COGNITIVE RESTORATION IN FOLLOWING EXPOSURE TO GREEN INFRASTRUCTURE: AN EYE-TRACKING STUDY

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ABSTRACT

Complex stimuli in urban environments often lead to cognitive fatigue in residents. As a result, there is a growing demand from residents for restorative environments. Previous research has shown that the pure natural environment in the wild can help people achieve cognitive restoration. However, little attention has been paid to cognitive restoration through exposure to green infrastructure. Based on Attention Restoration Theory (ART), this study conducted an eye-tracking experiment in a controlled laboratory environment to investigate the effects of two view types, green infrastructure and urban, on individuals' cognitive restoration.

The results show that green infrastructure has a positive effect on the cognitive functioning of the participants in the experiment. The positive effect of green infrastructure on cognitive restoration is reflected in the restoration of directed attention. Less cognitive effort is an important factor contributing to cognitive restoration. Nature-relatedness plays a vital role in the eye movement behaviour of individuals when viewing landscape pictures and in the restorative benefits of cognition.

KEYWORDS

green infrastructure; cognitive restoration; eye-tracking; Attention Restoration Theory; nature-relatedness

1. INTRODUCTION

Currently, 55% of the world's population lives in urban areas, which is expected to increase to 70% by 2050 as urbanisation continues (Adam, 2022). The highly intensive urban built environment enhances the convenience of everyday life and meets the diverse needs of the citizen (Chan and Liu, 2018). However, while urban development has created enormous economic and social value, it has also brought some adverse effects: alienation of people from nature, a noisy and cramped working environment, increasing environmental pollution, and a fast-paced, high-stress urban life that may lead to severe physical and mental fatigue and even a series of social problems (Lederbogen et al., 2011). The COVID-19 pandemic has exacerbated this situation. Studies have shown that during the COVID-19 epidemic, people were more likely to suffer

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from depression, anxiety, insomnia, post-traumatic stress syndrome, and other psychological disorders (Wang et al., 2020; Wang et al., 2021).

Fortunately, people can effectively recover from the harmful effects of stressful city life through exposure to the natural environment (Hartig et al., 2014). Evidence suggests that the natural environment can reduce the incidence of cardiovascular disease, improve self-reported well-being, and that greener environments have a more positive impact (Hu et al., 2022; Markevych et al., 2017; Shanahan et al., 2016). Even windows overlooking greenery significantly reduce the risk of mental illnesses such as depression (Batool et al., 2021). In addition to the emotional and physiological restorative benefits, more importantly, exposure to nature improves cognitive function compared to urban environments, mainly in improved attention, working memory, and innovation (Berman et al., 2008; Berman et al., 2012). For example, walking in nature can lead to significant improvements in working memory compared to walking in the city (Janeczko et al., 2020). In addition, natural elements in the learning or work environment can also help students or employees regain cognitive abilities such as attention and thus improve their academic performance or productivity (Bratman et al., 2015). Children show higher levels of creativity, self-discipline, and concentration in environments with more green landscapes (Stevenson et al., 2019). Most of the above studies are guided by Attention Restoration Theory (ART). An important underlying assumption of the theory is that restorative environments have specific qualities that help cognitive resources recover and eliminate mental fatigue (Kaplan and Kaplan, 1989; Kaplan, 1995). In the search for these qualities and to clarify the underlying mechanisms of their positive impact on cognitive functioning, scholars have for a long time developed the classical Perceived Restorative Scale (PRS) as a subjective measure of the restorative benefits of the environment (Payne, 2013). They have also combined cognitive ability tests such as the Digital Span Forward/Backward Task (DSF/DSB), Sustained Attention to Response Task (SART), Necker Cube Pattern Control Task (NCPCT), Attention Network Test (ANT) and Eye Tracking (ET), Electro-EncephaloGram (EEG), Functional Magnetic Resonance Imaging (fMRI), Autonomous Nervous System (ANS) and other experimental cognitive neuroscience methods to conduct numerous studies (Annerstedt et al., 2013; Aspinall et al., 2015; Bendall et al., 2019; Beute and de Kort, 2018; Liu et al., 2022). Notably, in doing so, the researchers noted that the triggering of such restorative responses is likely to be closely related to the visual experience that the natural environment provides for people (Stevenson et al., 2019). Some studies have analyzed the link between different types of visual landscapes and cognitive functioning. The results show that cognitive restoration effects are significantly correlated with the number and proportion of natural elements presented in visual landscapes (Dupont et al., 2016). Moreover, experimental participants who were only briefly exposed to surrogate nature (e.g., photographs, posters, paintings, videos, etc.) were able to significantly improve some specific cognitive functions (Franek et al., 2019). For example, subjects' memory improved after viewing a video of a natural environment, whereas an urban video resulted in poorer performance on a subsequent attention task test (Pilotti et al., 2015). In particular, eye-tracking has been a relatively new approach in environmental psychology, which can provide real-time, objective, and in-depth insight into the behavioural characteristics and patterns of individual visual perception (Fu et al., 2020). Eye-tracking and hotspot mapping can help identify elements of the environment that have restorative benefits. Evidence suggests that some of the landscape elements that participants looked at the longest are likely to contribute most to the restorative benefits of cognitive performance (Gao et al., 2020). Additionally, oculomotor traits may serve as an objective reflection of the restorative perception of the environment. For example, people generally have lower levels of exploratory eye-movement behaviour during free viewing of natural views compared to urban landscapes (Van den Berg et al., 2016).

Scholars have also found that individual characteristics, such as gender, culture, personality, environmental attitudes, and degree of connection to nature, are likely to influence people's perceptions of the restorative potential of different types of landscapes (Maran et al., 2020; Pihel et al., 2015; Rauthmann et al., 2012). Individuals' preferred environments may be more restorative (Cottet et al., 2018). For example, people with an urban identity may perceive cities as more restorative than natural environments (Wilkie and Stavridou, 2013). Moreover, visual behaviour in different contexts may vary from person to person. While visiting national parks, male and female subjects differed in fixation duration, the number of saccades, and blink rate. Males preferred humanistic architectural landscapes, while females preferred natural landscapes (Sun et al., 2018). In addition, some scholars have divided people who were pathfinding in the wilderness into two categories based on the length of time they looked at various environmental elements, with one group paying more attention to natural elements. At the same time, the other group was mainly attracted to human factors, which may be related to the subjective reported emotional connection to nature by the participants in the experiment (Gholami et al., 2021). When observing natural views, individuals with higher nature-relatedness scores are more exploratory in their eye-movement patterns, whereas the opposite is true for urban landscapes. Therefore, the influence of nature-relatedness needs to be further considered when assessing the restorative benefits of complex outdoor views and the factors that drive individual eye-movement behaviour (Batool et al., 2022).

