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Associated and dissociated neural substrates of aesthetic judgment and aesthetic emotion during the appreciation of everyday designed products

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ABSTRACT

The aesthetics of designed products have become part of our life in modern society. This study explores the neural mechanisms of how aesthetic judgment and aesthetic emotion interplay during the appreciation of designed products that are commonly seen in daily life. Participants were 30 college students, and the stimuli were 90 pictures of everyday designed products. Based on an event-related paradigm, the findings of this study suggest that there are associative and dissociative neutral mechanisms underlying different types of aesthetic judgment and aesthetic emotion. The study identified the following main findings: (a) normative beauty and subjective beauty both involved the left anterior cingulate cortex (ACC); (b) subjective beauty and positive emotion both involved the right ACC; (c) subjective beauty and negative emotion both involved the precuneus; (d) subjective ugliness and negative emotion both involved the right inferior frontal gyrus; (e) subjective ugliness alone additionally activated the insula; and (f) subjective beauty alone additionally activated the caudate. The findings in this study shed light on complex but ordinary processes of aesthetic appreciation.

1. Introduction

Aesthetics have been identified as an important personal value from the very beginning of personality research (Townsend and Sood, 2012). Recently, the development of neroimaging techniques has led to a new approach for the study of aesthetics—neuroaesthetics. Neuroaesthetics focuses on the understanding of the neural basis of cognitive and affective processes that are engaged when a person takes an aesthetic approach toward a work of art, a nonartistic object, or a natural phenomenon (Nadal and Pearce, 2011). Aesthetics has a special relevance to consumer behaviour among the universal values in three ways: aesthetics is innately appreciated, has evolutionary benefits, and is applicable in a product context (Townsend and Sood, 2012). Good designs in modern societies usually combine technology, cognitive science, human need, and beauty. Therefore, utilizing the power of aesthetics is essential to well-designed products.

It has been suggested that aesthetic judgment and emotion are critical processes of aesthetic appreciation (e.g., Chatterjee, 2011; Zangwill, 2014). Many studies have investigated the neural mechanisms of aesthetic judgment in the past decade, but only a few studies have focused on aesthetic emotion. Moreover, few of these related studies have explored the aesthetic processes of everyday designed products that are closely associated with our life, such as a cup, a clock, etc. There is also an ongoing debate over whether aesthetic emotion is a unique emotion or whether this emotion is the same as emotions that are elicited by everyday situations (Chatterjee, 2011). In addition, related findings revealed that aesthetic judgment activates different brain areas when viewing different types of stimuli (Kawabata and Zeki, 2004). Accordingly, this study investigated the neural mechanisms of aesthetic judgment and aesthetic emotion during the appreciation of everyday designed products, which elucidated the ordinary aesthetic process compared to more abstract arts.

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1.1. Theories of aesthetic judgment and emotion

According to Leder's (2013) information processing model of aesthetics, aesthetic experiences include the processes of perceptual analysis, implicit memory integration, explicit classification, cognitive mastery, and evaluation. Aesthetic judgment in the process of valuation is made based on interpretations in the stage of cognitive mastery. Moreover, aesthetic emotion, which is the by-product of the process of aesthetic experience, interacts with aesthetic judgment. In their proposed model of aesthetic experience, (Brattico et al., 2013) emphasized that aesthetic experience comes to full fruition by inducing emotions in the individual and by prompting an evaluative judgment.

It has been suggested that aesthetic emotion is elicited by the portrayal of emotional content to which we relate, and the identification of the factors that influence the arousal of such emotion has become a challenge for empirical aesthetics and neuroaesthetics (Nadal and Skov, 2013). Similarly, Armstrong and Detweiler-Bedell (2008) claimed that beauty is an emotion that bears directly on the mind's goal of understanding challenging stimuli when the potential to realize such understanding is tangible but distant. Over the last decade, researchers have agreed that art offers pleasing and positive emotions, although various explanations have been proposed. The inducing mechanism may, through interest and finding meaning (Leder et al., 2004; Jakesch and Leder, 2009), induce sudden insight (Kuchinke et al., 2009) and sensory attraction (Verpooten and Nellissen, 2010).

On the other hand, many researchers (e.g., Chatterjee, 2011; Zangwill, 2014) noted that aesthetic judgment is central to aesthetic processes. The most common contemporary paradigm of aesthetic judgment is judgment of beauty and ugliness. Kant identified two fundamental necessary conditions for a judgment to be a judgment of taste, subjectivity and universality (as cited in Zangwill, 2014). The subjective principle determines what pleases and what displeases us through personal feeling. Universality reflects the transcendental principle of the general acceptability that emerges from the cognitive capacity that everyone possesses. In other words, Kant emphasizes that judgment of taste must have a subjective principle but with universal validity (Atalay, 2007). In the same vein, Okanoya (2013) claimed that sensing is not only a biological-based, but also a normatively-founded process. Jacobsen and Schubotz (2006) also suggested that aesthetic judgments of beauty rely on a network which partially overlaps with that underlies evaluative judgments on social and moral cues.

Based on the aforementioned literature, we propose that the outcome of aesthetic appreciation includes an emotional component (aesthetic emotion), which is rather subjective, and a cognitive component (aesthetic judgment), which is both subjective and normative. The subjectivity is derived from varied personal experiences, and normativity developed from human cognitive capacity and the universal rules underlying beauty. Moreover, we suggest that aesthetic judgment and aesthetic emotion are interactive.

1.2. Neural mechanisms of aesthetic judgment and emotion

Past studies on aesthetic judgment have found consistent and inconsistent brain activations. For example, Bohrn et al. (2013) found that aesthetic evaluation activated the right caudate nucleus, anterior cingulate, and cerebellum. (Pöppel et al., Lutz) found activations in the anterior cortical midline structures, right superior frontal gyrus, and left superior, middle, inferior frontal gyrus (IFG), insular cortex, orbitofrontal cortex, and temporal pole in the "non-beautiful" to "beautiful" contrast. Vartanian and Goel (2004) found that activity within the occipital gyri bilaterally and left anterior cingulate increased with preference ratings, whereas activity within the right caudate decreased as preference ratings decreased.

Aesthetic judgment can also activate different brain regions when viewing different types of stimuli. Kawabata and Zeki (2004) asked participants to rate abstract, still life, landscape, or portrait paintings as beautiful, neutral, or ugly, and they found different patterns of activity within ventral visual cortex between the four types of stimuli. Vartanian and Goel (2004) found that presentational paintings provoked more activity in the occipital poles, precuneus, and posterior middle temporal gyrus than abstract paintings. Accordingly, we expected that there would be both similar and different brain activities during the viewing of designed products compared to other types of art.

