不同视觉感知自然度水景照片对个体认知的影响
Effects of Pictures With Waterscapes of Varied Visual Perception of Naturalness on Individual Cognition

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摘要

自然环境有助于提升个体认知，而自然度是环境的一项重要特性。本研究从视觉感知自然度的视角，探究不同视觉感知自然度的水景对个体认知的影响，并尝试通过实验验证如下假设：1）不同自然度水景的主观恢复力存在差异；2）不同自然度水景对于工作记忆的影响有所不同。通过将被试随机分配到高自然度水景、中自然度水景、低自然度水景三个实验组及对照组，本研究采用知觉恢复力量表和恢复结果量表反映环境主观恢复力；运用活动记忆正确率、转换代价、Stroop任务指标反映被试个体工作记忆水平。依据研究过程中所得的不同自然度水平水景的特点和实验结果显示出的不同自然度水景所产生的认知效益特点，本文对指导景观设计实践的资源利用、资金投入等方面，以及人们以不同目的游览水景提供以下建议：1）在资金、生态等条件允许的情况下，应考虑建设水景，发挥其认知效益；2）以高主观恢复力、增强中央执行系统抑制功能为目的时，可优先选择高自然度水景；3）以较高主观恢复力、增强中央执行系统刷新功能为目的时，可优先选择中自然度水景；4）以注重提高注意力恢复水平，提高中央执行系统转换功能为目的时，可优先选择低自然度水平水景。

关键词
视觉感知；自然度；水景；认知；主观恢复力；注意力；工作记忆

ABSTRACT
Natural environments can provide individual cognitive benefits, and naturalness is often regarded as a valued property of environment. This research focuses on the visual perception of naturalness and investigates the impact of waterscapes of varied naturalness levels on people's cognition, by proposing and verifying two hypotheses: 1) subjective restoration varies across waterscapes of varied naturalness levels; and 2) waterscapes of varied naturalness levels affect people's working memory accordingly. Through a between-subjects experiment, participants in this research were randomized into three experiment groups (waterscapes of high, medium, and low naturalness level) and the control group, and the Perceived Restorative Scale and the Restoration Outcome Scale are introduced to measure the subjective restoration of the environment. The running memory accuracy, shifting cost, and Stroop task indicators are used to measure an individual's working memory. According to the characteristics of waterscapes of varied naturalness levels summarized upon the research and the findings on the corresponding cognitive benefits, suggestions are concluded for optimizing resource allocation and investments in landscape design practice, as well as guiding visitors' usage of waterscapes: 1) waterscapes are recommended in spatial creation for their productive cognitive benefits, if financial and ecological conditions permit; 2) in terms of cognitive benefits, waterscapes of high naturalness level are conducive to high subjective restoration and enhanced inhibition function of central executive system; 3) waterscapes of medium naturalness level can lead to a relatively high subjective restoration and improved updating function of central executive system; and 4) waterscapes of low naturalness level can bring about a better attention restoration and better performance on shifting function of central executive system.

KEYWORDS
Visual Perception; Naturalness; Waterscape; Cognition; Subjective Restoration; Attention; Working Memory

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1 引言

人的认知包括人们对于客观事物的感知、记忆、思维、想象等多个方面，往往通过人们主观感知到的恢复性、注意力和工作记忆等指标加以反映。其中，注意力可以通过各类量表反映[1]；而工作记忆是个体执行认知任务时临时性储存和操作信息的能力，常通过N-back、Stroop等经典实验范式的成绩来反映[2]。在城市化日益加剧的今天，越来越多的研究发现自然环境能够助益人类健康[3]，也有不少学者聚焦于其对认知的益处[4]。既有研究证明，自然环境在注意力恢复、促进学习、预防认知障碍、激发想象力和创造力，以及改善抑制性和坚持性自我控制等方面均有效果[5]~[11]。然而，自然环境对认知的影响存在两面性，如在提高人短时记忆力的同时，也会在一定程度上削弱其注意力网络功能（执行力、方位感和警觉度降低）[4]。

