

# The Differences of Emotional Restoration Effects of Colored-Leaves Plant Communities in Urban Parks

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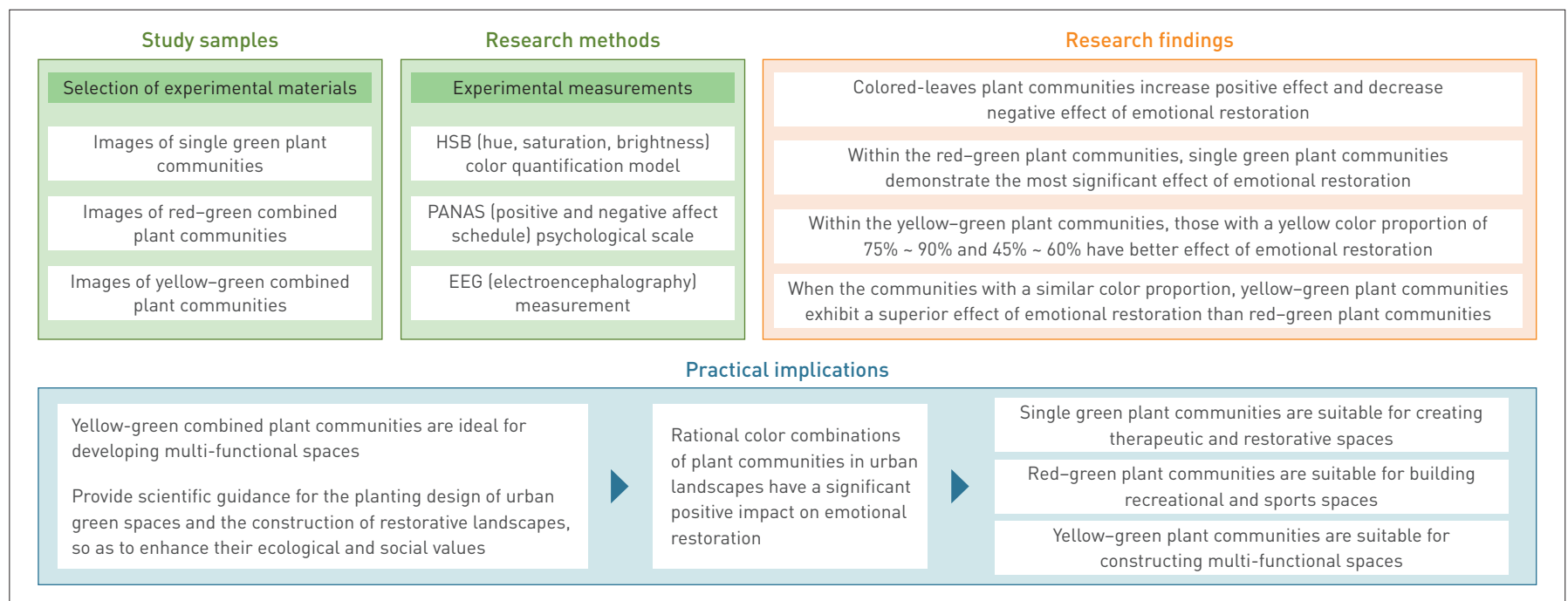
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## GRAPHICAL ABSTRACT



## ABSTRACT

The accelerating urbanization has exacerbated mental health challenges faced across social groups. College students, as an important group in the society, often experience multiple pressures from academic demands, familial responsibilities, and career uncertainties, making their emotional states especially susceptible to environmental influences. This study investigated and sampled the colored-leaves plant communities in urban parks of Suzhou, selected red-green palette, yellow-green palette, and single green plant communities with varied color proportions, and combined psychological indicators (PANAS scale) and physiological

indicators (EEG data) to scientifically examine the differences in the influence on college students' emotional restoration. The results included: 1) all plant communities significantly increased respondents' positive emotions and reduced negative emotions; 2) in the comparative experiment of red-green plant communities, single green plant communities had the best effect on emotional restoration; 3) in the comparative experiment of yellow-green plant communities, those with yellow color proportion of 75% ~ 90% and 45% ~ 60% had the best emotional restoration effect; and 4) when comparing the plant communities with the same red and yellow

color proportion, the yellow–green plant community performed better than the red–green plant community. This study responds to the urgent need to pay attention to the mental health of the youth in the current urbanization process by exploring the differences of emotional restoration effects of colored-leaves plant communities. It aims to provide scientific vegetation planting and configuration suggestions for emotional restoration environments, as well as theoretical guidance for the construction of restorative landscapes.

## KEYWORDS

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Emotional Restoration; Plant Community; Color Composition; Restorative Landscape; Urban Park; College Student; Plant Color

## HIGHLIGHTS

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- Explores whether plant communities with different color palettes lead to emotional restoration
- Combines plant community color quantification method with psychological and physiological measures
- Yellow–green plant community has better emotional restoration effect over single green and red–green communities

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## 1 Background

With the continuous progress of urbanization, the social pressure threatens people’s mental health. College students, as a special social group, are more vulnerable to emotional problems triggered by various issues such as studies and employment<sup>[1]</sup>. Under this background, it has become the research focus to explore how college students can mediate their psychological state through the natural environment. Previous research has indicated that exposure to the natural environment has a positive impact on emotional restoration. For example, restorative environment theory confirms that the natural environment has a significant effect on enhancing attention recovery<sup>[2]</sup> and relieving stress<sup>[3]</sup> and anxiety<sup>[4]</sup>. Among them, Attention Restoration Theory (ART) suggests that various natural elements in the natural environment can restore attention<sup>[5]</sup>; and Stress Reduction Theory (SRT) also emphasizes that exposure to the natural environment can enable people to recover from a state of stress<sup>[6]</sup>. As an important component of the natural environment, plants can bring positive perceptual changes in emotional induction<sup>[7]</sup>, ameliorating negative emotions<sup>[8]</sup>, and attention restoration<sup>[9]</sup>, in addition to aesthetic experience for urban residents.

Research in environmental psychology has shown that certain environmental features can provide individuals with restorative experiences that help reduce mental stress, relieve mental fatigue, and weaken negative emotions, thereby promoting the recovery of physical and mental health<sup>[10]</sup>. Color psychology suggests that color influences human emotions, behaviors, and cognition<sup>[11]</sup>. Plant color, as the most intuitively perceived and experienced factor in the natural environment, can effectively promote individuals’ physiological restoration<sup>[12]</sup> and regulate emotions<sup>[13]</sup>, and different plant colors have varied effects in emotional restoration. In relative studies, Michael Hemphill believed that green, yellow, and red colors can lead the public to a more positive response than other colors<sup>[14]</sup>, and the autumn forest landscapes featuring green, red, and yellow leaves can make the respondents relaxed and calm<sup>[15]</sup>. A study by Zimengqiu Wang<sup>[16]</sup> revealed that vegetation in both yellow–green and red–green palette showed significant positive effects on emotional restoration, while the former was more effective in alleviating negative emotions (e.g., tension, depression) and enhancing positive emotions. In addition, a study on flower colors by Qiqi Bao et al.<sup>[17]</sup> found that red and yellow roses were more effective in restoring people’s attention and enhancing their positive emotions.

