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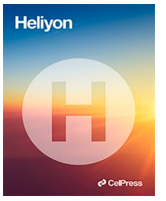

Research article

# Identify the significant landscape characteristics for the perceived restorativeness of 8 perceived sensory dimensions in urban green space

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ABSTRACT

The restorative benefits of urban green spaces (UGSs) have been supported by many studies. Eight perceived sensory dimensions (PSDs) are regarded as a tool to classify green spaces based on perception. However, little attention has been given to the effects of landscape characteristics (LCs) on the perceived restorativeness (PR) of green spaces. Thus, this study aims to clarify this relationship using the eight PSDs. The research collected information, via video stimulus, from 30 participants on the restorative experiences of urban green parks, according to the eight kinds of PSDs. The skin conductance level obtained via biosensors was used to measure the PR. The subjective satisfaction evaluation of 10 LCs was further obtained using a 5-point Likert scale. The data were analyzed using correlation and regression analyses. The results show that the UGSs with dominant "serene," "open," and "sheltered" PSDs are rated highest for restoration. Furthermore, the findings identify the significant factors affecting the restoration of green spaces using different PSDs. In green spaces controlled by PSD, scene, vegetation, water features, and disturbances are more reliable predictors for restoration. The results indicate how different PSD spaces can be distributed in green urban planning and provide key points for designing each PSD for restoration. The use of physiological indexes rather than subjective feelings provides an alternative for demonstrating the restorative benefits of the environment. However, before it can officially be used by designers, more research is needed.

## 1. Introduction

According to previous studies, nature has been proved capable of providing human beings with both physical and spiritual nourishment, which plays an important role in human health and wellbeing [1]. Specifically, the natural experience can help rebuild and strengthen the mental state by relieving psychological stress or restoring the directed attention [2–4]. However, urban residents have reduced access to nature due to the expansion of cities and the deterioration of the natural environment [5]. This has resulted in a variety of health problems caused by mental stress or inactivity, especially in China [6]. As an accessible natural resource for urban residents, urban green spaces (UGSs) play a positive role not only in physical [7] and cultural [8] aspects, but also in promoting overall health [9]. Positive emotional changes, increased physical activities, the relief of psychological stress, and enhanced social support

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have all been associated with exposure to UGS [10,11]. Therefore, enhancing urban residents' natural experience by optimizing UGS design is an important aspect of sustainable city planning.

It has been suggested that the restorative benefits of green experiences differ because of landscape characteristics (LCs) [12] and demographic variables [13]. However, present research on restorative environments mainly focuses on the restorative differences between artificial and natural environments, the accessibility or the exposureto UGS [14,15]. Less attention has been paid to the impact of the internal attributes of the UGS on its restorative function. With the expansion of the world population and urban growth, cities in the future will become more densely populated and have more artificial buildings, causing the natural environment to become an even more precious resource [16]. Therefore, there is a pressing and significant need to explore which qualities are more important to inhabitants' restorative experiences and perception in order to develop the natural environment in UGS further as an efficient resource for better health.

### *1.1. Relationship between psychological restoration and green spaces*

According to the Stress Recovery Theory (SRT) and Attention Restoration Theory (ART), Ulrich et al. (1991) elaborate the mechanisms by which natural environment promotes mental restoration respectively [17]. The former describes the premise of restoration as the relief of physical or psychological stress caused by suffering from danger or threat, which results in higher level of autonomic arousal and nervous state. The natural elements' safety, moderate complexity, clear structure, and central focus can contribute to restoration by inciting a shift towards positive emotions, stable physiological activity levels, and improved sustained attention capacity. In contrast, the ART regards the directed attention fatigue as a precondition. An environment with 4 features will restore the directed attention by arousing the undirected attention, which include Being away (unusual perceived content), Extent (coherent and rich settings), Fascination (effortless attention) and Compatibility (good match between environment and person). The process of restoration proceeds by stages for a longer time. The restorative outcomes benefit from increased directed attention, and they include more efficient cognitive activities, less mistakes, and improved ability to deal with stress.

In brief, the two theories differ in mechanisms of motivating restoration and the required time for restorative benefits [18]. However, the beneficial outcomes are similar, such as positive emotions, efficient activities, and good physical conditions. Thus we