自然度通常被认为是环境的一项重要特性[12]。在环境心理学相关领域的研究中，经常通过主观打分的方法从不同视角探究不同知觉自然度的环境对认知的影响。翁配怡等人研究发现，不同开发程度的环境可以引发观者不同程度的自然度感知，且感知程度与知觉恢复量表（Perceived Restorative Scale，PRS）中的远离、延展、魅力和兼容四个分维度均显著相关[13]。在各类自然环境中，水景对认知的改善效果要优于单纯的绿地[1]。一项针对不同森林景观类型的视觉行为特征与认知评价的研究显示，水景，尤其是动态水景，在平均凝视时间、总体满意度等指标上得到了更为积极的评价[14]。与城市环境相比，视觉感知自然环境对注意力和认知处理的要求较低，尤其是水景（如河流、湖泊和海洋）在使人们感觉到放松的指标中，评价显著高于城市环境[15]。

虽然关于水景影响认知的研究已有开展，然而鲜有学者在研究中将水景、自然度与认知相联系。然而，水景的建设需要考虑投资成本——其建设与维护需要大量人力、物力、财力的投入，因此是否建设水景和建设水景的类型常常是投资者、管理者所面临的棘手问题。

基于此，本研究关注视觉层面的知觉自然度，即视觉感知自然度（后文简称“自然度”），探究不同自然度水景对认知的影响，提出并尝试验证如下假设：1）不同自然度水景的主观恢复力存在差异；2）不同自然度水景对于工作记忆的影响有所不同。研究结论有助于公众更好

1 Introduction

Human cognition refers to individuals' perception, memory, reasoning, and imagination towards things and realities and is mainly measured by indicators in restoration, attention, and working memory. Perceived attention can be evaluated with different sorts of scales[1]; while working memory—the ability to temporarily maintain and manipulate information during the execution of cognition tasks—is commonly measured through classic experimental paradigms such as N-back and Stroop[2]. As urbanization accelerates, there is an increase in research proving that natural environments can benefit human health[3], much of which focuses on cognitive benefits[4]. It has been proven that natural environments are conducive to facilitating attention restoration and learning, preventing cognitive impairment, stimulating imagination and creativity, and enhancing inhibitory and persistent self-control[5]~[11]. However, natural environments can affect individuals' cognition in both ways: while improving short-term memories, it weakens people's attention networks such as declining executive control, orienting, and alerting[4].

Naturalness is often regarded as a highly valued property of environment[12]. In Environmental Psychology, subjective scoring is a frequently adopted approach in research on the impact of environments with varied perception of naturalness on cognition from different perspectives. Weng Peiyi et al. found that environments with different development levels trigger the respondents' perception of naturalness to varying degrees, and the perception degree is significantly correlated to the four sub-dimensions of the Perceived Restorative Scale (PRS), namely Being away, Extent, Fascination, and Compatibility[13]. Among various natural environments, waterscapes work better to enhance cognition than mere green spaces[1]. According to a study on visual behavior characteristics and cognitive evaluation of different types of forest landscape spaces, waterscapes, especially dynamic waterscapes, work better in terms of average gaze time and overall satisfaction[14]. Cognitive processing of natural environments is associated with lower attentional and cognitive load, and waterscapes (such as rivers, lakes, and sea) were particularly perceived as much more relaxing than urban scenery[15].

Although scholars have studied the impact of waterscapes on people's cognition, little research explores the correlations among waterscapes, naturalness, and cognition. However, waterscapes require considerable investment of manpower, materials, and funds for construction and maintenance. Project investors and managers often perplex about whether waterscapes, or which types of waterscapes should be constructed.