With regard to emotions, the amygdala has been regarded as an essential part in processing both fearful and rewarding environmental stimuli (Janak and Tye, 2015). It has also been found that processing of emotional faces was associated with increased activation in a number of visual, limbic, temporoparietal, and prefrontal areas, the putamen, and the cerebellum; moreover, happy, fearful, and sad faces specifically activated the amygdala, and insular activation was selectively reported during processing of disgusted and angry faces (Fusar-Poli et al., 2009). In the same vein, it has been found that that when children responded to negative task trials, there was increased connectivity between amygdala and superior frontal gyrus and bilateral postcentral gyri (Hwang et al., 2014).

More recently, fMRI studies found that when consumers are exposed to a higher level of beautiful products, brain activations are similar to getting rewards; in contrast, exposure to a lower level of beauty results in similar brain activations as feelings of nausea or unfairness (Chatterjee, 2011). In addition, a cortical network that consists of the ACC and insular cortex involves the control of emotional processing (Craig, 2009; Critchley et al., 2004). Cupchik et al. (2009) found that aesthetic perception activated bilateral insula which they attributed to the experience of emotion; moreover, they found, while adopting the aesthetic orientation activated the left lateral prefrontal cortex, paintings that facilitated visuospatial exploration activated the left superior parietal lobule, suggesting that aesthetic experience is a function of the interaction between top-down orienting of attention and bottom-up perceptual facilitation.

1.3. Shared neural substrates of aesthetic judgment and emotion

A review of the neurobiology of beauty reveals that the experience of visual, musical, and moral beauty all correlate with activity in the medial orbito-frontal cortex (mOFC), which includes segments of Brodmann Areas (BA) 10, 12, and 32 (includes ACC) (Zeki et al., 2014). The ACC and insular cortex play significant roles in emotional responses and regulation. However, an overlapping circuitry involving the ACC and insula has been implicated across various cognitive tasks, which suggests that the functions of these structures also relate to information processing in general (Fan et al., 2011).

Moreover, it has been suggested that the cuneus or precuneus region is active in response to a wide variety of stimuli, including memory-related and selective attention processes (Blood et al., 1999) and attentively processed emotional information (Reske et al., 2009). Reviews of preference judgment also found that increasing preference for presented paintings led to increased activation in the left anterior cingulate sulcus, which is involved in reward-related processing of stimuli with different emotional valence (Dio and Gallese, 2009).

The aforementioned findings suggest that there are both shared and distinct neural mechanisms of aesthetic judgment and emotion; notably, ACC, pre(cuneus), and OFC may play important roles in the process of aesthetic appreciation. This study therefore aimed to explore the associated and dissociated neural substrates of aesthetic judgment and aesthetic emotion during the appreciation of everyday designed products. Notably, in a review of 551 fMRI studies on emotions, Fusar-Poli et al. (2009) found that the employed emotional conditions were negative emotion (sad, angry, disgust, and fearful) (49%), neutral (32%), and happy (19%); however, most studies compared the differences between two types of the emotions. It's also common that recent fMRI studies in aesthetics focus on emotional contrasts of positive emotion to negative emotion (e.g. Bertamini, Makin and Rampone, 2013; Vessel et al., 2012). In addition, recent studies have found that emotional arousal is critical to aesthetic responses (Bertamini, Makin and Rampone, 2013; Okanoya, 2013) and suggested that emotional arousal should be included to account for aesthetic experience. To get a better understanding of aesthetic emotions, we therefore included emotional arousal in the behavioral measures and investigated the contrasts between the positive, neutral, and negative emotion in the fMRI data.

2. Method

2.1. Participants

Thirty-three neurologically healthy, right-handed Taiwanese college students participated in this study. One participant fell asleep, and two participants did not complete the fMRI scan. Finally, 30 participants (14 males and 16 females) aged 20–29 (22.93 ± 2.595 years) were included in this study. All participants were Mandarin speakers and had normal or corrected-to-normal vision. They were pre-screened and had no history of previous neurological or neuropsychological disorders. Written informed consent was obtained from all participants, and the Research Ethics Committee of the National Taiwan University, Taiwan approved the study (approval number: 201301HS024). Approximately $23 was rewarded for participation.

2.2. Stimuli

Ninety pictures of everyday designed products were employed as stimuli through E-prime in the fMRI study. The pictures were selected from "Aesthetic Pictures of Everyday Designed Products (APEDP)", which was tested on a sample of 401 college students (Yeh, 2013). APEDP includes 412 pictures that were collected from websites, books, and international awards of creative products. The pictures in the original APEDP were divided into three categories (beautiful, medium, and ugly) based on aesthetic judgment (degree of beauty). The perceived beauty of pictures was positively correlated with positive emotions of "happy/pleasant" and "relaxed/peaceful" (r's$=0.959$ and 0.963, respectively, p's<0.001) and negatively correlated with negative emotions of "disgusting/hateful" and "terrible/fearful" (r's$=-0.911$ and -0.884, respectively, p's<0.001) (Yeh, 2013).

A behavioral pilot study, which included a separate sample of participants, was conducted to validate the stimuli and experimental procedures prior to the fMRI experiment. Ninety-eight college students (11 males and 87 females) aged 20–29 (20.704 ± 2.683 years) participated in the behavioral pilot study. The 40 most salient pictures from each aesthetic judgment group (beautiful, medium, and ugly) in APEDP were selected. Based on a 6-point Likert type measurement (ranging from very ugly to very beautiful), the mean scores for the selected "beautiful", "medium", and "ugly" pictures were 4.877 (SD$=$0.146), 3.876 (SD$=$0.200), and 1.844 (SD$=$0.194), respectively.

We asked the participants to rate the aesthetic judgment (1$=$ugly, 2$=$medium, 3$=$beautiful), and aesthetic emotion (1$=$negative, 2$=$neutral, 3$=$positive) of each stimulus in this pilot study to match the design of the fMRI study. The use of fingers for button-press responses (1: index finger; 2: middle finger; 3: ring finger) was counterbalanced. We further selected the 30 most salient pictures from each aesthetic judgment group based on the results. The mean scores for the selected "beautiful", "medium", and "ugly" pictures were 2.245 (SD$=$0.093), 1.703 (SD$=$0.146), and 1.154 (SD$=$0.030), respectively. The mean scores of the three categories of pictures did not have gender differences in the original sample of 401 college students (Wilks' $\Lambda=0.903$, $p=0.123$, $\eta_p^2=0.097$), in the pilot sample of 98 college students (Wilks' $\Lambda=0.979$, $p=0.565$, $\eta_p^2=0.021$), or in the behavioral sample of this study (Wilks' $\Lambda=.918$, $p=0.519$, $\eta_p^2=0.082$).

