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Neural Responses to the Human Color Preference for Assessment of eco-friendliness: A functional Magnetic Resonance Imaging Study

Kim, T.H. [1], Song, J.K. [2], and Jeong, G.W. [1*]

[1] Department of Radiology, Chonnam National University Hospital, Chonnam National University Medical School, Gwangju, Republic of Korea

[2] Department of Architectural Engineering, Chonnam National University, Republic of Korea

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ABSTRACT: The purpose of this study was to investigate the brain activation patterns in response to the human color preference by using a functional magnetic resonance imaging (fMRI). A total of 31 healthy humans without color blindness were participated in this study. The brain activation was induced by viewing of eight different colors: black, gray, blue, green, earthy yellow, red, yellow and white. The questionnaires for color preference showed that green color was mostly favorite to the subjects, whereas the black color was mostly unfavorite. During the visual stimulation with favorite colors, the brain areas dominantly activated included the pons, supramarginal gyrus, paracentral lobule, midbrain and globus pallidus. During the stimulation with unfavorite colors, on the other hand, the predominantly activated brain areas included the body of the caudate nucleus, parahippocampal gyrus, anterior cingulate gyrus, splenium of the corpus callosum, hippocampus, orbitofrontal gyrus, amygdala, thalamus and angular gyrus. The differential brain activation patterns associated with color preference are assumed to reflect the human emotional response and status being assessed.

Key words: Brain activation, Favorite, Unfavorite, Functional magnetic resonance imaging (fMRI)

INTRODUCTION

During the last two decades, numerous studies concerning the impact of art, design and living environment on mental healthcare in humans have been performed (Daykin *et al.*, 2008; Basso *et al.*, 2012; Rasouli *et al.*, 2012; Salehi *et al.*, 2012). It has been well known that human beings are interrelated with the surrounding circumstance and living environments (Seifollahi and Faryadi, 2011; Faizi *et al.*, 2011; Kopnina, 2011; Odindi and Mhangara, 2012; Saffarnia *et al.*, 2012). Exposure to stressful visual and aural stimulation gives rise to a negative impact on healthcare, whereas peaceful and comfortable environment reduces anxiety and depression, leading to a positive impact (Daykin *et al.*, 2008). Recently, our study (Kim *et al.*, 2010) demonstrated the differential brain activation patterns in response to visual stimulation with rural and urban scenic viewing. These neuroscientific findings showed that viewing the peaceful and comfortable rural scenery brought about a positive impact, whereas the tumultuous and uncomfortable urban scenery led to a negative impact. The colors in connection with rural and urban scenery are specific: green color represents the rural scenery and gray color for the urban.

*Corresponding author E-mail: gwjeong@jnu.ac.kr

Color is one of the important factors to humans in its perceptual and cognitive properties associated with subjective preference. In choosing the colors of a house, clothing, car and other objects in daily life, human beings regard color as an aesthetic issue. Color preference is influenced by various factors such as gender (Hurlbert & Ling, 2007), personality (Oh *et al.*, 2006), geographical region (Saito, 1996) and culture (Saito, 1996). The perception of color preference is associated with the fundamental neural mechanism involving a variety of cognitive processes, such as categorization and recognition (Kim *et al.*, 2007). Researchers (Birren, 1980; Cotton, 1985; Gregorian *et al.*, 1996; Wadeson, 1971) have found that people in different emotional states interact with colors in different ways. Emotionally well-adjusted individuals respond to color openly, whereas people who are more emotionally inhibited avoid using colors (Birren, 1980). Kueller (Kueller, 1976; Kuller & Wetterberg, 1996) found that participants placed in rooms decorated with a variety of colors experienced not only the decreased alpha-wave component on the electroencephalogram (EEG) that was associated with the mental state of the participant, but also the lowered heart rates on the electrocardiogram (ECG). However, subjects placed in gray rooms experienced increases in the alpha-wave component and heart rate, sometimes to the point of feeling stressed and agitated. Wadeson (1971) found that patients with depression use significantly less colors in painting as compared to patients with schizophrenia. Especially in the same patients with depression, patients' pictures when more depressed revealed less color used and more empty space than when less depressed. Other studies (Cotton, 1985; Gregorian *et al.*, 1996) showed that the life-threatened children with leukemia or earthquake victims revealed a strong prevalence of the colors, red and black, in artwork. Goldstein (1995) reported an interesting finding through a holistic study that colors affect the sense of balance of the body. A patient with a cerebral disease, who is prone to falling while walking, seemed to fall more often when wearing red clothing; however, when wearing blue or green clothing, the sense of balance was almost completely restored.