This research focuses on visual perception of naturalness ("naturalness" hereafter) and investigates the impact of waterscapes of varied naturalness levels on people's cognition, by verifying two hypotheses: 1) subjective restoration varies across waterscapes of varied naturalness levels; and 2) waterscapes of varied naturalness levels affect people's working memory accordingly. The findings of

地通过水景促进认知，有助于投资者、管理者更好地分配资源，同时可以为水景建设的循证设计提供依据。

2 研究方法

2.1 实验设计

本实验采用被试间设计，将被试随机分配到实验组和对照组。实验组分为高自然度水景组、中自然度水景组和低自然度水景组，对照组为城市街景组。每个被试单独进行实验，被试之间不存在相互干扰。

实验开始前，由主试向被试介绍实验目的、程序、不适与保密问题等。实验中，被试在手机端App上进行认知前测后，通过抽签的方式被分入某个实验组或对照组；每组被试分别观看时长5分钟、内容不同的实验材料作为干预，之后填写PRS和恢复结果量表（Restoration Outcome Scale，ROS），并在手机端App上再次进行认知后测。认知前测和后测均包括活动记忆、数字转换和Stroop任务，单次测试时间约为25分钟。每个被试实验用时共计约1小时。

2.2 被试

本实验符合道德伦理标准，通过线上及线下招募被试137名，所有被试均签署了知情同意书并获得了一定的报酬。被试要求身体和心理健康，没有接受过精神治疗或心理辅导，亦无器质性病变及脑外伤。数据有效的被试135人，其中男61人、女74人；被试年龄范围为18 ~ 25岁，平均年龄20.35岁，均为在校本科生和研究生（表1）。

2.3 实验材料

已有研究证实视频、静态图片和幻灯片可以在一定程度上替代真实环境[16]。考虑到实验的可操作性，本研究的实验材料为一系列照片制作而成的PowerPoint文件。所采用照片来源于Scene Gist[17]和LabelMe影像资料库①，以及其他网络资料、研究团队拍摄的照片。选取实验组

表1：各组被试人口学指标
Table 1: Demographics of the participants in each group

组别 Groups	人数 Number of participants	男 Male	女 Female	平均年龄 Average age
高自然度水景组 Waterscapes of high naturalness level	34	17	17	20.24
中自然度水景组 Waterscapes of medium naturalness level	36	16	20	20.42
低自然度水景组 Waterscapes of low naturalness level	35	14	21	20.40
城市街景组 Urban streetscapes	30	14	16	20.35

this research would guide public usage of waterscapes to improve their cognition, improve resource allocations in project investment and management, and inform future waterscape design and construction.

2 Methodology

2.1 Experiment Design

Through a between-subjects experiment, participants in this research were randomized into three experiment groups (waterscapes of high, medium, and low naturalness level, Group W1, W2, W3) and the control group (urban streetscapes, Group S). Each participant took part in the experiment independently to avoid inter-subject influence.

Before the experiment, the participants were informed about the purpose, procedures, discomfort, and confidentiality of the experiment. During the experiment, the participants were firstly instructed to complete a cognition pre-test via a mobile application and then randomly divided into different groups. All participants watched the corresponding experimental materials for 5 minutes before they filled out the PRS and Restoration Outcome Scale (ROS). Finally, they were asked to complete the cognition post-test via the same mobile application. Both cognition pre-test and post-test, each about 25 minutes long, are batteries of running memory, digital shifting, and Stroop tasks. In total, the experiment takes about 1 hour per participant to finish.

2.2 Participants

Conforming to related ethical standards, all 137 participants recruited online/offline signed the informed consents and got paid fairly. All participants should be physically and mentally healthy, have received no psychiatric treatment or psychological counseling, or suffered from any organic lesions or brain trauma. A total of 135 participants (61 males and 74 females) finally selected, all of which were undergraduate and graduate students between 18 and 25 years old, 20.35 on average (Table 1).