2.3. Design and procedures

The study design and procedures were slightly adjusted based on the results of the behavioral pilot study to obtain valid data in the fMRI experiment. Notably, the reaction time for rating beautifulness and emotions of each stimulus in the behavioral pilot study was 2.316 s and 2.297 s. Therefore, we set the rating time at 3 s in the fMRI experiment. The fMRI experiment employed an event-related paradigm that was identical to the behavioral pilot study. Participants completed the consent form and required personal information, and a brief introduction and practice session followed.

The participant's head was fixed with foam pads during the fMRI scan to minimize head motions. All participants reported no difficulty in viewing stimuli or hearing instructions. Participants who required vision correction used either MRI-compatible contact lenses or MRI-compatible plastic goggles. The experiment was performed in two runs. During each run, participants were first presented with the word "ready" and a dummy scan for 6 s, and the 45 trials were presented. Within one trial, a stimulus was presented for 5 s following a fixation period with randomly jittered inter-trial intervals of 1, 2, or 3 s. Participants were requested to rate their aesthetic emotion (negative, neutral, or positive) (see Fig. 1). The response time was 3 s, and the participants could change their responses within the time limit. Moreover, the use of fingers for button-press responses (1: index finger; 2: middle finger; 3: ring finger) was counterbalanced. The stimuli of the three categories of aesthetic judgment were also randomly distributed in each run. There was a 2-min break between the two

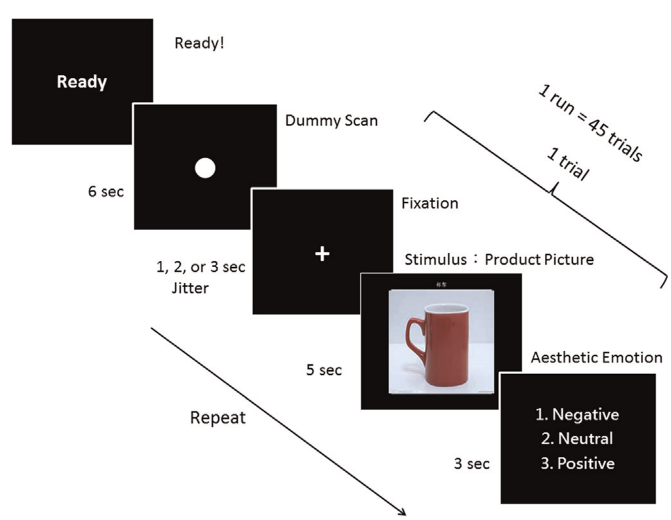

Fig. 1. Procedures of experimental design. The experiment was performed in two runs, and 45 trials were presented in each run.

runs, and each run took approximately 7 min and 36 s. The total duration of the experiment for each participant was approximately 17 min 12 s.

We also performed post-scan ratings on the aesthetic judgment and aesthetic emotion of each picture using the same rating scale during fMRI scans for all participants to evaluate the brain–behaviour relationship. We assessed aesthetic judgment in post-scan ratings for two reasons: first, to avoid exhaustion for too many ratings during fMRI scans; and second, we assumed that aesthetic judgment was less subject to change in short periods of time compared to emotional states. Participants were requested to go through all procedures immediately after the fMRI experiment, in which judgments of beauty (ugly, medium, and beautiful) and ratings of emotional arousal (1=very weak; 2=weak; 3=strong; 4=very weak) were also included.

2.4. Data acquisition

Scans were performed in a 3-tesla Siemens Megnetom Skyra Siemens MRI scanner using a 32-channel head coil. Visual stimuli were presented to the participants on a Hitachi CP-SX635 Projector. BOLD echoplanar images (EPIs) were collected using T2*-weighted gradient-echo echoplanar imaging sequences (voxel size, $4 \times 4 \times 3$ mm^3). Each volume contained 34 transversal slices of 3 mm slice thickness that were oriented parallel to the anterior and posterior commissure (AC–PC) line covering the entire brain (TR=2000 ms, TE=24 ms, flip angle= 90°, FOV=256 mm, 64×64 matrix, in plane-resolution=4.0×4.0 mm^2). High-resolution T1-weighted structural images were also acquired using the 3D MPRAGE pulse sequence: TR=1560 ms, TE=3.30 ms, flip angle=15.0°, 256×256 voxel matrix, FOV=256 mm, 192 contiguous axial slices, thickness=1.0 mm, and in-plane resolution: 1.0×1.0 mm^2. This study included two runs, and the first two TRs in each functional run were discarded to avoid T1 equilibrium effects. Each functional run acquired 228 volumes.

2.5. Image analyses

Functional data were analyzed using SPM8 software (Statistical Parametric Mapping, Wellcome Department of Cognitive Neurology, London, UK). Following Dicom, slice timing correction, and realignment, co-registered images were normalized to the standard Montreal Neurological Institute EPI template and the $4 \times 4 \times 3$ mm^3 voxel size of the written normalized images. Moreover, statistical analyses were calculated on data that had been spatially smoothed using an 8-mm full-width-at-half-maximum (FWHM) Gaussian kernel with a high-pass filter (128-s cutoff period) to remove low frequency artifacts.

Data from each participant were entered into a general linear model using an event-related analysis procedure. Statistical analysis was performed in a two-stage random-effects model. In the subject-specific first-level model, each stimulus type was modeled by a canonical hemodynamic response function and its temporal derivative. The functional data in these first-level models were high-pass filtered with a cutoff of 128 s. The parameter estimates in these first-level models, which reflected signal change for all paired conditions in aesthetic judgment and aesthetic emotion, were calculated in the context of a general linear model. Contrasts of interest were obtained for each participant from these first-level parameter estimates and used in a second-level random effects model. The averaged trials accepted for each condition in GLM analysis were as follows: 30 trails for the beautiful, medium, or ugly stimuli in normative aesthetic judgment contrasts; 45.83, 19.10, and 25.07 trials for the beautiful, medium, and ugly stimuli in subjective aesthetic judgment contrasts; 36.27, 26.10, and 26.60 for the positive, neutral, and negative emotion in aesthetic emotion contrasts. The threshold of p-value adjustment for control was set to 0.005. All reported areas of activation were considered significant at $p<0.05$ corrected for family-wise error rate (FWE) for multiple comparisons at the voxel level with a cluster size greater than or equal to 10 voxels. In addition, time courses were extracted from the beta values of peak voxels of the regions to visualize the signal change in significant brain regions.