In the natural environment, plant color exhibits primary visual characteristics, and the quantitative research on color is critical in landscape evaluation<sup>[18]</sup>. In recent years, color research is gradually

shifting from qualitative to quantitative studies, where there are three main quantification methods, namely colorimetric card method<sup>[19]</sup>, instrumental measurement<sup>[20]</sup>, and software-based quantification<sup>[21]</sup>. The former two methods are more suitable for single plant acquisition, while the software quantification method is more suitable for the color quantification of plant communities due to its convenience. Color quantitative indicators include two major categories: 1) spatial metrics of color patches, including color diversity index and color uniformity index; and 2) color coordination metrics, including the number and proportion of major colors, the proportion of color warmth and coldness, and the proportion between different colors<sup>[22]</sup>. The weights of these indicators vary among research at different scales. The spatial metrics of color patches are more employed in large-scale landscape color quantification research, for example, Xiaojing Zhang et al.<sup>[23]</sup> built a color quantification index system of autumn landscape forest, and used the spatial metrics of color patches, color richness, and visual contrast of color to evaluate the landscape aesthetic quality of subalpine forest landscape in western Sichuan region; while the color coordination metrics are more used in research on small- and medium-scale plant clusters or communities, which, for instance, have been applied in landscape color studies<sup>[21,24]</sup>.

Most of plant color studies focus on floral color<sup>[12]</sup>, individual plant color<sup>[25]</sup>, and large-scale forest color<sup>[26]</sup>, while there are few studies on color quantification and emotional restoration effect of plant communities at the landscape scale. This research gap necessitates further examination of the relationship between color composition and richness. Moreover, most color quantification studies on plant communities perform comparative studies for plants in different colors<sup>[12,13,27]</sup>, often resulting in the findings simply about the effects of one or several color palette on respondents' emotions. Research has suggested that different ratios of green visibility in the environment affect people's emotional recovery effect variedly<sup>[28]</sup>, whereas there are fewer studies focus on that of the ratio of different color palettes.

Previous studies on emotional restoration have been conducted using subjective evaluation methods. In contrast, the combination of subjective and objective evaluation methods—eye movement<sup>[29-30]</sup>, heart rate<sup>[12]</sup>, EEG (electroencephalography)<sup>[8]</sup>, etc.—has been used in many recent perception studies for emotional restoration research<sup>[31]</sup>. This study innovatively focuses on the emotional restoration effects of plant communities in different colors through the quantitative analysis of plant color by integrating psychological questionnaires

and EEG measurements. It aims to provide empirical support for the theory of restorative environments and scientific guidance for future restorative landscapes in urban green spaces like parks.

## 2 Materials and Methods

### 2.1 Study Area and Sample Site Selection

Suzhou City is located in East China. Its subtropical monsoon maritime climate, mild and rainy weathers, and fertile land make it superior conditions for plant growth. The urban parks in Suzhou enjoy a wealth of colorful foliage species resources, making them suitable for the sample sites for this research. First, this study conducted an overall survey of the major urban parks within the urban area in Suzhou. In order to control unrelated factors that would impact the experiment, as well as for considerations of species of plant communities, similarity and community composition, and safety reasons<sup>[8]</sup>, a total of nine popular urban parks with high quality of landscape were selected, namely Huqiu Wetland Park, Guihua Park, Central Park, Tongjing Park, Yushan Park, Suzhou Park, New District Park, Baitang Botanical Garden, and Shengdi Ecological Park.

### 2.2 Experimental Materials

#### 2.2.1 Experimental Material Photography and Screening

In previous quantitative studies of color, the use of photosensitive filming equipment to record color images of authentic environments is one of the most easy and effective means<sup>[20]</sup>, where the method of color extraction determines the evaluation effect of color<sup>[32]</sup>. In this study, plant community photographs were adopted as the experimental materials of visual stimulation, which were taken in September to December, 2023. In order to ensure the color quality of the photographs, all photographs were shot in sufficient sunlight conditions during 14:00 ~ 16:00 in sunny days. The shooting was operated by the same photographer, using the same photograph equipment (Canon EOS M50), and with a focal length range of 35 ~ 55 mm at a height of 1.6 m (imitating the view of human eyes). A total of 488 photographs were taken in the sample parks, which were subsequently screened according to the following principles: 1) the structure of the photographed plant communities had a tree-shrub-grass composite structure, and the tree species were basically consistent, and the number of plant species in the image was around 4 or 5; 2) the foreground of the image was not obviously shaded; and 3) the landscape quality of photographed plant communities was good, and no visually diseased or infested trees. After screening, 253 photographs were finally retained.

### 2.2.2 HSB-Model-Based Color Quantization

There have been many explorations in previous studies on the models used to quantitatively describe colors, such as the RGB color model<sup>[33]</sup>, which uses the three primary colors as the base channel; the CMYK color model<sup>[34]</sup>, which is used to determine mixing ratios of printing inks; and the HSB color model<sup>[21,26,35-36]</sup>, which is used to quantitatively express the three attributes of color (H for hue, S for saturation, and B for brightness). Among these models, HSB color is closer to the perceived color by human eyes, and calculating the Euclidean distance between two color points in space is more conducive to the extraction of quantitative colors that are consistent with human discrimination ability<sup>[22]</sup>. Therefore, the HSB color model was selected for color quantification in this study.

Firstly, in the non-uniform color quantization, the H values were divided into 16 intervals, and S and B values into 4 intervals<sup>[21,37]</sup>, thus a total of 256 colors were obtained. Secondly, the color values with low S and B values were normalized to white, grey, and black<sup>[26,36]</sup>, and then excluded. Finally, the 147 remained colors were further classified according to their chromatic phases: H1, H2, and H16 are red; H3 and H4 are yellow; H5, H6, H7, H8, and H9 are green; H10, H11, and H12 are blue; H13, H14, and H15 are purple<sup>①</sup><sup>[21]</sup> (Fig. 1).

### 2.2.3 Color Composition and Color Frequency Quantification

This study first used the ColorImpact 4 software in the HSB color mode to quantitatively analyze the color composition and color frequency of the images. In the image processing, to eliminate the invalid color extraction, the color which took a ratio less than 1% in the image, or in the interval of S1 and B1 were sifted out, so as to ensure that 4 or 5 major colors (i.e., valid colors) in each image can be extracted. Subsequently, the images were re-classified by H, S, and B values of their major colors, gaining 52 images in single green, 68 images in red-green, 57 images in yellow-green, 22 images in purple-green, 7 images in blue-green, and 47 images in mixed colors (Fig. 2). In this study, the valid colors in the images except green color was defined as the contrast valid color. The pixel proportion of the contrast valid color to all valid colors in each image was

① In this study, each interval of H value corresponds to a specific angle range of the color phase ring, and the range of H value was divided as H1: 345 ~ 0 and 0 ~ 15; H2: 16 ~ 25; H3: 26 ~ 45; H4: 46 ~ 55; H5: 56 ~ 80; H6: 81 ~ 108; H7: 109 ~ 140; H8: 141 ~ 165; H9: 166 ~ 190; H10: 191 ~ 220; H11: 221 ~ 255; H12: 256 ~ 275; H13: 276 ~ 290; H14: 291 ~ 316; H15: 317 ~ 330; H16: 331 ~ 345. The values of each interval of S value and B value were expressed as equal percentage. The range of S value was divided as S1: 0 ~ 25; S2: 26 ~ 50; S3: 51 ~ 75; S4: 76 ~ 100; the range of B value was divided as B1: 0 ~ 25; B2: 26 ~ 50; B3: 51 ~ 75; B4: 76 ~ 100.