However, much of the previous research has been based on a natural-urban dichotomy, i.e., directly comparing urban street environments with pure wilderness natural environments to conclude that the latter is more restorative (Franěk et al., 2018). However, in the highly-dense urban built-up environment, there are hardly any absolute natural places. Even if the area people live in lacks natural elements, these city dwellers do not visit wild environments such as distant forests with high frequency (Wang et al., 2019). Public urban open spaces (e.g., green spaces, greenways, parks, urban wetlands, etc.) created by artificial or semi-artificial natural environment-led Green Infrastructure not only serve to maintain urban ecosystems (Liu and Russo, 2021), but are also considered to have the potential to mitigate the adverse effects of densely built urban environments on people's physical and mental health, and to have restorative benefits similar to those of the natural environment. (Cizek and Fox, 2015; Logan et al., 2010; Zhang et al., 2021). Green infrastructure (GI) is more than just a green space. A widely cited definition of green infrastructure is "an interconnected network of greenspace that conserves natural ecosystem values and functions and provides associated benefits to human populations." In urban environments, neighborhood and national parks, parkways, green roofs, community gardens, and the myriad other forms of private and public components of seminatural landscape (green spaces), taken together and considered as a system, could also be regarded as green infrastructure (Coutts and Hahn, 2015). Evidence suggests a positive relationship between green infrastructure and many aspects of human physical and mental health and well-being. It removes a certain amount of particulate matter from the air and has a beneficial effect on cardiovascular and respiratory diseases in the local population (Dennis et al., 2020). However, to date, research has only reflected that green infrastructure may have a restorative potential on the physical health of residents, and little attention has been paid to the restorative benefits of green infrastructure on cognitive functions such as attention (Venkataramanan et al., 2019). Most of these studies have used subjective assessments or indirect measurements of physiological indicators such as heart rate, blood pressure, and electrodermal activity as the primary method. However, subjective evaluations have the disadvantage of being poorly described and inconsistent with actual perceptions (Fu and Liu, 2017; Hou et al., 2021). Indirect physiological indicators are also vulnerable to external interference and are not intuitive to evaluate (Fu et al., 2022; Liu et al., 2022). Furthermore, more importantly, the identification of oculomotor characteristics that can measure the process of cognitive restoration in a given context and the mapping between cognitive load, oculomotor indicators, restorative benefits, and natural correlates have not been studied in depth (Kerimova et al., 2022). This gap in the eye movement research literature raises the question of whether this restorative potential may also be based on specific visual features of GI.

Therefore, to enhance and extend previous findings, the present study conducted an eye-tracking experiment in a controlled laboratory environment and combined it with the Digit Span Backward Task (DSB), a typical task for testing attention (Ohly et al., 2016), to investigate the effects of two view types, GI and urban, on individuals' cognitive load and cognitive restoration. The moderating role of individual natural correlates was explored to assess further the link between cognitive restoration and individuals' visual attention patterns. The aim is to test and expand the attentional restoration theory on the potential physiological and psychological mechanisms of restorative environments to produce restorative benefits on cognitive functions based on the microscopic perspective of the human visual perception system, to provide a new experimental basis for the restorative benefits of green infrastructure, and to provide a reference for the planning and construction of green infrastructure and renovation management solutions.

2. THEORY AND HYPOTHESIS DEVELOPMENT

2.1 Attention Restoration Theory (ART)

Attention, the cognitive ability of an individual to focus on and process specific information, is a form of perception and cognition of the physical environment that can be a significant predictor for evaluating external stimuli and measuring an individual's cognitive state (Carrasco, 2011). In ART, attentional mechanisms are divided into bottom-up directed attention (exogenous process, mainly based on signal-driven visual attention, very fast, involuntary, task-independent) and top-down undirected attention (endogenous process, driven by higher cognitive factors, slower, voluntary, task-dependent, mainly subconscious) (Kaplan and Kaplan, 1989; Kaplan, 1995). Directed attention is a limited resource. When individuals need to focus on unattractive things for long periods, considerable cognitive effort is required to suppress distractions that may be inherently more interesting. During this process, the individual's directed attention is heavily depleted, resulting in directed attention fatigue. Conversely, undirected attention mechanisms work when people can concentrate on something without much cognitive effort (Buschman and Miller, 2007). Recent research suggests that when people are exposed to high levels of stress or high cognitive load for prolonged periods, it is likely that potentially toxic by-products accumulate in the prefrontal cortex of the brain, triggering cognitive fatigue. Individuals in a state of cognitive fatigue have less self-control and are more likely to turn to low-cost behaviours that do not require effort or thought, resulting in poorer decision-making (Wiehler et al., 2022). According to ART, the antidote is a withdrawal from the complex tasks and stimuli of urban life (Kaplan and Berman, 2010).

The "restorative environment" has the following four attributes. (1) Being away, which refers to the opportunity for the environment to trigger the individual's Spontaneous attention.

It is the primary condition and initial process by which the individual recovers. It takes the individual's mind away from the otherwise highly focused Directed attention, allowing the mind to calm down and become clear. (2) Fascination, refers to the ability of information in the environment to effortlessly attract an individual's attention, resulting in an aesthetic and pleasurable psychological experience. An environment filled with fascination stimulates the individual's undirected attention mechanisms, thus complementing and restoring "directed attention." (3) Extent, meaning that the stimulus in the environment is rich and coherent, creating a desire for exploration and a pleasurable state of mind for individuals. In this state, the individual's mind becomes fully engaged, distractions are reduced, and previously unconscious thoughts or questions begin to come back. (4) Compatibility, a dimension that emphasises the two-way choice between people and their environment, referring to the tendency of individuals to match their goals with the activities supported by that environment, leading people to reflect on priorities, desired outcomes, and their behaviour and goals (Kaplan and Kaplan, 1989; Kaplan, 1995).

Thus, informative and unattractive urban views can consume a lot of directed attention, leaving people with a high cognitive load and leading to cognitive or mental fatigue. Attractive environments, on the other hand, gently engage people's attention in a bottom-up manner requiring less cognitive effort, during which top-down directed attention resources have the opportunity to be replenished. Previous research has shown that environments filled with natural elements tend to be rated high in charisma in PRS tests (Berto et al., 2008). Therefore, this study argues that the public open space created by green infrastructure produces restorative benefits in terms of cognitive function.

In view of the above literature, we had the following expectations:

H1: There are significant differences in the effects of the two view types (GI, urban) on individual cognitive restoration.

2.2 Relationship among view type, cognitive load, and eye movement

Cognitive load, also known as mental workload, refers to the degree to which an individual's attentional resources are occupied during the working state (Han et al., 2020). Cognitive strategies and attention attribution are influenced by different cognitive load conditions (Gog et al., 2009). For example, previous EEG experiments have found that the processing of natural landscapes is associated with lower attentional and cognitive load compared to urban landscapes (Grassini et al., 2019).

Eye movement is an outward manifestation of cognitive load (Alruwaythi and Goodrum, 2019; Shi et al., 2020). Eye-tracking captures the visual perceptual behaviour of individuals, captures eye movement data, and is an effective method for directly measuring attentional deployment and systematically analysing the mental activity and cognitive effort of individuals while observing a target (Fu et al., 2022; Just and Carpenter, 1980). Ocular events can be categorized mainly into fixation, saccade, and pupillary response. Fixation means that the eye remains relatively still for a certain period, allowing the central fossa to stabilise in a specific place so that the visual system can obtain detailed information about the object. The number of fixations (NF) refers to the number of fixations that occur within a single stimulus material. More NF tends to reflect more cognitive effort (Schneider et al., 2012). The average duration of fixations (ADF) is the average duration between the first and last sample points that make up a gaze point. Longer ADF means the view is more engaging and reflects less cognitive load (Sekicki and Staudte, 2018). Saccade is the oculomotor act of moving the central fossa's vision rapidly from one point to another. Total amplitude of saccades (TAS) is the total amplitude of all saccades in an interval. The more complex the stimulus material, the greater the TAS and the higher the cognitive load. The number of saccades (NS) is the total number of saccades in a single stimulus material. NS increases as cognitive processing becomes more difficult (Bachurina and Arsalidou, 2022). Average pupil diameter is the average pupil diameter of all fixation samples in an interval. It is related to the amount of cognitive control, attention, and cognitive processing required by a given task (Wierda et al., 2012). Previous studies have shown that greater APD reflects a higher cognitive load (Alnaes et al., 2014).