3. Results

3.1. Behavioral data

The mean rating scores for aesthetic judgment, aesthetic emotion, and emotional arousal are displayed in Table 1. Analysis of variance showed that there were significant differences between the three categories of stimuli with regard to aesthetic judgment, aesthetic emotion, and emotional arousal, $F(2, 2697)=$ 941.711, 1958.156, and 378.982, $\eta_p^2=0.411$, 0.592, and 0.220, p's $<.001$; all post-hoc tests were significant as well. In other words, our categorizations of stimuli are reliable and valid. We also found that ugly stimuli provoked stronger emotional arousal then did the beautiful and the medium stimuli.

With a total of 2700 evaluations of the 90 pictures, the judgment of beauty was positively associated with positive emotion ($r=0.794$, $p<0.001$). Further examining the relationships between aesthetic judgment, aesthetic emotion, and emotional arousal in each of the stimuli category, we found that within the category of beautiful and medium stimuli, aesthetic judgment, aesthetic emotion, and emotional arousal were all positive correlated, r's=0.332–0.514, p's <0.001. In the category of ugly stimuli, although aesthetic judgment and aesthetic emotion were still positive correlated, emotional arousal was negatively related to aesthetic judgment and aesthetic emotion (r's$=-0.351$ and -0.272, p's <0.001), suggesting that participants tended to have more negative emotion and stronger emotional arousal when viewing ugly pictures then viewing beautiful pictures (see Table 2). Moreover, the emotions rated in-scan and post-scan had great consistency ($r=0.979$, $p<0.001$), which suggests that the participants' ratings in-scan and post-scan were highly reliable.

3.2. fMRI data: differences in neural activity associated with aesthetic judgment conditions

We compared the activated brain regions of the subjective aesthetic judgment (based on the participant's own categorization) and the normative aesthetic judgment (based on the categorization of pilot studies) to check the validity and categorization of the employed stimuli. Four contrasts (beautiful–ugly, ugly–beautiful, beautiful–medium, and medium–ugly) were made

Table 1
Means and standard deviations of aesthetic judgment, aesthetic emotion, and arousal in each of the stimuli groups.

Stimuli group	Aesthetic judgment		Aesthetic emotion		Emotional arousal	
	M	*SD*	*M*	*SD*	*M*	*SD*
Beautiful	2.07	0.604	2.69	0.516	2.67	0.713
Medium	1.68	0.576	2.34	0.561	2.25	0.612
Ugly	1.05	0.241	1.21	0.505	3.19	0.835

Note: aesthetic judgment: 1=ugly; 2=medium; 3=beautiful. Aesthetic emotion: 1=negative; 2=neutral; 3=positive. Emotional arousal: 1=very weak; 2=weak; 3=strong; 4=very strong. 72.11% of the beautiful stimuli were reported to provoke positive emotion; 84.00% of the ugly stimuli were reported to provoke negative emotion; 2.67% of the beautiful stimuli were reported to provoke negative emotion; 4.55% of the ugly stimuli were reported to provoke positive emotion.

Table 2
Correlations of aesthetic judgment, aesthetic emotion, and emotional arousal within the category of beautiful, medium, and ugly stimuli.

Response	Beautiful stimuli			Medium stimuli			Ugly stimuli		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Judgment (1)	1.000			1.000			1.000		
Emotion (2)	0.402*	1.000		0.504*	1.000		0.502*	1.000	
Arousal (3)	0.445*	0.416*	1.000	0.353*	0.394*	1.000	−0.145*	−0.272*	1.000

Note: Judgment: 1=ugly; 2=medium; 3=beautiful. Emotion: 1=negative; 2=neutral; 3=positive. Arousal: 1=very weak; 2=weak; 3=strong; 4=very strong.
* $p < 0.001$.

Table 3
Regions significantly activated for contrasts of aesthetic judgment

Conditions	Regions	Side	BA	Voxels	*Z* max	MNI coordinate			*P* (FWE-corr)
						X	*Y*	*Z*	
Normative judgments									
B–U	ACC	L	32	1278	4.00	−20	30	18	0.000
U–B	Insula	R	13	1953	4.33	38	14	−6	0.000
B–M									n. s.
U–M									n. s.
Subjective judgments									
B–U	Precuneus	L	7	2804	4.40	−26	−52	44	0.000
B–U	ACC	L	32	1183	3.90	−22	32	20	0.000
B–U	ACC	R	32	1250	3.90	22	34	12	0.000
B–U	Caudate	L		413	4.30	−28	−40	10	0.043
U–B	IFG	R	13	794	4.16	32	16	−16	0.001
B–N									n.s.
U–N									n.s.

Note: MNI=Montreal Neurological Institute; B=beautiful; U=ugly; M=medium; L=left; R=right; BA=Brodmann's area; ACC=anterior cingulate cortex; IFG=inferior frontal gyrus. Voxels=number of voxels in cluster; only clusters with an extent threshold of $p < 0.005$, corrected for whole brain and cluster 10 or greater are presented; threshold of $p < 0.05$, FWE (family-wise error rate) corrected.

separately based on the subjective and normative judgment.

3.2.1. Normative aesthetic judgment

The region that showed significant brain activation in the beautiful to ugly pictures was the left ACC (BA 32, $p < 0.001$). The region that showed significant brain activation in ugly to beautiful pictures was the right insula (BA 13, $p < 0.001$). The other two contrasts (beautiful to medium and ugly to medium) did not have significant brain activations (see Table 3 and Fig. 2).

3.2.2. Subjective aesthetic judgment

Regions that showed significant brain activation in the beautiful to the ugly pictures were the left precuneus (BA 7, $p < 0.001$), left and right ACC (BA 32, p's < 0.001), and left caudate ($p < 0.001$). However, the region that showed significant brain activation in the ugly to beautiful pictures was the right inferior frontal gyrus (IFG) (BA 13, $p < 0.001$). The other two comparisons (beautiful to medium and medium to neutral) did not have significant brain activations (see Table 3 and Fig. 3).

3.3. fMRI data: differences in neural activity associated with aesthetic emotion conditions

We compared brain activations for the three types of aesthetic emotion, positive, neutral, and negative, based on the participants' responses. The region that showed significant brain activation in positive to negative emotion was the right ACC (BA 32, $p = 0.028$). The regions that showed significant brain activations in negative to positive emotion were the right precuneus (BA 7, $p = 0.016$) and right inferior frontal gyrus (BA 45, $p = 0.049$). Comparisons of positive to neutral emotions and negative to neutral emotions were not significant (see Table 4 and Fig. 4).