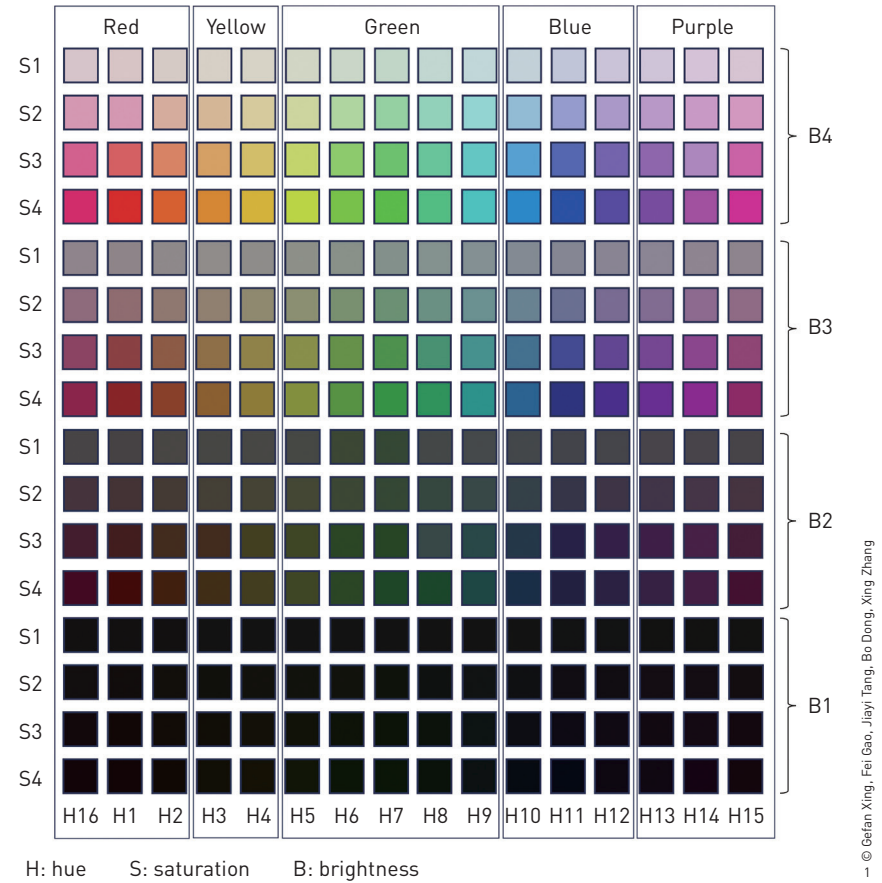


Fig. 1 HSB color quantization intervals.

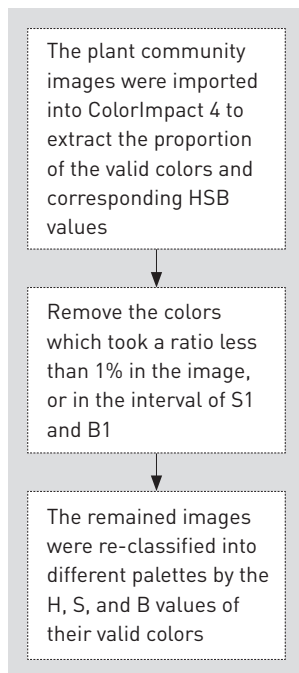
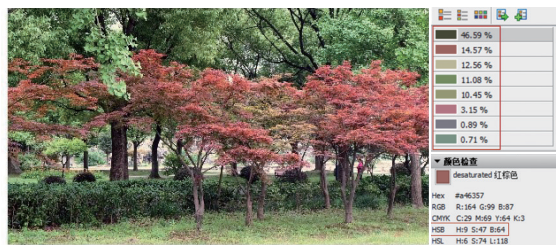
calculated. For example, the calculation of the proportion of a red-green plant community was performed by the following formulas:

$$X_{\text{valid color}} = X_{\text{sum of red color proportion}} + X_{\text{sum of green color proportion}}, \quad (1)$$

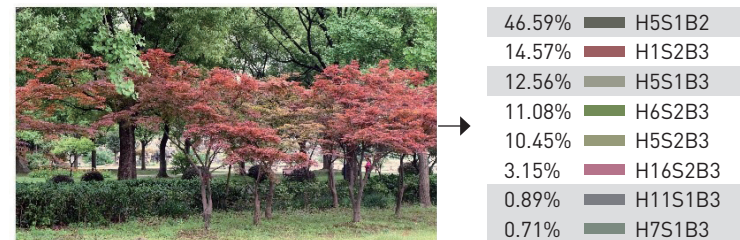
$$N_{\text{red proportion}} = X_{\text{sum of red color proportion}} / X_{\text{valid color}}, \quad (2)$$

where the  $X_{\text{valid color}}$  is the sum of the pixel proportion of the valid colors; The  $X_{\text{sum of red color proportion}}$  is the sum of pixel proportion of one or several red colors; the  $X_{\text{sum of green color proportion}}$  is the sum of pixel proportion of one or several green colors; and  $N_{\text{red proportion}}$  is the proportion of red color to valid color pixels (Fig. 3).

In order to control the number of experimental variables of color proportion, a questionnaire survey was conducted before the formal experiment to investigate the emotional restoration effect of different color proportions of plant community images. 108 questionnaires were distributed in November 2023 to college students (undergraduate or graduate), aged between 18 and 25 years old. Finally, 107 valid questionnaires were collected. The questionnaire contained questions about the restorative effects of the plant community images in different color palettes and



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Among the valid colors in this image, H1 and H16 represent red color, while H5 and H6 represent green color

According to Formula (1), the pixel proportion of red is calculated as  $14.57\% + 3.15\% = 17.72\%$ ; the pixel proportion of green is calculated as  $11.08\% + 10.45\% = 21.53\%$

According to Formula (2), the proportion of red color to valid color pixels in this image is calculated as  $17.72\% / (17.72\% + 21.53\%) = 45.15\%$

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**Fig. 2** Major color extraction and hue classification of plant community.

**Fig. 3** An example of the calculation of the proportion of the contrast valid color to valid colors.

different color proportions on the respondents, who were asked to choose 1 to 3 options out of 6 that they feel can help restore their emotions (Table 1). In the questionnaire survey, color palettes included single green, red-green, yellow-green, purple-green, blue-green, and mixed colors; and different proportions of colors included 0 ~ 15%, 15% ~ 30%, 30% ~ 45%, 45% ~ 60%, 60% ~ 75%, and 75% ~ 90%. The results showed that 47.66%, 42.06%, and 39.25% of the respondents reported that plant communities in yellow-green, red-green, and single green color, respectively, made them feel restorative. At the same time, the color proportion of foliage species in the ranges of 15% ~ 30%, 45% ~ 60%, and 75% ~ 90% made 34.58%, 33.64%, and 40.19% of the respondents felt emotionally restored, respectively. Meanwhile, the images made the respondents gained emotional restoration in purple-green (11.21%), blue-green (22.43%), and mixed color (24.30%) plant communities accounted for smaller percentages. This might be due to that most color-leaved tree species in the sample parks turn into red or yellow in autumn and winter, and are often combined with green plants. Therefore, the images in single green, red-green, and yellow-













green were determined as experimental materials in this study. From the questionnaire results, it can be also known that the color proportions between 15% ~ 30%, 45% ~ 60%, and 75% ~ 90% make the respondents feel more emotionally restored. Therefore, in order to further determine whether there is a decreasing or increasing correlation with people's emotional restoration between different color proportions, each color palette was refined into three ratio intervals, i.e., 15% ~ 30% (Interval 1), 45% ~ 60% (Interval 2), and 75% ~ 90% (Interval 3).

