buildings

MDPI

Article

Improving the Restorative Potential of Living Environments by Optimizing the Spatial Luminance Distribution

Yuting Wu [1,2], Lixiong Wang [1,2], Juan Yu [1,2,*], Peng Chen [1,2] and Aiying Wang [1,2]

[1] School of Architecture, Tianjin University, Tianjin 300072, China; wuyuting2018@tju.edu.cn (Y.W.); wlixiong0011@sina.com (L.W.); chenpeng_1995@tju.edu.cn (P.C.); wayway@tju.edu.cn (A.W.)
[2] Tianjin Key Laboratory of Architectural Physics and Environmental Technology, Tianjin 300072, China
* Correspondence: juan.yu@tju.edu.cn; Tel.: +86-150-0220-8052

Abstract: Changing the spatial luminance distribution patterns has the potential to improve the restorative potential of indoor environments through spatial visual perception intervention, which is helpful to meet our growing need for psychological restoration and well-being. However, the efficiency, progress, and principles for improving the spatial luminance distribution of indoor environments have not been verified, and the reusable and restorative spatial luminance distribution patterns that can be applied to the restorative reserve levels created by the architectural configurations and dispositions of the different spaces have yet to be established. Using a living room environment as the typical space and a hotel room as the research subject, we conducted this study by setting up a control group for the assessment experiment, combining three subjective and objective measures: the Perceived Restorativeness Scale (PRS), the eye-movement test, and the case interview. The results showed the following. (1) The spatial luminance distribution of artificial lighting can improve the PRS score by 30.9%. (2) The spatial luminance distribution of artificial lighting improves the restorative perception potential, which negatively correlates with the restorative reserve level of the environment (the correlation coefficient values were -0.405, $p < 0.01$). (3) The spatial luminance distribution elicited two visual cognitive responses: visual attraction and visual load, with the former being positively correlated with restorative perception (the correlation coefficient values were 0.288, $p < 0.01$), while the latter was negatively correlated (the correlation coefficient values were -0.264, $p < 0.01$). (4) The visual cognitive conclusions of spatial luminance distribution including the six dimensions present the visual characteristics of the status quo in the restorative spatial luminance distribution of artificial lighting. Based on the findings, this study starts from the optimization of visual attraction and visual load by improving both the restorative level and the degree of restorative perception, proposing a restorative spatial luminance distribution pattern of artificial lighting applicable to environments with different restorative reserve levels.

Keywords: architectural lighting; spatial luminance distribution; living environment; environmental restorativeness; visual cognition

check for updates

Citation: Wu, Y.; Wang, L.; Yu, J.; Chen, P.; Wang, A. Improving the Restorative Potential of Living Environments by Optimizing the Spatial Luminance Distribution. *Buildings* **2023**, *13*, 1708. https://doi.org/10.3390/buildings13071708

Academic Editors: Dorukalp Durmus, Wenye Hu and Lambros T. Doulos

Received: 16 May 2023
Revised: 29 June 2023
Accepted: 30 June 2023
Published: 4 July 2023

Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

1.1. Research Background and Origin

The pursuit of well-being is not just a goal of the built environment [1]. However, social and psychological health problems such as stress and anxiety are on the rise year by year [2], and youth groups are increasingly being affected [3]. Research in environmental psychology shows that creating and implementing an effective restorative environment can relieve stress and fatigue, stimulate positive emotions, offset negative emotions, and promote attention recovery. This process is referred to as psychological recovery [4].

It is believed that the indoor environment is less restorative than the natural environment [5]. As we spend more than 80% of our time in indoor environments, researchers have tried to introduce restorative elements into the indoor environment to improve its

restorative level [6]. Such studies have confirmed that elements with "natural affinity" attributes such as window scenery [7], green plants [8], wood texture [9], etc. can play a positive role and can be considered as restorative elements. However, there remains a scarcity of restorative elements that can be introduced into indoor environments and problems persist such as the difficulty of introducing restorative elements, their occupation of a large amount of indoor space, and their potential failure to match the indoor decor. Therefore, the key elements that affect the restorative potential of the indoor environment are still unclear.

The indoor environment of buildings with certain characteristics is considered to be restorative; these can bring people a spatial experience of psychological recovery. Previous research has proven that some environmental features in the indoor environment of these buildings can promote the perception of a restorative environment; these features include the awe-inspiring, quiet, and beautiful environmental features of monasteries [10], or the clear routes and orderly spaces of museums [11]. Some studies have also pointed out that individual experiences of space (e.g., personal preference, relaxation, and excitement) also affect the restorative properties. However, the relationship between restorative elements and factors affecting perception is still unclear, and is currently insufficient to guide the improvement in the restorative potential of indoor environments.

Overall, to improve the restorative potential of indoor environments, two issues need to be clarified: the internal restorative elements of the indoor environment, or those that can be introduced, and the factors that affect the perceived restorative potential of the indoor environment. The former improves the restorative reserve level of environments and the latter improves the degree of environmental restorative perception.

Twedt pointed out that visual appeal was the strongest predictor of the perceived restorative potential of the environment [12]. Although it has not been determined whether elements with visual attractiveness are equivalent to restorative elements, it has been confirmed that environmental visual attractiveness plays a mediating role in promoting environmental restoration perception by 42%.

Established studies have shown that the two main evaluation factors related to spatial luminance distribution—visual brightness and visual interest—are closely related to environmental perception and environmental attractiveness [13,14], which represents a new resource and way of improving environmental restorativeness. Specifically, as a necessary condition of indoor environments, artificial lighting (hereinafter referred to as lighting) does not require a special introduction. In particular, the application of LED line and surface light sources of new forms and the extension of artificial lighting design objective procedures, the achievement of a more diverse, convenient, and controllable spatial luminance distribution pattern, and the formation of more abundant and novel shadow–dark relations have the potential to provide a new spatial lighting experience [15,16]. Whether providing visually attractive elements (restorative reserve level) or significantly improving the visual attractiveness of an environment (the degree of restorative perception), optimizing the spatial luminance distribution of lighting using LED intelligent dimming technology is an effective way to improve the environmental restorativeness of indoor environments.

In a study of indoor lighting environments, it was confirmed that luminance distribution is an important factor that influences the lighting quality, which significantly impacts visual comfort, visual fatigue, and other visual considerations. Leccese et al. [17] pointed out that the lighting quality and visual comfort not only depend on the illumination level in the area of the main task, but also on factors such as luminance distribution; they proposed a lighting quality assessment method for the evaluation of lighting in educational rooms to create a ranking related to the impact of visual comfort. Kong et al. [18] conducted a field study on the lighting quality in higher education classrooms in Singapore and suggested that the mean luminance of the horizontal 40° band was an effective predictor in terms of subjective lighting comfort. Moreover, in the classroom environment, Dang et al. [19] introduced the idea of a luminance gradient and concluded that directional luminance gradients and the mean value of luminance in an environment have a significant effect on

visual fatigue. Leccese et al. [20] studied the lighting of workstations used for diagnostic radiology reporting and proposed the use of an LED backlight system to reduce the difference in luminance in the field of view of the radiologist, thus reducing the visual fatigue of the physician. These studies focused on the effect of luminance distribution on visual effect, however, there is a lack of research on the effect of luminance distribution visual perception on mental health.

In addition, the psychological health properties of natural lighting environments and the outdoor landscape views they provide are well-recognized [21]. However, the widely available lighting environments, isolated from natural light and outdoor landscape views in the spatiotemporal dimension, make people susceptible to psychological problems such as irritability and anxiety and cognitive decline [22]. Thus, this study focused on lighting in the hope of achieving environmental restorative enhancement by relying on the advantages of pure artificial lighting technology in spatial luminance distribution pattern modulation.

1.2. Literature Review

1.2.1. Restorative Potential of Indoor Lighting Environments

It has been proven in previous studies that a reasonable spatial light–dark relationship can significantly affect people's emotional response to the spatial atmosphere, stimulate positive emotions, and relieve stress, thus achieving a positive intervention in psychological states [23–25]. Studies have shown that the outdoor environment at night, with landscape lighting including urban building nightscape lighting [26] and near-home street nightscape lighting [27], is restorative. However, there is a lack of research on the relationship between lighting and the restorative properties of indoor environments.

It should be noted that, at the spatial perception level, lighting is the presentation of light to the architectural configuration and disposition of the space. Visual perceptions of lighting environment are based on the interaction of lighting and entity elements in the environment. As stated by Tregenza, light in the architecture is not only a physical energy, but also an information carrier in the design practice of architectural environments [28]. In the process of studying the restorative potential of lighting environments, even if the purpose is to use lighting energy or the regulating role of lighting energy, the basic role of the architectural configuration and disposition cannot be overlooked. This means that to study the improvement of lighting on the restorativeness of environments, it is necessary to eliminate the interference of the conditions of various elements, and when applying lighting to achieve a restorative environment, the applicability of various elements should be considered.

1.2.2. Role of Visual Cognition in the Process of Environmental Restorative Perception

Visual appeal and visual load are two kinds of visual cognitive responses that play a key role in the process of the perception of environmental restoration.

1. Visual appeal

The relevant literature on restorative environments has repeatedly shown that the natural environment is more restorative than the building environment [29,30]. However, the category of natural environment is too broad to accurately define the restorative environment. By evaluating the visual appeal of the environment [12], researchers have found that it can be used as a perception dimension to evaluate the restorative potential of the natural environment and building sites. Numerous studies on the restorative properties of the natural environment have proven that perception dimensions such as personal preference and esthetic feeling can promote the perception of restoration, which can be partially explained by appeal. Some studies have further revealed that the perception of restoration is mediated by perceived attractiveness [31].

2. Visual load

Some researchers believe that, compared with the artificial environment, the natural environment is more easily processed by the visual system and exerts less cognitive load

on the visual system, which can reduce the pressure on people [32]. This has been proven by studies that use eye tracking. These studies showed that there is less eye movement when viewing images of the natural environment than when viewing images of building environments [33].

From the perspective of visual perception, improving the restorative potential of the environment can be achieved by improving the visual attractiveness of the environment or by reducing the visual load demanded by the environment.

1.2.3. Restorative Potential of Spatial Luminance Distribution

In the space of an architectural environment, the attributes of lighting include three basic aspects: intensity, chroma, and light distribution. Of these, light distribution is the most influential factor for the overall perception and function of the environment [34].

As Cuttle et al. [16,35] pointed out, lighting at this stage has shifted from evaluating the light incident on a plane to evaluating the light reaching the eye, and these parameters, related to the amount and spatial distribution of light within an interior space, can anticipate the relevant human response. Luminance responds to and quantifies the light perceived by the human eye. Therefore, spatial luminance distribution is not only applicable to reflect the actual perceived effect of light distribution on the human eye produced in architectural spaces, but can also be used to quantify the amount of light distribution.

It has been proven that the luminance distribution in the vertical plane of a space creates visual brightness; the uneven distribution of luminance forms spatial visual interest. Visual brightness can facilitate the identification of elements in the environment (potential restorative elements), promoting the perception of restorative elements of the environment and reducing the visual cognitive load. At the same time, visual interest is part of the visual appeal of the environment, adding a restorative element to it, which is conducive to the perception of environmental restoration. Therefore, spatial luminance distribution affects the restorative potential through visual brightness and visual interest. This was also the assumption of this study.

Research has proven that the appropriate light–dark spatial relationship formed by a reasonable spatial luminance distribution has a positive effect on space shaping and the users' psychological perception [24,36,37]. However, the essential attribute of the light–dark spatial relationship has not been clearly defined. In fact, the spatial light–dark relationship includes two factors: (i) the assignment of the physical energy of lighting (i.e., the proportion and relationship of the position between light and shadow), and (ii) the layout of the information-carrying properties (elements in the lighting environment), in other words, the highlighting and hiding of spatial entity elements. Therefore, to improve environmental restoration by adjusting spatial luminance distribution, it is necessary to distinguish between the two factors. From the perspective of the assignment of energy, spatial luminance distribution and information-carrying properties are independent environmental visual elements. In this case, the light–dark relationship is a component of the visual appeal of the environment, which can improve the restorative reserve level of environments but also exerts a visual load. From the perspective of layout, it is the elements in the environment that provide visual appeal. The change in the light–dark relationship only affects the degree of restorative perception while the visual elements and the visual cognitive load remain unchanged. On the other hand, the visual cognitive load can be reduced by hiding or highlighting relevant elements.

1.3. Research Overview

The purpose of this study was to identify the potential of spatial luminance distribution to improve environmental restoration. The problems to be solved in the study include:

(1) Obtaining a spatial luminance distribution pattern that can improve the restorative properties of the lighting environment while remaining suitable for different architectural configurations and disposition conditions;

(2) Clarifying the role of spatial luminance distribution in improving environmental restoration. Specifically, the relationship between visual appeal and visual load caused by spatial luminance distribution in the process of restoration perception will be discussed as well as the influence path of spatial luminance distribution to improve the restorative potential (i.e., to improve visual attractiveness by increasing visual interest or to reduce visual load by changing the visual brightness);

(3) Clarifying the connotation of restorative spatial luminance distribution (i.e., whether the visual cognitive conclusions of restorative spatial luminance distribution are the relationship between light and shadow or the layout relationship of lighting objects). On the basis of this conclusion, a construction strategy for restorative spatial luminance distribution is proposed.