4. Discussion

Everyday designed products have become part of our life in modern society. An understanding of the neurological mechanisms of cognitive appraisals that are activated by the aesthetic properties of these products can help us better understand how this often subconscious process can affect outcomes, such as aesthetic judgment and emotional response (Kumar and Garg, 2010). Neuroimaging techniques can provide a new analytical level of evidence in the understanding of cognitive processes (Nadal and Skov, 2013). Therefore, we explored the neural substrates of aesthetic judgment and emotions that pertain to everyday designed products using fMRI. The findings of this study revealed that the participants' aesthetic judgments were highly related to their aesthetic emotions. Moreover, this study found that the emotional arousal was related to aesthetic judgments, which lends support to the multiple-layer theory of emotional expression (Juslin, 2013) in that associative coding adds a richer level of emotional expression and intrinsically-coded expression adds dynamically changing contours (e.g., arousal or intensity) which help to shape more time-dependent emotional expressions.

The fMRI data are consistent with the behavioral data and also indicate the associative and dissociative neutral mechanisms underlying different types of aesthetic judgments and aesthetic emotions. Basically, the findings of this study lend support to the arguments that aesthetic experience involves the interaction of top-down attention and bottom-up perceptual facilitation (Craig, 2009; Cupchik et al., 2009; Critchley et al., 2004). The following

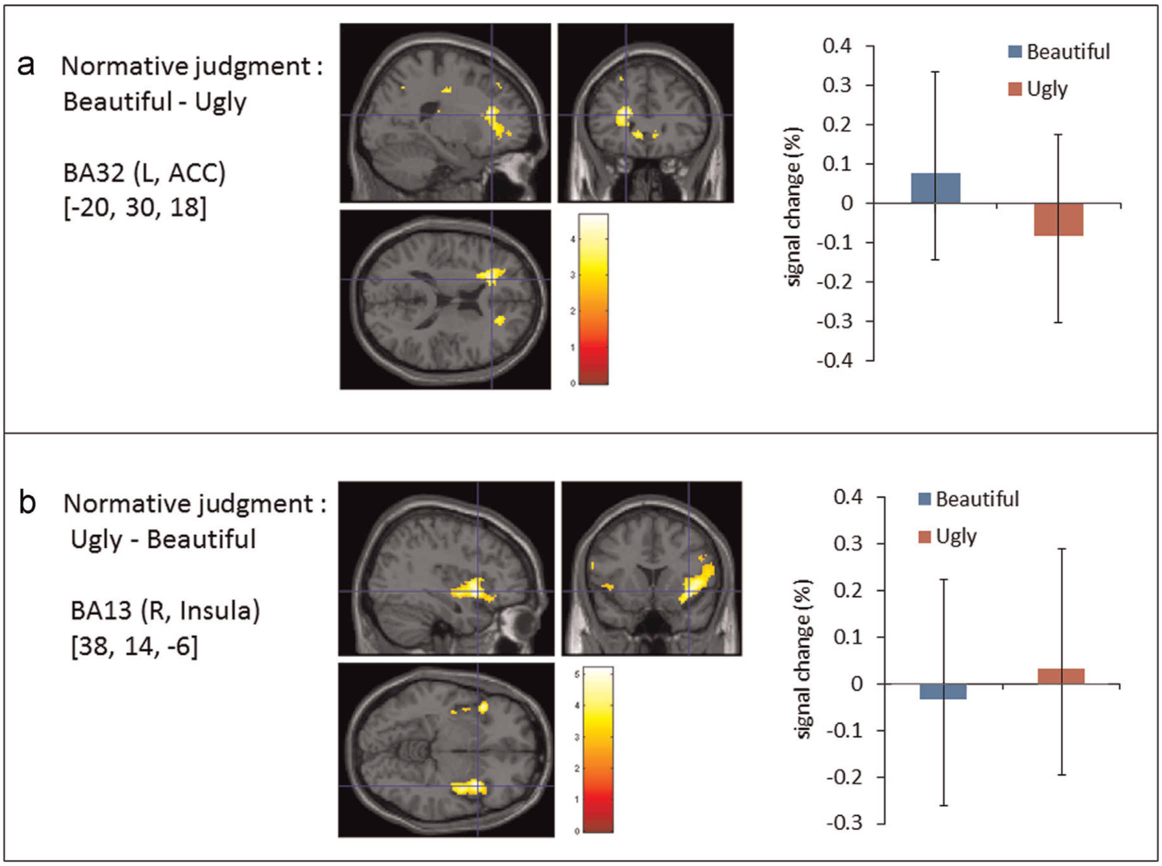

Fig. 2. Regions showing brain activation for the beautiful versus ugly and ugly versus beautiful contrasts in normative aesthetic judgments. Bar-charts show beta values for regions of interests (ROIs). Error bars represent standard error of the mean (SEM) from the mean. Significant activations at a $p < 0.05$ FWE-corrected level. MNI coordinates for distinct regions can be found in Table 3. L=left; R=right; ACC=anterior cingulate cortex.

main findings are included: (a) normative beauty and subjective beauty both involve the left ACC; (b) subjective beauty and positive emotions both involve the right ACC; (c) subjective beauty and negative emotions both involve the precuneus; (d) subjective ugliness and negative emotion both involve the right IFG; (e) subjective ugliness alone additionally activated the insula; and (f) subjective beauty alone additionally activated the caudate (see Fig. 5 for the overlaps).

First, we found that both the normative and subjective judgment of beauty activated the left ACC, whereas the subjective judgment of beauty additionally activated the right ACC, precuneus, and left caudate. These findings support the coexistence of subjective beauty and normative beauty (Atalay, 2007; Zangwill, 2014) and suggest that these two types of beauty, although highly correlated based on shared neural substrates, are distinguishable by their underlying neural substrates. As Atalay (2007) suggested, judgment of tastes cannot be separated from the actual situation it precedes, and we have to conceive the inner unity between the subjective and the universal. As a result, we evaluate a product based on our subjective feelings, but our evaluation is also a universal one. The findings here are also in line with the argument that aesthetic preference of a product is related to a balance between typicality to the norm and novelty to the individual (Hancock et al., 2005) as well as that the caudate nucleus and the ACC indicate processes of spontaneous aesthetic evaluation (Bohrn et al., 2013).

In addition, the strong activation of the ACC that was found in this study confirms that the ACC is critical to aesthetic judgments across domains (Goldberg et al., 2014; Zeki et al., 2014). However, the activation of the caudate during the viewing of beautiful products contradicts the review that decreased preferences for observed paintings decreases activation in the caudate nucleus (Dio and Gallese, 2009), which suggests that aesthetic judgment is partially domain-specific. On the other hand, the importance of precuneus to aesthetic judgment may relate to their role in memory retrieval, especially in successful episodic memory retrieval. Past studies have found that aesthetic judgment is related to a subjective valence system, by which individuals engage in a spontaneous comparison of what they see with patterns they are already familiar with through retrieving previous judgments or running comparisons between patterns of stimuli (Bohrn et al., 2013; Jacobsen et al., 2006). Chatterjee and Vartanian (2014) also suggested that the precuneus contributes to visuospatial exploration of pictorial stimuli. Accordingly, precuneus is associated with fitting new information into an established mental framework of prior knowledge (Jacobsen et al., 2006). Since individuals' prior knowledge and episodic memory vary greatly, the activation of precuneus in subjective aesthetic judgement only provides explanations for the difference between subjective and normative aesthetic judgment.