In order to compare and analyze the effect of emotional restoration between plant communities in red-green and yellow-green palettes, group experiments were conducted. The experimental materials of the first group included the single green images and the red-green images in three intervals, and the experimental materials of the second group consisted of the single green images and the yellow-green images in three intervals. In sum, a total of 7 sets of images were selected, including 6 images for each (Fig. 4).

## 2.3 Experiment Respondents

Referring to the steps of sample size determination in existing

**Table 1: Questionnaire results on the emotional restoration effects of plant community images with different color palettes and varied color proportions**

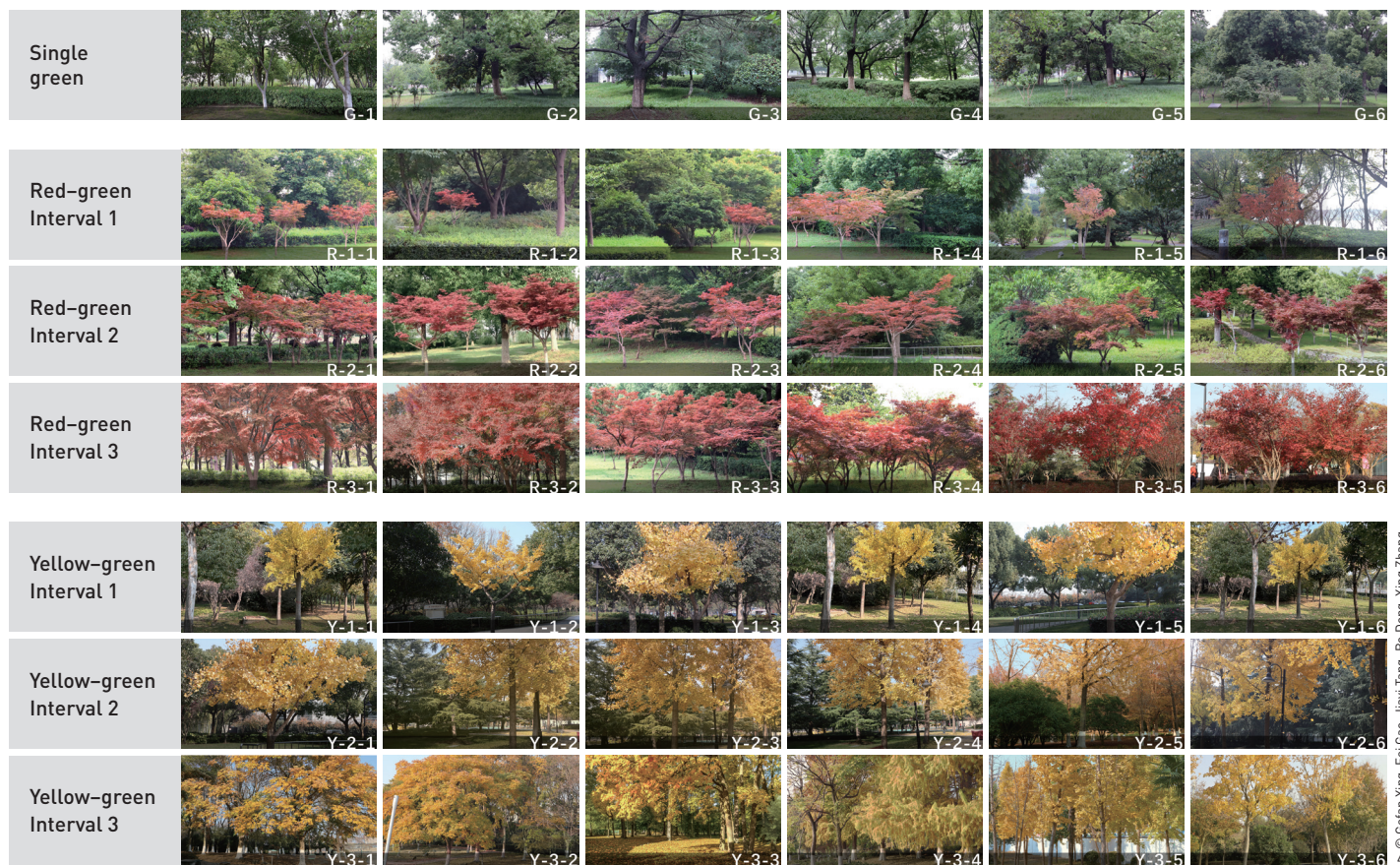
Question	Option		Number of respondents selected	Ratio	Question	Option		Number of respondents selected	Ratio
Please choose from the following plant community images the one(s) that you find emotionally restorative (1 to 3 options)	Mixed colors		26	24.30%	Please choose from the following plant community images the one(s) that you find emotionally restorative (1 to 3 options)	75% ~ 90% of color proportion		43	40.19%
	Blue-green		24	22.43%		60% ~ 75% of color proportion		28	26.17%
	Purple-green		12	11.21%		45% ~ 60% of color proportion		36	33.64%
	Yellow-green		51	47.66%		30% ~ 45% of color proportion		33	30.84%
	Red-green		45	42.06%		15% ~ 30% of color proportion		37	34.58%
Single-green		42	39.25%	0 ~ 15% of color proportion		24	22.43%		

research<sup>[8]</sup>, the calculation of the experimental sample sizes was performed using G\*Power 3.1 software, where the class I error probability was set to 0.05 and the test power was set to 0.8, medium effect size ( $f = 0.25$ ) was assumed and the final sample size was calculated to be 24. Each group experiment recruited 26 respondents, who aged 18 to 25 years old and were right-handed with normal vision and no history of mental illness or brain injury. In order to avoid the influence of other mental factors on EEG data collection, the respondents were required to have enough sleep time the day before the experiment, without drinking stimulating drinks such as coffee, or doing fasting or stimulating exercise. After excluding invalid data by four respondents, the final valid data in this study was 24 in each group, totaling 48 records of data. The respondents contributing to the valid data showed an average age of 21 years old, and the first group including 14 males and 10 females, and the second group including 11 males and 13 females, which met the sample size requirements.

## 2.4 Experiment Procedure

The experiment was conducted in the EEG laboratory in the Suzhou University of Science and Technology, which was kept closed and quiet, with a temperature of 24°C and humidity of 60%. All the lights were turned off to prevent the respondents from being disturbed by external noise and light. The red-green palette experiment was conducted during March to April, 2024. The yellow-green palette experiment was conducted during May to June, 2024. Each respondent conducted the experiment under the same laboratory conditions.

Before the experiment, respondents were informed about the experiment steps and requirements and signed the experiment consent. They were also asked to wear the EEG caps and sit stably to avoid shaking their heads or swallowing saliva, so as to ensure the well collection of EEG signals. The EEG data collection equipment used in this experiment included the Quick-Cap EEG cap, SynAmps2 amplifier, and other connecting devices. Other recording and