2. Methods

This research adopted the method based on the theory of "evidence-based design". This method first appeared in the journal Science in 1984 to prove that scenery outside a window can promote the postoperative rehabilitation of patients [29]. Evidence-based design theory has been widely applied to various types of architectural design, which uses scientific research methods and statistical data to analyze the empirical effect and impact of the building environment on the users' health, work efficiency, and building energy consumption [38].

According to Section 1.2, it may be possible to make the following speculative conclusion and hypothetical interpretations of the evidence-based research hypothesis (Figure 1).

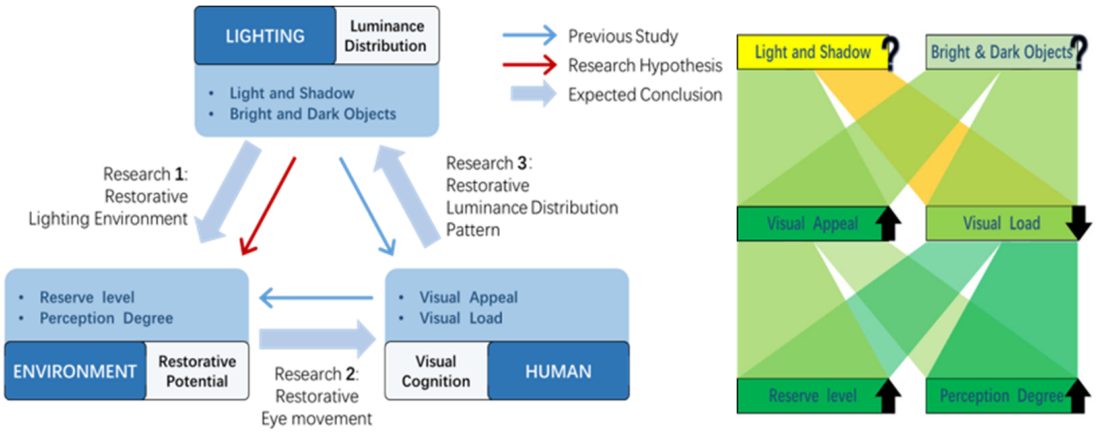


Figure 1. Research hypothesis. (**a**) Speculative conclusion. (**b**) Hypothetical interpretation. (**a**) "Previous Study" refers to a previous study that confirmed that lighting luminance distribution generates light and shade relationships, triggers a sense of visual brightness and visual interest, and correlates two types of human visual cognitive responses: attraction and load, which are significantly related to the perception of environmental restorativeness. "Research Hypothesis" is based on the findings of the above-mentioned studies, and the speculative conclusion is that optimizing spatial luminance distribution can enhance environmental restoration. The "Expected Conclusion" first obtains the restorative illumination environment, and then obtains the visual response (eye movement index) during the restorative perception, and, finally, refines the restorative luminance distribution pattern. (**b**) The key to optimizing the spatial luminance distribution to improve the restorative nature of the environment lies in how to configure the "Light and Shadow" relationship generated by the lighting luminance distribution and the "Bright and Dark Objects" relationship, because the "Light and Shadow" relationship increases the "Visual Appeal" elements, but also increases the "Visual Load", while the "Bright and Dark Objects" relationship does not increase the "Visual Appeal" element, but can filter the visual elements to optimize the environment's "Visual Appeal" and not increase or even reduce the "Visual Load".

Speculative conclusion: Optimizing the spatial luminance distribution is able to improve environmental restorativeness.

Hypothetical interpretation: The spatial luminance distribution has two cognitive conclusions of the light–shadow relationship and lighting object layout relationship, thus regulating two visual cognitive responses of visual attraction (increase) and visual load (decrease), aiming to improve both the restorative level and the degree of the restorative perception of lighting.

Therefore, the content of the experimental phase of this study included three parts:

(1) The restorative potential of the lighting environment with different information-carrying conditions was evaluated using the Perceived Restorativeness Scale (PRS). To eliminate the influence of various information-carrying conditions, the natural light environment was set as the control.
(2) Eye-movement indicators such as scanning, gaze behavior, and pupillary changes were measured using an eye tracker on the participants in the process of the perception restoration evaluation. The visual cognitive response data were extracted and the relationship between visual attraction and visual load caused by spatial luminance distribution was obtained.
(3) Screening the typical lighting environment of Part 1 and using the comparison of cases and the focus group interview, the visual cognitive conclusions of spatial luminance distribution and the design optimization strategies of a restorative spatial luminance distribution pattern were explored.

2.1. Experimental Methods

2.1.1. Evaluation of Perceived Environmental Restorativeness

The Perceived Restorativeness Scale (PRS) (Table 1) used in this study was based on Wang's hotel restorativeness scale [39] and Nikunen outdoor lighting environment restorativeness scale [27], and modified according to the principles of brevity, understandability, and the ability of the experimental participants to respond quickly and accurately.

Table 1. Perceived Restorativeness Scale (PRS).

No.	Questions and Explanation
1	Q1: This room makes it easy for you to relax and stay away from daily pressures and worries.
	Explanation: Leaving a stressful and tense environment to avoid psychological fatigue and allow attention to recover.
2	Q2: This room is charming and interesting, which makes you want to know more about it.
	Explanation: The environment is attractive enough, and there is no need for extra effort to improve attention, thus allowing attention to recover.
3	Q3: This room makes you feel comfortable and can do what you like.
	Explanation: The content of the environment fills in one's visual field and mind, allowing concentrated attention to rest.
4	Q4: This is a room suitable for your rest.
	Explanation: The environment provides a good fit with one's purposes or inclinations

Each item in the PRS has a score of 1–5, corresponding to "nothing; seems to be a little; comparison; equivalent; special". The higher the score, the better the restorative potential for the environment.

2.1.2. Eye-Movement Index Monitoring

In this study, seven eye-movement indicators were analyzed, covering three aspects of visual behavior (Table 2) (i.e., saccade, fixation behavior, and pupil change). All information related to eye-movement indicators was recorded using a Tobii Pro Glasses 2 wearable eye tracker and analyzed using ErgoLAB 3.0 software(Beijing, China).

Table 2. Definition of eye-movement indicators [40,41].

No.	Type	Eye-Movement Indicators	Definition
1	Saccade	Saccade count (SC)	Search process
2		Total saccading time (ST)	Cognitive processing difficulty of the overall environment
3	Fixation	Fixation count (FC)	Distribution of visual attention
4		Total fixation time (TFT)	Overall attractiveness of the environment
5		Average fixation time (AFT)	Attractiveness of the target (point of interest)
6		Fixation duration ratio of AOI (FDR)	Attractiveness of areas of interest
7	Pupil change	Average pupil diameter (APD)	Visual cognitive load of participants

According to the statistical data of the points of interest, the area of interest (AOI) was sorted into nine types, as shown in Table 3.

Table 3. Classification of AOI.

No.	AOI	Map of the Exhibition
1	Ceiling	
2	Floor	
3	Sidewall beside TV	
4	Sidewall at bedhead	
5	Window side wall	
6	Furniture	
7	Decoration	
8	Luminaire	
9	Greenery	

Note: The natural lighting environment adopted the same AOI classification as the map of the exhibition.

2.1.3. Case Selection and Interview

Typical cases were selected according to the evaluation results of the PRS test and were sorted as high and low groups (Figure 2); see Section 3.3.1 for details. Interviews were conducted for a single case, same group cases, and a control group case. By coding and classifying the interview data, the descriptive words and explanations of the lighting distribution were obtained and their cognitive conclusions were discussed. The perception dimension and preference of restorative lighting distribution were obtained by further coding analysis.

A semi-structured focus group interview method was adopted. During the interview, the participants' subjective cognitive feelings about the lighting distribution of typical cases (groups) were recorded. The semantic vocabulary was then collected through summarizing and analyzing the interview records.

In particular, the concept of "spatial luminance distribution" was clarified to the participants before the experiment began, and the participants were shown images of daylight and lighting in the same room to visualize the spatial luminance distribution and its differences.

The data of the focus group interview were generated by the interaction between group members. During the interview, group members were encouraged to discuss the topics freely and the nature of interaction and synergy of the focus groups was used to enable participants to clarify or expand their contributions to the discussion according to the points put forward by other participants. The purpose was not to reach consensus, but to obtain data about the ideas, attitudes, understanding, and cognition, especially regarding the typical vocabulary and thinking mode of the target group when speaking about specific topics. The interview data collected in this study were coded, classified (conceptualized), and analyzed (relational/analytical) using NVivo 12 Plus software (Denver, CO, USA).

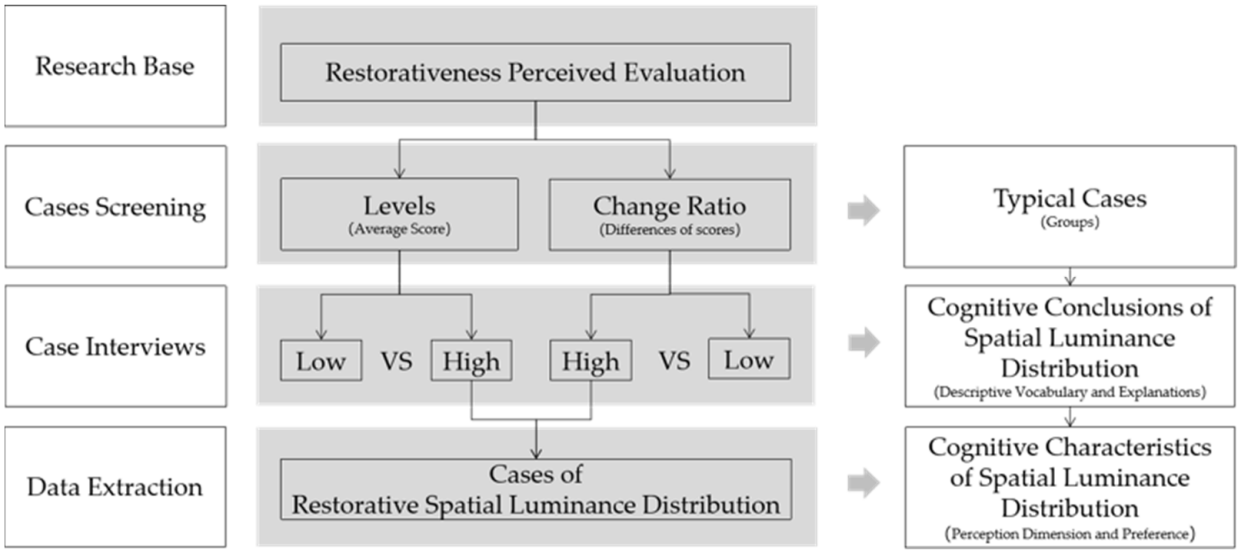


Figure 2. The process of case selection and interview. VS is an acronym for "Versus", which refers to a comparison of cases with high and low levels of restorativeness. The typical cases were selected based on the restorativeness of the lighting environment score (L) and the change ratio of environmental restorativeness under the influence of the spatial luminance distribution of lighting (D/N). The highest L group and highest D/N group were selected, and the lowest L group and lowest D/N (negative) group were also selected. The purpose was to use the "positive inspiration of negative teaching materials" to conduct a comparative study between high and low groups, to obtain descriptive words and explanations of the cognitive conclusions of the response spatial luminance distribution, to further screen the cases of restorative spatial luminance distribution, and to clearly propose cognitive characteristics from the perceptual dimension and preference level.

Table 4 shows the outline of the interview questions. Question 1 was applied to all typical cases to obtain cognitive conclusions. The common perception characteristics and feature perception dimensions of the cases in the same group were obtained by asking Question 2. The differences in the feature perception dimension of the control group were obtained by asking Question 3.

Table 4. Outline of the interview questions.

No.	Interviewees	Questions
1	Single case	Please describe the characteristics of the lighting environment according to its luminance distribution.
2	Cases in the same group	Please describe the common characteristics of the lighting environment in this group according to the luminance distribution.
3	Control	Please describe the difference of the characteristics of these two groups of lighting environments according to the luminance distribution.

2.2. Experimental Design

2.2.1. Selection of Indoor Spatial Environment

The indoor environments that possess the restorative potential above-mentioned such as the monastery belong to the public space and are shared by many people. This provides less opportunities for individuals to pay attention to themselves and recover their perception. In contrast, the habitable space is private and is used by individuals every day; therefore, it is more valuable in terms of improving the individuals' restorative needs [42]. Meanwhile, habitable space is a typical space without specific visual tasks [43] and more diversified visual requirements; therefore, it requires diversified luminance distribution patterns [44,45]. The indoor space environment selected in this study was a hotel room

because the spatial luminance distribution pattern of hotel rooms is the most diversified among various living spaces and is relatively open and easy to investigate.

In order to ensure the comprehensiveness and representativeness of lighting information-carrying conditions, the survey included hotels and rooms of different grades and standards as well as rooms with different decoration and lighting methods as far as possible (Figure 3). A total of 43 guest rooms were investigated; these were distributed throughout 15 cities in China and were newly opened or renovated in recent years, which can reflect the current level of the hotel room environment.