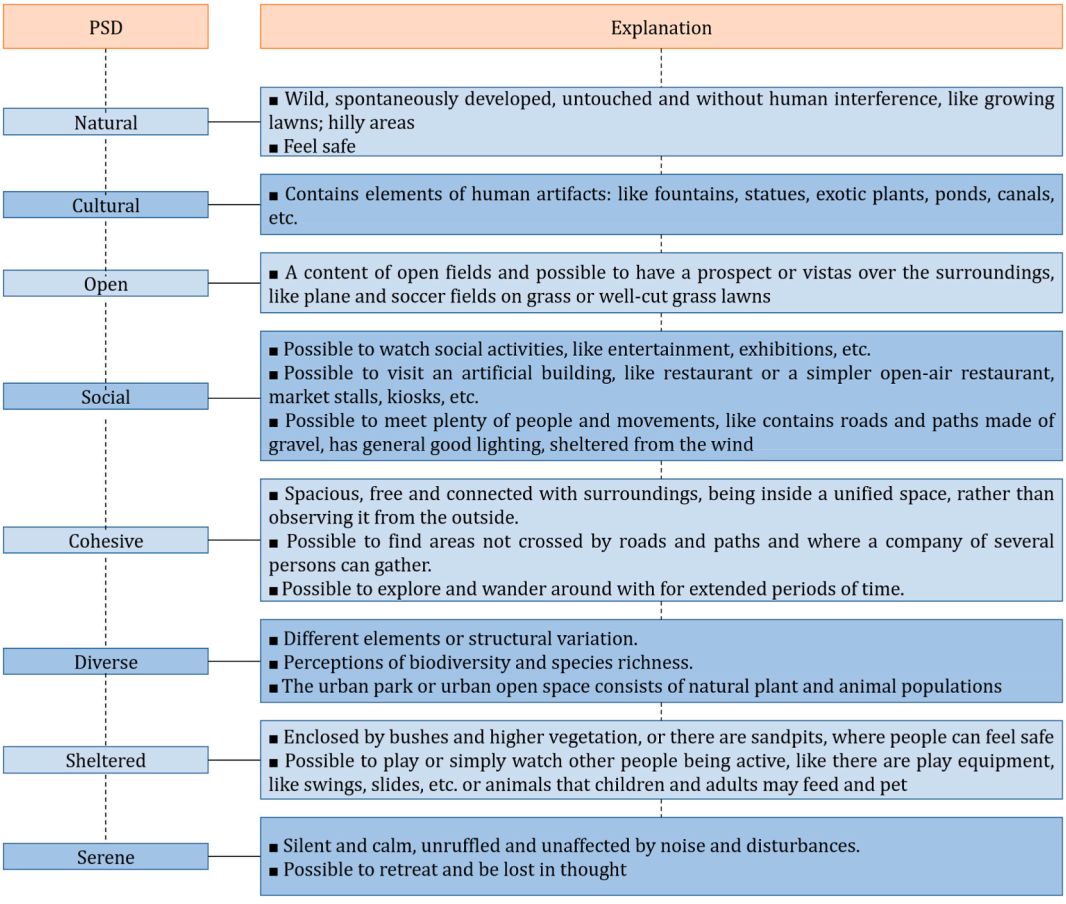



**Fig. 1.** The explanations of different PSDs based on Stoltz and Grahn (2021a,b).

considered both when focusing on the health benefits of the natural experience. Based on both theories, UGSs as main places for urban residents to obtain the natural experience can be seen to play a significant role on human health and well-being. Many empirical studies have proved that the frequency and accessibility of urban residents to UGSs can influence their health and mood [19,20]. These restorative benefits can further increase with more intense physical activity and a higher level of involvement. Walking, running, and other sports are better choices for restoration than just sitting or looking [21]. The recovery of stress is also related to multiple sensory modalities such as olfaction [22], audition [23], and tactile sensation [24], but the specific impact of visual stimuli remains relatively unclear, particularly regarding the diverse visual forms presented by green spaces and their restorative effects. Further research is needed to investigate this aspect. In terms of mechanism, this study was mainly motivated by the SRT after considering the compatibility with our experimental design: physiological signals, such as blood pressure and heart rate, are more reliable indicators of stress, compared to attention and self-reported stress levels, which might change within a short time.

Visiting and experiencing green spaces can be seen as the premise of restorative effects. The directed natural experience has been divided into two categories including intentional and incidental, the restorative potential of which has been compared and proved distinct in existing studies [25,26]. Generally speaking, the incidental nature experience is more complicated because it grows out of unexpected focus or sudden attention. Therefore, UGSs are perceived in an unplanned manner, which means more considerations about visual attraction or significance are required when discussing this. The present study is focused on intentional visits to UGS because we aim to identify the impact of the spatial environment itself on visual or auditory perception without consideration of visiting purpose.

### *1.2. Perceived sensory dimensions of natural environment*

People have an inherent desire to seek some special environmental characteristics at first when experiencing nature, which are described as the perceived sensory dimensions (PSDs) of natural environment [27]. The initial studies described four main dimensions of perceived restorativeness (PR), including Being Away, Extent, Fascination, and Compatibility Building on the ART, some attempts to further categorize and describe them have been carried out. Grahn and Stigsdotter (2010) proposed that eight different PSDs of natural environment have a significant influence on the restorative perception of the natural environment [28]. Stigsdotter et al. (2017) further identified the psychologically restorative qualities of forest environments by analyzing the feelings of participants who visited a forest park according to the features of the eight PSDs [29]. Later, Stoltz and Grahn (2021) updated the PSDs' titles by reviewing related studies conducted between 1984 and 2018 to provide a more comprehensive and accurate expression, which included the PSDs of Natural, Cultural, Open, Social, Cohesive, Diverse, Sheltered, Serene [30,31]. According to that, the explanations of eight PSDs are summarized in Fig. 1 and their internal relations have been illustrated as in Fig. 2. The adjacent PSDs are related and have similar contents. The PSDs at both ends of the basic axes are opposite and may highlight two extremes of the same category. Therefore, their relationships could be understood along four basic axes. Since the PSDs can be used to describe the differences within a single natural environment, the urban green space can be divided into distinct special units accordingly.

Defined as perceived qualities, the PSDs are not combinations of some specific landscape features. However, there are always close connections between certain physical attributes and some kinds of PSDs, which have differed slightly in above studies. For example, Grahn and Stigsdotter (2010) described the PSD Prospect as plane and well-cut grass surfaces, open fields, primarily well-cut grass

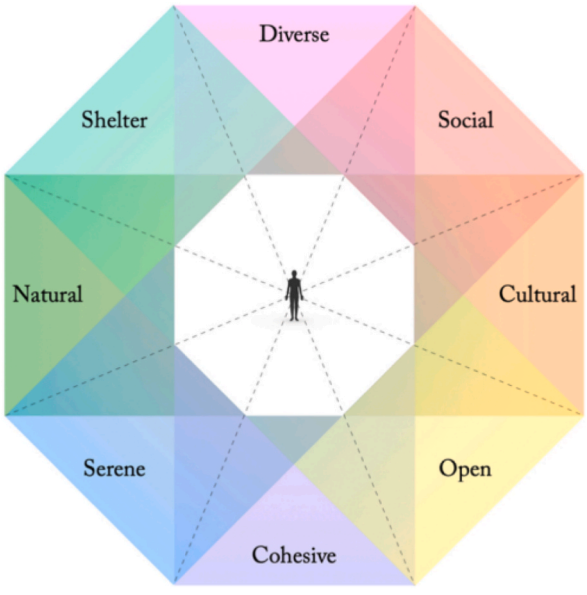



**Fig. 2.** The relationship diagram of 8 PSDs cited from Stoltz and Grahn (2021).

lawns. While Stoltz and Grahn (2021) labeled the PSD as Open and emphasized on the support for various activities except long unbroken sightless. The PSD social was interpreted as dense, bustling city squares or parks, with stores and commerce, restaurants, cafes, etc. And Stoltz & Grahn (2021) further suggested that the realization of this PSD needed small green areas reinforced through a densified design and planning of the site. The PSD Rich in species was labeled as "Diverse", which was described as structural variation and the presence of different elements, not just experiencing many species. Moreover, Stoltz et al. (2016) tried to establish links between structural parameters (such as tree age, tree sparsity, and tree height) and the PSDs in a forest context [32]. Therefore, these connections seem be explained more comprehensively and more detailedly in Stoltz and Grahn's discussions, which are adopted by our study.