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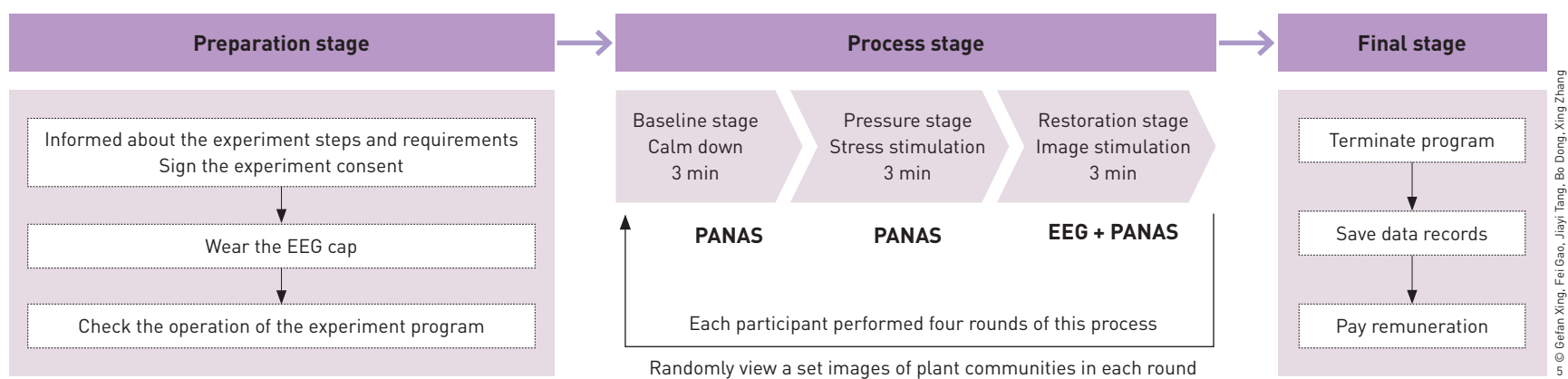
Fig. 4 Selected plant community images.

analysis software included E-prime, Curry, and MATLAB R2022b.

During the experiment, respondents were asked to calm down and fill in the Positive and Negative Affect Schedule (PANAS) to collect their psychological data at the baseline stage followed by a 3-minute stress stimulation (using mathematical calculation questions with a rapid countdown sound to stimulate high levels of stress) and filling in the PANAS again at the stress stage. Subsequently, the respondents were asked to randomly select one

of the four image sets, which lasted for 3 min<sup>[38]</sup>. During this period, the EEG data of the respondents were recorded, and then a post-test PANAS was filled in. After finishing the first round of experiment, the respondents were given a 5-minute rest period. Such steps repeated for four rounds in total, and the four image sets were all presented (Fig. 5). At the end of each group experiment, the four rounds of PANAS data were collected, and the EEG signal data were examined and saved.

Fig. 5 Experiment procedure.



## 2.5 Psychological and Physiological Data Collection

### 2.5.1 Psychological Data

Psychological data collected from the questionnaires were measured using the PANAS scale<sup>[39]</sup>. The 5-points PANAS scale consists of 10 words representing positive emotions and 10 words representing negative emotions, and the respondents' positive emotions (PA values) and negative emotions (NA values) were calculated, with 1 point representing strongly disagree and 5 points representing strongly agree; higher PA values or lower NA values indicate better emotional restoration.

### 2.5.2 Physiological Data

The EEG physiological data were analyzed by measuring the  $\alpha$ -wave energy values and  $\beta/\alpha$  ratio of participants. The  $\alpha$  waves are typically associated with wakefulness and relaxation, while the  $\beta$  waves are typically associated with tension, attention, and focus<sup>[40]</sup>. An increase in  $\alpha$ -waves indicates greater relaxation, while a decrease indicates greater tension; an increase in  $\beta$  waves indicates greater tension, a decrease indicates greater relaxation. The  $\beta/\alpha$  ratio is used to describe the impact of stress on the nervous system<sup>[41]</sup>. A higher  $\beta/\alpha$  ratio indicates a higher stress level, while a decreased one indicates a lower stress level. In this study, the brain waves are presented by the whole-brain average spectrogram, that is, the spectrogram generated by the overall analysis and statistical integration of brain wave data through MATLAB R2022b.

## 2.6 Data Processing

IBM SPSS Statistics 26 was used to process the PANAS data. The formulas for calculating emotional changes between the stress stage and restoration stage, as well as the changes of PA and NA values are as follows. Emotional change value in stress stage is calculated as

$$\Delta P_1 = P_{\text{stress}} - P_{\text{baseline}}, \quad (3)$$

where  $P$  represents the average emotion score,  $P_{\text{baseline}}$  represents the average emotion score during the baseline stage,  $P_{\text{stress}}$  represents the average emotion score during the stress stage.

Emotional change value in restoration state is calculated as

$$\Delta P_2 = P_{\text{post-test}} - P_{\text{baseline}}, \quad (4)$$

where  $P_{\text{post-test}}$  represents the average emotion score during the post-test stage.

PA value change is calculated as

$$\Delta P_{\text{PA}} = (\Delta P_{1\text{PA}} - \Delta P_{2\text{PA}}) / \Delta P_{\text{stressPA}}, \quad (5)$$

where  $\Delta P_{\text{PA}}$  is the PA value change,  $\Delta P_{1\text{PA}}$  is the PA value change during the stress stage,  $\Delta P_{2\text{PA}}$  is the PA value change during the post-test stage, and  $\Delta P_{\text{stressPA}}$  is the PA value during the stress stage.

NA value change is calculated as

$$\Delta P_{\text{NA}} = (\Delta P_{1\text{NA}} - \Delta P_{2\text{NA}}) / \Delta P_{\text{stressNA}}, \quad (6)$$

where  $\Delta P_{\text{NA}}$  is the NA value change,  $\Delta P_{1\text{NA}}$  is the NA value change during the stress stage,  $\Delta P_{2\text{NA}}$  is the NA value change during the post-test stage, and  $\Delta P_{\text{stressNA}}$  is the NA value during the stress stage<sup>[8]</sup>.

The current PANAS results were analyzed for Cronbach's reliability, where the Cronbach's  $\alpha$  coefficients for PA and NA values were 0.825 and 0.855, respectively, which were both greater than 0.8, indicating that the data reliability was high. The EEG data were then processed and analyzed by Matlab R2022b software and EEGLAB toolkit. The experimental data were analyzed with IBM SPSS Statistics 26.0, the emotional restoration differences in PANAS scale and EEG were analyzed by repeated-measures ANOVA, and the emotional restoration effects and differences of plant communities with the same color palette and varied color proportions were compared using paired samples t-tests and were considered statistically significant when  $p < 0.05$ .

## 3 Results and Analysis

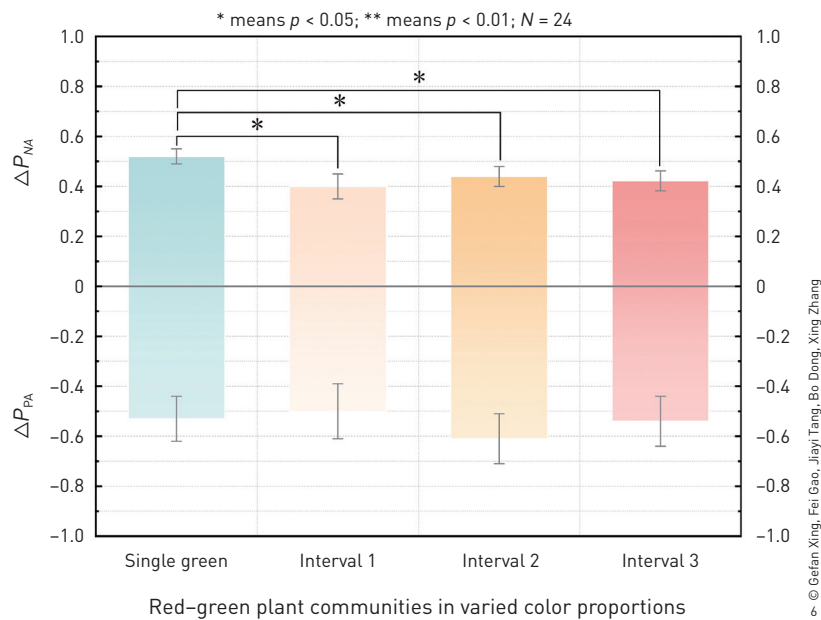
### 3.1 Disparity of Plant Communities of Red-Green Palette on Emotional Restoration

#### 3.1.1 Differences in Emotional Restoration Effect of Psychological Indicators

In order to investigate the differences in emotional restoration effect among the red-green plant communities, the changes of PA and NA values of the three red-green plant communities and the single green plant community were subjected to the repeated-measures ANOVA (Fig. 6). The results showed that there was no significant difference among the four image sets of plant communities in PA values, while revealing a significant difference in NA values ( $p < 0.05$ ). The changes of NA values of the respondents after viewing the four image sets in the restoration stage were in the following order: single green (0.525) > Interval 2 (0.441) > Interval 3 (0.422) > Interval 1 (0.400).