Based on the above analysis, Hypothesis 2 is formulated.

H2: The cognitive load induced by the two view types (GI, urban) is significantly different.

2.3 Potential visual mechanisms for cognitive restoration process

As mentioned earlier, view type is likely to affect individual cognitive load and may be associated with eventual cognitive restoration. Attentional mechanisms and cognitive load status may also have an impact on the final cognitive restoration outcome. Eye movement behaviour is an external manifestation of cognitive load (Clifton et al., 2016). Using eye-tracking technology is possible to track and analyze the unconscious eye trajectories and indicators of people when observing environmental images, to obtain the characteristics and patterns of individuals' visual perception of the landscape, and then to reveal the cognitive restoration mechanism of individuals in the process of image perception, which also provides favorable conditions for restorative environmental evaluation research based on visual perception.

An earlier study showed that subjects showed less exploratory eye-movement behaviour when viewing pictures of natural environments (high fascination) compared to photographs of urban areas (low fascination) (Berto et al., 2008). Similarly, several recent studies have found that subjects' eye-movement behaviour in natural views is characterised by fewer fixation numbers, shorter total fixation durations, and less blink rate than in urban landscapes (Franek et al., 2019; Gholami et al., 2021; Liu et al., 2022). Overall, these results support the interpretation of ART that individuals have lower levels of directed attentional engagement and lower levels of eye movement activity when observing restorative environmental images relative to environments with low restorative potential, reflecting lower cognitive effort, which is likely to be a potential mechanism for the restorative benefits of cognitive functions such as attention.

In summary, Hypothesis 3 is formulated.

H3: Cognitive load is a mediating variable between the effect of view type on cognitive restoration.

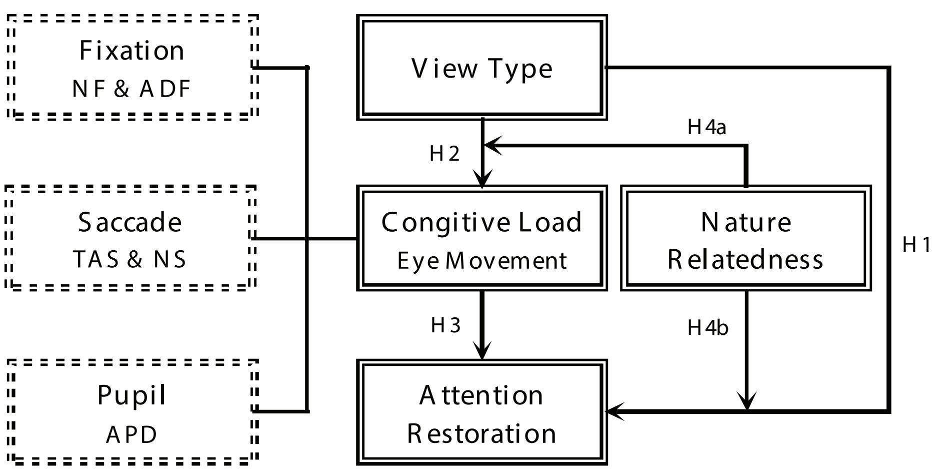
2.4 Effects of nature-relatedness (NR) on human behaviour

The biophilic hypothesis suggests humans have an innate tendency to approach natural things. It is human nature to pay attention to and learn from the natural environment (Chang et al., 2020). However, a recent study suggests that the evolutionary journey in an urban setting and prolonged alienation from nature has altered the structure and function of some people's brains, which may have further altered their social perception and ability to perceive nature (Xu et al., 2022). Individual differences in the extent to which people are connected to nature may reflect a personal orientation toward nature and the extent to which they perceive biophilic affinity or how much their biophilic tendencies are supported or suppressed (Tam, 2013). Nisbet developed the concept of nature-relatedness (NR) as an individual-level characteristic that reflects individual differences in how people view the natural world and their desire for access to nature. He also developed the multidimensional 21-item nature-related scale to measure the cognitive, emotional, or experiential connection between humans and the natural environment (Nisbet et al., 2008).

NR, closely linked to individual behaviour and psychological conditions, is likely to drive people's interactions with nature and affect well-being and has been the focus of scholarly attention in recent years. Evidence suggests that people with higher levels of NR are less likely to use their smartphones excessively frequently in their daily lives and are more likely to engage in adequate physical activity (Colleony et al., 2019). In addition, they enjoy spending more time in green spaces and are even happy to go to faraway forests with lush vegetation, and they also have fewer worries and anxieties (Richardson et al., 2018). The study found that people who are more connected to nature prefer the natural environment and see it as more restorative. In contrast, the 'city person' sees cities as equally restorative as nature (Wilkie and Stavridou, 2013).

Thus, differences in perceived restorative benefits are dependent not only on the type and physical characteristics of the environment but may also be attributable to individual NR. More importantly, while many relationships have been observed between NR and an individual's daily life and mental state, few studies have focused on its association with subtle body movements, such as eye movements. Eye movements are a fundamental human behaviour with cognitive, emotional, motivational, and social underpinnings and are likely to produce individual differences related to nature-relatedness. For example, a recent study found that nature-related people prefer to look at trees rather than buildings, while people with low nature-relatedness spend more time looking at buildings than trees (Chen et al., 2022).

FIGURE 1. Conceptual framework.



Note. NF means the number of fixations; ADF means the average duration of fixations; TAS means the total amplitude of saccade; NS means the number of saccades; APD means the average pupil diameter.

In summary, hypothesis 4 is formulated.

H4a: The effect of cognitive restoration is modulated by individual NR levels.

H4b: Similarly, an individual's cognitive load is modulated by their NR level.

2.5 Theoretical framework

The conceptual framework of the present study is as Figure 1.

3. METHODS

3.1 Stimulus materials

Previous research has shown that photographs of landscape spaces can be an adequate substitute for field surveys of the environment. For controlled experiments, conducting field tests instead has certain drawbacks, with objective factors such as weather conditions, temperature, sound, research costs, and outbreak containment measures affecting the investigation (Franek et al., 2019). Therefore, landscape photographs were also used as stimulus material for this eye-movement experiment. A total of 40 images were selected, including 20 photographs of public open spaces created by green infrastructure (parks, greenways, green roofs, etc.) and 20 photographs of urban views (industrial areas, streets, etc.). The selected photographs are of moderate resolution, with the same number of pixels, and the brightness and contrast are balanced in post-processing. The photographs used in this study represented outdoor environments that were easy to recognize, where no incongruent or salient elements were present that could affect the eye movement patterns. Although the measurement of visual complexity was not of concern in this study, the number of details and their distribution were balanced across the photographs. An example of the stimulus material is shown in Figure 2. It should be noted that these materials are taken from StockSnap (https://stocksnap.io/). The site offers a complete and extensive database of all stock material under the Creative Commons license, which allows users to use the photos for any purpose, free of charge and without the need to obtain permission from the original author or to attribute names or sources.