### *1.3. Landscape characteristics affecting the perception of green spaces*

Some LCs can be perceived more easily or they might have deeper and stronger effects on cognitive and perceptual process, such as mental restoration. Many discussions have been held on these significant elements; we abstracted them through literature review [33–39]. We chose environmental elements commonly found in the UGS, which have been proven as significant predictors of mental restoration or aesthetic preference. Therefore, they should be considered as elementary materials in the process of UGS design. Following this, we researched peer-reviewed English-language studies published in scientific journals via Web of Science and Google Scholar, taking UGSs as the topic and mental restoration, restorative environment, stress reduction, health promotion, and mental health as subject terms. Then, 36 studies which mainly discussed specific environmental factors that focused on visual or auditory stimulus were selected, and studies on the accessibility, layout, the overall environment, and other sensory stimuli were excluded. Since our aim is to obtain subjective satisfaction evaluations of these elements, we ignored their own attributes or internal classifications like size, amount, density, location, color, and condition etc. to simplify the study variables. For example, the water surface area, the volatility of water, and the cleanliness of water are summarized as water features. Based on this principle, we excluded repeated studies and summarized 10 from 76 LCs as research variables, which are: (1) Vegetation, (2) Flower, (3) Water features (e.g., lake, pool, fountain, waterfalls, and streams), (4) Sky view, (5) Small animals (birds, fishes, and squirrels etc.), (6) Buildings, (7) Pass way (trail, roads, and pedestrian walkways). (8) Furniture or facility (park furniture or activity facility such as benches, trash cans, tables, and fitness equipment) (9) Decorations (such as pictures, statues, or decorative stones), (10) Disturbances (distractive artificial things, such as heavy traffic, noise pollution, or large crowds).

### *1.4. Measurement of perceived environmental restorativeness*

Hartig et al. (1996) proposed a scale consisting of four dimensions to assess the environmental PR, which has been widely used in related studies and translated into different languages [40] With the recent development of medicine and digital technology, some physiological parameters, like Skin Conductance Level (SCL) and Heart Rate Variability (HRV), which can reflect the autonomic nervous system activity level, have also been utilized to measure mental restoration levels [41]. Specifically, decreased nervous system activity and emotional arousal levels indicate a change from a nervous and stressed state to a relaxed and awake state; this is the process of psychological restoration [42]. Therefore, the quantitative measurement and visualization of PR is possible with these means. For example, Bergner et al. (2013) successfully measured people's emotion changes by measuring skin conductivity and skin temperature recorded by wristband sensors to analyze the relationship between their feelings and the environment [43].

### *1.5. Hypotheses and aims*

Although the PR ranking of the eight PSDs have been discussed in previous studies, the role of LCs in this issue has not been explored. Considering the proven effects of LCs on PR, we hypothesize that some LCs are more important than others for restorative perception when people are experiencing UGSs, which is characterized mainly by a special PSD. In order to verify this hypothesis, this study aims to identify the LCs which have the most significant impact on the PR of the UGSs which are characterized by the eight kinds of PSDs respectively.

## 2. Methods

### *2.1. Stimuli*

Xuzhou City (34 °N and 117 °E) of Jiangsu Province, China has been selected as our study area because it has a monsoon climate of medium latitudes and their vegetation characteristics are similar to most cities in China. 3 urban parks were selected, including Yun Long Park, Quan Shan Park and Huaihai Park, the selection of these 3 parks was primarily based on 3 reasons. Firstly, the chosen parks should encompass the 3 main types of urban green spaces, namely citizen leisure parks, natural ecological parks, and historical-cultural parks, in order to maximize the coverage of different landscape features. Secondly, the selected parks needed to have relatively well-planned construction and a large land area to eliminate non-landscape factors' interference. Thirdly, to obtain enough research samples, the selected parks should contain a diversity of landscape element combinations and 10 LCs in order to select 8 PSDs. Finally, the chosen parks should be geographically dispersed within the city and have a significant number of visitors to ensure their representativeness (Table 1).

Second, according to the specific explanations of the eight PSDs as referred in Fig. 1. Each place resembles a special "room" which

has well defined boundaries and a distinct scenery from its surroundings, so that it can be experienced or visited separately. In order to maintain the independence of the variables, the scene selection for each room excludes the interference of irrelevant elements to make it composed by only one kind of perceived sensory dimension. Then, 24 rooms were selected as research samples (Table 2).

Third, 15-s videos were taken at eye level (about 160 cm above the ground) in April on clear days from 9 a.m. to 10 p.m. to keep the light consistent. The equipment used was a Nikon D7000 digital camera with resolution ratio of 4928 × 3264. Continuous auto focus was maintained during shooting. Photographers were also asked to ensure that the videos wholly reflect the PSDs of the scene from different angles. The proposed videos were then reviewed by 5 experts who majored in Landscape Architecture Design to verify their accuracy and representativeness. Experts were asked to classify different scenes into PSDs, and if a scene video was misclassified more than twice, it was excluded, and then the park scene or shooting angle was changed and reclassified until all experts gave the most consistent classification results. At last, 24 videos representing eight different characteristics from three parks were collected as stimulus materials. The use of videos as stimulus material representing a real-life scenery (especially in visual evaluation) has been proven to have good reliability. For example, Jaeyoung and Hyung (2021) used 360-degree view videos as visual stimulus in their study of the campus landscape's restoration. This method can eliminate the interference of weather, noise, and crowd [44]. The videos also provide a more comprehensive description of the environment than pictures. Schutte et al. (2017) have proved nature videos have effects on mental restoration within 6 min [45].