#### 3.1.2 Differences in Emotional Restoration Effect of Physiological Indicators

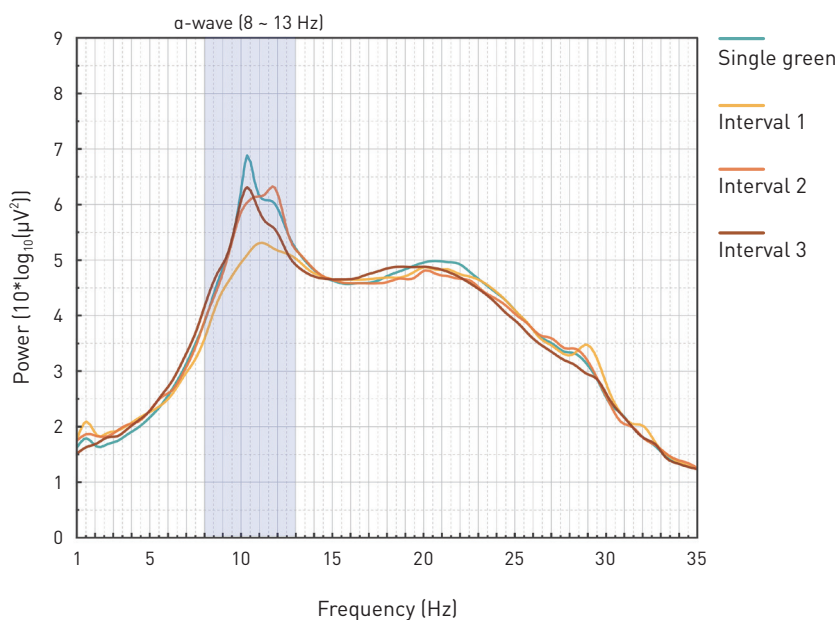
The EEG data after the processing were analyzed and the whole-brain average spectrograms were obtained between the red-



**Fig. 6** Comparative analysis of psychological indicators between red-green groups.

green plant communities (Fig. 7). The peaks of the spectrograms of the four plant communities were all found in the  $\alpha$ -band. Subsequently, the values of  $\alpha$ -wave and  $\beta/\alpha$  of the four groups of plant communities were subjected to the repeated-measures ANOVA (Table 2), with a significant difference between the  $\alpha$ -wave and  $\beta/\alpha$  values of all the four groups of plant communities ( $p < 0.05$ ). It was found that the  $\alpha$ -wave values of the respondents after viewing the four image sets in the restoration stage were in the

**Fig. 7** Comparative analysis of physiological indicators between red-green groups.



**Table 2: Comparison results of  $\alpha$ -wave and  $\beta/\alpha$  values of red-green plant communities**

Indicator	Plant communities	Mean	SD	F	p	$\eta^2$
$\alpha$	Single green	4.945	0.428	2.973	0.038*	0.114
	Interval 1	4.241	0.270			
	Interval 2	4.781	0.357			
	Interval 3	4.661	0.333			
$\beta/\alpha$	Single green	1.006	0.094	2.955	0.038*	0.114
	Interval 1	1.090	0.085			
	Interval 2	0.968	0.077			
	Interval 3	0.971	0.078			

**NOTE**

\* means  $p < 0.05$ .

following order: single green (4.945) > Interval 2 (4.781) > Interval 3 (4.661) > Interval 1 (4.241); and the  $\beta/\alpha$  values after viewing the four image sets were in the following order: Interval 1 (1.090) > single green (1.006) > Interval 3 (0.971) > Interval 2 (0.968).

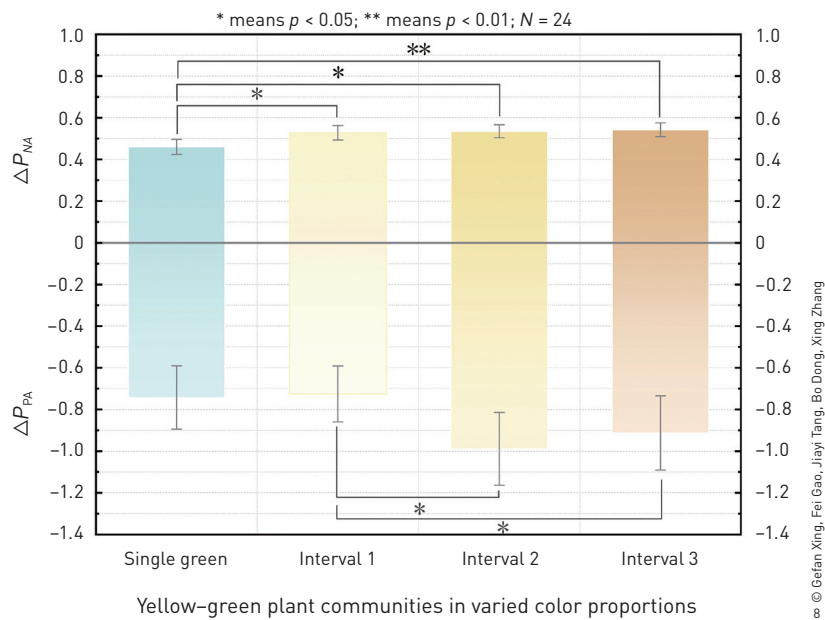
**3.2 Disparity of Yellow-Green Plant Communities on Emotional Restoration Effect**

**3.2.1 Differences in Emotional Restoration Effect of Psychological Indicators**

Among them, significant differences ( $p < 0.05$ ) were found in both PA and NA change values. The changes of PA values of the respondents after viewing the four image sets at the restoration stage were in the following order: Interval 2 (-0.990) > Interval 3 (-0.914) > single green (-0.744) > Interval 1 (-0.726); the changes of NA values were in the following order: Interval 3 (0.542) > Interval 2 (0.535) > Interval 1 (0.528) > single green (0.460) (Fig. 8).