3.2 PARTICIPANTS

A two-factor mixed design was used in this study, with view type (GI, urban) as a between-group factor and NR level (high, low) as a within-group factor. The experiment recruited

FIGURE 2. Examples of stimulus material. a. Urban streetscape, b. Green infrastructure

a. Urban streetscape   b. Green infrastructure (park)

82 participants with normal or corrected vision via social media and online advertisements. Based on socio-demographic information collected online, such as age, gender, and profession, participants were balanced and divided equally into two experimental control groups. We obtained valid eye movement data from a total of 80 participants (40 per group) after excluding samples that were incompletely recorded or failed calibration. Furthermore, the experiment was conducted in accordance with the Declaration of Helsinki and was ethically approved by the Neuroengineering Management Laboratory of Xi'an University of Architecture and Technology. All participants participate voluntarily in this experiment, knowing and agreeing that their eye movement data and attention test results will be recorded for scientific purposes. Participants can withdraw from the experiment anytime (World Med, 2013).

3.3 Apparatus

In this experiment, we used the Tobii Pro Fusion eye-tracking device to collect eye movement data from participants. The eye-tracking device was attached to the monitor of a laptop. We connected the eye-tracking device to the computer via a Type-C connector and presented the stimulus material on the screen. We set the display resolution to 1920*1080, and the picture scaling was 100%. Each participant was seated approximately 60 cm from the display equipped with an eye-tracking device. Although we did not use a chin rest, we asked the subjects to keep their heads moving as much as possible during the experiment.

3.4 Procedure

One week before the experiment, we collected all participants' NR scores through an online questionnaire. The one-week interval was designed to eliminate potential interference between the questionnaire survey and the image stimulus.

The experiments were carried out in August 2022 in the neuromanagement in engineering laboratory at Xi'an University of Architecture and Technology. The laboratory is soundproof and is not affected by natural light. In addition, the rooms were controlled to have bright light conditions and appropriate air conditioning temperatures. Each subject was accompanied and guided by a research assistant. Upon arrival, participants read and signed the informed consent form for the experiment and sat in silence for 5 minutes. During that time, the research assistant briefed them on the procedure but did not inform them of the true purpose of the study. After the break, the first DSB test was administered to the participants. Afterwards, the participant was given the following instructions: "A series of photographs will now appear on the computer screen. You need to look at the photographs freely and not try to remember any details as this is not a memory task." Next, eye-movement calibration was performed, and once completed, the presentation of the stimulus material began. During this procedure, we displayed 20 images of urban views or green infrastructure landscapes in a fixed sequence to participants in different control groups. We followed the practice of previous studies and presented each image to participants for 12 seconds (Engelke and Le Callet 2015). It should be noted that before each image stimulus was given, we displayed a crosshair ("+") in the center of the screen on a white background. Participants were asked to look at the cross for 1 second to focus their eyes and ensure that they explored each image from the same point, followed by a blank screen of 1 second duration after the stimulus material. Once we displayed all the stimulus material and the research assistant confirmed that the eye movement data had been successfully collected, the participant was given a second DSB test. Then the experiment is over. Each participant received a memento worth approximately US$5 as a reward. The whole experiment took about

25 minutes. The experimental steps and the order of presentation of the oculomotor stimulus material are shown in Figure 3.

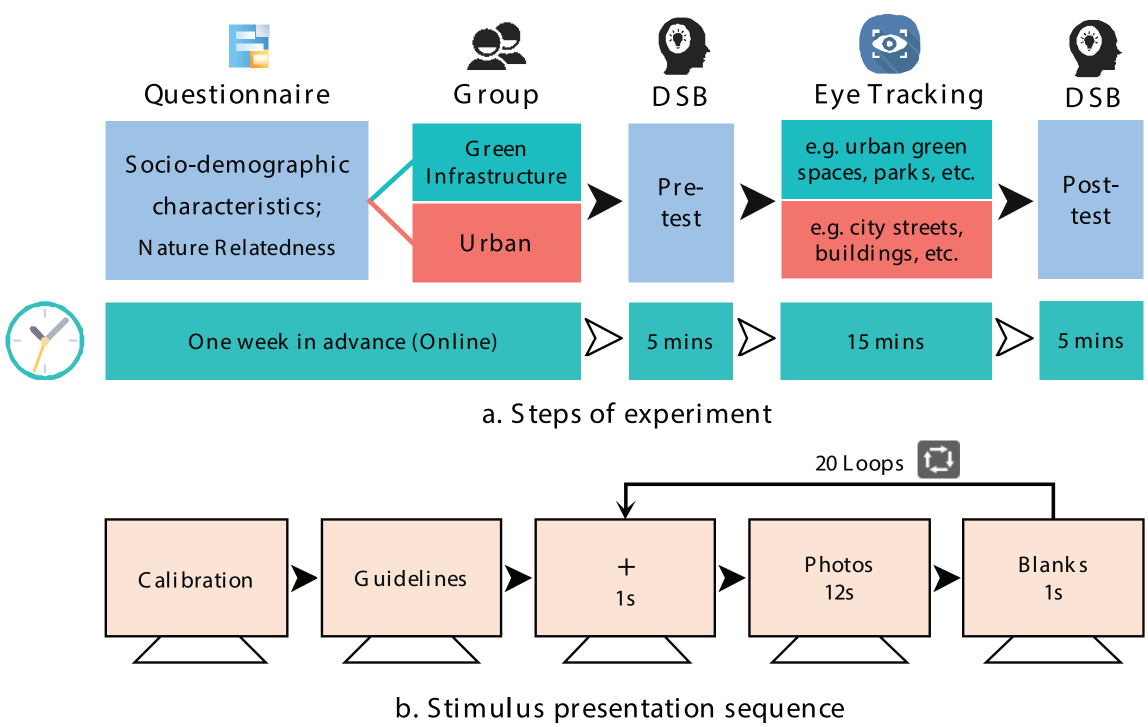
3.5 Measures

3.5.1 Level of cognitive restoration

This experiment used the Digit Span Backward (DSB) test to analyse the cognitive restoration of participants. We use the DSB test to measure "an individual's ability to control distractions through inhibitory mechanisms" or "directed attention capacity" as defined in ART. Participants must move items in and out of their attentional focus, which is a significant component of short-term memory during the execution of the DSB test. The DSB test requires participants to both remember a series of numbers and to reverse Operate these numbers. Specifically, it requires participants to say the sequence of numbers they hear in reverse order (e.g., if the digits "3, 4, 5" were presented, the participant had to report "5, 4, 3"). If this task succeeds twice in a row, they get a longer list of digits (e.g., from 3 to 4 digits). The starting length of the list was two digits, with no fixed maximum length. The sequence length was increased until the participant failed to accurately recall a list of that length in turn on the next two trials. The final score for this test was calculated by multiplying the length of the longest list that the participant could recall by 2.

In addition, because this study was concerned with whether and to what extent individuals recovered their cognitive functioning after viewing green infrastructure landscapes or urban views, two DSB tests were administered. For the first test, baseline attention was measured

FIGURE 3. Experimental procedure. a. Steps of the experiment, b. Stimulus presentation sequence.



while inducing mental fatigue in the participant. Then the participant was exposed to the green infrastructure landscape or urban views. After we presented all views, the second test was administered. The change in participants' scores on the two tests was used as an indicator of the participants' cognitive restoration. Let the superscript refer to the order of tasks. The calculation formula is as follows.

$$\Delta L = L^2 - L^1 \tag{1}$$

Where ΔL refers to the change in attention score, L^1 is the pre-test attention score, and L^2 is the post-test attention score.