### 2.2. Measuring mental restoration and landscape characteristics judgment

30 college students were selected as subjects to ensure uniform distribution of grades, majors, and genders (15 men and 15 women with m. age = 20.34 years and age range = 18–24 years). People with professional knowledge, alcohol or drug addiction, mental or physical illnesses, emotional frustration, and academic challenges were excluded. We notified each participant about the content and purpose of our experiment and obtained their permission before proceeding.

In order to avoid the practice and fatigue effect caused by continuous cognitive tasks and familiarity with the experimental situation, each participant experienced all the scenes eight times across 4 weeks with a one-week interval between each test. They took part in the project at a fixed time each week to guarantee a relatively constant physiological index without the disturbance of time change. Each experience contained a 90s video symbol of one type Room consisting of different scenes from 3 parks (random order, twice repeated for an equal length of time). We confirmed that participants had no violent emotional fluctuations and physical activity an hour before the experiment.

At the beginning of each experiment, participants were required to finish The PEBL PASAT-Paced Auditory Serial Addition Test which is an auditory neuropsychological task that can rapidly deplete participants' attention and elevate their SCL to a higher level. The individuals hear a number every 3 s and asked to add the two most recent digits they just heard (Tombaugh, 2006) within 30 s. After a 3 s prompt, they started to watch the videos. Their SCL data was recorded and sent to the computer via a portable physiological sensor (produced by Beijing Kingfar Technology Company) throughout each session. At last, they were invited to complete a satisfaction evaluation of the 10 LCs (listed in Section 2.2) appeared in the videos. Participants were asked to rate their satisfaction about the LCs on a 5-point Likert scale (1 = not at all, 5 = very much). The meaning of each LC was explained with professional terminology to ensure that the participants would be able to respond clearly (see Fig. 2 for the specific process). (see Fig. 3 for the specific process).

**Table 1**
Information of study areas.

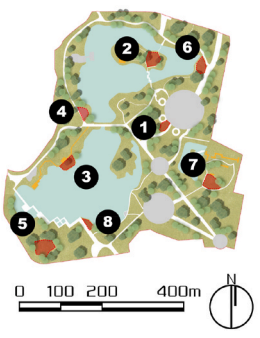
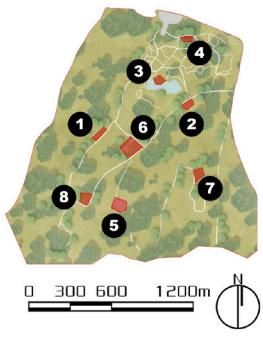
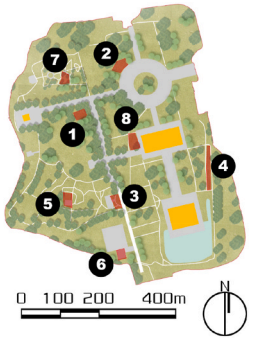
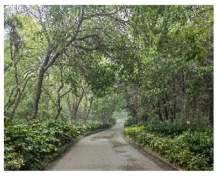
| | Yun Long Park (A) | Quan Shan Park (B) | Huaihai Park (C) |
|---|---|---|---|
| **Location and size** | ■ City center;<br>■ 30.67ha, including 8ha of water surface;<br>■ 1.7 million tourists annually | ■ South of city;<br>■ 113.33ha, including 0.21ha of water surface;<br>■ 3.5 million tourists annually | ■ East of city;<br>■ 39.85ha, including 0.43ha of water surface;<br>■ 2.8 million tourists annually |
| **Selected places** |  |  |  |

**Table 2**
The pictures of eight natural environment types from three parks.

| PSD of natural environment | Park A | Park B | Park C |
|---|---|---|---|
| **1.Social** |  |  |  |
| **2.Open** |  |  |  |
| **3. Diverse** |  |  |  |
| **4.Serene** |  |  |  |
| **5.Cultural** |  |  |  |
| **6.Cohesive** |  |  |  |
| **7.Natural** |  |  |  |
| **8.Sheltered** |  |  |  |

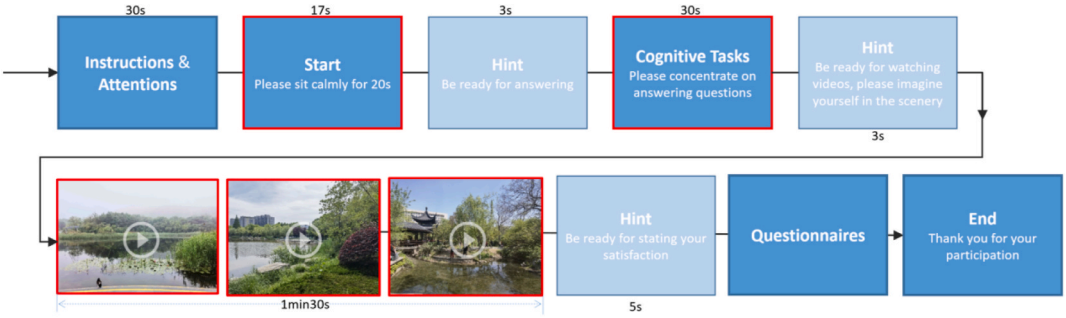



**Fig. 3.** The experiment process diagram.

### 2.3. Analysis

Data analysis was carried out using SPSS 22.0 software and ErgoLab software. Firstly, The SCL data was processed and visualized using ErgoLab software. According to the data, the time elapsed between the end of the cognitive task and the drop to the baseline is calculated to show the PR after experiencing the UGS. In addition, the difference on restoration among eight PSDs will serve as the basis and precondition of our study. However, the ranking of PSDs differs partly from previous studies, which might result from distinct measurements, samples, or stimulus. Therefore a prerequisite step should be conducted to obtain the rankings in present experimental settings before the further analysis by calculating the mean value and standard deviation. Second, the relationship between the satisfaction evaluation of LC and the restorative scores of UGS was explored by means of correlation analysis. On that basis, the degree of influence that LCs have on the restoration of UGS with different PSDs is further identified by stepwise multiple linear regression analysis.