2.3 Experiment Materials

Studies have proven that videos, static pictures, and slides are effective substitutes of authentic environments[16]. In this research, PowerPoint slides presenting pictures—sourced from Scene Gist[17], LabelMe①, online or taken onsite by the researchers—are used as stimuli. Morphological characteristics of waterscapes were taken into consideration when selecting pictures for each experiment group. The candidates were sorted into 7 categories, namely fountains/sprays, waterfalls, ditches, streams/rivers, ponds/lakes, wetlands, and seas. The proportion of each category was kept roughly equivalent and covering all naturalness levels. After a three-month-long photo collection and selection, 308 pictures were obtained. In the further screening, after ranking the pictures into high, medium, and low naturalness levels (considering natural characteristics and artificial intervention degree②), a total of 56 representative pictures were obtained, 16 ~ 22 for each rank.


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1-1


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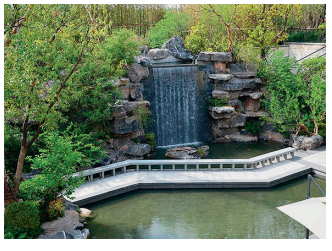
1-2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1-3


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1. 本研究中用于实验的代表照片：高（图1－1）、中（图1－2，取自OJB景观设计事务所的普拉亚维斯塔中央公园）、低（图1－3，取自奥雅设计的上海北方城投佘山玺樾示范区景观）自然度水景组，以及城市街景组（图1－4）各一张。

① 更多信息详见LabelMe影像资料库官方网站。

② 照片中水景自然特性及人工干预程度的评判标准包括：水质澄澈程度、流动性、驳岸类型、植被生长情况／丰茂程度、建构筑物的有／无和建构筑物外形风格、近远景的自然／人工类型。

1. Typical pictures presented in the research: waterscapes of high (Fig. 1–1), medium (Fig. 1–2, Playa Vista Central Park in Los Angeles, California, the USA, designed by OJB Landscape Architecture), and low (Fig. 1–3, Landscape of Sheshan Xiyue Demonstration Zone in Shanghai, China, designed by L&A Design) naturalness level groups, and urban streetscapes group (Fig. 1–4).

① For more information on the database, please visit the official website of LabelMe.

② In the photo screening, the evaluation criteria adopted to grade the natural characteristics of and artificial intervention degree over the waterscapes include: water transparency, water mobility, form of waterfront, lushness of vegetation, presence/absence and appearance of artificial structures, and natural/artificial environment from foreground to background in pictures.

照片时综合考虑了水景的形态特征，涵盖了喷泉／喷雾、跌水瀑布、沟渠、溪流河流、池塘湖泊、湿地、海域7种类型。每种类型的水景照片尽可能数量一致，并且涵盖各种自然度水平。经过三个月的照片搜集与筛选，共遴选水景照片308张。研究者根据照片中水景的自然特性及人工干预程度②对其自然度预设为高、中、低三个水平，并依据照片中水景的代表性进行进一步筛选，最终每组选取照片16～22张，共计56张。

此后，研究者进行线上问卷调查：将筛选出的56张照片的分辨率和图幅进行统一处理，制成问卷并通过问卷星平台线上发放。调查要求问卷填写者根据自己的直观感受，对这些照片中环境的自然度进行里克特量表法评分（1～5分，1分代表低自然度水平，5分代表高自然度水平）。本次线上调查共收回有效问卷141份。计算每张照片的平均得分，用照片自然度得分的最高分和最低分之差除以组数求得组距；再以数据不落在边界值及尽可能确保各组数量均衡为原则，获得高中低三个自然度水平的划分阈值：高水平（3.95，4.76］、中水平［2.83，3.95］、低水平［1.71，2.83）。据此获得高自然度水景组照片22张、中自然度组18张、低自然度组16张。另选取相同分辨率和图幅的对照组照片——不含任何水景的城市街道场景，照片中的主题为道路、广场等城市居民生活、工作中较为常见、较具代表性的纯人工建成环境场景。

