52	31	Right Supramarginal Gyrus	40	
(c) With inconsistent social evaluation > without social evaluation									
Cluster	Voxel			MNI coordinates			Region	BA	
	k_E	T	Z	p_{unc}	x	y			
10	5.01	3.95	0.000	-39	20	-35	Left Superior Temporal Gyrus	38	
23	4.42	3.62	0.000	-27	-34	-35	Left Culmen	-	
	4.33	3.57	0.000	-24	-31	-20	Left Parahippocampal Gyrus	36	
	4.11	3.43	0.000	-21	-34	-29	Left Culmen	-	

N = 20; $p < .001$ (uncorrected w/ extended threshold of 10 contiguous voxels)

These comparisons showed that no voxels were activated.

Discussion and Conclusions

This study proposed a design database consisting of creative and noncreative designs for creative research. The first experiment confirmed the validity of the creative and noncreative designs.

We now discuss (1) brain areas related to creativity assessment and (2) effects of social evaluation when assessing creative designs.

Brain Areas Related to Creativity Assessment

The left inferior and middle temporal gyri (BA 37) were more strongly activated when assessing creative designs rather than noncreative designs. Several studies have reported that the left inferior temporal gyrus (BA37) correlates with metaphor processing (Rapp et al., 2004), attention to semantic relations (McDermott et al., 2003), and deductive reasoning (Goel et al., 1998). Our results suggest that an inference process to understand design intents underlying creative designs is important in creativity assessment.

Moreover, the left superior frontal gyrus (BA8) was also more activated when assessing creative designs rather than noncreative designs. This area is involved in the management of uncertainty. The fMRI study demonstrated that BA 8 activation occurs when test subjects experience uncertainty and that with increasing uncertainty there is increasing activation (Volz et al., 2005). This activation as demonstrated in our

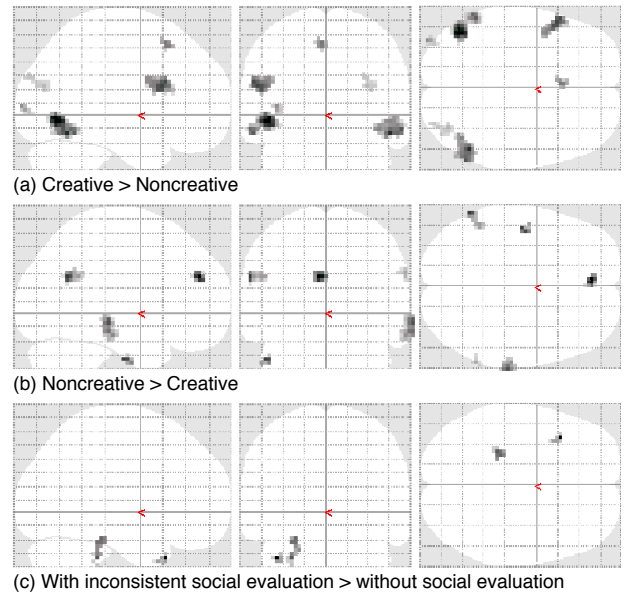


Figure 5: Activation areas during creative assessment

experiment suggests that assessing creative designs required even more uncertain decision-making than assessing noncreative designs.

Theory of Mind in Creativity Assessment

The behavioral results showed that there was no significant effect of social evaluation on creativity assessment behavior. During the brain activity, there were significant activations in brain areas when the inconsistent social evaluation was presented to the participants in contrast to when no social evaluation was presented: left superior temporal gyrus (BA 38) and left parahippocampal gyrus (BA 36).

Previous research has revealed that the temporal pole relates to social and emotional processing including theory of mind (Olson et al., 2007). For example, Grezes (2004) reported temporal pole activations when participants were asked to detect deception. Moll et al. (2002) also reported temporal pole activations when participants were asked to make moral decisions. Moreover, Carr et al. (2003) and Völlm et al. (2006) reported temporal pole activations while inferring the emotional state of others.

The left parahippocampal gyrus (BA 36) has been associated with many cognitive processes, including visuospatial processing and episodic memory (Aminoff et al., 2013). For example, Bar et al. (2008) proposed that this region should instead be seen as intrinsically mediating contextual associations and not place/scene processing or episodic memory exclusively. In their experiment, the parahippocampal gyrus (BA 36) was significantly activated when participants were shown colorful photographs of everyday scenes with strong context between a foreground object and a background in contrast to a weak context between them.

Our experimental results in this contrast are summarized

as follows: First, the activation of the left superior temporal gyrus (BA 38) in the inconsistent condition indicates that the participants considered the intentions of the evaluations of others; whereas, the decision behavior for creativity assessment was robust. Second, the activation of the left parahippocampal gyrus (BA 36) in the inconsistent condition indicates that participants might assess creative designs with inconsistent social evaluation based on concrete contexts.

Limitations and Future Works

We proposed a design database consisting of creative and noncreative designs for creative research. We also revealed brain areas related to assessing creative designs and the influence of inconsistent social evaluation on creativity assessment of creative designs.

However, there are several limitations to our study. We were not aware of the physical features related to the creativity of designs. Moreover, there was no evidence about the effects of social evaluations for noncreative designs despite discussing their effects on creative designs in our experiments.

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