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Research Paper

Using functional Magnetic Resonance Imaging (fMRI) to analyze brain region activity when viewing landscapes

I-Chun Tang[a,1], Yu-Ping Tsai[b,1], Ying-Ju Lin[b], Jyh-Horng Chen[c], Chao-Hsien Hsieh[c], Shih-Han Hung[b], William C. Sullivan[d], Hsing-Fen Tang[e], Chun-Yen Chang[b,*]

[a] General Education Center, Chang Jung Christian University, Tainan, Taiwan
[b] Department of Horticulture and Landscape Architecture, National Taiwan University, Taipei, Taiwan
[c] Department of Electrical Engineering, National Taiwan University, Taipei, Taiwan
[d] Department of Landscape Architecture, University of Illinois at Urbana-Champaign, Champaign, IL, USA
[e] Department of Leisure Industry and Health Promotion, National Taipei University of Nursing and Health Sciences, Taipei, Taiwan

HIGHLIGHTS

- A new neuroscience approach using functional magnetic resonance imaging (fMRI) in landscape evaluation is proposed.
- Urban and nature landscape effect differently not only in attention restorative measuring scale but also in brain activities.
- Brain activated differently with urban and other nature landscapes, especially water.

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ABSTRACT

Over the years, the restorative benefits of the natural environment have been taken seriously. These restorative effects continue to be verified in research from both the psychological and physiological perspectives. The latest functional magnetic resonance imaging (fMRI) technology provides an opportunity to further explore the psychophysiological aspects of these benefits from the natural environment. This study aimed to compare the restorative value of four types of landscape environments (urban, mountain, forest, and water) through questionnaires and by investigating the relationship between the different environments and brain region activity by means of fMRI. Based on a one-way analysis of variance, a significant difference was found between the restorative value of the urban and natural environments—the most value being in the water and mountain environments and least in the urban environment. In support of this psychological result, the brain was found to respond similarly, showing increased activity in the visual and attentional focus areas when an urban environment is viewed as opposed to a natural environment. These findings reveal a new approach to test the restorative value of an environment and support the restorative effect of the natural environment.

1. Introduction

1.1. Background

In recent years, the benefits of natural landscapes have become an important feature of study in landscape research, with recent works confirming that compared to urban settings, exposure to the natural environment can produce positive psychological and physiological effects on people (Berman, Jonides, & Kaplan, 2008; Berto, 2005; Hartig, Mang, & Evans, 1991; Ulrich, 1981). In previous studies, researchers have mainly used the questionnaire or biofeedback instruments to record human responses to different environments (Berman et al., 2008; Berto, 2005; Chang & Chen,

* Corresponding author.
E-mail addresses: tangichun@mail.cjcu.edu.tw (I.-C. Tang), ypt1024@hotmail.com (Y.-P. Tsai), r99628305@ntu.edu.tw (Y.-J. Lin), jhchen@ntu.edu.tw (J.-H. Chen), hchjoe.hsieh@gmail.com (C.-H. Hsieh), shelly6327@hotmail.com (S.-H. Hung), wcsulliv@illinois.edu (W.C. Sullivan), hsingfen@ntunhs.edu.tw (H.-F. Tang), cycmail@ntu.edu.tw, cycpaper@gmail.com (C.-Y. Chang).

[1] These authors contributed equally to this work.

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2005; Chang, Hammitt, Chen, Machnik, & Su, 2008; Chang & Perng, 1998; Hartig et al., 1991; Ulrich, 1981), but empirical research has still been inadequate in determining the neurological function of human beings and the environments encountered. With the development of brain research and the latest technology, scientists can now investigate the effect of viewing the landscape environment on human brain activity by using functional magnetic resonance imaging (fMRI). This study attempts to uncover the effect of natural landscape visualization on brain activity in an attempt to establish the relationship between the two.

1.2. Effect of the visible landscape

It is commonly believed that contact with nature may enhance positive emotions, restore attention, and relieve stress (Kaplan & Kaplan, 1989; Laumann, Garling, & Stormark, 2003; Staats, Kieviet, & Hartig, 2003). Even without actually visiting a natural environment, simply viewing nature through a window or having some natural elements in the room, such as leafy plants or sunlight, could have a positive influence on mental health, work attitude, and productivity in the workspace (An, Colarelli, O'Brien, & Boyajian, 2016; Chang & Chen, 2005; Hartig, Evans, Jamner, Davis, & Gärling, 2003; Knight and Haslam, 2010). A literature review of publications linking visible landscapes and health effects showed that natural landscapes yielded a stronger positive health effect compared to urban landscapes (Velarde, Fry, & Tveit, 2007). Since the effect of the visible landscape has been recognized, the additional evidence of brain region activity may provide a forward-looking approach to this field of research.