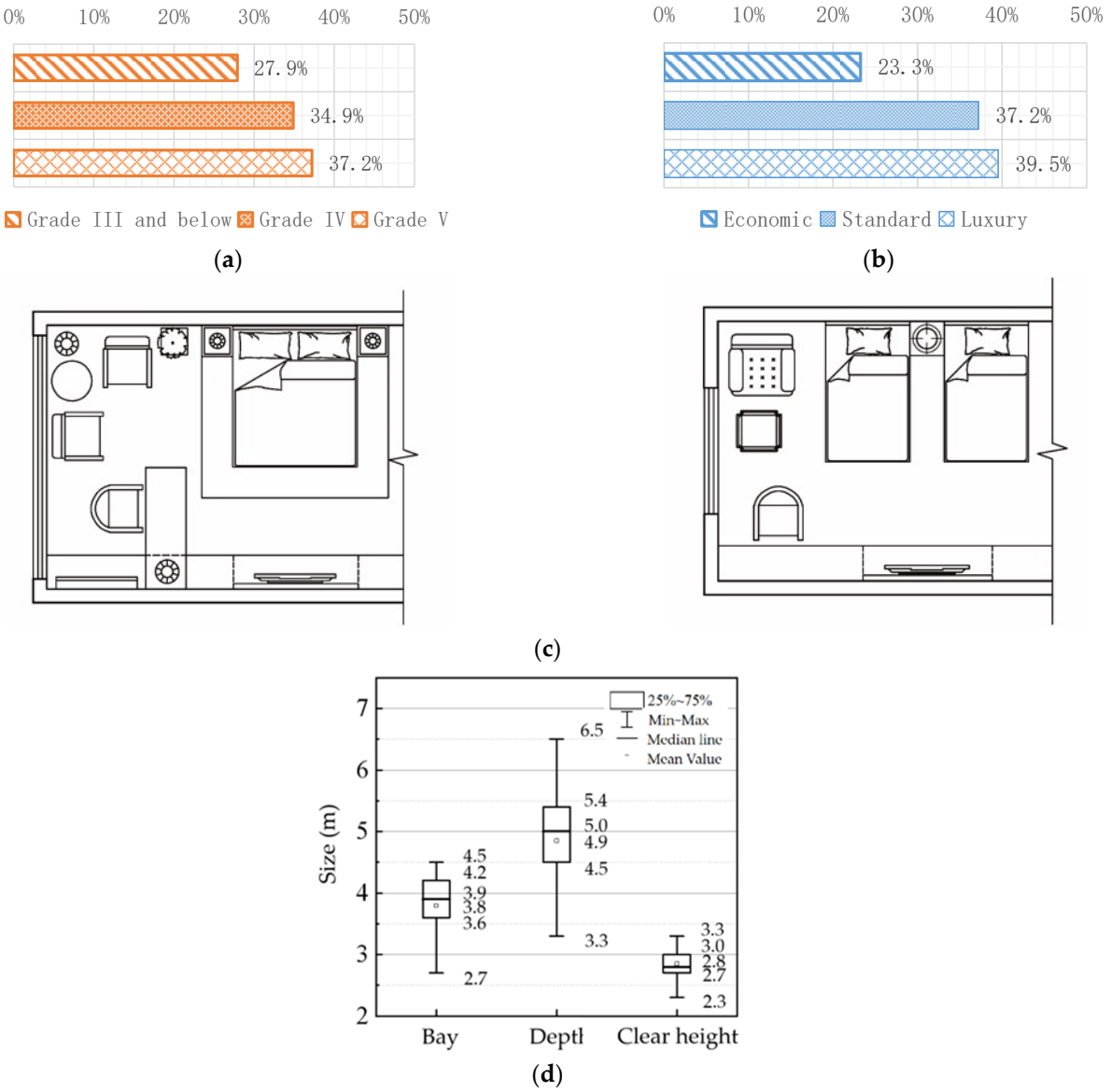


Figure 3. Conditions of the investigated hotels and rooms. (**a**) Percentage of hotel grades. (**b**) Percentage of room standards. (**c**) Schematic diagram of a typical layout form. (**d**) Room space size statistics. The dimensions of the accommodation space are presented in (**d**).

2.2.2. Spatial Luminance Measurement

To comprehensively understand the overall luminance levels in the rooms studied, the LS-100 luminance meter was used to measure the luminance values in each room. Figure 4 shows the locations of the luminance tests in the guest rooms.



Figure 4. Diagram of the luminance measurement point locations. The test points include test data for each interface, with three levels of subjective visual light, medium, and dark for different materials. The points locations on each interface of different materials are distinguished by Letter+Number with Color, as follow: CXX with ■—ceiling; BXX with ■—sidewall at the bedhead; WXX with ■—window side wall; TXX with ■—sidewall beside TV; DXX with ■—floor; PXX with ■—decoration; FXX with ■—furniture.

Separate statistical analyses of the light source and interface luminance data were carried out: the measured surface luminance of the light source ranged from 1206.8 cd/m^2 to 4618.2 cd/m^2, which is in line with studies that considered 1000 cd/m^2 or more as the luminance of the light source [46]. Figure 5 shows the box plot's measured interface luminance values for the 43 rooms. The maximum measured luminance for each room ranged from 9.99 cd/m^2 to 354.4 cd/m^2, with a standard deviation of 91.51. The median measured luminance for each room ranged from 1.59 cd/m^2 to 43.16 cd/m^2, with a standard deviation of 8.57. The maximum to median measured luminance ratio for each room ranged from 2.6 to 71.89, with a standard deviation of 16.04.

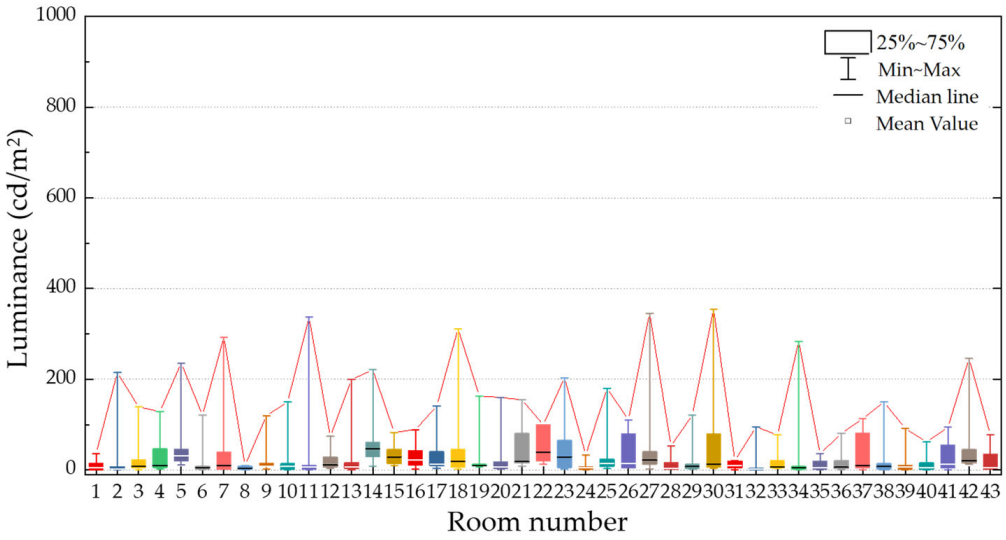


Figure 5. Measured luminance in the guest rooms. The measured values in the graph do not include the surface luminance of the light source.

2.2.3. Participants

The target group of this research was people under pressure. The participants recruited in this study were individuals who felt great pressure and had stayed in hotels frequently during their daily work and study. In order to make the recovery effect easier to measure, a stressful scenario was created through the scenario description during the experiment.

When comparing between-subject design and within-subject design experiments, the within-subject design effectively eliminates the effect of individual differences on the results compared to the between-subject design experiments. In addition, the within-subject design requires a relatively small number of participants and is simpler and more effective. Therefore, we used a within-subject design in which all participants evaluated all 43 rooms.

A total of 37 participants were involved including two participants tested onsite and 35 participants tested through recurring scenario experiments and case interviews. The number of participants was greater than 30, meeting the general requirements for optical experimental studies and statistical methods [47]. Among the participants, the ratio of male to female was 18:19, and their age was between 20 and 35 years old. Their educational levels were basically the same, all of them were free of eye disease and color blindness or color weakness, and their naked eye power or that of their corrected vision was above 1.0.

2.2.4. Control Group

The PRS was used to evaluate the overall restorative potential of the environment. This scale cannot evaluate the restorative potential of a particular element in the environment.

In order to obtain the effect of spatial luminance distribution on environmental restoration and eliminate the interference of information-carrying conditions, a natural lighting environment with side window diffuse lighting was used for the control group in this study. This was based on the assumptions of the uniform luminance distribution in the natural lighting environment, which is the basic condition for the visibility of physical elements and the perceived environmental restorativeness.

We chose rooms without direct light to achieve diffuse lighting including selecting north-facing rooms or south-facing rooms on all cloudy days and in the morning and evening hours to ensure uniform luminosity distribution in the natural lighting environment.

As shown in Table 5, the difference between the experimental group and control group lies in the spatial luminance distribution and window view.

Table 5. Comparison of the environmental factors between the experimental group and control group.

Group	Environmental Conditions	Commonality	Difference	
			Spatial Luminance Distribution	**Window View**
Control	Natural lighting	Carrier (interface, decoration, parts, and other indoor physical elements)	Uniform luminance distribution pattern	Natural outdoor view
Experimental	Lighting		Lighting luminance distribution pattern	Covered by curtain, no outdoor view

As shown in Table 5, in addition to the spatial luminance distribution, there was also a difference in the window view between the experimental group and control group. Therefore, this study used an alternative parameter to represent the restorative effect of the lighting luminance distribution. For ease of quantitative interpretation, this study first applied the following definitions:

- L represents the restorativeness of the lighting environment; this is the average PRS score of a room under lighting environment.
- R represents the restorativeness of the indoor information-carrying conditions, which is the restorativeness of the indoor environment composed of intrinsic physical elements under a homogeneous luminance distribution pattern.
- N represents the restorativeness of the natural light environment, which we considered the restorative reserve level of environments. N represents the average PRS score of a room under natural lighting environment.
- W represents the restorativeness of the window view.
- P represents the change in environmental restorativeness under the influence of spatial luminance distribution (the value of P can be positive or negative).

Among these, L and N represent the overall environmental restorativeness abovementioned, which can be evaluated using the PRS; W has been proven to have restorative effects, that is, W > 0.

Therefore, some formulas can be obtained:

$$L = R + P, \tag{1}$$

$$N = R + W, \tag{2}$$

Then:

$$P = L - R = L - (N - W) = L - N + W > L - N, \tag{3}$$

This step eliminates R, which removes the interference of information-carrying conditions.

If L − N is recorded as D, it can be inferred that P > D; thus, when D > 0, P > 0. This means that D (D > 0) can be used as an alternative parameter to P > 0 to represent the restorative effect of the spatial luminance distribution of lighting.

Similarly, Formula (4) can be proposed to represent the change ratio of environmental restorativeness under the influence of the spatial luminance distribution of lighting:

$$\frac{P}{R} > \frac{D}{R} > \frac{D}{R+W} = \frac{D}{N}, \tag{4}$$

where D/N can be used as an alternative parameter to P/R.

Therefore, in this study, both D (D > 0) and D/N were used as alternative parameters to represent the restorative effect (difference between values of PRS) and change ratio (PRS change ratio) of environmental restorativeness due to the luminance distribution pattern. It should be noted that both alternative parameters were less than the actual parameters. This means that the restorative effect and change ratio described by the alternative parameters in this study were lower than the actual values. However, the use of alternative parameters is feasible and can be useful in certain research contexts.

2.2.5. Scenario Recurrence Method

Apart from conducting an onsite evaluation experiment, this study also used a picture recurrence scene experimental method to compensate for the question of the wide geographical distribution of the room sites and the difficulty of our participants to visit the sites one by one for evaluation.

Due to the advantages of convenient operation and control, the picture recurrence scene is widely used in the experimental research on the evaluation of restorative potential and that of eye-movement behavior and has been proven by relevant research to be equally effective regarding onsite viewing [41,45]. In this study, the scenario recurrence method was used to simulate the scene of a guest room by displaying images of a guest room in a darkroom laboratory (Figure 6). The images displayed were 1920 × 1080 pixels, obtained on site from a fixed shooting height at the entrance of the guest room. The images should reflect the first image of the guest room presented to the guest, be able to present the overall view of the guest room, and restore the actual scene perspective and lighting effect. In the scenario recurrence experiment, a total of 86 images were played (i.e., one image each of the indoor lighting and of the natural lighting environment for 43 guest rooms). The display model was a Panasonic TH-P46S10C. The size of the display screen was 1.1 m × 0.7 m with 1920 × 1080 full HD resolution. The contrast was set to 50, and the luminance was set to −50. The white balance luminance of the display was 43.20 cd/m^2, a value determined by pre-experimentation to adjust the display luminance for the visual comfort of the participants. The distance from the participant to the display screen was 1.2 m, and the height of the participant's vision was flush with the center line of the display screen in the vertical direction, which was 1.2 m from the ground.