In spite of the ubiquity of preference decisions in everyday life, the underlying neural mechanisms for color preference are little known. We have hypothesized that the function of the human brain is associated with color preference and shows differential brain activation patterns in response to the stimuli with favorite and unfavorite colors. In this study, we utilized a functional magnetic resonance imaging (fMRI) (Ogawa *et al.*, 1990) to explore the brain centers associated with the human color preference, and further to discriminate the differential activation patterns in response to visual stimuli with favorite and unfavorite colors.

MATERIALS & METHODS

A total of 31 healthy volunteers (13 males with a mean age of 26.6 ± 1.3 years and 18 females with a mean age of 25.3 ± 5.4 years) with normal visual perception and no history of neurological illnesses were recruited for the study. All participants underwent a color blind test with the Ishihara 24 pseudo-isochromatic plates, and none was color deficient. The protocol of this study was approved by the Medical Ethics Committee of Chonnam National University Hospital. All of the participants submitted informed written consent prior to participation in the study. The stimulation paradigm consisted of alternative rest and activation periods for 30 seconds each. Each activation block presented eight different colors, which were defined by the Commission Internationale de l'Eclairage (CIE) color model with a three axial coordinates, L^*(lightness), a^*(red-green), and b^*(blue-yellow), as follows (Table 1): black (L^*, a^*, and b^* value– 0, 0, 0), gray (61, -1, 1), blue (30, 68, -112), green (88, -79, 81), earthy-yellow (62, 16, 66), red (54, 81, 70), yellow (98, -16, 93) and white (100, 0, 0). Together with primary colors, living environment-oriented colors (i.e., green for the rural environment, earth-yellow for the traditional house made yellow-ocher, and gray for the urban environment) were used for this study. During the activation period, each color was flickered every 3 seconds. During the rest period, a white cross on the center of black screen was presented. The color stimuli were projected from outside of the magnet room onto a translucent screen, and each stimulus was presented to the subjects through a mirror angled at 45 degrees located at the top of the head coil.

The lightness and chromaticity of each color were calibrated using a chroma meter (CS-100A, Minolta, New Jersey, U.S.A.) (Table 1). For the color-preference tasks, participants viewed the colors on the 15" computer screen (Samsung Sense P28) with a resolution of 1024×768 pixels supported by 32-bit true color. The CIE xyY values were measured 10 times per each color using a chroma meter. The fMRI experiment was performed on a 3 Tesla MRI scanner (Magnetom Trio, Siemens Medical Solutions, Erlangen, Germany) with a birdcage type head coil. The fMRI data were acquired by using a gradient echo planner imaging (GRE-EPI) sequence with the following parameters: repetition time/echo time (TR/TE) = 2000/30 ms, flip angle = 90°, matrix size = 64 × 64, field of view (FOV) = 22 × 22 cm^2, number of excitations (NEX) = 1, slice thickness = 4 mm, number of transverse slices = 25 parallel to the anterior and posterior commissures. A total of 6,000 T2* images per examination were acquired. After the fMRI experiments, the participants were asked to fill out a simple questionnaire for subjective preference of the most and least favorite colors.

Image processing and statistical analysis were carried out using Statistical Parametric Mapping (SPM) software (Wellcome Department of Cognitive Neurology, University College London, London, UK). The first two volume images were discarded due to T1 saturation effects. Prior to the statistical analysis, all the fMRI data were realigned to remove brain motion artifacts and were spatially normalized to the Montreal Neurological Institute (MNI) EPI template images. The images were smoothed with an 8 mm full-width at a half-maximum Gaussian filter to increase signal-to-noise ratios. After specifying the appropriate design matrix, changes in the hemodynamic response produced by the different experimental conditions were assessed at each voxel using a general linear model with a box-car function. The difference of the brain activation patterns between favorite and unfavorite colors was evaluated by the use of the random effect group analysis with one-sample and two-sample *t*-tests. Then, the x, y and z coordinates of the MNI brain space were converted to Talairach's space (Talairach & Tournoux, 1988) by using the MNI2TAL function in SPM and the activation areas were labeled with the help of Talairach Demon software (Lancaster *et al.*, 2000).