Second, this study found that subjective beauty, normative beauty, and positive emotion all activate the ACC, which suggests that the ACC plays a key role in the aesthetic appreciation of designed products. The ACC includes the dorsal ACC (also known as MCC) and ventral ACC. The dorsal ACC has extensive connections with cognitive (e.g., lateral prefrontal) and motor-related (e.g., premotor and primary motor) areas of the cortex, whereas the ventral ACC has extensive connections with areas that are important for emotion (e.g., amygdala), autonomic (e.g., lateral hypothalamus, brainstem centres), memory (e.g., hippocampal region), and reward-(e.g., orbitofrontal cortex)related functions (Stevens et al., 2011). The finding that the ACC is strongly activated

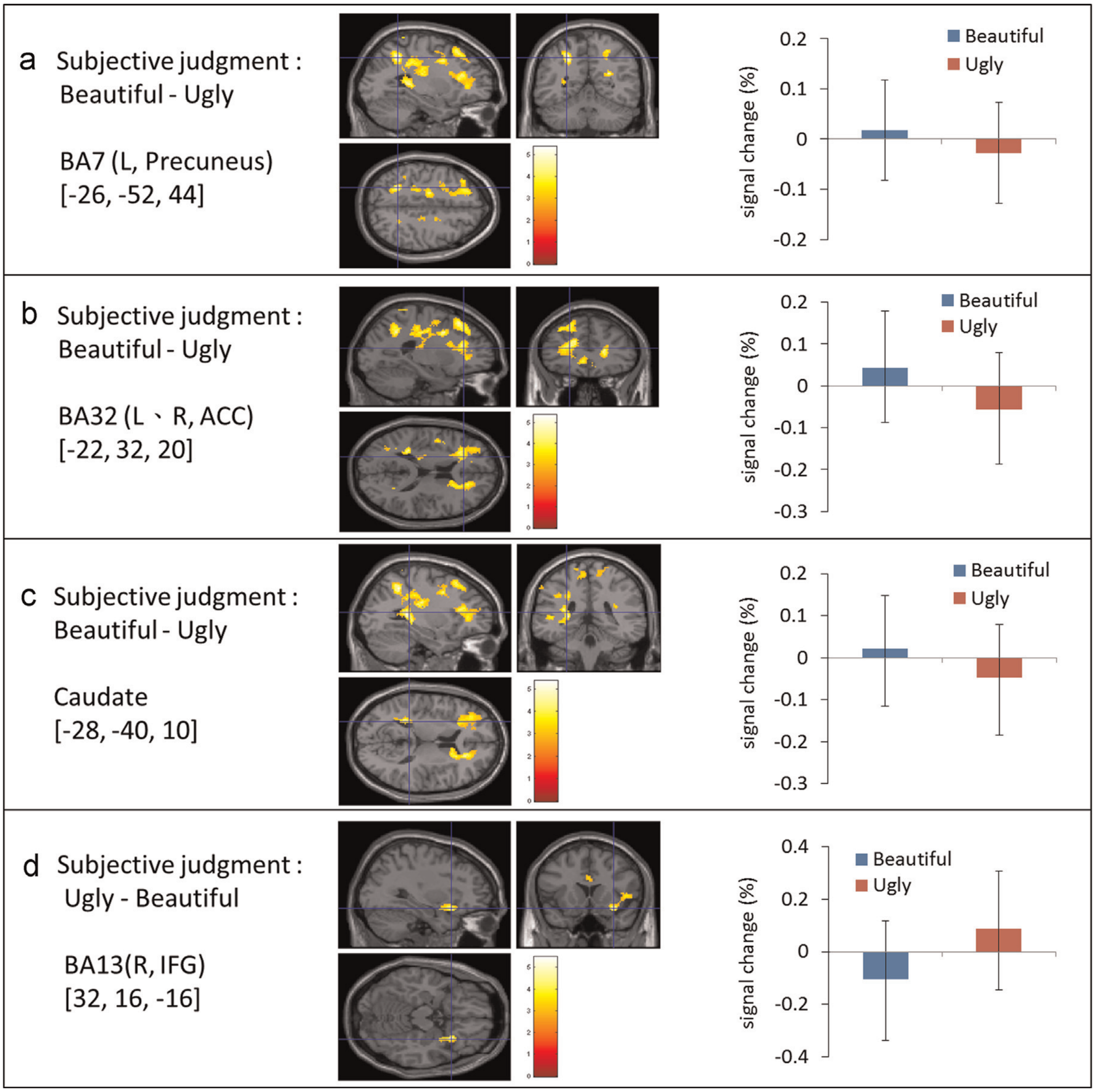

Fig. 3. Regions showing brain activation for beautiful versus ugly and ugly versus beautiful contrasts in subjective aesthetic judgments. Bar-charts show beta values for regions of interests (ROIs). Error bars represent standard error of the mean (SEM) from the mean. Significant activations at a $p<0.05$ FWE-corrected level. MNI coordinates for distinct regions can be found in Table 3. L=left; R=right; ACC=anterior cingulate cortex; IFG=inferior frontal gyrus.

Table 4
Regions significantly activated for contrasts of aesthetic emotions.

Conditions	Regions	Side	BA	Voxel	*Z* max	MNI coordinate			*P* (FWE-corr)
						X	*Y*	*Z*	
P-Neg	ACC	R	32	674	3.90	2	48	−2	0.028
Neg-P	Precuneus	R	7	774	4.20	8	−72	34	0.016
Neg-P	IFG	R	45	586	3.89	46	22	6	0.049
P–N									n.s.
Neg-N									n.s.

Note: MNI=Montreal Neurological Institute; P=positive; N=neutral; Neg=negative; L=left; R=right; BA=Brodmann's area; ACC=anterior cingulate cortex; IFG=inferior frontal gyrus. Voxels=number of voxels in cluster; only clusters with an extent threshold of $p<0.005$, corrected for whole brain and cluster 10 or greater are presented; threshold of $p<0.05$, FWE (family-wise error rate) corrected.

when viewing beautiful products with positive emotion supports the two-pathway theory of the ACC. Moreover, an inspection of the activated brain regions revealed that beautiful products lead to activations in both the dorsal and ventral ACC (see Fig. 2), whereas positive emotion only leads to activations in the ventral ACC, which suggests that aesthetic judgments of designed products include the process of aesthetic emotion. These findings support the claims that aesthetic judgments and aesthetic emotions are interactive (Armstrong and Detweiler-Bedell, 2008; Dio and Gallese, 2009; Zeki et al., 2014) and the argument that beauty is best thought of as an exhilarating emotional experience (Armstrong and Detweiler-Bedell, 2008).