其后，按各组照片数量一致、标准差合理、水景类型全面等原则，各组均最终保留16张照片，并分别制成PowerPoint文件，作为实验的直接材料（图1）。本研究参照既有研究设定单张照片总展示时间[18]和播放时长[19]，保证实验干预对于注意力的恢复效益足以达到显著水平。其中图片展示顺序随机，每张照片出现两次、每次出现约8～9s，总放映时长为5分钟；放映画面为15.75cm×21.60cm。

2.4 实验指标

2.4.1 主观指标

为评估不同环境所体现的主观恢复力，本实验采用PRS和ROS评价实验干预对主观认知的影响。一处环境若要具备主观恢复力，需要具备远离、魅力、延展和兼容四个属性：

The researchers then launched an online survey on wjx.cn after synchronizing the resolution and size of the selected pictures. The respondents were required to self-assess their subjective perception on naturalness of the environment in these pictures by scoring with the Likert Scale (1 for low naturalness and 5 for high). A total of 141 valid questionnaires were collected. After calculating the average score of each picture, the researchers worked out the difference between the highest and lowest scored pictures, and divided it by 3 to find the threshold of the high, medium and low ranks. Then, by ensuring that no data fall on the threshold and that the proportion of each range was balanced, the thresholds for three ranks are (3.95, 4.76] for high, [2.83, 3.95] for medium, and [1.71, 2.83) for low. Accordingly, there are 22 pictures in the high-naturalness rank, 18 in the medium-naturalness rank, and 16 in the low-naturalness rank. In addition, streetscape pictures synchronized with the same resolution and size but containing no waterscape were selected for the control group. These pictures are featured with representative urban living or working scenarios of built environments, such as roads and squares.

Finally, aiming at covering most waterscape categories and keeping the smallest standard deviations, 16 pictures were eventually selected in each rank. The pictures were presented in form of PowerPoint slides, as stimuli for the experiment (Fig. 1). To ensure a significant attention restoration outcome, the viewing period for each picture[18] and total duration[19] in this experiment were set referring from previous research: each picture is presented twice in a random order, 8 ~ 9 s per time, and the total duration last about 5 minutes. The display screen was 15.75 cm × 21.60 cm in size.

2.4 Experiment Indicators

2.4.1 Subjective Indicators

PRS and ROS were adopted to assess the four core interrelated factors of an environment with subjective restoration, namely Being Away, Extent, Fascination, and Compatibility.

1）远离（Being Away），指环境因为有别于常规情景而能够使人们产生不同的心理。通过物理意义上真实地“远离”，或者心理意识上“远离”（即分心）日常环境，或两者的融合，人们可以远离责任、义务、追求、目标等压力，因而获得恢复。2）魅力（Fascination），指环境中的内容具有美学价值，使人可以通过注意力转换抵抗疲劳，从而获得恢复。3）延展（Extent），指环境内容和结构丰富且连贯，可以占据大脑足够多的空间，使人能从集中注意的状态得到休息。连通性与范围是延展的两个特性——连通性使人能够将感受到的元素关联起来，构建出一个完整的认知地图；充足的范围将概念化的场景纳入认知地图，使其存在更具意义。4）兼容（Compatibility），指环境所提供的、引导的或要求的活动内容能够很好地契合使用者的目标或倾向，满足人们的爱好与行为需求，使人产生共鸣。[20][21]

PRS基于以上理论架构，对应上述各属性分别设立4个分维度并为其设定评价内容，反映环境对个体所产生的主观恢复作用[20][21]。有研究证实，中文版PRS在对城市公园进行恢复性评价时具有良好的一致性、代表性与适宜性[22]。量表共22道题目，采用里克特量表1～7打分法，判断题中表述与自身感受的符合程度，1分为最不符合，7分为最符合。