3.5.2 Eye movement metrics reflecting cognitive load during image viewing

As mentioned above, eye-tracking is a physiological measurement technique widely used in psychology, which can reveal the cognitive behaviour and mental activity of individuals when viewing images in different situations. By reviewing the relevant literature, this paper selects eye movement indicators such as NF, ADF, TAS, NS, and APD to operationalise the definition of cognitive load. For the specific meaning of these indicators, their association with mental activity, and their characterisation of cognitive load, please refer to section 2.2. It should also be noted that in the Tobii Pro Lab software, "metric" is defined as different statistical indicators that can be obtained from the recorded eye movement data. These eye movement statistics can be exported in different forms or file formats for an overview of the overall data and extraction of summary statistics.

3.5.3 nature-relatedness(NR)

NR Scores were collected by the nature-relatedness scale (NRS). NRS is a self-report scale that measures a person's emotional, cognitive, and experiential connection to the natural world through 21 items (containing three sub-dimensions). Each item uses a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The scores were averaged across all items (eight of which were reverse scored) to give the participants a final composite NR score, with higher scores reflecting a stronger connection to nature. Because most participants were not fluent in English, the Chinese version of the scale was used. In addition, the NR scale had a Cronbach alpha of 0.82 in this study, showing good internal consistency. Similar to previous studies, we defined the top 50% of participants as high NR and the bottom 50% as low NR based on the NR composite score.

3.6 Statistical analysis

We used the Tobii Pro Lab software to implement the various stages of the eye-tracking experiment, including stimulus programming, eye-tracking data collection, and visualization. OriginPro 2021 was used for illustration.

First, for hypothesis 1, in addition to independent sample t-tests, we introduced time points (pre- and post-test) to examine the effect of view type on cognitive restoration using a two-way ANOVA. Immediately following, for hypothesis 2, a one-way ANOVA was used to investigate the difference in cognitive load (as represented by the eye movement index) between the two view types. In addition, based on SPSS, Andrew F. Hayes developed "PROCESS," a plug-in for mediated effects analysis. PROCESS makes it possible to analyze mediating effects in one step, simplifying the process considerably. Furthermore, PROCESS makes it easier to handle multivariate mediating and moderating effects (Bolin, 2014). We used this method to examine the mediating role of cognitive load (eye movement data) in the relationship between view type and cognitive restoration (H3). Finally, a two-way ANOVA was used to examine the moderating effect of NR between view type and cognitive restoration and between view type and cognitive load (H4a and H4b).

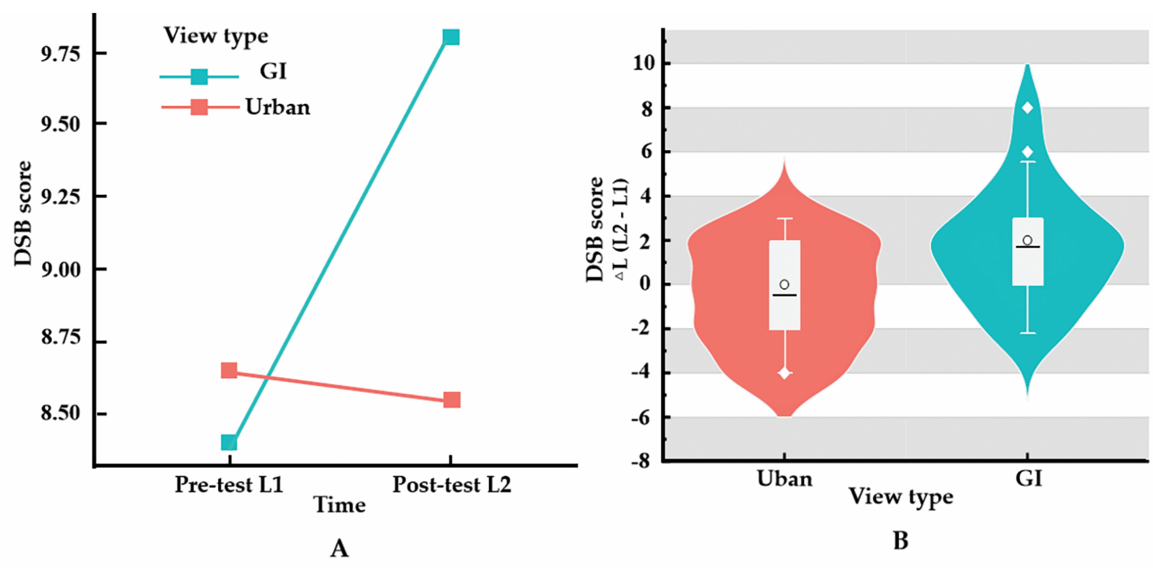
4. RESULTS

4.1 Effect of view type on cognitive restoration

A two-way ANOVA was conducted with view type (GI, urban) and time (pre-test L1, post-test L2) as independent variables and DSB scores as dependent variables. The results showed a significant interaction between view type and time on DSB scores, $F(1, 156) = 22.500$, $P = .020$, $\eta^2_p = .034$. As shown in Figure 4a, the DSB post-test scores of the GI group increased substantially compared to the pre-test, while the pre-test and post-test scores of the urban group did not change significantly.

As shown in Figure 4b, to further test whether view type influenced cognitive restoration, an independent samples t-test was used to determine the difference in means of DSB score change between the GI and urban groups. The results showed that ΔL was higher in the GI group (1.700 ± 2.584) than in the urban group (–0.470 ± 2.320), with a difference of 2.170 (95% confidence interval 1.906–7.074). The independent samples t-test showed that t = –3.961, p < .001, indicating a significant difference in ΔL between the GI and urban groups, with the mean value of ΔL being higher in the GI group than in the urban group.

FIGURE 4. Effect of view type on cognitive restoration as measured by DSB score. b. Interaction effect, b. Violin plot.



Note. Pre-test and post-test DSB scores are shown in graph A. Graph B illustrates the difference in change calculated by subtracting the pre-test from the post-test as a violin plot, with 0 indicating no change. Boxplot plots show median (circles), first and third quartile ranges (lower and upper hinge of the box, respectively), and outliers (diamonds). The mean is shown by the horizontal line inside the box.

4.2 Effect of view type on cognitive load

A one-way ANOVA was conducted with view type (GI, urban) as the categorical independent variable and eye movement indicators such as NF, ADF, TAS, NS, and APD as the dependent variables. The results are shown in Table 1. It was found that both Urban and GI view types had significant differences in the effects of the above five eye-movement indicators reflecting cognitive load in the participants.

First, for fixation behaviour, participants in the GI group had an NF level of (17.470 ± 10.568) counts compared to (21.370 ± 10.430) counts in the urban group, with higher NF in the urban group and a significant effect of view type on NF (F = 55.013, p < .001). Participants in the GI group had ADF of (380.370 ± 547.841) ms and (321.760 ± 246.081) ms in the Urban group, with a longer ADF in the GI group and a significant effect of view type on ADF (F = 7.569, P < .01).

Second, for saccade behaviour, participants in the GI group had a TAS level of (77.650 ± 53.307) deg compared to (94.090 ± 56.981) deg in the urban group, which had more TAS and a significant effect of view type on TAS (F = 34.885, p < .001). Participants in the GI group had an NS of (14.430 ± 9.773) count, and in the urban group the count was (18.290 ± 9.651), with more NS in the urban group and a significant effect of view type on TAS (F = 63.305, P < .001).