**3.2.2 Differences in Emotional Restoration Effect of Physiological Indicators**

In the whole-brain average spectrograms of the yellow-green plant communities, the peaks of the four groups of plant communities were shown in the  $\alpha$ -wave band (Fig. 9). There was a significant difference between the energy values of  $\alpha$ -wave ( $p < 0.01$ ) and the values of  $\beta/\alpha$  ( $p < 0.05$ ) of the four groups

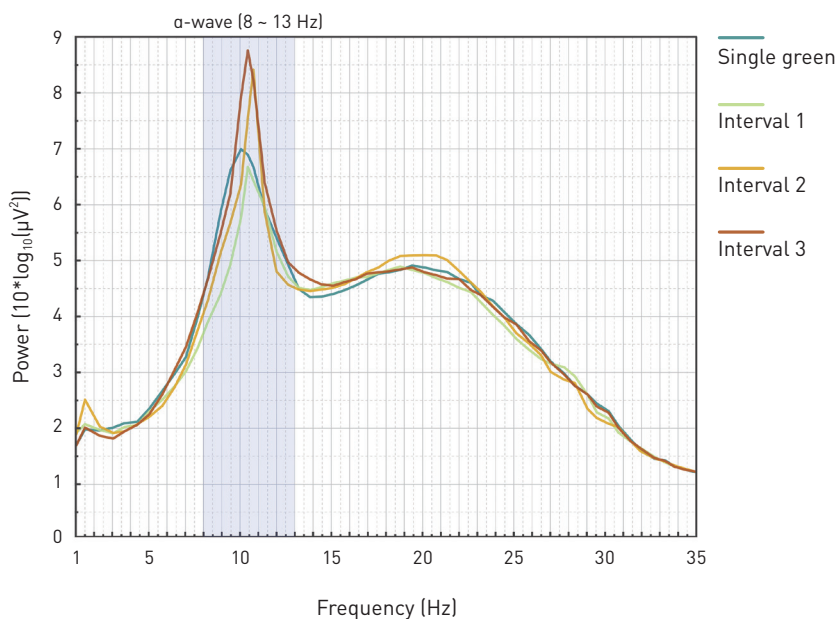


**Table 3: Comparison results of  $\alpha$ -wave and  $\beta/\alpha$  values of yellow-green plant communities**

Indicator	Plant communities	Mean	SD	F	p	$\eta^2$
$\alpha$	Single green	5.046	0.526	6.174	0.003**	0.212
	Interval 1	5.009	0.459			
	Interval 2	6.377	0.677			
	Interval 3	6.435	0.644			
$\beta/\alpha$	Single green	0.945	0.071	4.029	0.021*	0.149
	Interval 1	0.918	0.068			
	Interval 2	0.843	0.671			
	Interval 3	0.798	0.057			

**NOTE**

\* means  $p < 0.05$ ; \*\* means  $p < 0.01$ .



**Fig. 8** Comparative analysis of psychological indicators between yellow-green groups.

**Fig. 9** Comparative analysis of physiological indicators between yellow-green groups.

of plant communities (Table 3). Among them, the  $\alpha$ -wave energy values of the respondents after viewing the four groups of plant communities at the restoration stage were in the following order: Interval 3 (6.435) > Interval 2 (6.377) > single green (5.046) > Interval 1 (5.009), whereas the  $\beta/\alpha$  values of the respondents after viewing the four groups of plant communities were in the following order: single green (0.945) > Interval 1 (0.918) > Interval 2 (0.843) > Interval 3 (0.798).

### 3.3 Disparity Between Red-Green and Yellow-Green Plant Communities on Emotional Restoration Effects

#### 3.3.1 Differences in Emotional Restoration Effect by Psychological Indicators

By comparing and analyzing the PA and NA values of the respondents after viewing the plant communities in red-green and yellow-green color palettes (Fig. 10), it can be learned that in terms of the PA value change, there was a significant difference between the two groups under Interval 3 ( $p < 0.05$ ); regarding the NA value change, there was also a significant difference ( $p < 0.01$ ) between the two color palettes under Interval 1 and Interval 3.

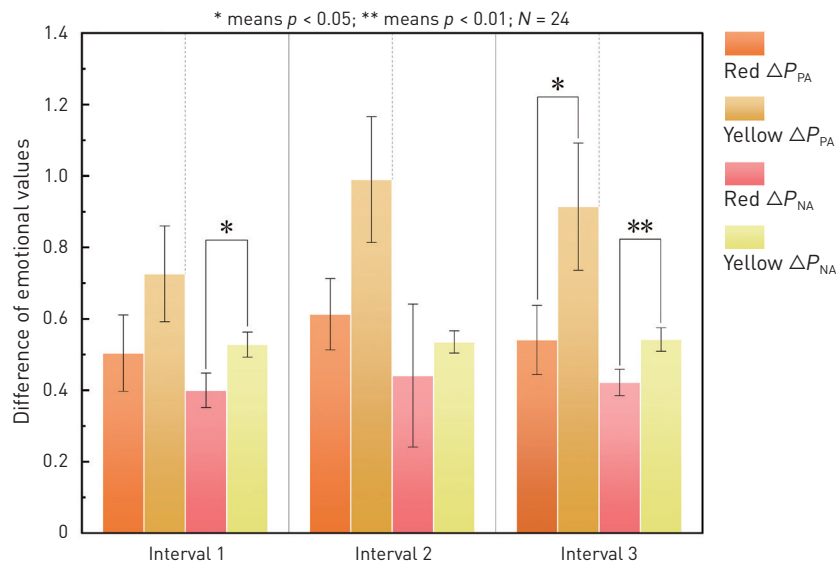
#### 3.3.2 Differences in Emotional Restoration Effect by Physiological Indicators

By analyzing the  $\alpha$ -wave and  $\beta/\alpha$  values of the respondents after viewing the two color palette (Fig. 11), it is known that there was a significant difference in the  $\alpha$ -wave energy values under Interval 2 and Interval 3 ( $p < 0.05$ ).

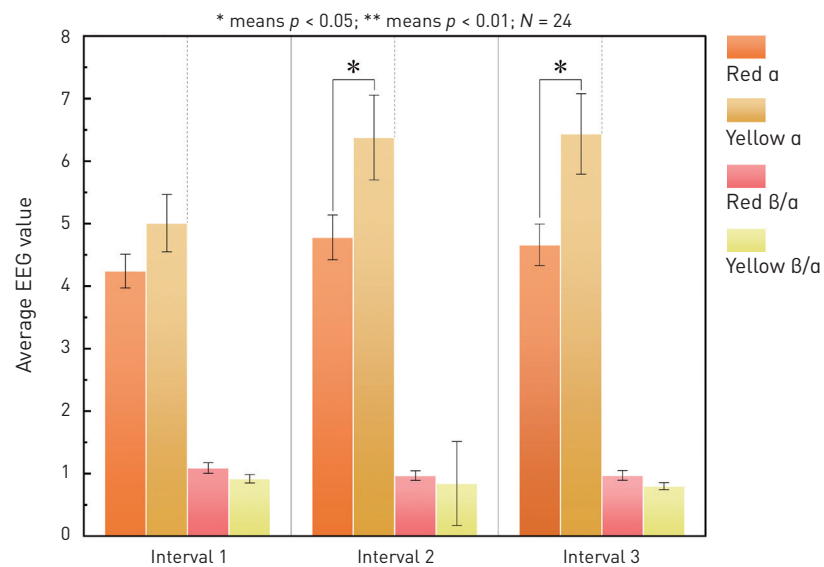
## 4 Discussion

### 4.1 The Effect on Emotional Restoration of Plant Communities in Different Color Palettes

The color green is often considered associated with relaxation and has been described as a calming emotional response<sup>[42]</sup>. In



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**Fig. 10** Comparison of psychological indicators between red–green and yellow–green color palettes.