1.3. Effect of landscape type on human response

Research has discussed the interplay between landscape types and the physiological response of human beings. Ulrich (1983) divided the concept of the environment into the natural environment, which includes the "plants/no plants" and "water/no water" classifications, and the artificial environment, which comprises the "building/no building" and "vehicles/no vehicles" classifications. In subsequent research, the environment was classified into six types: plant environment, including trees and other vegetation; water environment, primarily flowing water and that which involved trees; congested traffic; normal traffic; crowded pedestrian environment; and common pedestrian environment (Ulrich et al., 1991). Heart rate, blood pressure, electromyography (EMG), and forehead muscle reaction were measured after exposure to each of these environments. The results showed that when participants viewed the water environment after experiencing stress, their EMG rate decreased and respiratory rate slowed, indicating restorative benefits.

Studies have also discussed the interplay between landscape types and the psychological responses of humans. Classifying environments as either natural (forests, mountains, and water) or urban (parks and cities), Laumann, Garling, and Stormark (2001) tested the restorative qualities of different environments and developed a questionnaire to pinpoint the restorative effect perceived by people in a given environment. The results showed that the perceived restorative effect in the forest, mountain, and water environments were significantly higher than that in the city environment. Incorporating the methods and definitions in Ulrich et al. (1991) and Laumann et al. (2001), the present study represented the natural environment in terms of forests, mountains, and water and the urban environment in terms of congested traffic.

1.4. Attention restoration and the associated brain region activity

Attention has been characterized as playing a prominent role in effective cognitive and emotional functioning among human beings (Posner & Rothbart, 2007). Since the Attention Restoration Theory (ART) proposed by Kaplan (1995), the restorative benefits of the natural environment have continued to be corroborated in the research from both the psychological and physiological perspectives. The latest fMRI technology provides an opportunity to further explore the psychophysiological perspective of these benefits from the natural environment.

Scholars have established a possible association between attention restoration and brain activity. Kaplan and Berman (2010) used the concept of automaticity to describe voluntary attention (termed "directed attention" by neurologists) and involuntary attention. Involuntary attention could be compared to bottom-up attention, where the active brain areas are the ventral frontal cortex and the temporal cortical. Directed attention could be analogous to the top-down attention system, where the active brain areas are the dorsal-anterior, dorsal-frontal, and parietal cortical. A possible association between attention restoration and brain region activity has been proposed; however, there is currently no empirical evidence to prove this association.

Based on subsequent empirical research on ART and the research on attention, it has been hypothesized that a fascinating natural environment could lead to involuntary attention, causing modest bottom-up attention, and an urban environment could prompt the use of directed attention to overcome different kinds of stimuli (e.g., to avoid cars accidents, and disregard advertisements). Further research is required to verify the attention-restorative effects of the natural landscape on the human brain. The present study aims to determine the effect of viewing different landscapes on brain region activity through fMRI.

2. Methods

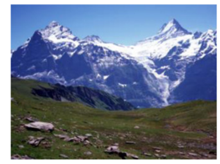
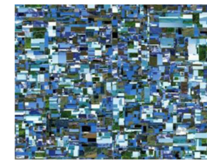
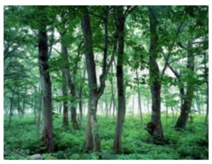
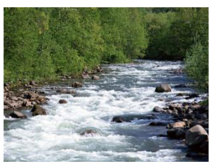
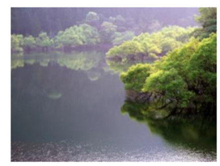
For the purpose of understanding the psychological and physiological responses to various landscape environments, two types of data were collected: in the psychological study, the perceived restorative values of four types of landscape environments (urban, mountain, forest, and water) were evaluated by using questionnaires, and in the physiological study, brain activity was detected while viewing different types of landscape environments through fMRI.

2.1. Stimulus of experimental images

The present study employed two methods of collecting landscape images: images of urban landscapes were retrieved via the Internet, depicting congestion in the city, whereas natural landscape images were chosen from an online gallery of photographs taken from the Japanese company Datacraft and the U.S. company Corbis. Ten photographs were selected to represent each type of common natural settings, including mountains, forests, and water. Then, 15 people with more than five years of landscape design were asked to rate each photo on a scale of 1–5. The scores were added, and the five highest scoring photographs were extracted. Avoiding the effect of low-level visual properties, three photographs with similar color, lightness, and layout were ultimately selected for each landscape type. In total, 12 photographs were used in the experiment (Table 1).