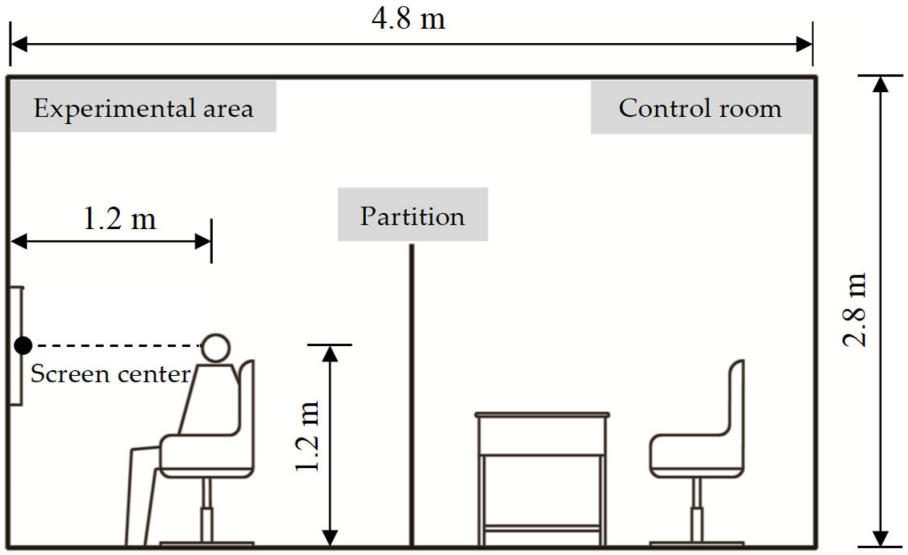
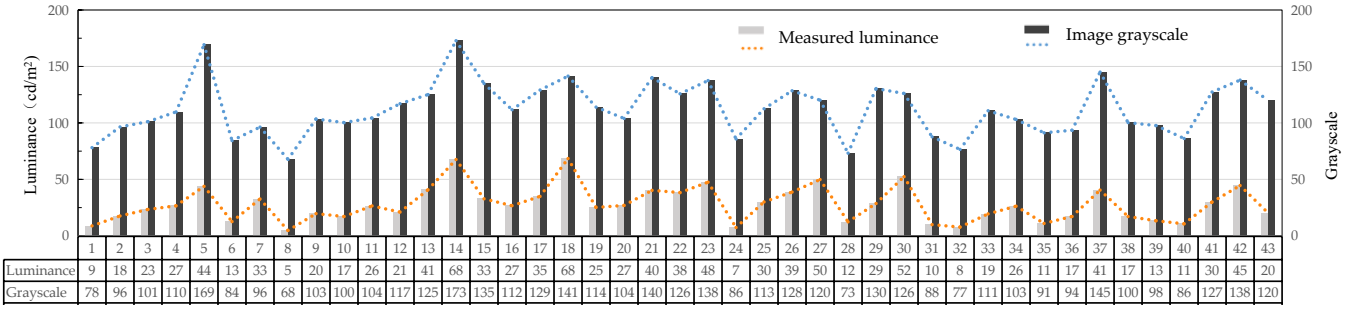


Figure 6. Layout of the darkroom laboratory.

During the image capture, the researcher manually adjusted the focus point and exposure of the image in automatic mode to obtain a sense of brightness in the captured image, consistent with the scene as agreed by the participants in the field. The agreement is also illustrated by the data on the average measured luminance of the live scene and the average grayscale of the measured points in the image, as shown in Figure 7.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
Luminance	9	18	23	27	44	13	33	5	20	17	26	21	41	68	33	27	35	68	25	27	40	38	48	7	30	39	50	12	29	52	10	8	19	26	11	17	41	17	13	11	30	45	20
Grayscale	78	96	101	110	169	84	96	68	103	100	104	117	125	173	135	112	129	141	114	104	140	126	138	86	113	128	120	73	130	126	88	77	111	103	91	94	145	100	98	86	127	138	120

Figure 7. Average measured luminance and average image grayscale in guest rooms.

For the overall 43 rooms, connecting the average by blue and orange gave an initial indication of a consistent trend in brightness levels between the two. The results of the correlation analysis showed that the correlation coefficient was 0.866 (>0.8 is a robust correlation). This indicates that the luminance levels of the images had good agreement with the luminance levels of the scene.

Correlation analysis and single-factor analysis of variance were conducted between the onsite experiment data of two participants and the scenario recurrence experiment data of 35 participants. The correlation coefficient was 0.68 (>0.6 is strong correlation) and the single-factor analysis of variance result was F (3.4) < F crit (3.9). The results showed that there was no significant difference between the two groups of data, indicating that the scenario recurrence experiment conducted in this study has good agreement with the onsite environment.

2.2.6. Experimental Procedures

Before the experiment, the participants were informed of the experimental plan and signed the informed consent form.

In the onsite experiment, the participants completed the experiment independently. The participants were required to read the description of the stress situation, and then fully perceive the room environment, and, finally, fill in the Perceived Restorativeness Scale.

Figure 8 shows the procedure of the scenario recurrence experiment. Before the experiment, the researcher calibrated the eye tracker to ensure that the eye-movement data could be collected correctly. In order to prevent the influence of the preferred effect on the experimental results, the researcher instructed the participants to quickly browse all 86 images, which were played in random order. At the same time, the researcher played a prerecorded audio description to create a stressful environment for the participants. The content of the audio description was "Recently, your study and work tasks have been heavy, but you have worked very hard to complete them. Now the task has just finished, and you will travel soon. However, you are too tired, and you are also worried about the mistakes made in the previous task". This method of scene creation has been proven by many studies to constitute an effective way to increase mental stress [48].

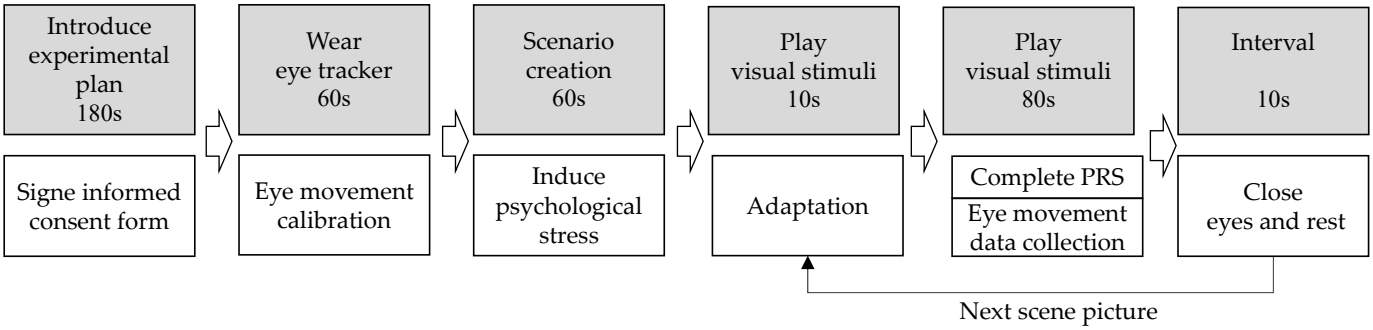


Figure 8. Experimental procedure of the restorativeness evaluation of the environment.

After the preparation, the 86 images were randomly played to each participant; the experiment time of each image was 100 s. The first 10 s was the adaptation time, participants were only required to imagine themselves in the scene displayed by the image. Then, the participants were free to watch and continuously experience the environment for about 80 s without specific visual tasks and were asked to answer the questions of the PRS orally at the same time. After 10 s of rest with their eyes closed, the participants were then required to view the next image. The eye-movement tracker was worn throughout the test. The tracker began recording when the participants were asked questions and stopped recording when the participants' eyes were closed. The method of playing the scenario creation audio and the participants' verbal responses and the researcher recording the answers to the PRS questions was used to ensure the eye-movement data collection.

The total testing time of each participant was about 150 min (86 × 100 s). In order to avoid eye and cognitive fatigue and boredom caused by a long experiment, the duration of each phase was not more than 40 min, and the experiment was divided into four phases in two days.

3. Results

3.1. Results of Perceived Restorativeness Evaluation

Before the data analysis, a reliability test was conducted on the data of the PRS. The value of Cronbach's alpha was 0.929, indicating that the evaluation results obtained from the scale used had good internal consistency and high reliability.

Pearson correlation analysis was used to study the relationship between the PRS score of lighting environment and that of the natural lighting environment (L and N, respectively). The analysis showed that the correlation coefficient value was r = 0.72, which was greater than 0.6, and showed that the data's significance was p = 0.000, which was less than 0.05. This indicates that the restorative potential of a lighting environment has a significant positive correlation with that of a natural lighting environment. A paired-sample t-test showed that the significance of the p value was 0.028, which is less than 0.05,

indicating that there was a significant difference between the restorative potential of a lighting environment and that of a natural lighting environment.

3.1.1. Average Score of the Perceived Restorativeness Scale

The PRS score of each room was the average of the scores of 35 participants. To comprehensively understand the participants' evaluation of the restoration of two environments, the scores of 43 rooms were presented using a box plot. As can be seen from Figure 9, the range of restorative scores of the lighting environment and that of the natural lighting environment was 1.82–3.86 (L) and 1.84–4.21 (N), respectively. The average value and median value of the natural lighting environment were generally higher than those of the lighting environment. The score fluctuation of the lighting environment was smaller than that of the natural lighting environment. The score (L) of 17 rooms was higher than 3 (i.e., 17 rooms were "moderately restorative"), accounting for 39.5% of the total. These results show that the investigated hotel rooms demonstrated restorative lighting properties under both lighting environments. Although not at a very high level, numerous guest rooms possessed restorative lighting environments.

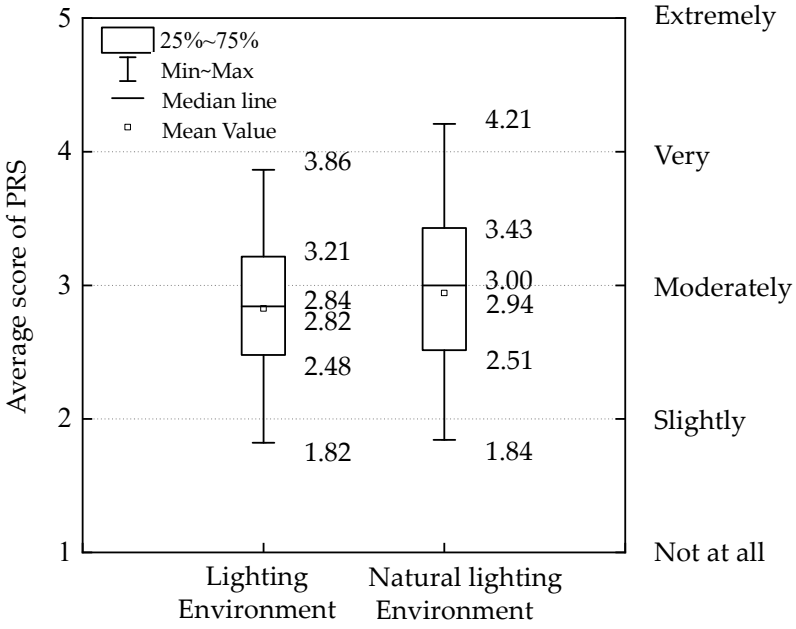


Figure 9. Average score of the PRS.

3.1.2. Difference between Scores of the Perceived Restorativeness Scale

In order to clarify the impact of the spatial luminance distribution of lighting on the restorativeness of the rooms, the rooms were sorted according to their natural lighting environment PRS score; the difference between the PRS scores of lighting and the natural lighting environment was presented correspondingly (L and D = L − N, respectively). As shown in Figure 10, the PRS score of the rooms under natural lighting is represented by a line with a triangle marker, whose value increased from left to right, and the corresponding difference is represented by a histogram with values in the range of −1 to 1.

It can be seen from Figure 10 that the difference between the PRS score of the lighting environment and the natural light environment in the 16 rooms was D > 0, accounting for 37.2% (16/43) of the rooms, indicating that the spatial luminance distribution of lighting is able to improve environmental restorativeness.

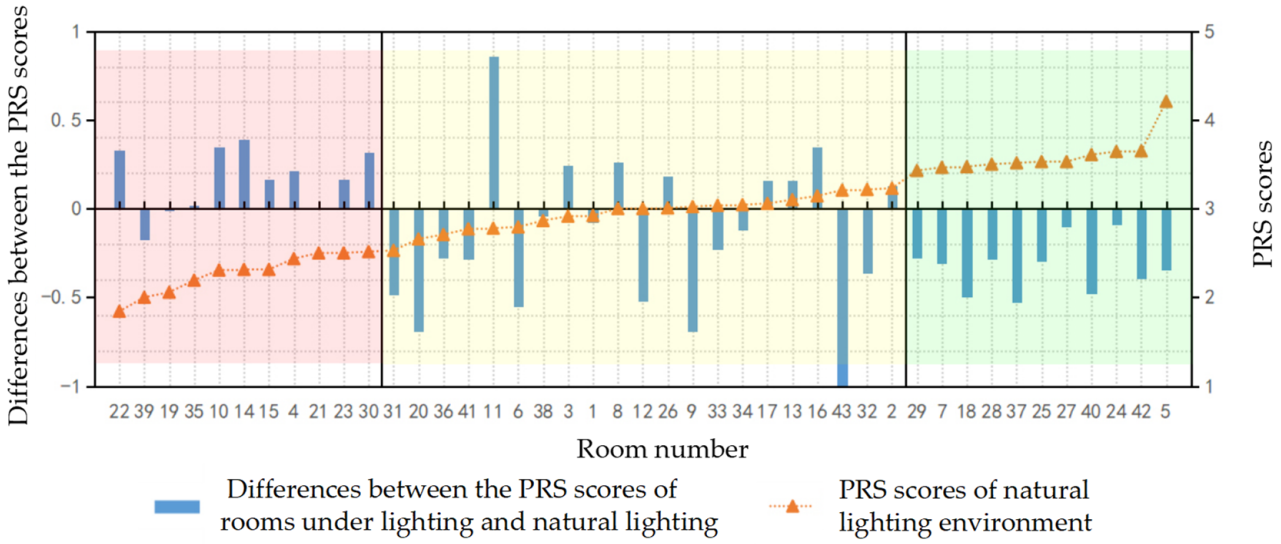


Figure 10. Differences between the PRS scores of rooms under lighting and natural lighting (rooms are numbered according to the random order in the experiment). ☐ represents N between 1.84 and 2.51. ☐ represents N between 2.53 and 3.23. ☐ represents N between 3.43 and 4.21.