## 3. Results

### 3.1. Rating restorative experiences of eight rooms

Fig. 4 below shows the SCL curve from Participant 1 when watching the Room 4 video. From the SCL data obtained while sitting quietly, the baseline of SCL is obtained. Thus, we know he took 17.25 s to return to baseline from a stressed state caused by tasks. Following this method, the mean time and standard deviation within participants were calculated for each Rooms. As seen from Table 3, the PSD Serene had the lowest restorative time and is considered to have the strongest restorative potential, followed by the PSD Open, PSD Sheltered, and PSD Natural. The PSD Diverse, the PSD Cohesive, and the PSD Social were in the middle. PSD Cultural showed the longest restorative time and had the least restorative potential.

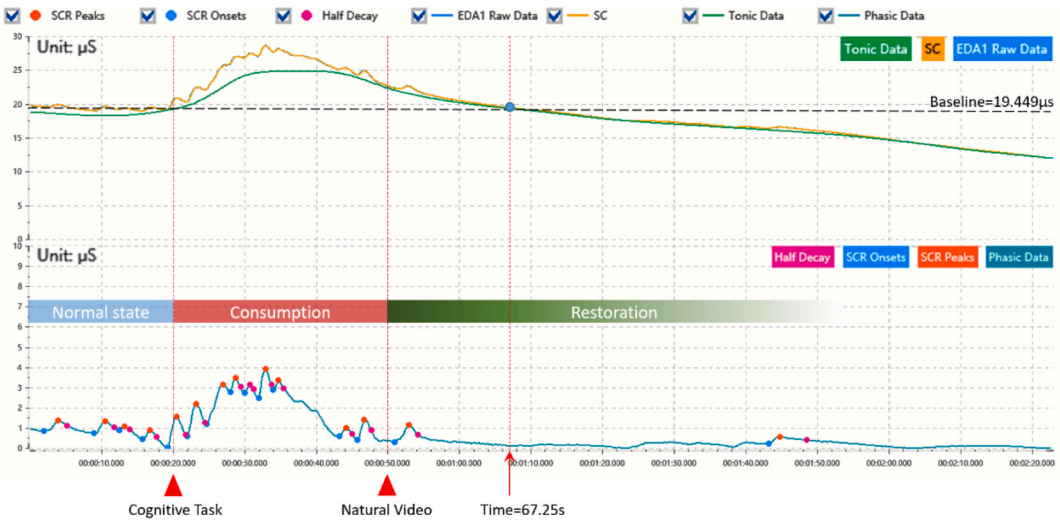



**Fig. 4.** The SCL change of Participant 1 experiencing Room 1.

**Table 3**
The time to return the baseline happening in eight Rooms.

| Room | Room 1 | Room 2 | Room 3 | Room4 | Room 5 | Room 6 | Room 7 | Room 8 |
|---|---|---|---|---|---|---|---|---|
| PSD | Natural | Cultural | Open | Social | Cohesive | Diverse | Sheltered | Serene |
| Mean | 17.975 | 20.450 | 16.725 | 19.400 | 18.400 | 18.075 | 17.025 | 16.425 |
| SD | 1.36 | 2.02 | 0.98 | 1.37 | 1.58 | 1.92 | 0.77 | 1.42 |
| Ranking | 4 | 8 | 2 | 7 | 6 | 5 | 3 | 1 |

### 3.2. The influence of landscape characteristics on perceived restorativeness

First, via one-way ANOVA analysis, significant differences were identified among the restoration time causing by different satisfaction evaluation scores of some LCs including vegetation ($F = 21.271$, $p = 0.000$), disturbance ($F = 21.893$, $p = 0.000$), water feature ($F = 9.476$, $p = 0.000$), flower (($F = 9.545$, $p = 0.000$), furniture & facility ($F = 21.250$, $p = 0.000$), decoration (($F = 4.469$, $p = 0.008$) and sky view ($F = 3.546$, $p = 0.037$). However, the other LCs did not cause a significant difference in restoration time, including building ($F = 1.290$, $p = 0.289$), small animal ($F = 2.177$, $p = 0.087$), pass way ($F = 2.285$, $p = 0.075$).

Second, by means of correlation analysis, it was obvious that the restoration had correlations with vegetation and disturbance, followed by water feature, flower, and furniture & facility, but almost none with small animal, sky view, decoration, pass way, and building (Table 4). The results from the multiple linear regression analysis further clarify the influence of LCs on UGSs' restorativeness in Table 5 which indicated that vegetation, water features, disturbances, and flowers had a significant influence on the restorativeness of UGSs, while the others had weak influences.

At last, variance analysis and multi-collinearity were conducted to verify the significance and reliability of the model ($F = 15.436$, $p = 0.000 < 0.05$), which revealed no multi-collinearity (VIF < 5) or correlation (D-W = 1.785) problems among independents. Moreover, the model could fit and describe the data well (Adjusted $R^2 = 0.746$).

### 3.3. Description of significant factors for each PSD

To detect the influence of LCs on the UGS's restorativeness characterized by eight PSDs respectively, the stepwise multiple linear regression analysis was conducted using the restorative time of each participant from eight kinds of scenes as dependents, and the satisfaction evaluation scores of 10 LCs as independents. The results showed that vegetation, water features, and disturbances were reliable predictors for PSD Natural, PSD Serene, and most other PSDs which were in line with overall impact. Nonetheless, there were still some obvious differences among the PSDs in terms of significant influencing factors (see Table 6). For example, the LCs of vegetation, water features, and decorations had a greater influence on the PR of PSD Cultural.