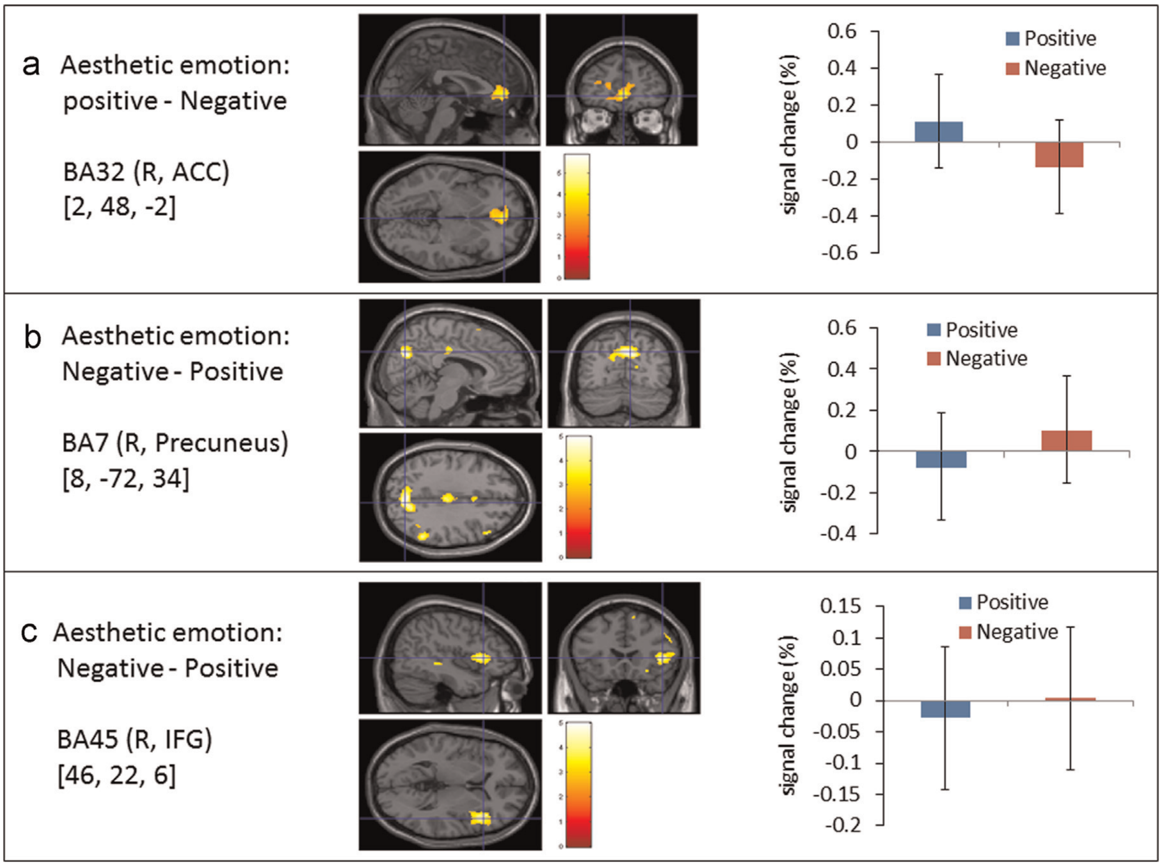

Fig. 4. Regions showing brain activation for the positive versus negative and negative versus positive contrasts in subjective aesthetic judgments. Bar-charts show beta values for regions of interests (ROIs). Error bars represent standard error of the mean (SEM) from the mean. Significant activations at a $p < 0.05$ FWE-corrected level. MNI coordinates for distinct regions can be found in Table 4. L=left; R=right; ACC=anterior cingulate cortex; IFG=inferior frontal gyrus.

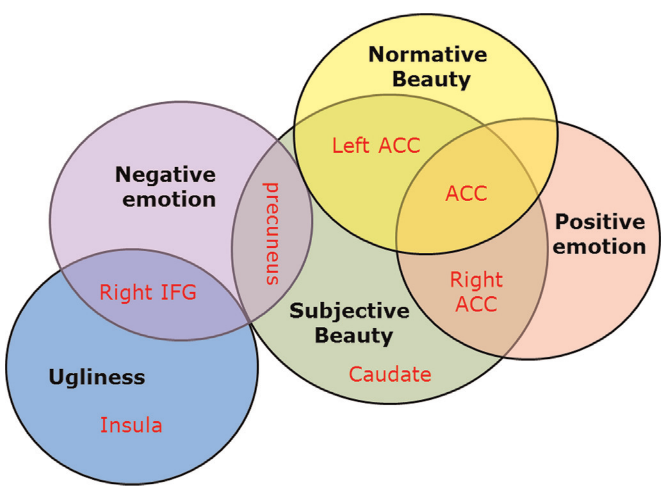

Fig. 5. Associated and dissociated neural substrates of aesthetic judgments and aesthetic emotions.

Third, the findings in this study suggest that beautiful pictures that arouse positive emotions and that arouse negative emotions are based on different neural mechanisms. Behavioral data in this study showed that 2.667% of the beautiful pictures were rated as a negative emotion. fMRI data showed that subjective beauty and positive emotion activated the right ACC but that subjective beauty and negative emotion activated the precuneus. The precuneus is linked to emotional and memory-related processes (Lundstrom et al., 2005; Reske et al., 2009) and aesthetic experiences (Fletcher et al., 1995; Maguire et al., 1999). Individuals need to compare sensory representation with past experiences when consciously processing emotional stimuli and this integration occurs in the cuneus/precuneus region (Reske et al., 2009). These results are consistent with Skov's (2010) finding that different brain regions were activated when participants rated unpleasant images as beautiful and rated pleasant images as beautiful, especially those ratings involved high-level perceptual processing areas and rewards. Moreover, our findings are consistent with the finding that the ACC is related to positive, but not negative, emotion (Garrett and Maddock, 2006). Accordingly, different cognitive and affective mechanisms come into play when we appreciate designed products with emotionally negative and positive contents.