Using Adobe Photoshop 7.0 to adjust the RGB values during post-processing, the picture size of each photograph was set to 800×600 pixels, with a resolution of 300 pixels per inch. In addition, a baseline image was created by shuffling the three photographs in each

Table 1
Example of experimental images (left: 3 images of the environment; right: baseline images).

Urban				
Mountain				
Forest				
Water				

landscape category using the Pixuffle software. Maintaining the same color and contrast, the baseline images were disrupted 15 times so that participants had difficulty identifying the content.

2.2. Psychological response measurement

2.2.1. Psychological variables

Aligned with Kaplan & Kaplan's attention restoration theory, and in an effort to avoid participant fatigue as a result of completing the lengthy questionnaire, short version of the Perceived Restorativeness Scale (PRS) by Berto (2005) was used as the research tool. The PRS involves four aspects: being away, fascination, extent (under which fall coherence and scope), and compatibility. When dealing with extent, this study only included coherence due to difficulty comprehending the intangible aspect of scope in a 2D image. There are four items in this version, and internal consistency among them was acceptable (Cronbach's $\alpha = 0.79$). The four items were as follows:(1) Being away. This is a place which is away from everyday demands and where I would be able to relax and think about what interests me. (2) Fascination. This place is fascinating; it is large enough for me to discover and be curious about things. (3) Coherence. This a place where the activities and the items are ordered and organized. (4) Compatibility. In this place, it is easy to orient and move around so that I can do what I like.

2.2.2. Psychological experiment procedure

Using an online survey created with the LimeSurvey application, participants viewed each type of environmental image for 45 s (15 s per image) and then assigned a restorative value to the environment, completing these steps four times. Four types of environmental images were shown randomly. After completing the questionnaire, the participants submitted their background information and exited the experiment.

2.2.3. Psychological response analysis

The data collected from the online questionnaire were analyzed using the Statistical Product and Service Solutions (SPSS) software, version 17.0. After verifying the reliability of the data, descriptive statistics and a one-way analysis of variance were calculated, and Scheffe's post hoc test was used to examine various combined effects.

2.3. fMRI data acquisition

2.3.1. Participants

The participants included 39 adults from Taipei, Taiwan, aged between 20 and 30 years, who were healthy enough to complete the entire experiment. The conditions for participation included normal vision and hearing, no color blindness, no brain damage, no cranial nerve disease, no history of cardiovascular diseases, no permanent or temporary metal implants, no history of depression, no post-traumatic stress disorder, no fears or phobias, non-consumption of alcohol or drugs (prescription or non-prescription) within a 24-h period prior to the experiment, no tattoos, no make-up, and no accessories.

Due to the head or body movements of participants during the MRI process, the data of 8 participants were excluded. The final sample consisted of 31 adults, including 14 men and 17 women. Prior to the experiment, the participants were briefed on the procedure, allowed to ask questions, and asked to fill out a preliminary health survey to ensure that they fit the health requirements for the test. If they chose to proceed, the participants were required to sign an informed consent form, which was approved by the Research Ethics Office.

2.3.2. fMRI experimental procedure

A 3T Bruker Medspec MRI (Bruker, Kalsruhe, Germany) in the nuclear magnetic resonance spectroscopy laboratory (Interdisciplinary MRI/MRS Lab) was used. Equipped with a head coil and goggles, this instrument is used for imaging the effects of experimental stimuli. The following process outlines the experimental procedure involving fMRI:

(1) Before entering the fMRI room, the participants were asked to remove all rings, watches, credit cards, and other devices that might interfere with the data recording. They were also provided an opportunity to use the bathroom prior to entering the fMRI room.
(2) After entering the fMRI room, the participants lay on the fMRI table outside of the machine. Operators affixed stabilizing equipment to their heads to prevent any slight movements that would lead to measurement errors during the experiment. Participants held a safety ball in their dominant hand; if participants squeezed the ball during the experiment, it would signal to the operator that they were uncomfortable and the experiment would stop.
(3) During the nerve scan phase of the experiment, the participants entered the fMRI machine. Beginning with a structural scan of the brain including both horizontal and vertical sections and yielding 35 images each, the operators could correct the position of the brain in case of any slightly movements. The participants were encouraged to relax during these initial scans and were told to close their eyes if they preferred to do so.