Finally, regarding pupil diameter, the level of APD was (3.142 ± 0.409) mm for participants in the GI group and (3.209 ± 0.466) mm in the urban group, which had a larger APD and a significant effect of view type on APD (F = 9.363, p < .01).

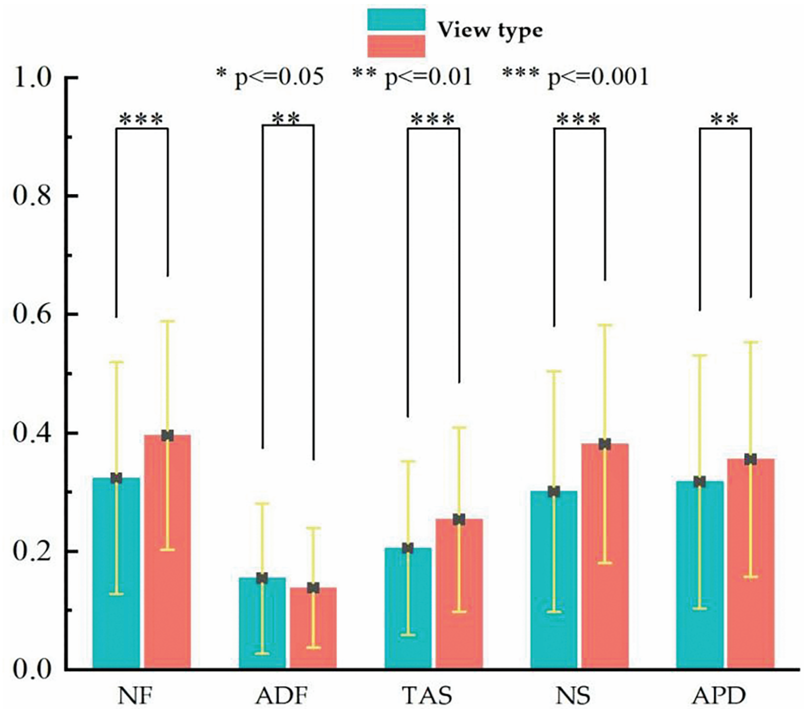
Using the maximum-minimum standardisation method, each eye movement index was standardised individually. Figure 5 shows a histogram of the standardised eye movement data. The AFD index is significantly longer in the GI group than in the urban group, and NF, TAS, NS, and APD are all significantly higher in the urban group than in the GI group.

TABLE 1. One-way ANOVA results for the effect of view type on eye movement metrics.

Metrics	Group	Mean	SD	F	P
NF(count)	GI	17.470	10.568	55.013	0.000***
	Urban	21.370↑	10.430		
ADF(ms)	GI	380.370↑	547.841	7.569	0.006**
	Urban	321.760	246.081		
TAS(deg)	GI	77.650	53.307	34.885	0.000***
	Urban	94.090↑	56.981		
NS(count)	GI	14.430	9.773	63.305	0.000***
	Urban	18.290↑	9.651		
APD(mm)	GI	3.142	0.409	9.363	0.002**
	Urban	3.209↑	0.466		

Note. * *P* <= .05,** *P* <= .01, *** *P* <= .001

FIGURE 5. Between-group differences in eye movement data reflecting cognitive load



4.3 Mediating effect of cognitive load on the relationship between view type and cognitive restoration

To further elucidate the psychological mechanisms by which view type affects cognitive restoration, the SPSS macro program Process, developed by Hayes, was used to analyse the mediation between cognitive load (as represented by the five indicators of NF, ADF, TAS, NS, and APD) in the relationship between view type and cognitive restoration, concerning to previous studies (Wang et al., 2019). We converted the view type to a dummy variable (0:GI; 1:urban), and Model 4 was selected and tested at a 95% confidence interval using the Bootstrap method with a sample size of 5000. The results are shown in Table 2. We found a significant co-mediator effect for the five eye movement indicators (Index = –0.515, SE = 0.036, 95% CI = [–0.101– –0.241]).

As shown in Table 3: NF (Index = –0.031, SE = 0.014, 95% CI = [–0.009– –0.062]), ADF (Index = 0.118, SE = 0.055, 95% CI = [0.230–0.016]), TAS (Index = –0.151, SE = 0.041, 95% CI = [–0.080– –0.239]), NS (Index = –0.190, SE = 0.055, 95% CI = [–0.096– –0.312]), APD (Index = –0.087, SE = 0.048, 95% CI = [–0.196– –0.011]). We can find that each of the five eye movement indicators plays a significant mediating role. Among them, ADF played a positive mediating role, while the rest of the indicators played a negative mediating effect.

4.4 Moderating effect of NR

4.4.1 The role of NR in the relationship between view type and cognitive restoration

To investigate the differences in DSB test score change after viewing GI landscape and Urban scenes for individuals with different NR levels, we investigated the moderating effect of NR on

TABLE 2. The co-mediating effect of five eye movement metrics.

	Effect	BootSE	BootLLCI	BootULCI	% Effect
Total effect	–2.428	0.111	–2.962	–1.528	100%
Direct effect	–1.913	0.110	–2.128	–1.697	78.79%
Total mediating effect	–0.515	0.036	–0.101	–0.241	21.21%

the relationship between view type and DSB score change. A two-way ANOVA was conducted with view type (GI, urban) and NR level (Low, High) as independent variables and DSB score change as the dependent variable.

The results indicated a significant interaction between the two factors of view type and NR level on the change in DSB score, $F(1, 76) = 60.288$, $p < .001$, $\eta^2_p = .442$. As shown in Figure 6, for participants with a high NR level, their DSB test performance improved considerably after viewing the GI landscape and decreased after experiencing the urban scene. Conversely, for participants with a low NR level, their DSB test performance improved slightly after viewing the urban settings. In contrast, their DSB test scores remained almost unchanged after observing the GI landscape.

In summary, in the GI scenario, individuals with high NR show better results than participants with low NR. In contrast, the opposite is true in the urban scenario.

4.4.2 The role of NR in the relationship between view type and cognitive load

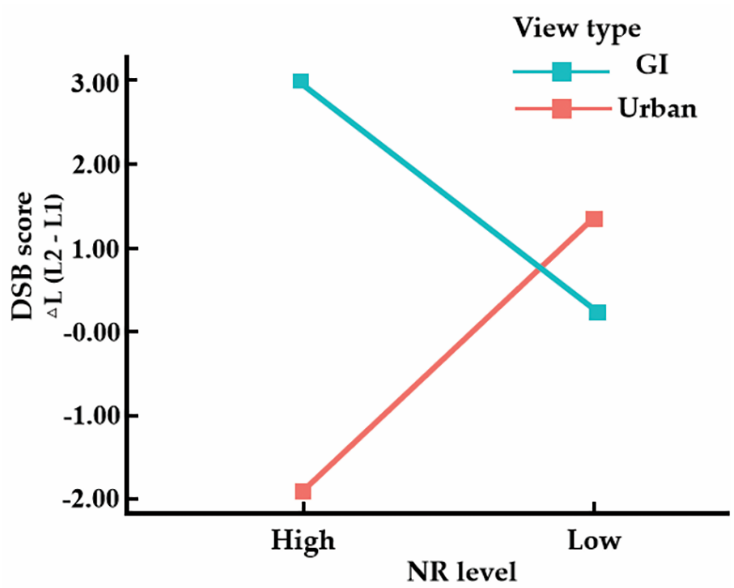
To analyze the differences in cognitive load between individuals with different NR levels when viewing GI landscapes and Urban scenes, we investigated the moderating effect of NR on the relationship between view type and eye-movement behaviour. Similarly, a two-factor ANOVA was conducted with scene type (GI, urban) and NR level (Low, High) as independent variables and five eye-movement indicators (NF, ADF, TAS, NS, APD) as dependent variables, respectively.