Table 1. CIE L*a*b* and CIE xyY values representing the eight different colors

Colors	CIE $L^*a^*b^*$ color			Monitor setting (CIE xyY)			Observer setting via mirror (CIE xyY)		
	L^*	a^*	b^*	x	y	Y (Cd/m^2)	x	y	Y (Cd/m^2)
Black	0	0	0	0.323 ± 0.003	0.369 ± 0.003	3.111 ± 0.076	0.347 ± 0.007	0.407 ± 0.016	0.798 ± 0.130
Gray	61	-1	1	0.296 ± 0.001	0.332 ± 0.001	17.430 ± 0.698	0.316 ± 0.002	0.397 ± 0.003	126.100 ± 23.487
Blue	30	68	-112	0.173 ± 0.000	0.177 ± 0.001	14.060 ± 0.643	0.138 ± 0.001	0.102 ± 0.001	18.700 ± 4.194
Green	88	-79	81	0.317 ± 0.000	0.531 ± 0.001	46.610 ± 1.251	0.297 ± 0.003	0.539 ± 0.003	226.100 ± 51.800
Earthy-yellow	62	16	66	0.437 ± 0.001	0.398 ± 0.002	15.750 ± 0.938	0.425 ± 0.004	0.467 ± 0.004	101.640 ± 35.010
Red	54	81	70	0.539 ± 0.001	0.352 ± 0.001	21.330 ± 0.648	0.629 ± 0.003	0.361 ± 0.002	57.040 ± 9.141
Yellow	98	-16	93	0.415 ± 0.001	0.464 ± 0.001	67.910 ± 1.206	0.383 ± 0.000	0.504 ± 0.001	773.000 ± 89.080
White	100	0	0	0.327 ± 0.000	0.361 ± 0.001	80.740 ± 2.183	0.316 ± 0.003	0.394 ± 0.003	505.100 ± 110.582

Note-. CIE $L^*a^*b^*$ color model system; L^*: lightness; a^*: red-green axis; and b^*: blue-yellow axis. CIE stands for the Commission Internationale de l'Eclairage (International Commission on Illumination).

RESULTS & DISCUSSION

Fig. 1 shows the subjective response to color preference. The most favorite color was green, while the most unfavorite included both black and red colors. Note that nobody likes black, while nobody dislikes green, yellow, and white. Thus, green was selected as the most favorite over other colors, and black was the most unfavorite color. The color is one of the most important factors for the assessment of eco-friendliness in the ecological housing in conjunction with its interior and living environments. Although numerous studies (Hurlbert & Ling, 2007; McManus *et al.*, 1982) for color preference have been performed, most of the findings resulted from organ or sensual experiments. In this study, therefore, a systematic study on the functional neuroanatomy related with color preference was performed by using the fMRI.

Fig. 2 demonstrates the brain activation maps induced by viewing the favorite and unfavorite colors (two-sample *t*-test, $p<0.01$). During the stimulation with the most favorite colors, predominantly activated brain areas included the pons (z-score 2.64), supramarginal gyrus (2.55), midbrain (2.32), paracentral lobule (2.20) and globus pallidus (2.10), while the stimulation with the most unfavorite colors showed predominant activity in the brain areas including the body of the caudate nucleus (3.59), parahippocampal gyrus (3.49), anterior cingulate gyrus (2.97), splenium of the corpus callosum (2.78), hippocampus (2.69), orbitofrontal gyrus (2.68), amygdala (2.44), thalamus (2.38) and angular gyrus (2.33).

In this study, a two-sample *t*-test was used to derive the contrast of favorite vs. unfavorite colors