We found that the impact of the lighting environment on rooms with different restorative reserve levels of environments varied. Therefore, it is necessary to discuss the proportion of rooms with D > 0 when considering the restorative reserve level of environments (PRS score under natural light environment, N). Specifically, the scores were divided into three ranges:

(1) N was between 1.84 and 2.51, D > 0 in most rooms, accounting for 73% (8/11);
(2) N was between 2.53 and 3.23, D fluctuates, D > 0 in rooms, accounting for 38% (8/21);
(3) N was between 3.43 and 4.21, D > 0 in rooms, accounting for 0% (0/11).

The proportion of cases in which the spatial luminance distribution of the lighting improved environmental resilience was negatively correlated with the restorative reserve level of environments. The results of the Pearson correlation analysis were consistent. The Pearson correlation analysis showed that the spatial luminance distribution of lighting improved the restorative perception potential and was negatively correlated with the restorative reserve level of the environments. The Pearson correlation analysis was used to study the relationship between the PRS score of the lighting environment and the difference between the PRS scores of lighting and the natural lighting environment (L and D, respectively). The analysis showed that the correlation coefficient value was $r = -0.405$ and the significance was $p = 0.007$, which was less than 0.01. These data, to some extent, verify the interference of information-carrying conditions, but the negative correlation was an unexpected result (this will be discussed in detail in Section 4.1.1).

3.1.3. Change Ratio in the Scores of the Perceived Restorativeness Scale

According to the PRS score of the natural lighting environment (N), the level of environmental resilience was divided into three levels: low [1.82, 2.50], medium (2.50, 3.50), and high [3.50, 4.21]. Further analysis of the PRS change ratio D/N is shown in Figure 11.

Regarding the improvement ratio (D > 0), when the restorative reserve level of environments was low (N), there was a total of six cases where lighting could improve restorativeness, with a maximum improvement ratio of 17.9% (Room 22). When the restorative reserve level of environments was medium (N), there were a total of eight cases where lighting could improve restorativeness, with a maximum improvement ratio of 30.9% (Room 11). Compared to the low reserve level, a medium reserve level had a relatively greater potential for improvement. However, the improvement ratio data of the remaining cases also showed considerable potential for the improvement of a low reserve level.

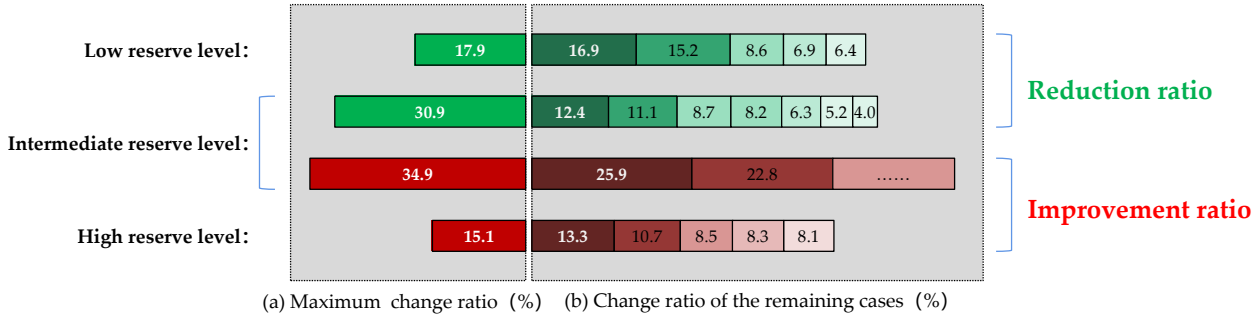


Figure 11. Change ratio statistics. To prevent randomness, the change ratios of all of the surveyed guest rooms were surveyed. Red represents the improvement ratio, green represents the reduction ratio. (**a**) The maximum absolute value of the change ratio, while (**b**) shows the change ratio of the remaining cases sorted in ascending order of the absolute value of the change ratio. The cases with a medium reduction ratio are listed with the results of the highest total sum of the intermediate reduction ratio.

Regarding the reduction ratio (D < 0): when the restorative reserve level of environments was medium (N), there was a total of 12 cases where lighting could reduce restorativeness, with a maximum reduction ratio of 34.9% (Room 43). When the restorative reserve level of environments was high (N), there were a total of six cases where lighting could reduce restorativeness, with a maximum reduction ratio of 15.1% (Room 37). Compared to the high reserve level, a medium reserve level had a much greater probability of reduction.

In summary, first of all, these data further illustrate the effectiveness of the spatial luminance distribution of lighting in improving restorativeness, with improvement ratios of 17.9% and 30.9% being significant. However, at the same time, there was an equal reduction ratio, which is the significance of studying and optimizing the spatial luminance distribution. In addition, the discovered maximum change ratio in the environment with a medium reserve level of restorativeness indicates that medium reserve level is the most significant for both improvement and reduction, which is a result worth discussing (this will be discussed in detail in Section 4.1.1).

3.2. Eye-Movement Indicator

The reliability test was also conducted on the eye-movement data, and the data with an eye-movement capture rate of less than 80% were eliminated.

3.2.1. Comparison of Eye-Movement Indicators

The saccadic index and the number of fixations were no different while the fixation duration and pupil diameter were different, indicating that the same objects attracted the eye, but there were differences in visual appeal and cognitive load.

Table 6 presents the results of the paired-sample *t*-tests for eye-movement data between the lighting and natural light environments. Combined with the meanings of the indicators (Table 2), these data show that during the evaluation of the restorativeness of lighting and natural light environments, there was no difference in the search process, overall cognitive processing difficulty, and gaze distribution, indicating no difference in the objects that attract visual attention. However, there were differences in the attractiveness of the environment, the attractiveness of the target (focus), and the cognitive load of the participants, indicating that the attractiveness and cognitive load of the objects that attract visual attention vary.

Table 6. Results of the paired-sample *t*-tests of eye-movement indicators.

Eye-Movement Indicators		Lighting	Natural Lighting	t	*p*
		Mean ± SE	Mean ± SE		
Saccade	Saccade count	300.546 ± 3.605 ↑	294.707 ± 4.033	−1.129	0.172
	Total saccade time	13.255 ± 0.188 ↑	12.896 ± 0.211	−1.301	0.201
Fixation	Fixation count	107.389 ± 1.681 ↓	110.483 ± 1.877	1.365	0.179
	Total fixation time	21.871 ± 0.499 ↓	23.290 ± 0.579	2.043	0.047 *
	Average fixation time	0.206 ± 0.002 ↓	0.214 ± 0.002	2.687	0.010 *
Pupil	Mean pupil diameter	3.774 ± 0.029 ↑	3.630 ± 0.20	−3.792	0.000 **

Note: * $p < 0.05$. ** $p < 0.01$. Blue represents statistically significant. ↑ represents the indicator is increasing. ↓ represents the indicator is decreasing.

These data preliminarily verify the hypothetical interpretation of the research hypothesis: that the spatial luminance distribution of lighting causes the two visual cognitive responses of visual appeal and visual load.

At the same time, although there was no significant change in the magnitude of the values, compared with the natural light environment, the fixation indicators for the lighting environment were decreased while the pupil and saccadic indicators were increased. This suggests that overall, for the 43 guest rooms, lighting reduced the attractiveness of the environment and increased the visual load. This corresponded to the slightly lower restorativeness score of the lighting environment in Section 3.1.1. Although this result was for the 43 guest rooms overall and does not represent all possible luminance distributions, it still indicates the current problem: that the spatial luminance distribution of lighting not only fails to improve attractiveness, but also increases the visual load. This reminds us once again of the significance of studying and optimizing the spatial luminance distribution of lighting.

3.2.2. Analysis of the Fixation Duration Ratio of Different Material Information Carriers

The distribution of the proportion of fixation duration was biased toward the illuminated objects, indicating an increase in visual appeal after the objects were illuminated.

Table 7 shows the proportion of the fixation duration data for nine AOIs: paired-sample *t*-tests showed that, except for AOI 3, Sidewall beside TV, and AOI 9, Greenery, the average values of the other seven AOIs in the lighting and natural light environments were different, except for AOI 2, Floor, AOI 5, Window side wall, and AOI 9, Greenery; the proportion of the fixation duration for six AOIs in the lighting environment was higher than that in the natural light environment; the highest difference in the proportion of the fixation duration was for AOI 4, Sidewall at bedhead (increased), and for AOI 5, Window side wall (decreased). Excluding the influence of the AOI area, the ranking of the change ratio of the proportion of the fixation duration was as follows: AOI 8, Luminaire; AOI 1, Ceiling; AOI 4, Sidewall at bedhead; AOI 7, Decoration. All of these objects were emphasized by lighting.

The above data indicate that the distribution of the proportion of fixation duration was biased toward illuminated objects, which is consistent with the intuition that objects emphasized by focused lighting are more likely to be noticed, indicating an increase in visual appeal after the objects are illuminated. This result, once again, demonstrates that the spatial luminance distribution of lighting can change the capacity of environmental elements (visual objects') to attract visual attention and further verifies the intervention effect of the spatial luminance distribution on the visual cognitive responses and, more specifically, on visual attraction responses. This also provides preliminary evidence that spatial luminance distribution can regulate the attractiveness of the environment.

Table 7. Fixation duration ratio of different material information carriers.

AOI	Lighting	Natural Lighting	t	*p*	Cohen's d	D-Value	Change Ratio
	Mean ± SE	Mean ± SE					
1 Ceiling	4.408 ± 0.488	2.192 ± 0.241	−4.819	0.000 **	0.735	2.216	**101.1%**
2 Floor	7.369 ± 0.648	9.127 ± 0.841	3.439	0.001 **	0.524	−1.758	−19.3%
3 Sidewall beside TV	4.758 ± 0.866	4.510 ± 0.868	−0.503	0.618	0.077	0.248	5.5%
4 Sidewall at bedhead	19.141 ± 1.664	12.288 ± 1.417	−6.093	0.000 **	0.929	**6.853**	**55.8%**
5 Window side wall	24.407 ± 1.242	29.628 ± 1.471	4.272	0.000 **	0.652	**−5.221**	−17.6%
6 Furniture	44.660 ± 1.653	42.195 ± 1.648	−2.114	0.041 *	0.322	2.465	5.8%
7 Decoration	4.959 ± 0.918	3.852 ± 0.853	−2.028	0.049 *	0.309	1.107	**28.7%**
8 Luminaire	2.290 ± 0.433	0.612 ± 0.113	−4.407	0.000 **	0.672	1.678	**274.2%**
9 Greenery	0.118 ± 0.077	0.136 ± 0.079	0.419	0.678	0.064	−0.018	−13.2%

Note: * $p < 0.05$. ** $p < 0.01$. Blue represents statistically significant. Green represents the maximum and minimum values of the difference. Red represents the top rank of the change ratio. Cohen's d: Effect sizes of 0.20~0.50 are considered small while effect sizes of 0.50~0.80 are considered intermediate, and effect sizes of 0.80 or above are considered large.

3.2.3. Relationship between Perceived Restorativeness Evaluation and Eye-Movement Indicators

Pearson correlation analysis showed that there was a significant linear correlation among the six eye-tracking indicators in this experiment. Therefore, principal component analysis was used to reduce and integrate the eye-tracking indicators, resulting in two common factors. After using the maximum variance method, the KMO was 0.641 with a significance of 0.000, which met the requirements for principal component analysis. The cumulative contribution rate of the two common factors was 84.709% (component 1: 42.860%; component 2: 41.848%).

As shown in Table 8, the first principal component had a significant contribution to the first three visual fixation indicators, which could be defined as the "visual appeal" factor. The second principal component had a significant contribution to the last three visual search and cognitive load indicators, which could be defined as the "visual load" factor.

Table 8. Principal component matrix of eye-movement indicators (PCA).

	FC	TFT	AFT	SC	ST	APD
Component 1	**0.777**	**0.921**	**0.869**	0.408	0.372	0.000
Component 2	0.392	0.324	0.020	**0.854**	**0.880**	**0.899**

Note: Values are represented as the factor loading values. Blue represents the factor loading values greater than 0.5.

The results of the correlation analysis showed that the PRS score was significantly positively correlated with the "visual appeal" factor (the correlation coefficient values were 0.288, $p < 0.01$) and significantly negatively correlated with the "visual load" factor (the correlation coefficient values were −0.264, $p < 0.01$). These data were consistent with the hypothetical explanation in this study: increasing the visual appeal and reducing the visual load can improve the restorativeness of the environment. The data also demonstrated the opposing and coexisting relationship between visual appeal and visual load.

3.3. Results of Case Interview

After multiple consecutive samples of 37 subjects, no new critical information emerged. Strauss [49] proposed the data saturation theory, where data saturation is considered to be reached, the sample size is sufficient, and the interview process is adequate, when the interviewees' perspectives are sufficiently explored and no new information is presented after multiple consecutive interviews.