2.3.3. Experimental design

In this study, anatomical T1-weighted three-dimensional images were acquired with TE = 46 ms, TR = 3000 ms, flip angle $\alpha = 30^\circ$, and field-of-view (FOV) $204 \times 240\ mm^2$. Each volume consisted of 35 slices with a voxel size of $0.9375 \times 0.9375 \times 3.75\ mm^3$. Two-dimensional echo-planar images (EPI) were acquired with TE = 30 ms, TR = 3000 ms, flip angle $\alpha = 90^\circ$, and field-of-view (FOV) $240 \times 240\ mm^2$. Each volume consisted of 35 slices with a voxel size of $3.75 \times 3.75 \times 3.75\ mm^3$. The experimental design of this study comprised four blocks and each block involved one type of landscape imagery as experimental stimuli, including the urban, mountain, forest, and water environments. The participants viewed the block of urban images first and then three blocks of natural landscapes presented in random order. The experiment began with a four-page narration detailing the process. After this, a cross symbol appeared on the screen, which participants were instructed to focus on. Next, a baseline image appeared for 12 s to establish a baseline of the brain activity for each participant. The main part of each block entailed 30 s flashes of three landscape images (Fig. 1). The process was repeated four times for a total time of 459 s.

2.3.4. fMRI analysis

The fMRI experiment employed version 8 of the Statistical Parametric Mapping software (SPM 8; Welcome Department of Imaging Neuroscience, London, UK), accessed through MATLAB. The standard analysis included the pretreatment of data and brain position analysis. Pretreatment steps included slice timing, realignment, co-register, segment, normalizing, and smoothness to correct the temporal offset between brain image slices, adjust the head movement and rotation, standardize the individuals' fMRI data to fit the brain template coordinates, and strengthen the signal in active brain areas. It is important to note that the fMRI used the BOLD (blood oxygenation level dependent) signal, which is sensitive to changing levels of blood oxygenation, to compare cognitive differences occurring at various points during the experiment; therefore, in the results, three "contrast " images were created, including the urban images versus the mountain, forest, and water images, respectively. Each participant's corresponding contrast images were then analyzed at the second level of SPM8 in order to determine the variance between participants. Our aim during this process was to distinguish between the impact of the urban and natural environment images on the brain.

3. Results

The results are presented in two parts. First, this study determined the psychological response to four types of landscape environments from the results of the PRS; second, this study presented three brain region activities from the comparison of urban images versus the natural images obtained via fMRI, which showed significant brain activity with an intensity threshold of $P_{FWE} = 0.05$.

3.1. Psychological response to different landscape environments

In the psychological experiment, 142 valid samples were collected, including 52 males (36.6%) and 90 females (63.4%). The mean age of the sample was 23 years.

Results of the experiment indicated that mountain and water landscapes have the highest restorative qualities, with no significant difference between them. Forest landscapes ranked second, while urban settings scored the lowest (Table 2 and Figs. 2 and 3). In other words, as compared to the forest and urban landscapes, the mountain and water landscapes are more likely to restore attention among participants.

3.2. Brain region activities in response to different landscape environments by using fMRI

3.2.1. Difference between the "urban and mountain" landscapes

Brain activity that was most closely associated with the "urban versus mountain " contrast was located in the left and right cuneus (Table 3 and Fig. 4). The cuneus is known for its involvement in basic visual processing.

3.2.2. Difference between the "urban and forest" landscapes

By an intensity threshold of $P_{FWE} = 0.05$, no brain activity region existed in terms of the "urban versus forest " contrast. According to this finding, the brain response upon viewing urban and forest images was similar. Therefore, no significant differences were seen in this contrast.

3.2.3. Difference between the "urban and water" landscapes

The brain activity related to the "urban versus water " contract was located in the left and right cuneus (Table 4, Fig. 5). As mentioned previously, the cuneus is primarily known for its involvement in basic visual processing. Furthermore, the right cingulate gyrus and left precuneus were also activated. These regions, which are part of Brodmann area 31 (BA31) and known as the dorsal posterior cingulate cortex, are assumed to influence the focus of attention by adjusting whole-brain metastability (Leech & Sharp, 2014).

4. Discussion and conclusion

The findings of the psychological experiment suggested that the participants perceived less restorative effects when viewing urban landscapes than when viewing natural landscapes. This result supported the earlier finding that compared to natural landscapes, individuals show reduced ability to recover from fatigue when viewing an urban landscape (Kuo, 2001; Laumann et al., 2003; Tennessen & Cimprich, 1995; van den Berg, Koole, & van der Wulp, 2003). The result also indicated that among the four types of landscapes, the water and mountain landscapes had the best attention-restorative abilities, followed by the forest and urban landscapes.