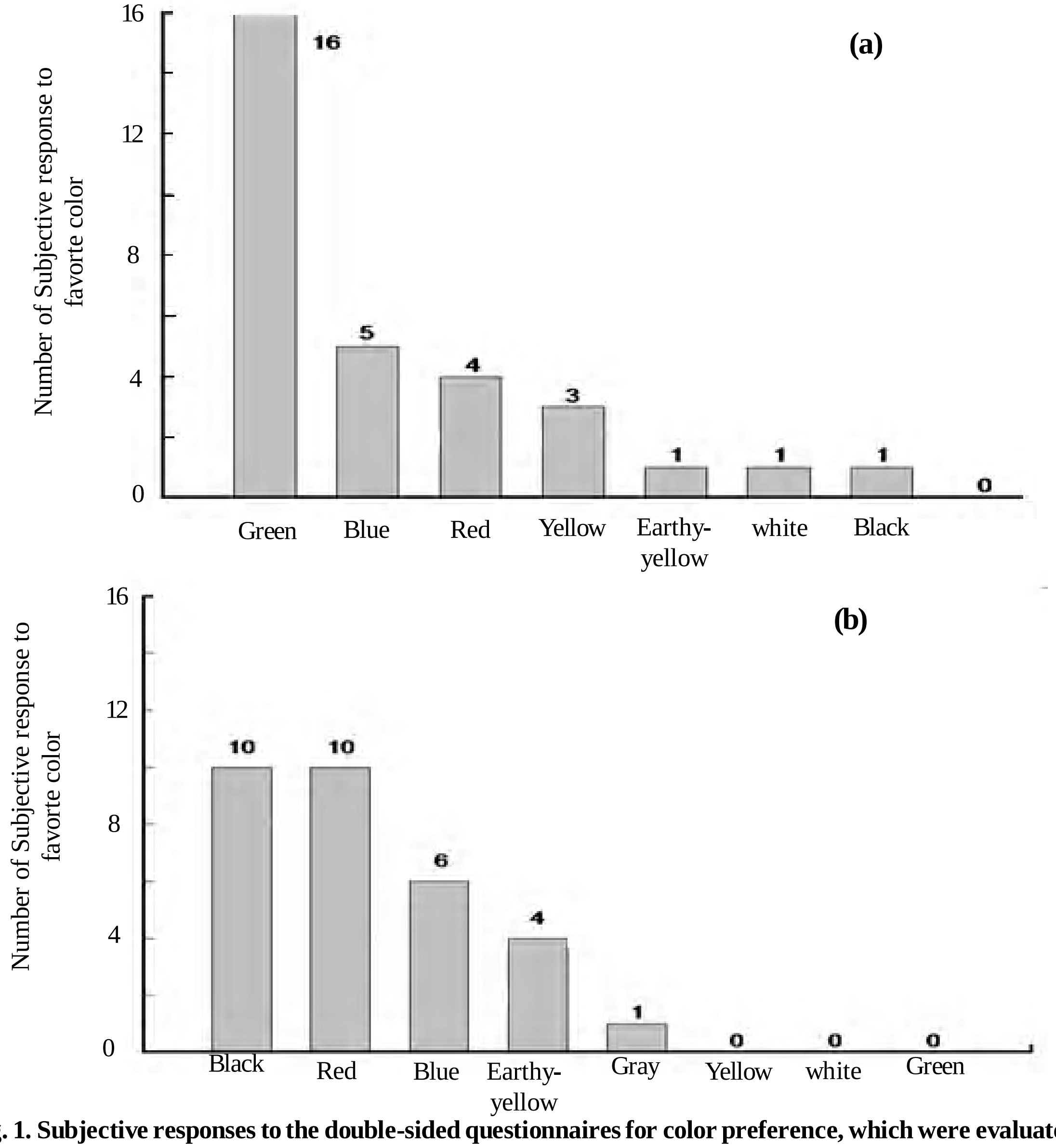

Fig. 1. Subjective responses to the double-sided questionnaires for color preference, which were evaluated on the basis of favorite (a) and unfavorite (b) colors in 31 subjects