3.3.1. Typical Cases (Groups)

As shown in Table 9, typical cases were selected based on the L score and D/N. The highest L group and highest D/N group were selected, and the lowest L group and lowest D/N (negative) group were also selected. The purpose was to use the "positive inspiration of negative teaching materials" to conduct a comparative study between the high and low groups. In addition, based on the N level, the D/N typical cases were divided into groups for discussion. Finally, six groups were formed, each with four selected guest rooms. A total of 20 cases were selected, with four cases repeated in different groups.

Table 9. Typical cases for the lighting environment.

No.	Screening Criterion	Typical Lighting Environment Cases	
1	L	Highest L Lowest L	
2	D/N	Highest D/N	N is low (and L is not low) N is medium
		Lowest D/N	N is medium N is high

(1) The lighting environment with the highest and lowest L scores.

As shown in Figure 12, the difference between the guest rooms with high and low scores lies in the fact that those with high scores mostly adopted linear indirect lighting, while those with low scores mostly adopted point light sources for direct lighting. Compared to those with low scores, those with high scores provided an overall impression of luminance, with a smooth and uniform transition of luminance on the illuminated surfaces.



Figure 12. Rooms with high (**upper**) and low (**lower**) PRS scores.

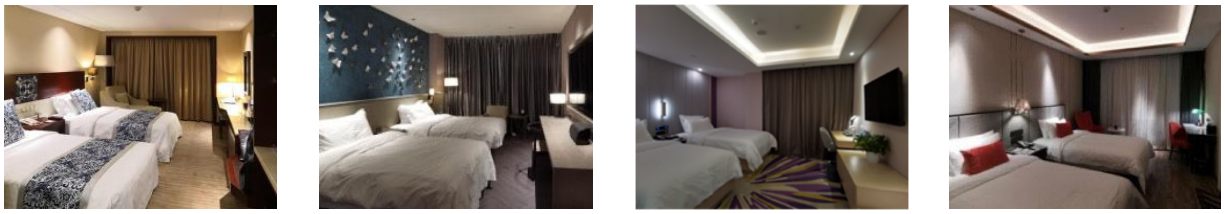
(2) The lighting environment with the highest and lowest D/N

As shown in Figure 13:

- When D/N was the highest, comparing N low with N medium (i.e., Figure 13a with Figure 13b), the luminance transition on the illuminated surfaces was also generally uniform and soft. The difference lay in the lighting method, but unlike the difference in the above-mentioned score, it is not a complete separation of linear and point sources, but mainly the involvement of point sources (N low has point sources, N medium does not). The overall feeling of the luminance of N medium was slightly brighter than that of N low.
- When N was medium, comparing the highest and lowest D/N (i.e., Figure 13b with Figure 13c), there was no significant difference in the overall feeling of luminance. In

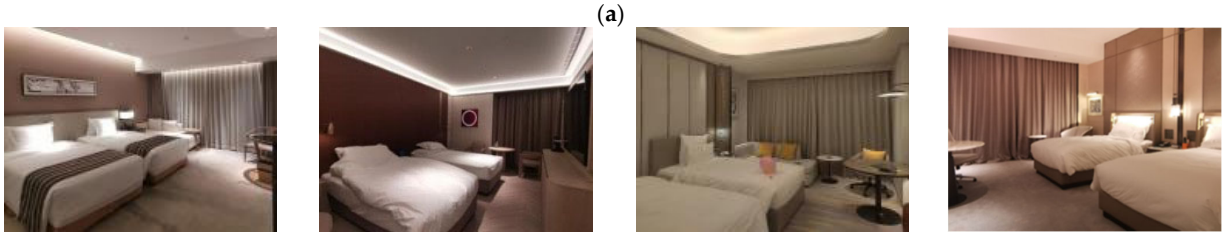
addition, similar to the difference in the above-mentioned score, the difference lay in the use of linear indirect lighting for high D/N, and point light sources for direct lighting for low D/N. Compared to the low D/N cases, high D/N cases had a more uniform and soft luminance transition on the illuminated surfaces.

- When D/N was the lowest, we compared the N medium with N high. Comparing Figure 13c with Figure 13d, the difference in the lighting method was not significant. This comparison seems to indicate that there is no significant correlation between the lowest D/N and spatial luminance distribution. Analyzing the natural light environment, as shown in Figure 14, most of these rooms had large windows with particularly open views, and the natural landscape in the window view accounted for a large proportion of the view. Therefore, the reduction in restorativeness was mainly due to the lack of window view restoration rather than the spatial luminance distribution.



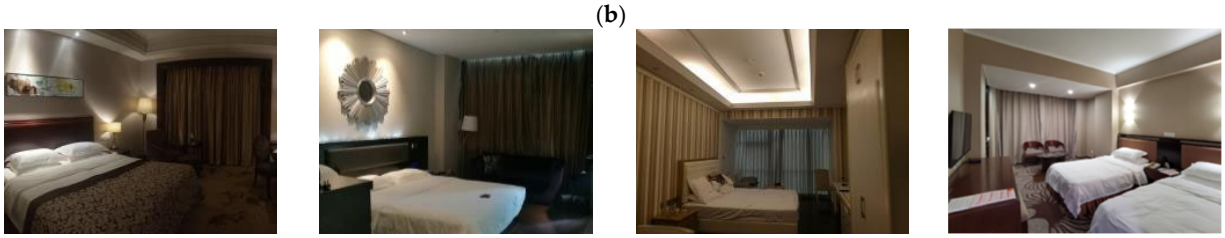
Guest room 15, D/N = 16.9% L = 2.71; N = 2.31; D = 0.3 | Guest room 10, D/N = 15.2% L = 2.66; N = 2.31; D = 0.35 | Guest room 4, D/N = 8.6% L = 2.65; N = 2.44; D = 0.21 | Guest room 23, D/N = 6.4% L = 2.66; N = 2.50; D = 0.1

(**a**)



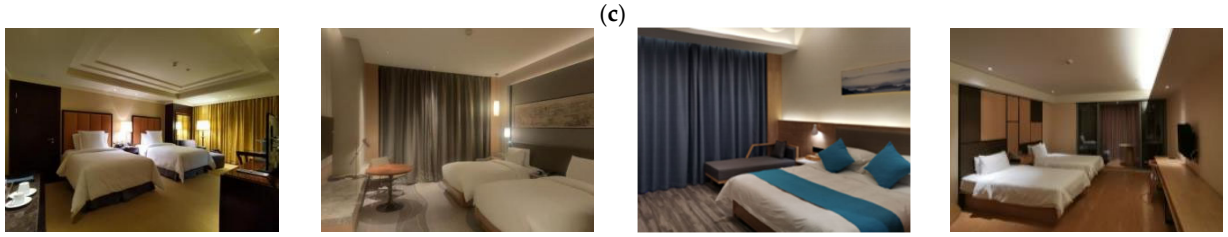
Guest room 11, D/N = 30.9% L = 3.64; N = 2.78; D = 0.86 | Guest room 30, D/N = 12.4% L = 2.83; N = 2.51; D = 0.31 | Guest room 16, D/N = 11.1% L = 3.49; N = 3.14; D = 0.35 | Guest room 12, D/N = 8.7% L = 3.26; N = 3.00; D = 0.26

(**b**)



Guest room 43, D/N = −34.9% L = 2.09; N = 3.21; D = −1.12 | Guest room 20, D/N = −25.9% L = 1.96; N = 2.66; D = −0.69 | Guest room 9, D/N = −22.8% L = 2.33; N = 3.02; D = −0.69 | Guest room 6, D/N = −19.7% L = 2.24; N = 2.79; D = −0.55

(**c**)



Guest room 37, D/N = −15.1% L = 2.99; N = 3.51; D = −0.52 | Guest room 40, D/N = −13.3% L = 3.13; N = 3.61; D = −0.48 | Guest room 42, D/N = −10.7% L = 3.26; N = 3.65; D = −0.39 | Guest room 25, D/N = −8.5% L = 3.23; N = 3.53; D = −0.30

(**d**)

Figure 13. Rooms with the highest and lowest PRS change ratio. (**a**) The lighting environment with the highest D/N when N was low. (**b**) The lighting environment with the highest D/N when N was medium. (**c**) The lighting environment with the lowest D/N when N was medium. (**d**) The lighting environment with the lowest D/N when N was high.



Figure 14. Rooms under a natural lighting environment with the lowest PRS change ratio.

3.3.2. Conclusions on the Visual Perception of Spatial Luminance Distribution

Table 10 shows the coded categories and descriptive vocabulary extracted from the interview data using NVivo 12 Plus software(Denver, USA), which reflects the conclusions on the visual perception of spatial luminance distribution. Based on the vocabulary and explanations, we have summarized the intrinsic properties of spatial luminance distribution.

Table 10. Results of spatial luminance distribution in the focus group interviews.

No.	Descriptive Vocabulary	Vocabulary Explanation	Intrinsic Property
1	Light source	Provides illumination	Light
2	Highlights	Directly illuminated by light source	
3	Bright objects	Illuminated sufficiently by light	Objects highlighted by lighting
4	Visible objects	Illuminated by diffused light	
5	Dim objects	Insufficiently illuminated	Objects hidden by lighting
6	Shadow	No illumination, blocked by an object	Shadow

The conclusions on the visual perception of spatial luminance distribution include six descriptive vocabulary terms: light source, highlights, bright objects, visible objects, dim objects, and shadow. Among these, the intrinsic property of the light source and highlights is "light", the intrinsic property of bright objects and visible objects is "objects highlighted by lighting", the intrinsic property of dim objects is "objects hidden by lighting", and the intrinsic property of shadow is "shadow". This conclusion verifies that the visual perception of spatial luminance distribution can be divided into the relationship between light and shadow and the layout relationship of illuminated objects. Furthermore, this conclusion further subdivides the relationship between light and shadow into "highlights", and subdivides the layout relationship of illuminated objects into those that are highlighted and those that are hidden.

3.3.3. Cognitive Characteristics of Restorative Spatial Luminance Distribution

(1) Restorative Spatial Luminance Distribution Case Study

If we use the dual criteria of a restorative score (L) greater than 3 (moderately restorative) and a significant improvement ratio (D/N) greater than 10%, then only Rooms 11 and 16 meet these requirements. Therefore, we expanded our criteria to include rooms that meet either "L > 3 and D/N > 5%" or "D/N > 10% and L > 2.5". We identified six rooms that met these criteria and will be used as case studies for restorative spatial luminance distribution in this study (see Figure 15).



Figure 15. Restorative spatial luminance distribution cases.

(2) Cognitive Characteristics of Restorative Spatial Luminance Distribution

Using Nvivo 12 Plus software (Denver, USA) to analyze the interview data for the six selected rooms, we identified the cognitive characteristics of restorative spatial luminance distribution, as shown in Table 11. We found that the perception of "highlights" and "bright objects" was only reflected in two aspects: "single" and "combination". We identified the common features of restorative spatial luminance distribution as well as the dimensions and preferences of perception: a single highlight should have a uniform and homogeneous transition without any stray light while the form of highlights within a group should be consistent and the order of highlights between groups should be orderly. A single bright object should have appropriate illumination. The existence of both "single" and "combination" aspects reminds us that the optimization of spatial luminance distribution not only requires attention to the illumination effects for each light and shadow shape and each illuminated object, but also requires an optimization of the layout relationship from the overall spatial perspective. Additionally, although the combined features of bright objects have also been considered, there is no clear preference in perception.

Table 11. Results of the spatial luminance distribution in the focus group interviews.

Cognitive Conclusion	Perception Dimension	Vocabulary Explanation	Feature Evaluation Pairs (Perception Preference)
Highlight	Single highlight	Transition Stray light	Non-uniform ←→ Uniform Present ←→ Absent
	Highlight group *	Intra-group form Inter-group order	Inconsistent ←→ Consistent Disorderly ←→ Orderly
Bright object	Single bright object	Illumination effect	Inappropriate ←→ Appropriate
	Bright object group *	Overall hierarchy Overall layout	Monotonous ←→ Rich Inharmonious ←→ Harmonious

Note *: Highlights that are similar in shape and adjacent in position are considered as a group. There is no clear evidence of grouping for the combination of bright objects, so the evaluation was based on the overall hierarchy.

4. Discussion

4.1. Discussion of Results

4.1.1. Discussion of the Results of the Perceived Restorativeness Evaluation

In total, 39.5% of the lighting environments were found to be "moderately restorative". The spatial luminance distribution of the lighting environment could improve the restorativeness of the environment, with a maximum improvement ratio of 30.9%. These results are consistent with our expectations and were even better than expected. However, the research also showed that the overall restorativeness of a lighting environment is lower than that of a natural environment, and that the reduction and improvement ratios of the restorativeness of spatial luminance distribution are at similar levels, indicating the existence of two current problems. In fact, the current situation of both extremes highlights the possibility of optimizing the spatial luminance distribution of lighting and the need for further research in this area.