在注意力恢复理论和其他前人研究的基础上开发的ROS[23]是研究恢复效果的有效量表，目前应用广泛[24]。其总共包含6道题目，用以反映环境主观恢复力的结果，包括注意力恢复、清楚思维、放松与平静三个分维度（其中注意力恢复维度只包含一道题目）；量表采用里克特量表1～7打分法，判断题中表述与自身感受的符合程度，1分为最不符合，7分为最符合。

2.4.2 客观指标

工作记忆主要通过中央执行系统刷新、转换、抑制的核心功能进行表达，这三种功能相对独立，可以通过不同的指标进行反映[25]。本研究采用李雪冰等人基于该理论开发的App[26]在干预前后分别进行测评，以此评价实验干预对工作记忆的影响（表2）。该App仅适用于安卓系统的手机。

（1）活动记忆任务

活动记忆反映中央执行系统的刷新功能。被试会看到5～9个随机出现的数字，每个数字显示1,000毫秒，间隔800毫秒。被试被要求不断更新记忆，当数字呈现完毕后，填写出最后4个数字。任务包括14个试次，4个数字全部正确计为正确，活动记忆正确率＝正确试次／总任务试次×100%。

（2）数字转换任务

任务转换反映中央执行系统的转换功能，要求被试在不少于两个的简单任务间进行转换。数字转换任务是一种常用的任务转换范式：任务分为数字大小重复判断、奇偶重复判断和根据颜色做大小或奇偶转换判断三个阶段，每个阶段会出现32个数字。阶段一随机呈现除5之外1～9的数字，比5大按左键，比5小按右键；阶段二随机出现除5之外1～9的数字，奇数按左键，偶数按右键；阶段三随机出现带有颜色的、除5之外1～9的数字，蓝色的数字要求被试判断大小（比5大按左键，比5小按

1) Being Away, meaning that the environment at least in principle, frees one from daily routines so that a sense of being away can come about. By getting distance geographically or psychologically (i.e. getting distracted) or some mix of the two, one could escape from the pressures of responsibilities, obligations, pursuits, and goals, thus achieve subjective restoration. 2) Fascination, can be brought up by the contents in the environment that are aesthetically pleasing, capable of drawing effortless attention that is likely to be resistant to fatigue, thus support subjective restoration. 3) Extent, refers to the environment that is rich and coherent in contents and structures, which may take up a substantial portion of the available room in one's head, allowing for the relief of directed attention fatigue. It is a function of connectedness and scope: with connectedness, one can relate the immediately perceived elements or features of the environment as coherent cognitive maps; and a substantial scope adds conceptual domain and meanings to the maps. 4) Compatibility means that the purposive and required activities informationally supported by the environment well match individuals' goals or inclinations, thus resonate with them.[20][21]

Therefore, PRS measures the subjective restoration of an environment by 4 subscales, corresponding to each factor[20][21]. The Chinese version of PRS has been proven its consistency reliability and generally coherent in evaluating the restorative qualities of urban parks[22]. The scale consists of 22 items and a seven-point Likert Scale, where 1 indicates the lowest consistency and 7 indicates the highest.

The ROS[23], developed based on the attention restoration theory and previous measures, is a widely accepted, effective instrument to study subjective restoration outcomes of the environment[24]. It comprises 6 items from 3 subscales, namely attention restoration, clearing one's thoughts, and relaxation and calmness, with only one item for attention restoration. This is a seven-point Likert Scale that requires the participants to rate their degree of feelings, 1 indicates “not at all” and 7 indicates “completely.”

2.4.2 Objective Indicators

Working memory performs through the updating, shifting, and inhibiting process of the central executive system. These functions are considered relatively independent and can be measured by different indicators[25]. A smartphone application[26] developed by Li Xuebing et al. was used for the pre-test and post-test to measure the effect of the stimuli on working memory (Table 2). The application works on Android system only.