## 4. Discussion

Compared with the existing research, the innovation of this study is mainly reflected in the following aspects: Firstly, it focuses on the UGSs in China, some of which have been designed or built under the influence of Chinese history or culture, such as memorial park. Secondly, we give more attention of the stimulus material. Videos rather than pictures have been used to represent the real scene more accurately. Thirdly, it considers in more detail some methodological problems that have troubled studies. The physiological indexes rather than subjective feelings have been measured to demonstrate the restorative benefits of the environment with the exclusion of interference caused by semantic guidance. In our results, the order from high to low is PSD Serene, Open (Prospect), Sheltered (Refuge), Natural, Diverse (Rich in species), Cohesive (Space), Social and Cultural, which is supportive of the higher ranking of PSD Serene, Natural and Diverse and lower ranking of Social, Cultural and Space. The PSD Prospect obtained better evaluation which is quite different from previous studies. On the whole, our studies confirmed the existing rankness partly and put forward more discussions.

### 4.1. Verify the rankness of different PSDs

Our results showed that the PSD Serene had the strongest restorative potential, followed by Open, Sheltered, Natural, Diverse, Cohesive, Social and Cultural, which were partly different from previous studies. According to Grahn and Stigsdotter (2010), people in general prefer the dimension Serene, followed by Space, Nature, Rich in Species (Diverse), Refuge, Culture, Prospect and Social. Gao

**Table 4**
The correlation between LCs and restoration (Kendall Tau statistic).

| | Vegetation | Flower | Water feature | Building | Pass way | Small animals | Sky view | Furniture & Facility | Decoration | Disturbance |
|---|---|---|---|---|---|---|---|---|---|---|
| Coefficients | 0.574** | 0.374* | 0.479** | 0.355 | 0.102 | 0.204 | 0.189 | 0.290* | 0.155 | 0.529** |
| Significance | 0.000 | 0.018 | 0.032 | 0.380 | 0.014 | 0.001 | 0.341 | 0.869 | 0.967 | 0.000 |

*Note:* * Correlation is significant at the 0.05 level. ** Correlation is significant at the 0.01 level.

**Table 5**
The effect of LCs on UGS's restoration according to MLRA.

| Variables | Unstandardized Beta | Standardized Beta | t | Sig. | VIF |
|---|---|---|---|---|---|
| (constant) | 25.43 | – | 17.426 | 0.000 | – |
| Building | −0.689 | −0.276 | −2.094 | 0.053 | 3.355 |
| Vegetation | −0.889 | −0.272 | −2.604 | 0.013 | 2.114 |
| Disturbance | −0.713 | −0.215 | −2.582 | 0.014 | 1.345 |
| Decoration | −0.203 | −0.062 | −0.457 | 0.65 | 3.546 |
| Flower | −0.743 | −0.305 | −2.326 | 0.025 | 3.334 |
| Furniture & Facility | −0.744 | −0.306 | −2.281 | 0.028 | 3.474 |
| Small animals | −0.191 | −0.056 | −0.707 | 0.484 | 1.199 |
| Sky view | −0.236 | −0.093 | −1.119 | 0.27 | 1.344 |
| Water feature | −0.709 | −0.214 | −2.553 | 0.015 | 1.358 |
| Pass way | −0.201 | −0.053 | −0.55 | 0.585 | 1.769 |

*Note:* Adjusted $R^2 = 0.746$, D-W = 1.785, n = 240.

**Table 6**
Significant LCs for PR of UGSs characterized by eight different PSDs.

| Dependent (n = 30) | Independent | Unstandardized Beta | Standardized Beta | t | Sig. | VIF |
|---|---|---|---|---|---|---|
| Restoration of ***Cultural*** (adjust $R^2 = 0.879$) | (constant) | 9.088 | – | 5.484 | 0.000 | – |
| (F = 22.133, p = 0.000 < 0.05) | Vegetation | −1.653 | −0.672 | −4.267 | 0.000 | 4.960 |
| (D-W = 2.160) | Water feature | −0.782 | −0.263 | −2.900 | 0.009 | 1.974 |
| | Decoration | −0.743 | −0.246 | −2.096 | 0.050 | 3.316 |
| Restoration of ***Open*** (adjust $R^2 = 0.629$) | (constant) | 27.937 | – | 21.563 | 0.000 | – |
| (F = 9.323, p = 0.000 < 0.05) | Disturbance | −1.877 | −0.575 | −4.849 | 0.000 | 1.861 |
| (D-W = 1.636) | Vegetation | −1.160 | −0.378 | −3.158 | 0.003 | 1.891 |
| | Sky view | −1.183 | −0.339 | −3.089 | 0.004 | 1.593 |
| Restoration of ***Social*** (adjust $R^2 = 0.719$) | (constant) | 26.812 | – | 24.622 | 0.000 | – |
| (F = 13.532, p = 0.000 < 0.05) | Vegetation | −0.683 | −0.275 | −2.530 | 0.016 | 2.061 |
| (D-W = 1.635) | Disturbance | −0.842 | −0.258 | −2.449 | 0.019 | 1.935 |
| | Furniture & Facility | −0.736 | −0.303 | −2.188 | 0.035 | 3.336 |
| Restoration of ***Cohesive*** (adjust $R^2 = 0.786$) | (constant) | 8.521 | – | 3.823 | 0.001 | – |
| (F = 11.679, p = 0.000 < 0.05) | Vegetation | −1.348 | −0.447 | −3.189 | 0.005 | 2.663 |
| (D-W = 1.920) | Pass way | −0.846 | −0.284 | −2.344 | 0.030 | 1.997 |
| Restoration of ***Diverse*** (adjust $R^2 = 0.752$) | (constant) | 27.811 | – | 9.862 | 0.000 | – |
| (F = 9.787, p = 0.000 < 0.05) | Water feature | −1.062 | −0.388 | −2.455 | 0.024 | 2.921 |
| (D-W = 1.825) | Vegetation | −0.978 | −0.312 | −2.203 | 0.031 | 2.541 |
| | Flower | −0.689 | −0.248 | −2.075 | 0.052 | 1.668 |
| Restoration of ***Sheltered*** (adjust $R^2 = 0.746$) | (constant) | 25.560 | – | 17.101 | 0.000 | – |
| (F = 15.386, p = 0.000 < 0.05) | Disturbance | −0.944 | −0.289 | −2.884 | 0.006 | 1.940 |
| (D-W = 1.827) | Vegetation | −0.831 | −0.342 | −2.744 | 0.009 | 2.990 |
| | Furniture & Facility | −0.733 | −0.221 | −2.661 | 0.011 | 1.333 |