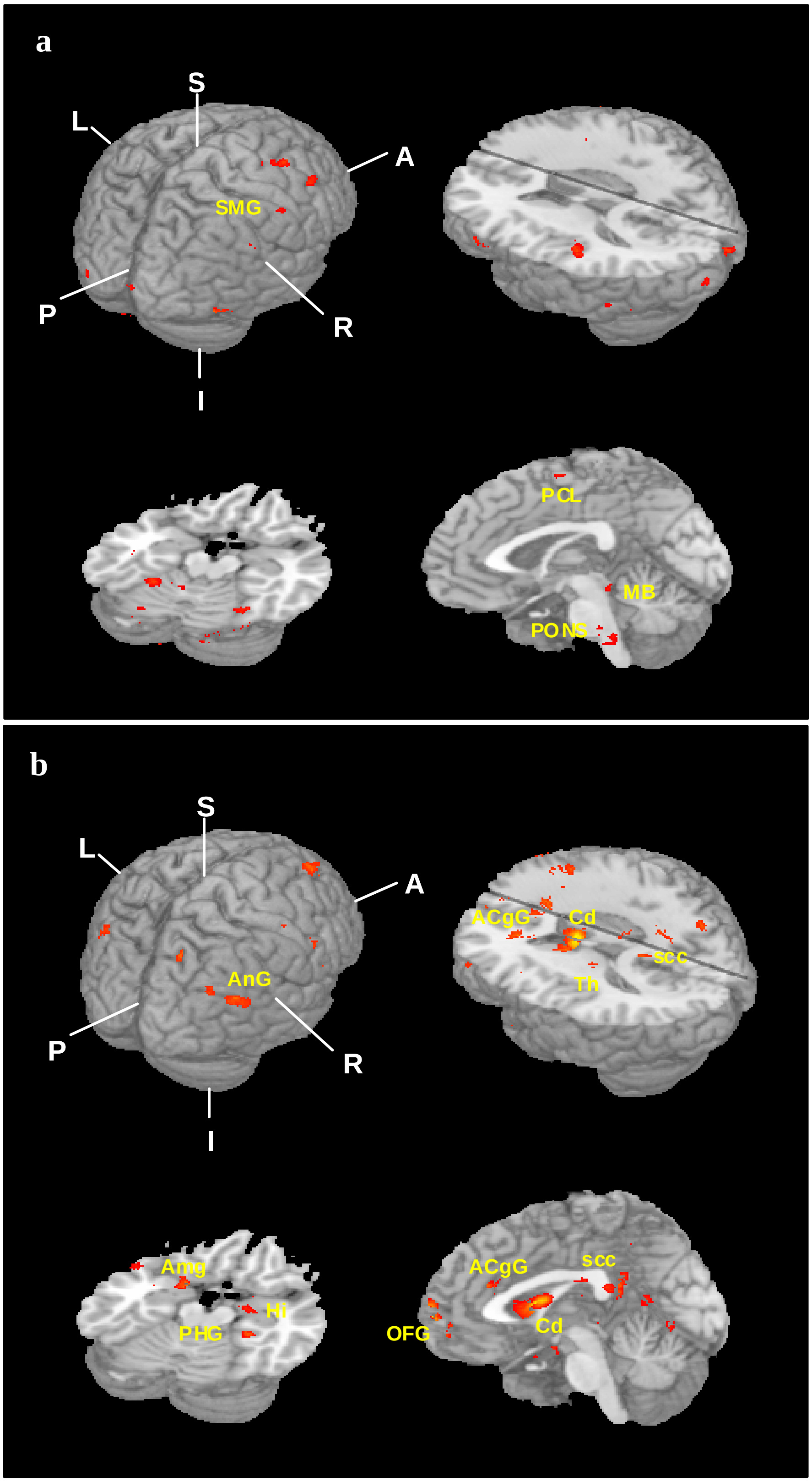

Fig. 2. Three-dimensional activation maps resulting from the two-sample *t*-tests ($p<0.01$) of (a) favorite over unfavorite colors, and (b) unfavorite over favorite colors
Amg: amygdala, AnG: angular gyrus, Cd: caudate nucleus, ACgG: anterior cingulate gyrus, scc: splenium of the corpus callosum, Hi: hippocampus, MB: midbrain, OFG: orbitofrontal gyrus, PCL: paracentral lobule, PHG: parahippocampal gyrus, SMG: supramarginal gyrus, Th: thalamus

for direct discriminating the differential brain activation patterns for color preference. The brain areas with predominant activities during stimulation with favorite colors over unfavorite colors included the pons, supramarginal gyrus, midbrain, paracentral lobule and globus pallidus (Fig. 2a and Table 2a). The pons and midbrain are the parts of the brain stem, which are involved in integrative functions with basic cognition, consciousness and alertness. Especially, the pons relays sensory information between the cerebellum and cerebrum, and aids in relaying a variety of messages (Richard, 2006). The supramarginal gyrus is well known to play an important role in higher cognitive functions and processing sensory information (Caspers *et al.*, 2006). The paracentral lobule processes the sensorimotor signals related to the lower extremities. The globus pallidus belongs to a part of the basal ganglia, which might be important for positive emotions such as happiness and reward. Recent studies have demonstrated that this region is activated by enjoyable activities when playing a video game (Koepp *et al.*, 1998), reward processing (Rolls, 1999), and responds to addictive substances and behaviors (Breiter *et al.*, 1997; Stein *et al.*, 1998). The globus pallidus is one of the important structures involved in the dopamine pathway and is potentially related with color perception associated with a positive emotional status.