(1) Running memory task

Running memory task can test the updating function of central executive system. To keep their memory updated, the participants were firstly presented with 5 ~ 9 random digits, 1,000 ms per display with 800 ms as intervals, and then instructed to recall the last 4 digits once the last number vanished. The task trial would repeat for 14 times and only be counted as “correct” when all 4 digits were filled in correctly. Running memory accuracy = correct trials / total task trials × 100%.

表2：中央执行系统工作记忆指标
Table 2: Indicators for working memory of central executive system

功能 Functions	任务类型 Task types	具体指标 Indicators
刷新 Updating	活动记忆任务 Running memory task	活动记忆正确率 Running memory accuracy
转换 Shifting	数字转换任务 Digital shifting task	转换代价 Shifting cost
抑制 Inhibition	Stroop任务 Stroop task	Stroop效应 Stroop effect
		Stroop基线正确率 Stroop baseline accuracy
		Stroop冲突正确率 Stroop conflict accuracy

右键），黄色的数字要求被试判断奇偶（奇数按左键，偶数按右键）。

在本研究中，数字转换任务使用转换代价作为具体指标。转换代价指重复任务（即阶段一、二）与转换任务的反应时的差值：转换代价＝阶段三平均反应时－（阶段一平均反应时＋阶段二平均反应时）/ 2。任务完成得越好转换代价越小。[25]

（3）Stroop任务

Stroop任务用于反映中央执行系统的抑制功能。本研究采用经典Stroop实验范式的数字变式。任务分为基线与冲突两个阶段，每个阶段各出现40个字符或数字。基线阶段中，被试会在屏幕中看到字符串，并被要求尽快正确地判断字符的个数，按键作答（如屏幕出现XXX，就按3）。冲突阶段中，字符串改为数字，被试需要尽快正确地判断数字的个数，并按键作答（如屏幕出现111，就按3）。正式开始任务前，被试者会分别进行10次练习。

在本研究中，Stroop任务使用Stroop效应与正确率作为具体指标。其中，Stroop效应指冲突情境与一致情境或无关情境反应时之差，Stroop效应值越高，说明抑制功能越差；正确率分为基线正确率与冲突正确率。

2.5 数据分析

研究利用SPSS Statistics 25及EXCEL进行数据的整理、统计与分析。对PRS和ROS的不同组别各维度指标进行单因素方差分析；对各认知指标进行各组别前测和后测的重复测量方差分析。

3 研究结果

3.1 PRS评价结果

单因素方差分析结果显示，实验组及对照组的各维度均具有显著差异，表现为远离F（3，131）=12.9，p=0.000，魅力F（3，131）=10.7，p=0.000，延展F（3，131）=2.6，p=0.052，兼容F（3，131）=15.6，p=0.000（图2）。

(2) Digital shifting task

Shifting task can characterize the shifting function of central executive system, which requires the participant to shift between two or more simple tasks. Typically, digital shifting task involves three phases—repeated value comparison, repeated parity telling, and shifts between these two—and 32 digits were presented in each phase. In Phase I, the participants need to compare 5 to the value of the randomly presented digit—ranging from 1 ~ 9 but excluding 5—and hit the left button when the digit is bigger and the right otherwise. In Phase II, with the same setting, hit the left button for odd digits and the right for even ones. In Phase III, the participants were asked to do the value comparison task when the digit is blue and the parity telling task when the digit is yellow.

In this research, shifting cost—the difference in reaction time between the repetitions (i.e. Phase I and II) and shifts—was adopted as the indicator to measure the performance of digital shifting task. Shifting cost = average reaction time in Phases III–(average reaction time of Phase I + average reaction time of Phase II) / 2. The better the performance, the smaller the shifting cost.[25]

(3) Stroop task

Stroop task can measure the inhibition function of central executive system. Digital variant, a classic Stroop task paradigm, was introduced. This task involves phases of the baseline and the conflict and each presents 40 characters or digits. In the baseline phase, presented with a string of characters, the participants were instructed to enter the amount of characters as quickly as possible (for example, enter “3” if “XXX” was presented). In the conflict phase, a string of digits was presented, and the participants were asked to enter the amount of digits as soon as possible (for example, press “3” if “111” was presented). Before the formal task, all participants were required to go through 10 exercise sessions.