First, as shown in Figure 7a, there was a significant interaction between view type, and NR level on NF, $F(1, 1596) = 6.834$, $p < .05$, $\eta^2_p = .120$. Participants with high NR had less

TABLE 3. The mediating effect of each of the five eye movement metrics.

	mediating Effect	BootSE	BootLLCI	BootULCI	% mediating Effect
NF	–0.031	0.014	–0.009	–0.062	6.02%
ADF	0.118	0.055	0.230	0.016	22.91%
TAS	–0.151	0.041	–0.080	–0.239	29.32%
NS	–0.190	0.055	–0.096	–0.312	36.89%
APD	–0.087	0.048	–0.196	–0.011	16.89%

FIGURE 6. Moderating effect of NR on the relationship between view type and DSB score (ΔL).



NF when enjoying the GI view and more NF when observing the urban scene. Conversely, participants with higher NR had less NF when enjoying the GI landscape and more NF when watching urban scenes. Then, as shown in Figure 7B, there was also a significant interaction between two factors, scene type view type and NR level, on ADF, $F(1, 1580) = 4.875$, $p < .01$, $\eta^2_p = .210$. For participants with high NR, they had a longer ADF when viewing the GI landscape and a shorter ADF when observing the Urban scene. Conversely, Participants with lower NR had a lower ADF when viewing the GI landscape and a higher ADF when viewing the urban scenes.

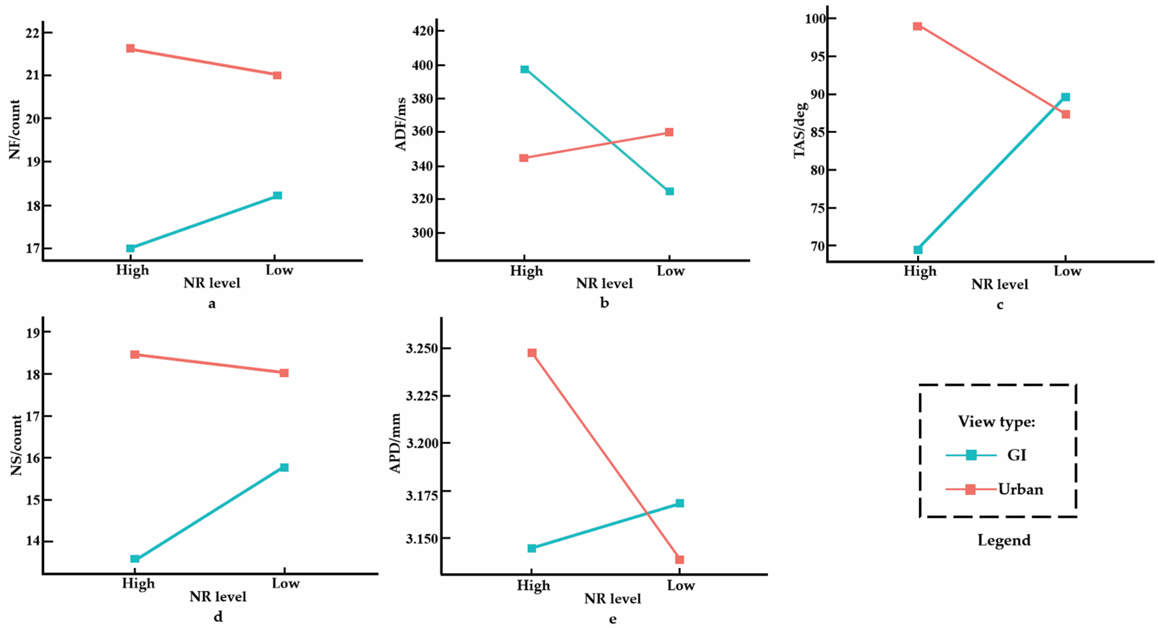
Next, as shown in Figure 7c, there was an equally significant interaction between the two factors of view type and NR level on TAS, $F(1, 1569) = 320.78$, $p < .001$, $\eta^2_p = .020$. For participants with higher NR, TAS was smaller when viewing the GI landscape and larger when observing the urban scene. Conversely, for participants with lower NR, their TAS was larger when viewing the GI landscape and smaller when observing the Urban scene.

Similarly, as shown in Figure 7d, there was a significant interaction between two factors, view type and NR level, on NS, $F(1, 1596) = 7.565$, $p < .01$, $\eta^2_p = .005$. Participants with higher NR had less NS when viewing the GI landscape and more NS when observing urban scenes. Conversely, participants with lower NR had more NS when viewing the GI landscape and less NS when observing urban scenes.

Finally, as shown in Figure 7e, there was also a significant interaction between two factors, view type, and NR level, on APD, $F(1, 1580) = 4.875$, $p < .01$, $\eta^2_p = .211$. For participants with higher NR, their APD was lower when viewing the GI landscape and a higher APD when observing the urban scene. Conversely, for participants with lower NR, their APD was larger when viewing the GI landscape and smaller when observing the urban scene.

In conclusion, from the above results, we found that individuals with higher NR showed less cognitive load when viewing GI landscapes compared to participants with lower NR, while the opposite was true when observing urban scenes.

FIGURE 7. Moderating effect of NR on the relationship between view type and cognitive load.



5. DISCUSSION

This study compares the differences in the effects of two view types on cognitive restoration effects, a public open space landscape created by green infrastructure and a scene in a bustling city. It explores the mediating effect of cognitive load in these view types. In addition, the current study also considers the moderating role played by an influential individual characteristic attribute, natural relatedness. In the above process, a classic attention test task, the DSB, was used to record changes in the subject's cognitive functioning. Eye movement analysis can reveal changes in attention allocation and cognitive load during image perception and is used to record data on individuals' visual perceptual behaviour when viewing two scenes to give indications of their cognitive load. Finally, the multidimensional 21-item nature-related scale was used to measure the extent to which individuals are connected to nature.

Firstly, the findings of the DSB test suggest that the public open space landscape created by green infrastructure has cognitive restorative benefits compared to the noisy urban scene. The DSB scores of the Green Infrastructure Landscape group were significantly higher on the post-test results than the pre-test results. In contrast, the post-test task scores of the urban group subjects were not quite different compared to the pre-test. After viewing the green infrastructure landscape, individuals' orientated attention was better rested and restored than in the urban scenes, resulting in better performance on the subsequent attention test. H1 was validated. Betro argues that DSB is uninteresting and unattractive. Participants need to concentrate to be better at the task (Berto et al. 2008). Thus, the participants in the present experiment, whose orienting attention was already in a state of fatigue and exhaustion after experiencing the DSB pre-test, i.e., before observing the pictures, showed increased scores on the post-test task as an indication of restored orienting attention. Attention allocation is a modulation of what is attended to during attention. Attention allocation strategies are divided into distraction, concentration, and contemplation. Distraction refers to diverting attention from the current situation.