et al. (2019) also regarded PSD Serene most restorative while the PSDs Culture and Social were least preferred [46]. Peschardt and Stigsdotter (2013) suggested the PSDs Serene and Social were the most important for PR of UGS [47]. Memari et al. (2021) proposed that Natural and Serene have the most powerful restorative effects [48].

Some PSDs had similar rankness to previous studies. The PSD Serene was the most important for restoration. This is consistent with previous studies, which concluded that Serene was described as more valuable than other qualities in arousing restorative feelings considering its profound and soft effects on the mind [49]. The serene settings contribute to deep thinking, creation, and self-reflection, which implies the release of painful or hard experience and the mental and psychological restoration at a deeper level [50]. Karmanov and Hamel (2008) explained that buildings, artifacts, facilities, symbols, or something related to culture or history will add interesting and unusual sensory inputs, which can improve the PR. However, this depends on whether people can understand or appreciate the cultural connotations. This may explain why PSD Cultural had repeatedly lower restorativeness.

The PSD Diversity (also labeled Rich in species) was ranked in the middle in our results, which was in line with most previous studies. This is probably due to its close connection with complexity, which contributes to environmental restoration. However, Memari et al. (2017) suggested its negative impacts on restoration [51]. This could be attributed to over-stimulation causing extra stress which distracts attention. This seems to suggest that some people suffering from direct attention fatigue may not have enough energy to perceive and understand complicated environment settings. This explains why the restorative potential of this PSD is debatable.

The PSD Open (also labeled Prospect) and Shelter were regarded as highly restorative in our results. This could be attributed to people's preference for the environment to provide both the necessary protection and a good view because it is beneficial for their survival and development [52]. Therefore, the PSD Sheltered and Open was highly evaluated in terms of restorativeness since they satisfy this innate need. However, the rankness of PSD Open was low in some earlier studies. We used videos instead of participant's actual physical presence in the investigated environments as stimulating material. Different from other PSDs, the PSD Open is also

associated with the subject actually being exposed in the Open, which might explain why this PSD shows less restorative potential in many earlier studies.

The rankness of PSD Social and Natural seemed very different from existing studies. The PSD Social showed less importance in our results, which was in accordance with former studies. However Peschardt and Stigsdotter (2013) underlined its importance. This could indicate that PSD Social is not suitable for everyone as a restorative resource. It could be explained that people in trouble or suffering illnesses always lack the desire, courage, and ability to socialize, social activities may add to their mental stress and worries. Many published studies explained the restorative effects of nature on people that natural setting would provide relief and cognitive restoration and help to get away from the harsh daily environment [53]. While the PSD Natural was ranked in the middle in our results which was not in line with most studies. This could be attribute to the wildness being regarded as uncontrollable and having unknown, dangerous factors [54].

Although PSD Serene, Prospect, and Refuge were rated highest in this study, the other five PSDs should not be ignored as their restorative potential have been proved individually. The restorative perception differed based on demographic characteristics and individual experience according to published research [55]. Such determinants include natural hobbies, life satisfaction, money problems, social relations and so on. Thus, we can infer that different groups have distinct opinions on the rankings of PR in terms of the eight PSDs. Each PSD was focused on a different type of restorative progress or mechanism and had varying restorative potential for different groups. Furthermore, UGSs are rarely dominated by one single PSD in reality. We usually visit and experience the UGSs as a combination of one or more PSDs. As a result, the ranking of PSDs in the present study does not intend to reflect their importance. The associated effects of multiple PSDs and individual difference should be further discussed.

### 4.2. Detect the influence of landscape characteristics on PR

In line with existing research, characteristics including *Vegetation, Disturbance* and *Water Features* were ranked in the front. The coverage of green vegetation in the field of view was always regarded as the most decisive factor influencing environmental restoration [56]. In addition, the presence of water is advantageous in terms of environment restoration with the same quality of green perception because of its pleasant sound and attractive reflection [57]. In support of Stress Recovery Theory (SRT), disturbance is a negative factor in the restorative process by unnecessarily consuming directed attention, therefore it has significant impact on restoration in natural settings.

*Flower* and *Furniture & Facility* which placed in the middle of the rankings were also reliable predictors of restoration. *Flowers* with their diversity in colors and species can enhance fascination or visual beauty, which arouse more pleasant experience and feelings [58]. Nonetheless, there is still some uncertainty in consideration of how the color of flowers can affect mood change [59]. There is little doubt that *Furniture & Facility* (like benches, pavilions, fitness equipment etc.) is a support for social or entertainment activities. Exercise or activity in green spaces can further enhance the positive effects of nature on the body and mind, which could explain the rank of *Furniture & Facility* [60].