Furthermore, this study obtained two unexpected results. First, the proportion of cases with improvement was negatively correlated with the restorative reserve level of environments. We can tentatively understand this as "poor performers are more likely to improve". Second, the maximum change ratio for cases with medium-level restorativeness was the highest, with both the improvement and reduction ratios being the greatest. These results, together with the first result, have led us to a discussion of potential implications. We speculate that: (1) when the restorative reserve level of environments is at a medium level, there may be a certain number of restorative elements present. A reasonable luminance distribution pattern that highlights these restorative elements will lead to the greatest optimization and improvement, while an unreasonable luminance distribution pattern will lead to the greatest reduction. Therefore, it is worth exploring what constitutes a reasonable luminance distribution pattern when inherent restorativeness is at a medium level. (2) When the restorative reserve level of environments is limited, improvement ratios may be limited by the availability of restorative elements. However, it is worth noting that in this situation, most of the spatial luminance distributions of the lighting contribute to an improvement in restorativeness. Does this mean that the lighting luminance distribution patten itself constitutes a certain level of restorative capability? (3) When the restorative reserve level of the environments was high, the lack of a window view was the main reason for the reduction in the restorativeness of the lighting environment. In addition, this may be due to the fact that this situation represents the best combination of restorative elements, whereby a bright and homogeneous luminance distribution (similar to the natural light environment) can effectively display all the restorative elements and become an applicable pattern.

Therefore, we believe that the creation of a restorative indoor lighting environment should be based on the inherent level of restorativeness and that the luminance distribution pattern should be determined accordingly: for high-level restorativeness, a homogeneous pattern should be provided; for medium-level restorativeness, the best optimization and improvement should be achieved by considering rationality and by utilizing and exploring patterns; for low-level restorativeness, a restorative pattern should be created whereby the spatial luminance distribution of lighting itself becomes a restorative environmental element.

4.1.2. Discussion of the Results of the Eye-Movement Indicator

Spatial luminance distribution does not change the attractiveness of environmental elements, but their visual appeal and visual load are altered by it. The visual appeal of the illuminated object is improved. Restorative perception is positively correlated with visual appeal and negatively correlated with visual load. Visual appeal and visual load have an opposing yet coexisting relationship. These results are generally consistent with our expectations. However, in retrospect, the results of the highlights obtained from the case interviews and the fact that this study did not separately divide the highlights when dividing the AOI may affect the rigor of this study's conclusions.

Unfortunately, the overall data of the 43 guest rooms showed that lighting did not improve attractiveness, but instead increased the visual load. This result was for the 43 guest rooms overall, and does not represent all of the spatial luminance distributions of lighting having no positive effect. However, even when this study separately analyzed the eye-tracking data from the six restorative cases, we were unable to obtain the expected conclusion of "improving visual appeal, reducing or not changing visual load". This is probably because the six cases were too few and the interference of information-carrying differences cannot provide sufficient data support from these six cases. Therefore, we plan to conduct further eye-tracking experiments in an environment with controlled information carriers to verify the relationship between visual appeal and visual load in the process of improving the environmental restorativeness of luminance distribution and determining the role of spatial luminance distribution.

4.1.3. Discussion of the Results of the Case Interviews

The visual cognitive conclusions of spatial luminance distribution include six dimensions: light source, highlights, bright objects, visible objects, dim objects, and shadow. The current restorative spatial luminance distribution characteristics are only related to highlights and bright objects, and the visual features and perceptual dimensions are a single highlight with uniform light and no stray light transition, a consistent highlight shape within the group and ordered highlight sequence between groups, and the appropriate illumination effect of a single bright object. This result seems to indicate that the connotation of restorative spatial luminance distribution in the current lighting environment is more concerned with the relationship between light and shadow, followed by the layout relationship of the illuminated objects. This was inconsistent with our expectations.

In fact, we hoped to verify the positive effect of the layout relationship of illuminated objects in laboratory experiments. After all, as the research results of the restorativeness of the lighting environment show, the current situation has only achieved the basic level of "moderately restorative". This may explain that the light and shadow relationship has met the basic requirements for improving environmental restorativeness, and if we want to achieve a higher level of restorativeness, the layout relationship of illuminated objects needs to meet the restorative requirements. This is also the goal that we, as lighting designers, are committed to achieving.

We believe that putting people first and analyzing indoor lighting from the perspective of human experience, the functionality of indoor lighting, or the necessity and meaning of indoor lighting, lies in identifying environmental entities and generating spatial perception. Light is perceived as an information carrier rather than perceiving the physical energy of light. Therefore, even though the conclusions based on the current research lean toward the relationship between light and shadow, the layout relationship of illuminated objects is still what we advocate.

There has been controversy among scholars about whether the relationship between light and shadow is appropriate or necessary. Early research based on the practicality of lighting believed that "If there is nothing worth looking at, there is nothing worth lighting [50]". With the optimization and improvement in lighting design quality, research has proposed opposing views, stating that "Although a white wall is not worth looking at in itself, it could be worth looking at if it has an interesting gradation or is scalloped by wall washers [36]".

Clearly, it is not easy to reach a consensus on whether or not to illuminate "white walls". However, with the development and popularization of modern architectural lighting design concepts, purely decorative spatial light and shadow designs are gradually fading away. These types of design are being replaced by architectural lighting designs that value the layout relationship of information carriers. The fact that the layout relationship of information carriers is being valued indicates a preference for it, proving that the layout relationship of illuminated objects is a better choice.

In addition, this study also subdivided "highlights" in the light and shadow relationship and subdivided the illuminated objects in the layout relationship into independent "entities" and non-independent "backgrounds". Previous research on light and shadow has mainly focused on the size of physical energy. From the perspective of information carriers, there have been more studies of the layout of illuminated objects instead of quantitative studies. However, there have been studies such as those of the Feu, which began to differentiate between light sources and bright surfaces [51,52]. Through this study, the importance of highlights in the cognitive properties of spatial luminance distribution has been improved. Furthermore, determining the characteristics of highlight transition, shape, and sequence within and between groups will constitute a new qualitative and quantitative task for describing the spatial luminance distribution; this task requires further research.

4.2. Optimization Strategies for Spatial Luminance Distribution in Environments with Different Restorative Reserve Levels, Guided by Environmental Restorativeness Improvement Goals

Based on the discussion of the results, we attempted to explore preliminary answers on optimizing the spatial luminance distribution to create effective indoor restorative environments that are fully perceived, as shown in Table 12.

Table 12. Optimization strategy of the spatial luminance distribution.

Restorative Reserve Levels	**Low**	**Medium**	**High**
Visually attractive elements	Lack	Present	Abundant
Overall visual appeal	Should be increased	Should be optimized	Should be maintained
Overall visual load	Low, can be increased	High, should be reduced	Strong, should not be increased
Restorative optimization approach	Improve restorative level	Intervene and optimize restorative perception	Maintain sufficient restorative perception
Applicable cognitive conclusions of luminance distribution	Relationship between light and shadow	Layout relationship of lighting objects	Layout relationship of lighting objects
Spatial luminance distribution configuration suggestions	Highlights + shadow	Bright objects + dim objects	Visible objects
Characteristics of restorative spatial luminance distribution pattern	Multiple hierarchy gradientsLarge contrast spans	Multiple hierarchy gradientsSmall contrast spans	Few hierarchy gradientsSmall contrast spans

First, based on Section 4.1.1, we needed to determine the spatial luminance distribution pattern based on the inherent restorative level of the space (the architectural configuration and disposition). Therefore, we discussed optimization strategies for spatial luminance distribution at three restorative reserve levels of environments: low, medium, and high. The reserve level corresponds to attractive visual elements in the environment.

Second, based on Section 4.1.2, we created optimization strategies for spatial luminance distribution by improving the overall visual attractiveness of the environment and reducing the overall visual load. Corresponding to environments with different reserve levels of environmental restorativeness, the visual attractiveness optimization goals "should be increased, should be optimized, should be maintained" and the visual load optimization goals "can be increased, should be reduced, should be avoided". As a result, the restorative optimization approaches for the spatial luminance distribution are divided into two aspects, restoration level and perception, with optimization levels of "improve, intervene, maintain".

Based on Section 4.1.3, we proposed a solution using a combination of the six cognitive characteristics of spatial luminance distribution. We initially suggested restorative spatial luminance distribution patterns suitable for different restorative reserve levels by using the relationship between light and shadow to improve the restorative level and using the

layout relationship of lighting objects to optimize the degree of restorative perception. Thus, summarizing the characteristics of the applicable patterns can be generalized in terms of the luminance hierarchy gradients and luminance contrast spans.

In conclusion, although the division between different restorative reserve levels is qualitative and fuzzy, it clarifies the optimization goals of visual appeal and visual load for environments with different restorative reserve levels. We also established initial optimization approaches and applicable spatial luminance distribution configurations under the optimization goals. The characteristics of the obtained restorative spatial luminance distribution pattern focused on the luminance hierarchy gradients and luminance contrast spans, which also describe the optimization strategy of restorative environmental lighting design.

4.3. Implications and Limitations

1. Limitations of eye tracking: As above-mentioned, the division of AOIs does not specifically consider the boundaries of highlights. Determining the boundaries of uniformly transitioning highlights is a problem that needs to be addressed in future research. Our current eye-movement measurements were performed in scenarios where the participants had no explicit visual task. For a comparison with previous studies [53], further research is needed for scenarios with explicitly focused visual tasks, which is a focus for future attention.
2. Limitations of the survey: (1) Although the survey ensured the comprehensiveness of the decoration level, currently, hotel rooms tend to have a simple and concise style, which is the mainstream trend from the perspective of saving on costs and space. However, whether the corresponding research conclusions apply to other living environments that are more complex and have a heavier visual load needs to be further validated in future research. (2) Although there was consistency in the layout of the surveyed rooms, the differences in the architectural configuration and disposition of the space and the spatial scale resulted in different classes of environmental restorative reserve levels. This study focused on the impact of window views and the material information-carrying properties of light (decoration basis) on the environmental restorative reserve level, but did not establish a clear causal relationship; at the same time, this study ignored the influence of factors such as spatial size and seasonal time, which are areas of research that should be supplemented and developed with the subsequent construction of a full-size laboratory.
3. Limitations on the findings of the "luminance distribution" study: The focus of this study was to prove that the restorative potential of the residential environment could be improved by optimizing the spatial luminance distribution, and the research conclusions proved our hypothesis. Our study of the spatial luminance distribution was based on images within a limited range of luminance levels in the room environment and at the display's set luminance. Therefore, validation from a broader range of empirical research is needed. Although we conducted a comprehensive collection of the spatial luminance parameter data, these data need to be made available for quantitative characterization of the distribution features. Therefore, a restorative spatial luminance distribution index was not proposed in this study, and will be the focus of our attention in a subsequent study.

5. Conclusions

The research in this paper experimentally demonstrated the potential of lighting luminance distribution to improve the restorativeness of hotel rooms. The main findings of the study are as follows:

(1) The spatial luminance distribution of lighting had a considerable improvement rate of 30.9% for environmental restorativeness. However, at the same time, there was an equal reduction ratio. The spatial luminance distribution of lighting improved the restorative perception potential, which was negatively correlated with the restorative reserve level of the environment (the correlation coefficient values were -0.405,

$p < 0.01$). Resilient spatial luminance distribution patterns suitable for different restorative reserve levels are recommended as follows: for high-level restorativeness, a homogeneous pattern should be provided; for medium-level restorativeness, the best optimization and improvement should be achieved by considering rationality and by utilizing and exploring patterns; for low-level restorativeness, a restorative pattern should be created whereby the spatial luminance distribution of lighting itself becomes a restorative environmental element.

(2) The eye-movement data findings clarify the role of visual perception in improving environmental restorativeness with spatial luminance distribution (i.e., restorative perception is positively correlated with visual appeal and negatively correlated with visual load). Visual appeal and visual load have an opposing yet coexisting relationship.

(3) The visual cognitive conclusions of spatial luminance distribution included six dimensions: light source, highlights, bright objects, visible objects, dim objects, and shadow. Common characteristics of restorative spatial luminance distribution include a single highlight with uniform light and no stray light transition, a consistent highlight shape within the group and ordered highlight sequence between groups, and the appropriate illumination effect of a single bright object.

(4) Based on the above conclusions, this paper developed a hierarchical classification according to the restorative reserve level, and clarified the optimization goals of visual appeal and visual load for environments with different restorative reserve levels. We also established initial optimization approaches and applicable spatial luminance distribution configurations under the optimization goals. The characteristics of the obtained restorative spatial luminance distribution pattern focused on the luminance hierarchy gradients and luminance contrast spans, which also describe the optimization strategy of restorative environmental lighting design.

In summary, this study demonstrated the effectiveness of improving the spatial luminance distribution and elucidated the cognitive conclusions of the spatial luminance distribution including six dimensions: light source, highlight, bright surface, bright object, dim object, and shadow. This study started from the optimization of the visual appeal and visual load of the spatial luminance distribution by improving both the restorative level and the degree of restorative perception and proposing a restorative spatial luminance distribution pattern applicable to different restorative reserve levels in the environment. This study also indicates that future research, mainly by means of a full-size building scene in a laboratory setting, should define the luminance boundary values of the visual cognitive dimension of spatial luminance distribution, propose spatial luminance distribution indices, further clarify the environmental restorative reserve level formed by the architectural configuration and disposition of the space, and create a mathematical model of the restorative spatial luminance distribution pattern applicable to different restorative reserve levels.