Concentration refers to devoting all cognitive resources to a particular task or emotionally evocative event. Contemplation refers to focusing attention on one's feelings (Kaplan, 1995). In the GI group, subjects were able to fully engage in the experience of the pictures, focusing their attention on the content of the environment and their internal experience, with fewer distractions from other factors, thus stimulating a greater restorative experience, allowing for the restoration of cognitive resources consumed on the pre-test and an increase in performance on the post-test. This finding supports the core idea of ART that restorative benefits are an immediate complement to the cognitive resources of directed attention. The public open spaces created by green infrastructure (greenways, wetlands, parks, etc.) produce restorative benefits similar to those of the natural environment. Therefore, they also fit the definition of 'restorative environment' in the Attention Restoration Theory.

Then, based on validating the existence of restorative benefits in green infrastructure, this study links attentional restoration theory with concepts related to cognitive load to further explore the mechanisms by which restorative benefits arise. The results of the analysis of the eye-movement data show that individuals have different levels of cognitive load when viewing urban scenes and green infrastructure landscapes and that this difference is reflected in visual behaviour patterns. Individuals who view green infrastructure landscapes invest less cognitive effort and thus have lower levels of eye movements, as evidenced by longer average duration of fixations, fewer fixation numbers, smaller saccade amplitude, fewer saccade numbers, and smaller average pupil diameter. H2 is verified. Similarly, eye-movement metrics have been used as a measure of cognitive processing and stress in several previous studies, showing that people's eye movement behaviour differs between urban and natural scenes, and that they aesthetically prefer natural landscapes (Batool et al., 2022; Kaplan and Berman, 2010; Van den Berg et al., 2016). These results corroborate the findings of this study that urban environments increase cognitive load and deplete cognitive resources, while natural environments do the opposite. This finding further elucidates how the cognitive restorative benefits proposed by Attention Restoration Theory are generated. In addition, the scope of application of the ART is extended. In addition to the purely natural environment, there are also artificial green landscapes created by green infrastructure that people can immerse themselves in and effortlessly and involuntarily enjoy, thus relaxing their minds and bodies and relieving their mental load.

Immediately afterwards, we found that the two view types, urban and GI, impacted the final cognitive restoration by affecting the cognitive load indicated by the oculomotor indicators during the individual's viewing of the images. H3 is verified. Thus, the effect of a restorative environment on an individual's cognitive restoration is produced by influencing cognitive load, and the possibility of immediate restoration of cognitive resources exists. It is well known that information processing as a cognitive psychological activity needs to be reflected by measurable indicators in research. Eye tracking is a widely used physiological measurement technique in psychology that can directly, objectively, finely, and quantitatively measure attention and cognitive load. This finding reflects the fact that the restorative environment relies heavily on direct visual stimuli for its effectiveness. Exposure to a restorative environment in the form of direct visuals activates activity levels in the corresponding brain regions, leading to greater immersion and reflection, clearing the mind of distracting thoughts and leading to a better experience of restorative benefits (Grassini et al., 2019). This finding is supported by previous research. For example, people who work in green infrastructure sites for long periods face lower burnout and higher levels of well-being at work, which is likely to be related to the green landscapes constructed by the GI (Coutts and Hahn, 2015).

Finally, the results of the two-way ANOVA showed that NR levels played a significant moderating role in both pathways in which view type affected cognitive restoration effects and cognitive load, respectively. H4a and H4b are verified. In urban scenes, the low NR group had better cognitive restoration and lower cognitive load, as evidenced by lower eye movement levels. In contrast, in the green infrastructure landscape, the high NR group had better cognitive restoration and would have a lower cognitive load, with correspondingly lower levels of eye movements. Scholars generally agree that the human preference for natural elements, known as pro-biology, is innate and results from long-term evolution. Even though previous studies have confirmed many of the physical and mental health benefits of nature and that subjects generally spend more time viewing natural scenes than built scenes at the same perceptual complexity. However, this experiment found that individuals with low NR levels generally enjoyed viewing urban industrial or architectural scenes more. The individuals with low NR achieved better cognitive restoration in urban scenes than in the green infrastructure landscape. This finding may support the idea that "human values and needs determine how they see the world." Furthermore, the results provide further evidence for the influence of NR correlations on visual attention on the one hand and the power of natural correlations on individual pro-environmental behaviour and subjective well-being on the other. Although many existing studies have demonstrated the relationship between NR and behaviour, most have used self-reported behavioural measures, such as questionnaires and interviews. As such, the results of these studies are subjective and may vary depending on individual and situational factors. More importantly, the results also provide evidence of a 'top-down' mechanism of cognitive influence on perception. In the same scene of the experiment, people with different levels of NR showed additional attention allocation and cognitive load when viewing green infrastructure or urban scenes. This finding reflects that human attention allocation and cognitive engagement during spontaneous exploration of the picture stimuli were mainly driven by their nature-relatedness as a property.

We can develop the application of the research findings in two ways. On the one hand, for individuals, in real life, when cognitive resources are depleted or fatigued, people can obtain restoration by viewing a green infrastructure landscape, which can be achieved in a short period. Even in green infrastructure sites, people can easily complete assignments that require a great deal of cognitive effort, as immediate replenishment is available while cognitive resources are depleted in a restorative environment. To achieve better restoration, it is advisable to have direct visual contact with the green infrastructure environment to get away from the daily environment that disturbs and fatigues you. On the other hand, social groups and government departments involved in public health should develop policies that not only make the public aware of the benefits of the environment for physical and mental health, but also create more opportunities and safeguards for the public to use green infrastructure. For example, the urban planning and construction departments should pay as much attention as possible to the layout and construction of parks, green spaces, and other environments in urban planning, and in the process of urban garden construction, can draw on the characteristics of the restorative environment as far as possible, presenting elements of the natural environment as realistically as possible in the urban environment.

6. CONCLUSION

Based on ART, the present study explored the mechanism of green infrastructure's influence on public perceived restoration from the perspective of environment-behaviour interaction, using eye-movement behaviour, which reflects cognitive load, as a mediating variable, and taking into account individual characteristics factors. We come to the following conclusions: (1) The public open space landscape created by green infrastructure has a cognitive restorative effect. (2) The visual processing of green infrastructure landscapes requires less cognitive load than urban scenes. (3) Restorative environments have a cognitive restorative effect on individuals by affecting cognitive load, and there is the potential for immediate restoration of cognitive resources. (4) Individual nature-relatedness plays an essential moderating role in the effect of view type on cognitive load and cognitive restoration.

Although this study was based on a rigorous theoretical foundation and employed standard experimental methods, inevitably, there are some limitations due to the experimental conditions and the impact of the epidemic. As the experiment was conducted during the epidemic when the city had adopted COVID restrictions, it was challenging to recruit experimental participants in the community. Consequently, the participants of this eye movement experiment were all students from the Xi'an University of Architecture and Technology, Xi'an, China. Although the data obtained in this study has high internal validity, whether it can be extended to other age groups and education levels requires further testing. In addition, this study focuses on the restorative benefits of the environment from the perspective of visual experience. In the subsequent study, we will further recruit a wide range of participants, enrich the experimental methods, and expand the dimensions of the study, such as combining VR and AR technologies, to investigate the influence of the auditory, olfactory, and tactile elements present in the environment on the restorative experience.

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