**Fig. 11** Comparison of physiological indexes in the same interval between different color palettes.

this study, the plant communities in single green color exerted emotional restoration effects in both group experiments, which was verified with the EEG results (rise in  $\alpha$ -waves) of the single green plant communities. The effect to arouse positive emotions by warm colors such as yellow and red have been proven in many plant color studies<sup>[12,13,43]</sup>. This study revealed that the yellow–green plant communities was better than the red–green plant communities in terms of both psychological and physiological indicators for emotional restoration. Although yellow and red are

both warm colors, red and green are complementary colors, while yellow and green are neighboring colors<sup>[44]</sup>. The combination of complementary colors often results in greater visual impact, and studies have indicated that the red color gradually triggers a nervous emotion<sup>[45]</sup>. Neighboring colors often lead to a softer visual feeling, and studies have shown that yellow–green plant communities are more beneficial to the emotional restoration of tourists<sup>[24]</sup>, confirming the findings of this study. At the same time, people often depict yellow plants in autumn in phrases like “golden leaves” or “golden plums,” and the yellow color, as the brightest and cheeriest color, usually symbolizes light and harvest, uplifting people’s spirit and bringing more positive emotions. In contrast, red leaves usually reflect the aesthetics of transience, passion, and vitality and are mostly associated with excitement or alertness. Some scholars believe that red plants can disrupt the individual’s emotional state and lead to inattention<sup>[46]</sup>.

#### 4.2 Variability in the Emotional Restoration Effect of Varied Color Proportions

The plant communities of different color palettes in this study have led to varied emotional restoration effects, which is consistent with the previous findings<sup>[8,39]</sup>. While, this study also proves that varied color proportions have differences in emotional restoration effects. Color proportion is an important factor in the optimize emotional uplift<sup>[43]</sup>. The experiment results of this study found that when the plant community with a red or yellow color proportion of 15% ~ 30%, the emotional restoration effect of the respondents was generally low. It may be due to the insufficient ratio of warm colors fails to effectively stimulate the effect of emotional restoration<sup>[12]</sup>. When the color proportion of red or yellow was 45% ~ 60%, the respondent’s emotional restoration effect was more obvious. The reason is presumed to be that one often feels an equilibrium of colors and gains a greater visual pleasure when the proportion of the contrast colors in one’s viewshed is close to 60%<sup>[28]</sup>, thus producing a better emotional restoration effect. Besides, when the color proportion of red was 75% ~ 90%, the PA value were not as significant as that of 45% ~ 60%. It is presumably because under the color proportion of 75% ~ 90%, the majority of one’s viewshed would be occupied by the red color, with a small amount of green, making people lose the equilibrium of colors; it is also possible that the large number of red leaves would cause a psychological image of “sadness of autumn,” which triggers the one’s negative associations with the state of life or other emotional changes by the environmental atmosphere<sup>[47]</sup>.

### 4.3 Practical Implications of Restorative Plant Communities of Different Colors

Reasonable creation of plant communities with different color palettes and color proportions have significant positive effects on emotional restoration for different groups of people, and the reasonable combination of plant communities can effectively improve the situation of sub-seasonal depression<sup>[48]</sup>. According to previous studies<sup>[8,28,39]</sup>, the single green plant community can effectively promote mental relaxation and bring a sense of calmness, it can significantly relieve stress, suitable for building recreational environments in urban parks or medical sites. But in this study, we can also know that the plant communities of red-green and yellow-green palettes can also bring positive effects to people's emotions. Although the emotional restoration effect of red-palette plant communities was relatively weak and a large number of red-leaved plants may have the psychological "sadness of autumn," an appropriate proportion of red plants can stimulate nervous emotion, suitable for the sports scenes in urban parks, which can effectively arouse people's physical vitality<sup>[49]</sup>. At the same time, the yellow-green plant communities with color proportions of 45% ~ 60% and 75% ~ 90% are particularly effective in emotional restoration, which is suitable for a variety of restorative landscape scenes. Therefore, in the planning and design of urban parks, different color palettes and color proportions of plant communities can be reasonably introduced to not only create pleasant restorative landscapes, but also enhance the ecological value and social benefits of urban green spaces.

### 4.4 Limitations

In this study, although the selected plant communities were all common colored-leaves tree species and were mainly based on group experiments between single green and red/yellow plant communities, the color quantitative analysis and color proportion interval division did not cover all the colors of visible plant communities. Moreover, the differences between plant community types and composites in the experiment might also affect the research results. Subsequent plant community color studies could cover other seasons, more plant communities with different color palettes and color proportions, and conduct in-depth studies on the effects between more diverse types and composites of plant communities. Due to the limitations of the experimental equipment, the respondents selected for this study were all from undergraduate and graduate students. Future research on emotional restoration can cover respondents of more age groups, and the different emotional restoration effects among varied age groups

or occupational backgrounds should be investigated. The present study used a combination of physiological and psychological methods to comprehensively investigate the emotional restoration effects of plant colors. However, there indeed were some differences between the represented colors and the authentic colors of plant communities; moreover, in the real world, multi-sensory landscape perception is a dynamic process rather than simple visual perception<sup>[28]</sup>. Future research can break through the constraints and uncertainties of field experiments and create more realistic and accurate color simulation environments.

## 5 Conclusions

Compared with previous studies on the color quantitative analysis of plant communities, this study comparatively investigated the emotional restoration effects of plant communities in different colors through the combination of emotional questionnaires and EEG energy spectrum measurements. The results of the study showed that compared with the red-green and single-green plant communities, yellow-green plant communities could promote the emotional restoration more effectively; the restoration effect was better when the color proportion of red-leaves species in the visual environment was 45% ~ 60%, and the restoration effect was optimal when the color proportion of yellow-leaves species in the visual environment was 45% ~ 60% and 75% ~ 90%. In the visual perception of the landscape, green-, red-, and yellow-palette plant communities can restore emotions to a certain extent, while yellow-palette plant communities have a more positive effect on emotional restoration. The above findings offer a reference for the planting design of urban parks, to better meet the actual needs of the public through comprehensive considerations on plant colors and functions of different sites.

### ELECTRONIC SUPPLEMENTARY MATERIAL

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Supplementary material is available in the online version of this article at <https://doi.org/10.15302/J-LAF-1-020114>.

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**Competing interests** | The authors declare that they have no competing interests.

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# 城市公园植物群落色彩的情绪恢复效果差异

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## 摘要

城市化进程的持续加速促使社会群体心理健康问题的不断加剧。大学生作为社会中的一类重要群体, 往往面临着学业、家庭、就业等多重压力, 其情绪更容易受到外界环境的影响。本研究通过对苏州市城市公园秋季植物群落色彩进行调研与采样, 选取了不同比例的红绿色组合、黄绿色组合与单一绿色植物群落, 将心理指标 (PANAS量表) 与生理指标 (脑电信号数据) 相结合, 探究了不同色彩的植物群落对大学生情绪恢复的影响差异。研究表明: 1) 公园中不同色彩的植物群落均促进了被试者的积极情绪提升、消极情绪减少; 2) 在红绿组植物群落对照实验中, 单一绿色植物群落对大学生情绪恢复效果最好; 3) 在黄绿组植物群落对照实验中, 黄色色相占比75%~90%与45%~60%的植物群落的恢复效果最好; 4) 对于具有相同色相的红色与黄色植物群落, 黄绿色植物群落恢复效果要优于红绿色植物群落。本研究回应了当前城市化进程中关注青年群体心理健康的迫切需求, 通过探索城市公园秋季植物群落色彩的情绪恢复效果差异, 旨在为情绪恢复环境提供科学的植物群落色彩配置建议, 并为构建恢复性景观空间提供理论指导。

## 关键词

情绪恢复; 植物群落; 色彩量化; 恢复性景观; 城市公园; 大学生; 植物色彩

## 文章亮点

- 探究心理与生理指标中不同色彩组合的植物群落是否能带来情绪的恢复效果
- 将植物群落色彩量化方法与心理、生理测量方法进行结合
- 黄绿组合植物群落的情绪恢复效果优于单一绿色与红绿组合的植物群落

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