In recent years, architectural lighting design and research have been continuously optimizing the real-time and cyclical regulation of "light energy", continuously generating breakthroughs regarding the quality of light and improving our visual and physiological comfort as well as our non-visual physiological health. In addition, as emphasized by research on natural light environment design, the additional value of light in buildings includes the relationship between light and space. Light is not only a physical energy, but is also a spatial information carrier. LED lighting cannot replace natural light but LED lighting can provide a spatial luminance distribution pattern that is a more powerful tool for shaping and improving the relationship between light and space. With new forms of LED light sources, increasingly refined design methods and intelligent and convenient control technology, the progress of the spatial luminance distribution has not reached an impasse, but is approaching perfection. This study attempted to explain how, even while it approaches perfection, lighting is no longer a wholesale presentation of the architectural configuration and disposition of the space, but can reshape the perception of space through the regulation of the lighting space luminance distribution. Lighting design presents the

possibility of resolving the contradiction between visual appeal and visual load, which originally coexist and are in opposition in architectural space, through regulation rather than balance. This can bring additional value including psychological health guidance to interventions in indoor lighting.

Author Contributions: Conceptualization, Y.W. and J.Y.; Data curation, Y.W. and J.Y.; Formal analysis, L.W. and P.C.; Investigation, Y.W. and J.Y.; Methodology, Y.W.; Resources, Y.W. and J.Y.; Supervision, L.W., J.Y. and A.W.; Visualization, Y.W. and J.Y.; Writing—original draft, Y.W.; Writing—review and editing, L.W., J.Y., P.C. and A.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China, grant number 52278120.

Data Availability Statement: Not applicable.

Acknowledgments: We would especially like to thank the support of Beijing Jinfa Technology Co. Ltd. for the experimental instruments, and Tianhuan Liang and Lili Guo for their support in setting up the experimental environment and recruiting subjects as well as their assistance in the experimental work.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Engineer, A.; Gualano, R.J.; Crocker, R.L.; Smith, J.L.; Maizes, V.; Weil, A.; Sternberg, E.M. An integrative health framework for wellbeing in the built environment. *Build. Environ.* **2021**, *205*, 108253. [CrossRef]
2. Gellatly, R.; Beck, A.T. Thrive: The Power of Evidence-Based Psychological Therapies. *J. Psychiatr. Pract.* **2014**, *20*, 412–413. [CrossRef]
3. Woolston, C.; O'Meara, S. PhD students in China report misery and hope. *Nature* **2019**, *575*, 711–713. [CrossRef] [PubMed]
4. Kaplan, S. A Model of Person-Environment Compatibility. *Environ. Behav.* **1983**, *15*, 311–332. [CrossRef]
5. Ottosson, J.; Grahn, P. A Comparison of Leisure Time Spent in a Garden with Leisure Time Spent Indoors: On Measures of Restoration in Residents in Geriatric Care. *Landsc. Res.* **2005**, *30*, 23–55. [CrossRef]
6. Lohr, V.I.; Pearson-Mims, C.H.; Goodwin, G.K. Interior Plants May Improve Worker Productivity and Reduce Stress in a Windowless Environment. *J. Environ. Hortic.* **1996**, *14*, 97–100. [CrossRef]
7. Ulrich, R.S. View Through a Window May Influence Recovery from Surgery. *Science* **1984**, *224*, 420–421. [CrossRef]
8. Xiao, L.; Wu, R.; Huang, J.; Yang, X.; Xu, A. Study on the Relationship between Restoration Benefit and Visual Satisfaction of LONG-PLAN's Indoor Vertical Greenery. *Buildings* **2022**, *12*, 1267. [CrossRef]
9. Wang, Y.T. Restoration Benefits Research on Bedrooms of Holiday Cabins. Master's Thesis, Harbin Institute of Technology, Harbin, China, 2018.
10. Ouellette, P.; Kaplan, R.; Kaplan, S. The monastery as a restorative environment. *J. Environ. Psychol.* **2005**, *25*, 175–188. [CrossRef]
11. Kaplan, S.; Bardwell, L.V.; Slakter, D.B. The Museum as a Restorative Environment. *Environ. Behav.* **1993**, *25*, 725–742. [CrossRef]
12. Twedt, E.; Rainey, R.M.; Proffitt, D.R. Beyond nature: The roles of visual appeal and individual differences in perceived restorative potential. *J. Environ. Psychol.* **2019**, *65*, 101322. [CrossRef]
13. Hawkes, R.J.; Loe, D.L.; Rowlands, E. A Note towards the Understanding of Lighting Quality. *J. Illum. Eng. Soc.* **1979**, *8*, 111–120. [CrossRef]
14. Loe, L.; Mansfield, K.P.; Rowlands, E. Appearance of lit environment and its relevance in lighting design: Experimental study. *Int. J. Light. Res. Technol.* **1994**, *26*, 119–133. [CrossRef]
15. Chen, T.; Wang, L.; Li, Y.; Chen, P.; Yu, J. Modeling perceptions of very small space in physical dimension: Effect of the form of line light-emitting units with preference. *Build. Environ.* **2023**, *228*, 109803. [CrossRef]
16. Cuttle, C. Extending the lighting design objectives procedure for holistic lighting solutions. *Light. Res. Technol.* **2022**, *54*, 631–656. [CrossRef]
17. Leccese, F.; Salvadori, G.; Rocca, M.; Buratti, C.; Belloni, E. A method to assess lighting quality in educational rooms using analytic hierarchy process. *Build. Environ.* **2020**, *168*, 106501. [CrossRef]
18. Kong, Z.; Jakubiec, J.A. Instantaneous lighting quality within higher educational classrooms in Singapore. *Front. Archit. Res.* **2021**, *10*, 787–802. [CrossRef]
19. Dang, R.; Liu, Y.; Chang, S. The impact patterns of classroom lighting parameters on visual fatigue and a mathematical model. *Build. Environ.* **2023**, 234. [CrossRef]
20. Leccese, F.; Salvadori, G.; Montagnani, C.; Ciconi, A.; Rocca, M. Lighting assessment of ergonomic workstation for radio diagnostic reporting. *Int. J. Ind. Ergon.* **2017**, *57*, 42–54. [CrossRef]

21. Aries MB, C.; Veitch, J.A.; Newsham, G.R. Windows, view, and office characteristics predict physical and psychological discomfort. *J Environ Psychol.* **2010**, *30*, 533–541. [CrossRef]
22. Rutten, S.; Vriend, C.; Smit, J.H.; Berendse, H.W.; Van Someren, E.J.; Hoogendoorn, A.W.; Twisk, J.W.; Van Der Werf, Y.D.; Van Den Heuvel, O.A. Bright light therapy for depression in Parkinson disease. *Neurology* **2019**, *92*, e1145. [CrossRef] [PubMed]
23. Tantanatewin, W.; Inkarojrit, V. Effects of color and lighting on retail impression and identity. *J. Environ. Psychol.* **2016**, *46*, 197–205. [CrossRef]
24. Schielke, T.; Leudesdorff, M. Impact of lighting design on brand image for fashion retail stores. *Light. Res. Technol.* **2015**, *47*, 672–692. [CrossRef]
25. Wessolowski, N.; Koenig, H.; Schulte-Markwort, M.; Barkmann, C. The effect of variable light on the fidgetiness and social behavior of pupils in school. *J. Environ. Psychol.* **2014**, *39*, 101–108. [CrossRef]
26. Nikunen, H.J.; Korpela, K.M. Restorative Lighting Environments-Does the Focus of Light Have an Effect on Restorative Experiences? *J. Light Vis. Environ.* **2009**, *33*, 37–45. [CrossRef]
27. Nikunen, H.; Puolakka, M.; Rantakallio, A.; Korpela, K.; Halonen, L. Perceived restorativeness and walkway lighting in near-home environments. *Light. Res. Technol.* **2013**, *46*, 308–328. [CrossRef]
28. Tregenza, P.; Mardaljevic, J. Daylighting buildings: Standards and the needs of the designer. *Light. Res. Technol.* **2018**, *50*, 63–79. [CrossRef]
29. Bowler, D.E.; Buyung-Ali, L.M.; Knight, T.M.; Pullin, A.S. A systematic review of evidence for the added benefits to health of exposure to natural environments. *BMC Public Health* **2010**, *10*, 456. [CrossRef]
30. Thompson Coon, J.; Boddy, K.; Stein, K.; Whear, R.; Barton, J.; Depledge, M.H. Does participating in physical activity in outdoor natural environments have a greater effect on physical and mental wellbeing than physical activity indoors? A systematic review. *Environ. Sci. Technol.* **2011**, *45*, 1761–1772. [CrossRef]
31. Stevenson, M.P.; Dewhurst, R.; Schilhab, T.; Bentsen, P. Cognitive Restoration in Children following Exposure to Nature: Evidence from the Attention Network Task and Mobile Eye Tracking. *Front. Psychol.* **2019**, *10*, 42. [CrossRef]
32. Joye, Y.; van den Berg, A. Is love for green in our genes? A critical analysis of evolutionary assumptions in restorative environments research. *Urban For. Urban Green.* **2011**, *10*, 261–268. [CrossRef]
33. Franěk, M.; Šefara, D.; Petružálek, J.; Cabal, J.; Myška, K. Differences in eye movements while viewing images with various levels of restorativeness. *J. Environ. Psychol.* **2018**, *57*, 10–16. [CrossRef]
34. Russell, S. *The Architecture of Light*, 2nd ed.; Conceptnine: La Jolla, CA, USA, 2012; pp. 13–97.
35. Cuttle, C. Towards the third stage of the lighting profession. *Light. Res. Technol.* **2009**, *42*, 73–93. [CrossRef]
36. Oi, N.; Mansfield, K.P. Lighting quality: Possibility of luminance distribution as its determinant. In Proceedings of the 28th Session of the CIE, Manchester, UK, 28 June–4 July 2015.
37. Liu, W. Research on Intelligent Control of Residential Artificial Lighting Light Environment. Ph.D. Thesis, Chongqing University, Chongqing, China, 2003.
38. Hamilton, D.K.; Watkins, D.H. *Evidence-Based Design for Multiple Building Types*; Wiley: Hoboken, NJ, USA, 2009; p. 255.
39. Wang, T.-C.; Tsai, C.-L.; Tang, T.-W. Restorative quality in tourist hotel marketing pictures: Natural and built characteristics. *Curr. Issues Tour.* **2019**, *22*, 1679–1685. [CrossRef]
40. Asberg Johnels, J.; Gillberg, C.; Falck-Ytter, T.; Miniscalco, C. Face-viewing patterns in young children with autism spectrum disorders: Speaking up for the role of language comprehension. *J. Speech Lang. Hear. Res.* **2014**, *57*, 2246–2252. [CrossRef]
41. Liu, Y.; Hu, M.; Zhao, B. Audio-visual interactive evaluation of the forest landscape based on eye-tracking experiments. *Urban For. Urban Green.* **2019**, *46*, 126476. [CrossRef]
42. Zhao, N.; Reinhart, C.F.; Paradiso, J.A. Image-based perceptual analysis of lit environments. *Light. Res. Technol.* **2018**, *51*, 704–724. [CrossRef]
43. Raynham, P. Room lighting in the absence of a defined visual task and the impact of mean room surface exitance. *Light. Res. Technol.* **2014**, *48*, 190–204. [CrossRef]
44. Flynn, J.; Spencer, T.; Martyniuk, O.; Hendrick, C. Interim Study of Procedures for Investigating the Effect of Light on Impression and Behavior. *J. Illum. Eng. Soc.* **2013**, *3*, 87–94. [CrossRef]
45. Hartig, T.; Korpela, K.; Evans, G.W.; Gärling, T. A measure of restorative quality in environments. *Scand. Hous. Plan. Res.* **1997**, *14*, 175–194. [CrossRef]
46. Chen, P.; Wang, A.; Wang, L.; Wu, Y.; Yu, J. Grayscale−luminance converting polynomial function for digital images to determine Feu and Lav in a low-contrast artificial lit space. *Light. Res. Technol.* **2022**, *55*, 258–280. [CrossRef]
47. Uttley, J. Power Analysis, Sample Size, and Assessment of Statistical Assumptions—Improving the Evidential Value of Lighting Research. *Leukos* **2019**, *15*, 143–162. [CrossRef]
48. Staats, H.; Kieviet, A.; Hartig, T. Where to recover from attentional fatigue: An expectancy-value analysis of environmental preference. *J. Environ. Psychol.* **2003**, *23*, 147–157. [CrossRef]
49. Strauss, A.; Corbin, J. *Basics of Qualitative Research*, 4th ed.; Sage Publications: London, UK, 1998.
50. Waldram, J.M. Studies in Interior Lighting. *Trans. Illum. Eng. Soc.* **1954**, *19*, 95–133. [CrossRef]
51. Wataru, I.; Masayuki, I. New lighting evaluation techniques for comfortable lighting spaces using sensation-of-room-brightness index "Feu". *Matsushita Tech. J.* **2008**, *53*, 132–134.

52. Yamaguchi, H.; Shinoda, H. Space Brightness Evaluated Using Border Luminance of Color Appearance Mode. *J. Illum. Eng. Inst. Jpn.* **2007**, *91*, 266–271. [CrossRef]
53. Holmqvist, K.; Örbom, S.L.; Hooge, I.T.; Niehorster, D.C.; Alexander, R.G.; Andersson, R.; Benjamins, J.S.; Blignaut, P.; Brouwer, A.M.; Chuang, L.L.; et al. Eye tracking: Empirical foundations for a minimal reporting guideline. *Behav. Res. Methods* **2023**, *55*, 364–416. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.