In terms of neural responses, as compared to the mountain and water landscapes, viewing the urban landscape required a greater visual attention focus, resulting in the activation of the cuneus. This result indicates that viewing mountain and water landscapes

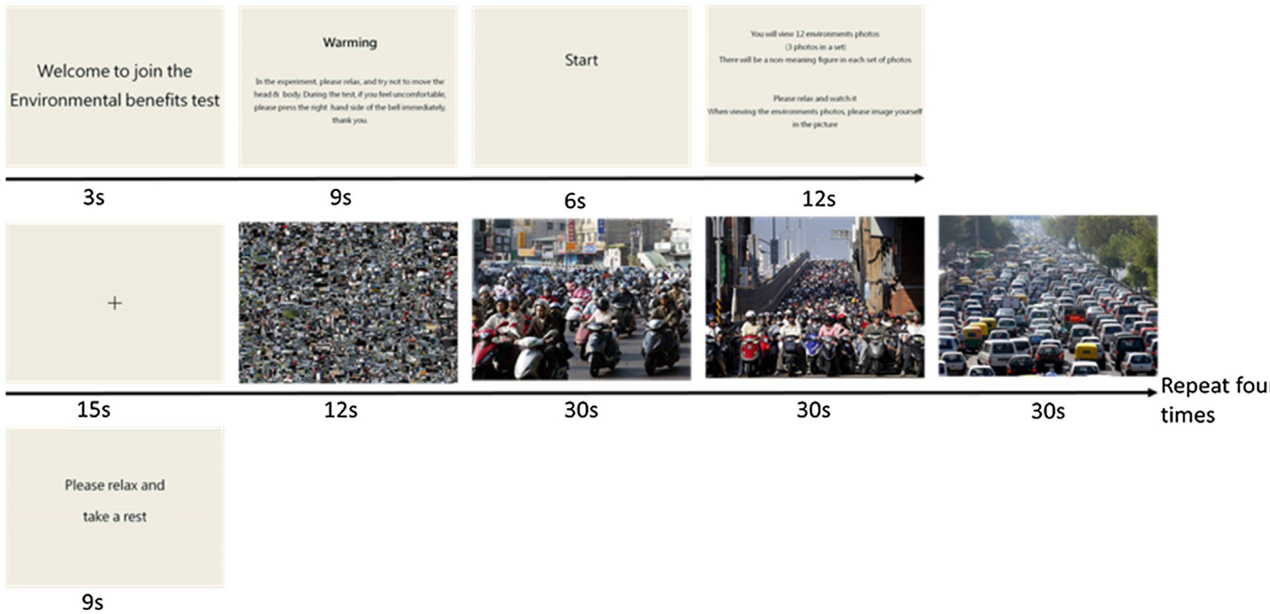


Fig. 1. Experimental design in fMRI.
Note: The "+" in the slide indicates the reorganized visual focus of the participants to ensure their attention. The last slide, which indicates a 9-s break, is to prepare participants for the next round of the test.

Table 2
Comparison of the perceived restorative effect of the different types of landscapes.

Psychological response	urban(G1)		mountain(G2)		forest(G3)		water(G4)				Scheffe' Post hoc
	M	S.D.	M	S.D.	M	S.D.	M	S.D.	F		
Being away	1.57	0.97	6.05	0.89	5.71	0.99	6.06	0.8	813.11	***	(G4 > G1) (G4 > G3) (G3 > G1) (G2 > G1) (G2 > G3)
Fascination	1.64	1.11	6.1	0.84	5.73	0.95	6.01	0.9	721.49	***	(G4 > G1) (G3 > G1) (G2 > G1) (G2 > G3)
Coherence	2.2	1.42	4.82	1.31	4.89	1.15	4.96	1.21	159.06	***	(G4 > G1) (G3 > G1) (G2 > G1)
Compatibility	1.47	0.9	5.72	1.03	5.06	1.31	5.54	1.19	455.6	***	(G4 > G1) (G4 > G3) (G3 > G1) (G2 > G1) (G2 > G3)
Perceived restorative quality	6.88	3.42	22.69	2.87	21.39	3.24	22.58	2.91	865.3	***	(G4 > G1) (G4 > G3) (G3 > G1) (G2 > G1) (G2 > G3)

***$p \leqq 0.001$.

Table 3
Activated brain regions associated with the "urban versus mountain" contrast.