The brain areas predominantly activated with the unfavorite colors over the favorite colors include the body of the caudate nucleus, parahippocampal gyrus, anterior cingulate gyrus, splenium of the corpus callosum, hippocampus, orbitofrontal gyrus, amygdala, thalamus and angular gyrus (Fig. 2b and Table 2b). Activation of the caudate nucleus is associated with a negative emotion (Davidson *et al.*, 1990; Phan *et al.*, 2002) and a state of preparedness triggered by a warning stimulus (Sprengelmeyer *et al.*, 1998).

The cingulate gyrus is a major part of the emotional circuit (Stern *et al.*, 1996). In particular, activation of the anterior part of the cingulate gyrus is very important because it is associated with both depression and elevation of blood pressure and is often related with aggressive behavior. Activation of the hippocampal formation including the parahippocampal gyrus and hippocampus is also important because of its connection with neighboring structures and function as well. The hippocampal formation is a part of the limbic system and it is concerned with emotional behavior by the link with the primitive cortices and subcortical areas. Activation of the parahippocampal gyrus in particular was induced by visual stimulation with masked traumatic images in posttraumatic stress disorder in memory processing (Astur & Constable, 2004; Sakamoto *et al.*, 2005). It is important to note that the amygdala showed predominant activity in viewing unfavorite colors. Several studies (Calder *et al.*, 1996; Halgren *et al.*, 1978; Ketter *et al.*, 1996; Kim *et al.*, 2010; Morris *et al.*, 1998b; Reiman *et al.*, 1997; Whalen *et al.*, 1998b) revealed that the amygdala played a pivotal role in the evaluation of emotional stimuli. The amygdala is involved in various functions such as the detection, generation, maintenance of fear-related emotions (Reiman *et al.*, 1997), recognition of fearful facial expressions (Calder *et al.*, 1996), feelings of fear after

Table 2. Brain areas with predominant activities resulting from the double contrasts of two-sample *t*-tests (*p*<0.01) of (a) favorite over unfavorite and (b) unfavorite over favorite colors

a. favorite over unfavorite colors

Brain areas	Talairach coordinates			z-scores
	x	y	z	
Pons	10	-27	-29	2.64
Supramarginal gyrus	61	-53	34	2.55
Midbrain	-2	-34	-10	2.32
Paracentral lobule	-20	-44	50	2.20
Globus pallidus	-22	-12	-3	2.10

b. unfavorite over favorite colors

Brain areas	Talairach coordinates			z-scores
	x	y	z	
Body of caudate nucleus	8	6	9	3.59
Parahippocampal gyrus	-22	-7	-23	3.49
Anterior cingulate gyrus	8	32	21	2.97
Splenium of corpus callosum	4	-34	20	2.78
Hippocampus	-24	-5	-24	2.69
Orbitofrontal gyrus	6	32	-22	2.68
Amygdala	-22	2	-21	2.44
Thalamus	20	-21	16	2.38
Angular gyrus	44	-74	33	2.33

procaine induction (Ketter *et al.*, 1996), fear conditioning (Morris *et al.*, 1998b; Whalen *et al.*, 1998b) and evocation of fearful emotional responses using electrical stimulation (Halgren *et al.*, 1978).

Although the cortical areas of the cerebrum play a role in higher visual functions, the visual information is mainly transferred through the splenium of the corpus callosum that interconnects both hemispheres of the occipital cortices (Pandya & Seltzer, 1986). Transection of the splenium impairs visual information transfer between the two hemispheres, as well as interhemispheric transfer of information about luminance, size and color of visual objects and object shape (Forster & Corballis, 2000). The orbitofrontal gyrus is an essential region for complex and flexible emotional, behavior (Rolls *et al.*, 1994), and visual discrimination for reversal learning and extinction testing (Rolls *et al.*, 1994). It should be noted that the inferior parietal lobule including the supramaginal gyrus and angular gyrus integrates information from different sensory modalities and plays an important role in a variety of higher cognitive functions (Caspers *et al.*, 2006). In our study, the supramarginal gyrus showed predominant activity in viewing the favorite colors, whereas the angular gyrus was predominantly activated during viewing the unfavorite colors.

CONCLUSION

This study has a potential impact upon an understanding of the differential neural mechanism on the subjective emotional states in viewing the favorite vs. unfavorite colors. This outcome is practically applicable for selecting subjective favorite colors in conjunction with the interior and living environments in the eco-friendly housing. In summary, the brain activation patterns in response to visual stimulation with favorite and unfavorite colors were different from each other; this finding is potentially valuable for an understanding of the neural mechanism on the subjective emotional states associated with color preference.

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