*Building, Small Animals, Sky View* and *Decoration* were rated lowest with regards to restoration. Most artificially built environments are likely to cause stress and psychological consumption instead of motivating restoration. As mentioned in related studies, *small animals* like birds or fishes would be positive elements for restoration because of their vitality [61]. On that basis, hearing birdsong and touching animal fur may arouse additional restorative experience. The present finding did not show a significant effect on restoration, which may be due to the limitations of video stimulation without consideration of sound and tactile sense. Unlike domestic pets, animals in the natural environment might potentially be dangerous, which may keep people away. People with a sky view had more opportunities to obtain restoration. This happens only under conditions of limited contact with nature. *Decoration* would be beneficial to creating visual richness, attraction, and fascination. However the decorative elements only occupy a very small field of view, especially in the videos, which may result in a weaker perception. From the above, we can depict the weak relationship between *Building, Small Animals, Sky View*, *Decoration,* and restoration.

### 4.3. Identify differences in LCs' contributions to PR for different PSD

Although reliable predictors of restoration are consistent, there was still considerable differences for some special PSDs. The PSD that was most obviously different from others was Cultural, for which *decoration* was taken into account as a significant factor instead of *disturbance* with regard to restoration. As artificial elements, *Decoration* can express the cultural or historical contents or images more intuitively and clearly, which is beneficial for understanding the scene. There are also less worries about danger or disturbances in the space characterized by PSD Cultural.

In addition, *flowers* showed more importance to restoration with regards to PSD Diverse, because they supported and strengthened the advantages of this PSD. In the same principle, *pass way* was emphasized in the restorative assessment of PSD Cohesive. These findings were in accordance with studies on the restoration of PSDs.

*Furniture & facility* can afford people more sheltered, hiding, or resting places. In addition, it is necessary for social activities such as eating and drinking together, watching entertainment, or people watching [62]. Sufficient furniture in good condition makes it easy for people to do physical or recreational activities. Thus, furniture seems more important for PSD Sheltered and PSD Social. As a kind of open area, a larger amount of sky in sight will add new vistas and strengthen visitors' control of the environment [63]. On the contrary, tall and dense trees which block out part of the sky have more possibilities to arouse fear or anxiety. Therefore, *Sky View* was regarded as a primary factor for the restoration of PSD Open.

### 4.4. Implications for planners and stakeholders of green space design

Based on related studies on the restorative environment, there is no doubt that the UGS has a positive effect on relieving pressure, mental restoration, and health promotion which should be made full use of by city planners, landscape architects, even decision makers. Our research specifies that the restoration of UGS differs based on the PSDs and LCs among them, which identifies key points in the process of landscape design and transformation with the goal of promoting restoration. Firstly, our findings suggest the PSDs Serene, Open, Shelter and Natural are more restorative, which should be the first choice of landscape design. However, the combination of various PSDs may be more effective, which would be discussed in future study. Secondly, the findings also identify landscape elements which have significant effects on environmental restoration featured by 8 PSDs, which provide evidence-based design recommendations for green spaces. Thirdly, the findings also supply some reference standards to evaluate the restoration of UGS, which could help identify the disadvantages of existing UGS with regard to promoting mental restoration. However, more empirical researches are needed for more accurate evaluation results.

### 4.5. Limitations of the study

In consideration of diversity, 3 types of parks were selected as research locations. However, the disadvantages of generalization are still present because study areas cannot fully contain all features of the UGS. The participants (only college students) and small sample size make the adaption of our conclusions to other groups uncertain. The non-consideration of the influence of demographic variables on individual perception also represent a possible bias. In addition, each side may contain components of other PSDs, hence the results may be impacted by the combination of different PSDs' features. And because the realization of 8 PSDs differed slightly in precious studies, the chosen places may not accurately describe some PSDs. The SCL as an indicator of restoration also has some limitations due to the presence of other sympathetic activities which have similar physiological changes as restoration. Compared to the on-site experiment, it is also much harder for participants to obtain an immersive experience from digital media. With the limitation of image resolution, participants could not also perceive each detailed element clearly, which may have influenced the overall restorative perception. Therefore, the findings have only provided preliminary indicators describing the relationship between LCs and PR of the UGS. To obtain more accurate and applicable conclusions, studies with larger samples and more comprehensive measurements should be conducted. In addition, the study results obtained by digital media stimuli should undergo further verification during on-site experiments.

## 5. Conclusions

Although the health-promoting functions of UGSs have been widely discussed in city planning and landscape design, it is still unclear how landscape elements in UGS contribute to mental restoration and stress reduction. Studies on PSDs indicate 8 important basic qualities, which helps us better evaluate the green spaces. However, when one special PSD is intended to be designed or analyzed, people still have no access to instruments that how landscape design elements will be organized and constructed to achieve more restorative benefits and more efficient utilization of resource.

Studies have already been done on the identification, description, and ranking of the eight PSDs. Our results are fairly consistent with them, even after applying a new measurement method to Chinese samples. This further confirms that similar preferences and perceived characteristics are displayed by people with diverse cultural background, which strengthens the foundation for application in future research. Rather than a study object, the PSD was used as a standard to divide and categorize the UGS in our study. We focused on the PR and how it influenced each kind of UGS selected based on the standards above, which led to our own set of rankings. Certain landscape design elements were considered and their impacts on PR were evaluated. As a whole, *vegetation*, *disturbance,* and *water features* were the most reliable predictors. On this basis, the identification of significant landscape elements for each PSD regarding restorative benefits further emphasizes the importance and novelty of this study. Given the widespread preference for the eight PSDs over others in terms of mental restoration, the optimization of landscape elements which compose the special PSDs is more effective in enhancing the PR of UGS compared to focusing on ordinary elements. The results presented here offer more evidence to understand the PSDs and guidance for developing or maintaining them. However, before the influencing factors can be used as a tool to evaluate or design the UGS, more verification is needed with a larger sample size to prove the reliability and universal applicability of the results.

## Data availability statement

Data associated with this study is not deposited into a publicly available repository. Data will be made available on request.

## CRediT authorship contribution statement

**Shiqi Wang:** Writing – original draft, Software, Resources, Project administration, Methodology, Funding acquisition, Conceptualization. **Ang Li:** Writing – review & editing, Visualization, Supervision, Investigation, Funding acquisition, Data curation.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to

influence the work reported in this paper.

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