Reaction brain areas*	MNI			Number of voxels	Peak intensity (t)	p-value
Left Cuneus	−10	−84	2	53	5.14	0.000
Right Cuneus	2	−80	12	10	4.80	0.000

Table 4
Activated brain regions associated with "urban versus water" contrast.

Reaction brain areas*	MNI			Number of voxels	Peak intensity (t)	p-value
Left Cuneus	0	−84	14	110	6.16	0.000
Right Cingulate Gyrus (BA31)	14	−58	28	42	5.67	0.000
Left Precuneus (BA31)	−10	−66	26	27	5.40	0.000
Right Cuneus (BA19)	8	−86	26	2	5.03	0.000

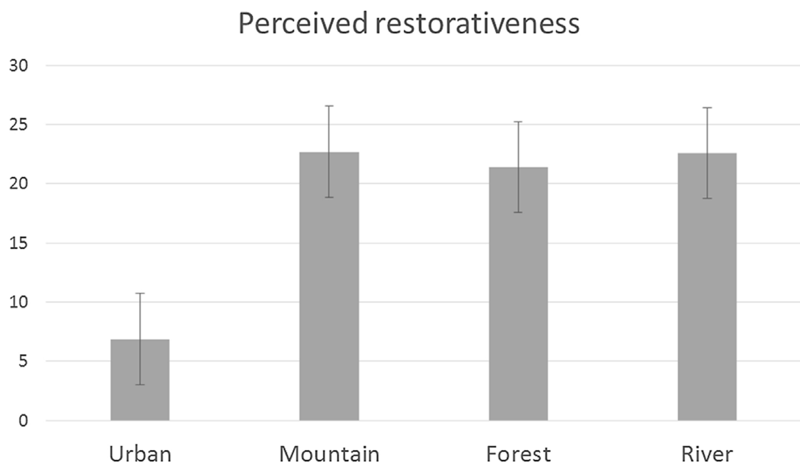


Fig. 2. Effect of different landscape types on the integrated perceived restorative value.

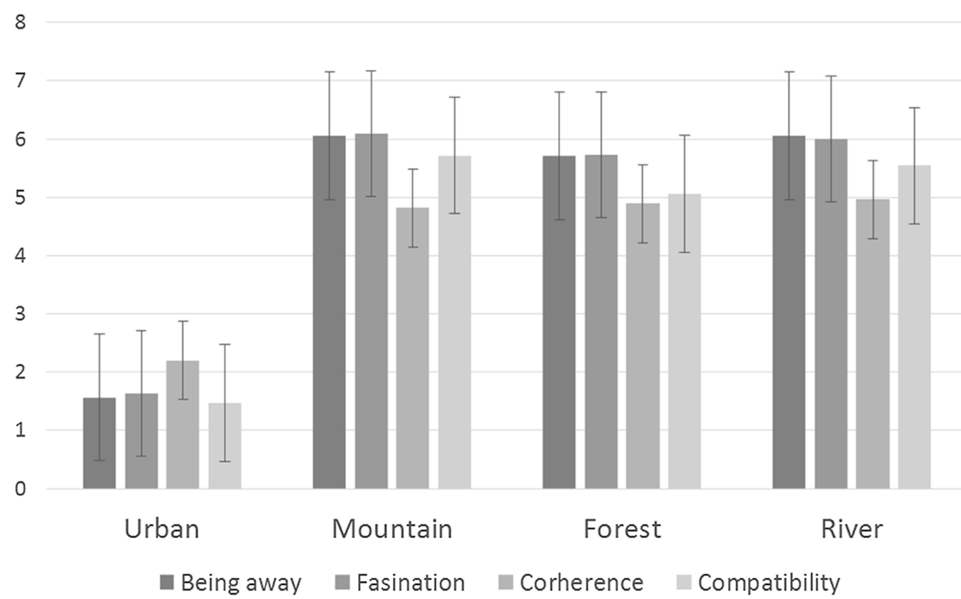


Fig. 3. Different landscape types of each perceived restorative aspect.