Finally, the finding that ugly pictures caused activations in the insula and the high correlation of ugliness and negative emotion found in the behavioral data support the finding that the insula is closely related to the processing of emotions (Cupchik et al., 2009; Lindquist and Barrett, 2012; Goldberg et al., 2014). Moreover, we found that subjective judgments of ugliness and negative emotions both activated the right IFG (RIFG), which is consistent with a recent finding that ugly pictures activated the IFG (Pöppel et al., 2013). The RIFG plays an important role in attentional control and rapidly adaptations to respond to currently relevant and salient stimuli with inhibitory control (Hampshire et al., 2010). Accordingly, ugly products that provoke negative emotion may lead to an avoidance of gazing at first insight followed by aesthetic appraisals in which the participant adjusts their mood and refocuses through the function of the RIFG.

Integrating the findings and the literature review in this study, we propose that the processes of aesthetic appreciation in designed products include five components: aesthetic perception, aesthetic analysis, aesthetic association, aesthetic judgment, and

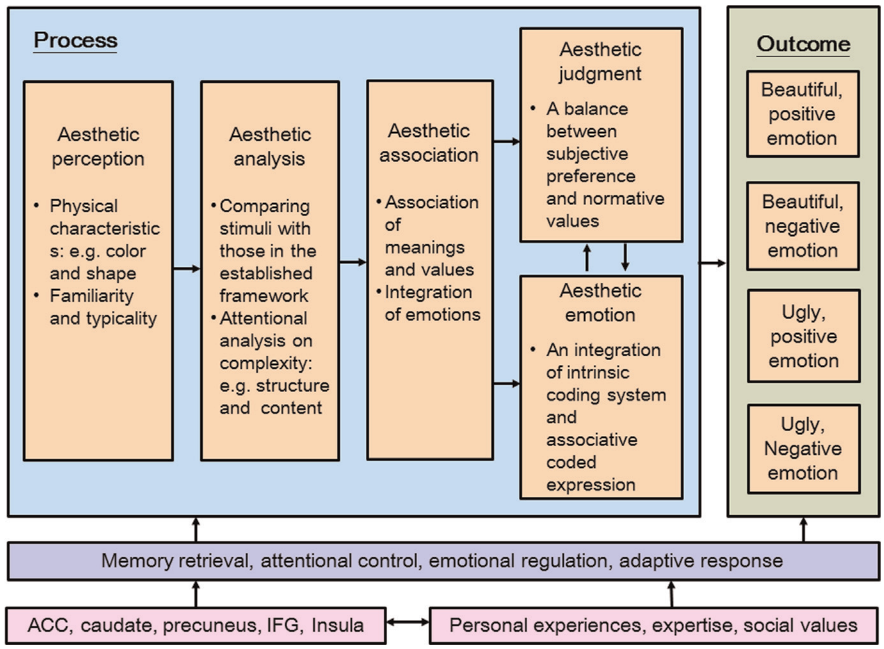

Fig. 6. A proposed model for aesthetic appreciation in designed products.

aesthetic emotion. While aesthetic perception involves more bottom-up processes, the other components involve more top-down processes. Moreover, aesthetic judgment and aesthetic emotion are interactive. Notably, aesthetic judgment is made based on a balance between subjective preference and normative values, whereas aesthetic emotion is resulted from an integration of intrinsic coding system and associative coded expression. Finally, under the interactions of the aesthetic processes, four types of outcomes can be brought about: feeling beautiful with positive emotion, feeling beautiful with negative emotion, feeling ugly with positive emotion, and feeling ugly with negative emotion. Importantly, such processes and outcomes are influenced by the mechanisms of memory retrieval, attentional control, emotional regulation, and adaptive response; these mechanisms are formed through the interactions of personal experiences, expertize, social values, and neural substrates, such as ACC, caudate, precuneus, IFG, and insula (see Fig. 6).

5. Conclusions

Currently, most related studies in neuroaesthetics were conducted in the context of the arts. Aesthetics have become an essential part of our life, and the appreciation of beauty should be more mundane. Therefore, this study used everyday designed products as stimuli to explore the neural mechanisms that underlie the ordinary process of aesthetic appreciation. The following main conclusions were found. First, the subjective beauty and normative beauty pertaining to everyday designed products share certain neural substrates, but subjective beauty seemed more strongly associated with past experiences and personal emotions, which suggests that when designing a product, creating systems that adapt to cultural norms and personal experience are required to maintain the balance between typicality and novelty of a product over time. Second, the underlying neural mechanisms of aesthetic judgment differed when the aroused emotions varied. Both associative and dissociative neutral substrates were found. Third, the judgment of beauty was strongly associated with positive emotions, whereas ugliness was closely related to negative emotions. In summary, aesthetic judgment and aesthetic emotion during the appreciation of designed products are interactive as evidenced by the shared activities in neutral substrates and the high correlation in the behavioral data. The findings of this study illuminate the complex but ordinary processes of aesthetic appreciation. Moreover, this study broadens the research scope of neuroaesthetics.

6. Limitations and suggestions

The findings in this study illustrate that aesthetic emotion is critical to the aesthetic judgment of designed products. However, how these factors influence each other was not examined due to the poor time resolution of MRI scan. Further studies can combine MRI scans and event-related potential techniques, which have good time resolution, to better understand the interaction patterns of aesthetic judgment and aesthetic emotion.

Moreover, appraisal plays a fundamental role in the eliciting of emotions, and different types of appraisal may evoke different types of emotions (Silvia, 2005, 2006; Silvia and Brown, 2007). Appraisals focused on novelty and familiarity may lead to knowledge emotions (i.e., interest and surprise). Appraisals of goal-incongruence or intentionality may elicit hostile emotions (i.e., anger or disgust). Appraisals concerning the congruence of artworks with our values and self-image may elicit self-conscious emotions (i.e., pride and shame) (Silvia, 2005, 2006; Silvia and Brown, 2007). It has been suggested that an understanding of the link between emotional response and design is particularly important because of the critical role that emotions often play in consumers' decision-making (Schwarz, 2000). Further studies can manipulate the types of appraisals of designed products and compare the neural mechanisms that lead to different types of emotions.

Finally, aesthetic judgments and emotions of everyday designed products could be influenced by shape, colour, texture, as well as such cognitive variables as personal experiences, expertize, social values, brand identification, and desirability of object. Past findings have suggested that visual shape information is processed within the lateral occipital complex, texture is processed in medial regions of the collateral sulcus (Podrebarac et al., 2014.), and colour was found medially within the left lingual gyrus as well as the anterior collateral sulcus (Cavina-Pratesi et al., 2010; Chatterjee and Vartanian, 2014). Future studies can further manipulate visual characteristics as well as cognitive variables to explore the neural mechanisms underlying aesthetic appreciation of designed products.

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