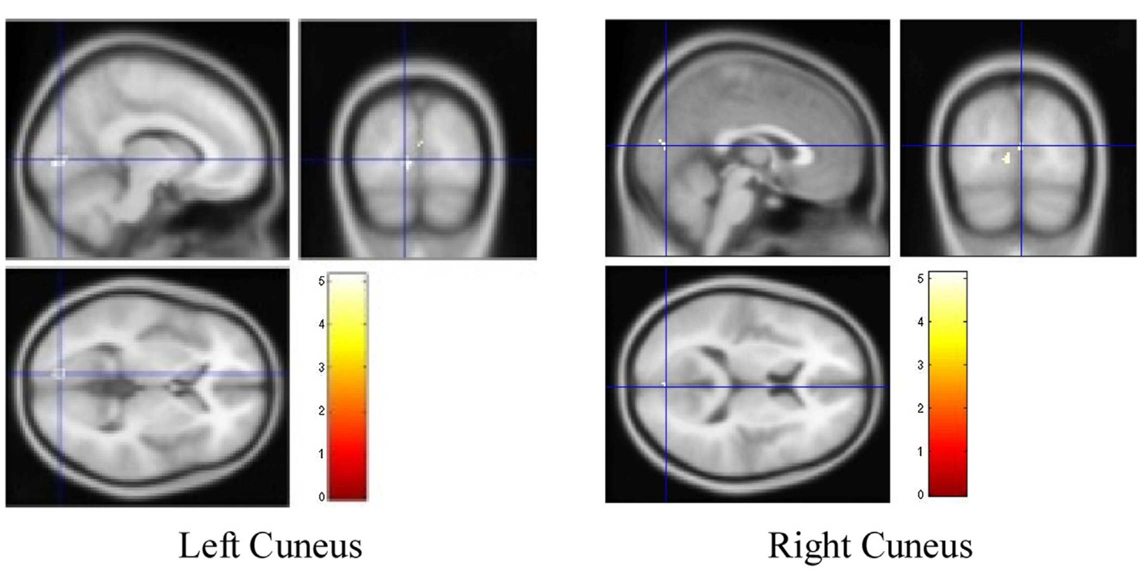


Fig. 4. Activated brain regions associated with the "urban versus mountain" contrast were located in the cuneus (basic visual processing brain area).

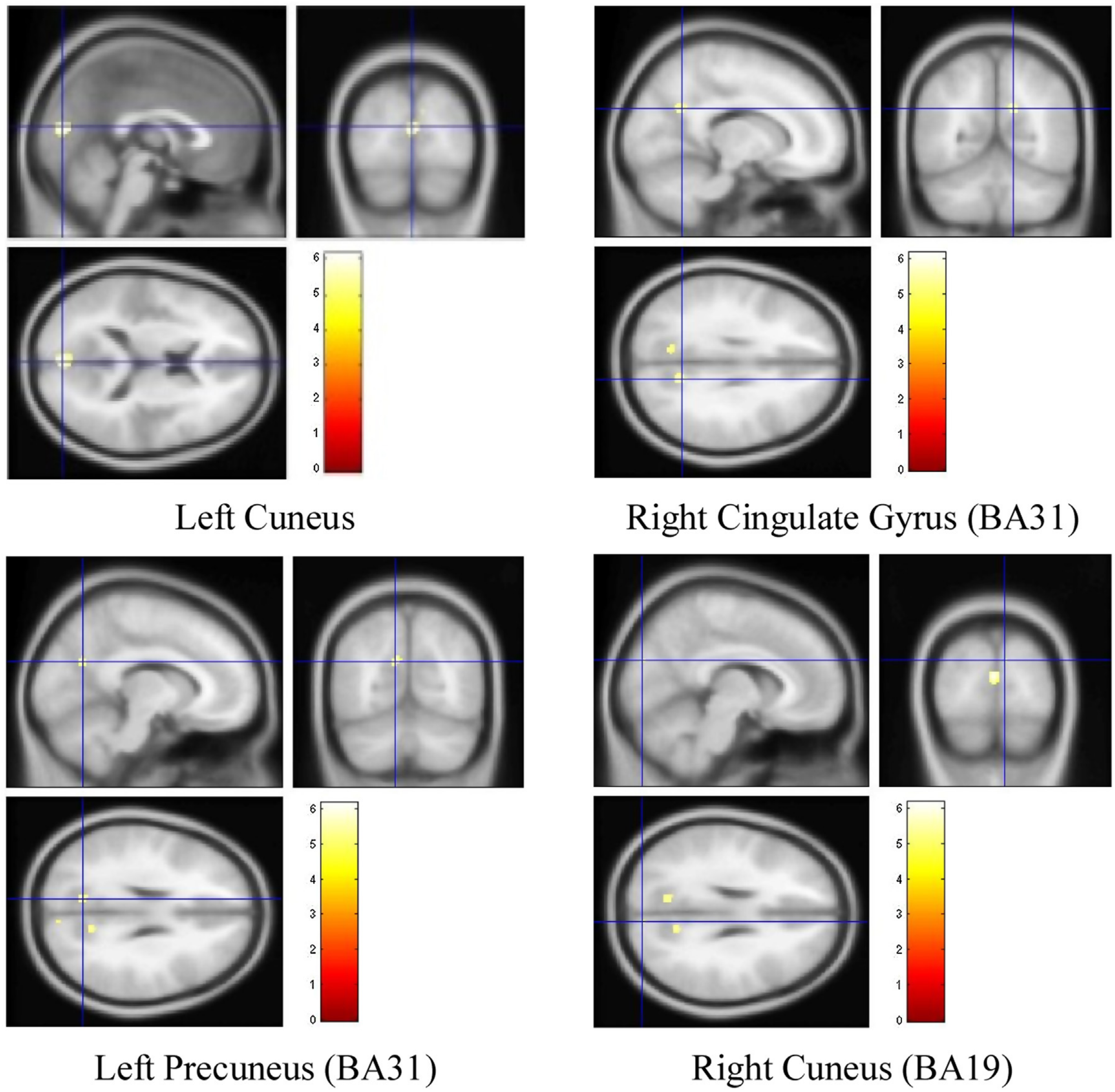


Fig. 5. Activated brain regions associated with the "urban versus water" contrast were located in the cuneus (responsible for basic visual processing) and Brodmann area 31 (responsible for adjusting attention).

after urban landscapes may significantly reduce the activation of the visual brain area and enable the rest of the attention system. Moreover, the neural response of the "urban versus water" contrast showed the activation of the attention area in the brain. This result also indicates that viewing water landscapes after urban landscapes may enable the rest of the attention system. The result corresponds with the psychological finding showing an extreme difference in the restoration value of the water and urban settings. According to the neural result, this study showed that the brain responded differently to the urban and natural environment images in terms of the visual and attentional brain areas and that viewing natural landscapes may enable the rest of the attention system.

A lack of significant brain activity in the "urban versus forest" contrast indicates some similarities in these two types of images. The performance of forest landscape in terms of perceived restorative ability was the lowest among the three nature landscapes, namely, mountain, forest, and water. Viewing the results of the psychological and physiological experiments together, the forest landscape might have a smaller effect on attention restoration as compared with the mountain and water landscapes.

This study attempted to link landscapes to brain region activity viewed through fMRI images. This was a novel approach, being a more direct consideration of the physiological response to landscape visualization in terms of brain region activity. The result of this study showed that the different landscape types did have different effects on brain region activity. The brain responded differently to images of the urban and natural environments in the visual and attentional areas, especially in the "urban versus water" landscape comparison. These findings yield a new approach to test the restorative value of the environment and support the restorative effect of natural environments. Future research may simply use the two extreme landscape types—urban and water landscapes—as stimuli to reinforce the attention-fatigue effect and then perform an attention task to explore the relationship between landscapes and the attention of the human brain.

It has been similarly argued that water plays an important role in physiological and psychological health (Nichols, 2014). The characteristics of water, including its auditory and tactile aspects and its flowing quality, are likely to be the reasons for associating water landscapes as a constant influence on the emotional and bodily health of human beings. Using modern technology, the current study investigated the human response to the visual characteristics of water landscapes. Future research may conduct an in-depth investigation of other characteristics of water landscapes on human brain region activity by using fMRI.

Several experimental studies could be undertaken to further explore the effect of landscape perception by means of fMRI and other technologies. Future research could examine the spatial frequency of different landscape types, which may provide more detailed information about the evaluation criteria of landscapes. In addition to the results of the present study, the spatial frequency of landscapes may explain the restorative effect of certain landscapes. Furthermore, if the spatial frequency of landscapes is known, a landscape database can be set up, and this data can be applied to machine learning research.

Although a considerable portion of landscape research is based on the perceptual evaluation of the landscape encountered, most of the previous studies in this field mainly used indirect measurements, such as self-reported scales or biofeedback data, to evaluate the psychological and physiological benefits of viewing natural environments. Direct evidence was seldom obtained. With the development of fMRI technology in recent years, direct evidence of the human brain has enabled a new vision for landscape research in this field. Observation of the brain region activity can provide an understanding of the mechanism of perceptual reactions associated with environmental stimuli based on direct evidence obtained from images of the brain. The latest fMRI technology provides an opportunity for landscape research to take a glimpse into the human brain and investigate the relationship between landscapes and human perception by using direct information about the brain. This study has been approved by the National Taiwan University Hospital of Research Ethics Committee (201201049RIC).

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