The Stroop effect and the accuracy rate of both phases were indicators for the Stroop task. Stroop effect is the difference in the reaction time between the two phases: the higher the Stroop effect score, the worse the inhibition function.

2.5 Data analysis

The SPSS Statistics 25 and MS Office Excel were employed for data sorting, statistics, and analyses, i.e. the single factor analyses of variance for all subscales of PRS and ROS, and the repeated measures analyses of variance for each cognitive indicator in pre- and post-tests.

3 Findings

3.1 PRS Results

Single factor analyses of variance shows significant differences between the experiment groups and the control group in all subscales: Being Away $F(3, 131) = 12.9$, $p = 0.000$; Fascination $F(3,131) = 10.7$, $p = 0.000$; Extent $F(3, 131) = 2.6$, $p = 0.052$; and Compatibility $F(3, 131) = 15.6$, $p = 0.000$ (Fig. 2).

进一步进行LSD事后检验发现：在远离维度，高自然度水景显著高于低自然度水景（p=0.005）和对照组（p=0.000）；中自然度水景和对照组之间边缘显著（p=0.055）。在魅力维度，高自然度水景显著高于中自然度水景（p=0.019）、低自然度水景（p=0.009）和对照组（p=0.000）；对照组同时显著低于中自然度水景（p=0.001）和低自然度水景（p=0.002）；中、低自然度水景组间在魅力维度未见显著差异。在延展维度，高自然度水景组（p=0.032）和中自然度水景组（p=0.022）均显著高于对照组。在兼容维度，高自然度水景显著高于中自然度水景（p=0.026）、低自然度水景（p=0.016）和对照组（p=0.000）；对照组同时显著低于中自然度水景（p=0.00）和低自然度水景（p=0.00）。

3.2 ROS评价结果

单因素方差分析结果显示，实验组与对照组各组间注意力恢复维度不存在显著差异，F（3，131）=1.9，p=0.125；清楚思维维度存在显著差异F（3，131）=3.4，p=0.020，放松与平静维度存在显著差异，F（3，131）=4.3，p=0.006（图3）。

进一步进行LSD事后检验发现：在注意力恢复维度，低自然度水景显著高于中自然度水景（p=0.033），也边缘显著高于对照组（p=0.058）。在清楚思维维度，对照组显著低于高自然度水景（p=0.005）和低自然度水景（p=0.010）。在放松与平静维度，对照组显著低于高自然度水景（p=0.001）、中自然度水景（p=0.022）和低自然度水景（p=0.003）。

The LSD (least significant difference) post hoc test discloses that in terms of Being Away, Group W1 scored significantly higher than both Group W3 (p = 0.005) and Group S (p = 0.000), and a marginally significant variance is found between Group W2 and Group S (p = 0.055). Regarding Fascination, Group W1 scores significantly higher than Group W2 (p = 0.019), W3 (p = 0.009), and S (p = 0.000); Group S scores significantly lower than Group W2 (p = 0.001) and W3 (p = 0.002); and there is no significant difference between Group W2 and W3. As for Extent, both Group W1 (p = 0.032) and W2 (p = 0.022) score significantly higher than Group S. In respect of Compatibility, Group W1 scores significantly higher than Group W2 (p = 0.026), W3 (p = 0.016), and S (p = 0.000); and Group S scores significantly lower than Group W2 (p = 0.00) and W3 (p = 0.00).

3.2 ROS Results

The single factor analyses of variance show no significant differences among the experimental groups and the control group in attention restoration [F (3, 131) = 1.9, p = 0.125)], but significant differences in clearing one's thoughts [F (3, 131) = 3.4, p = 0.020)] and relaxation and calmness [F (3, 131) = 4.3, p = 0.006)] (Fig. 3).

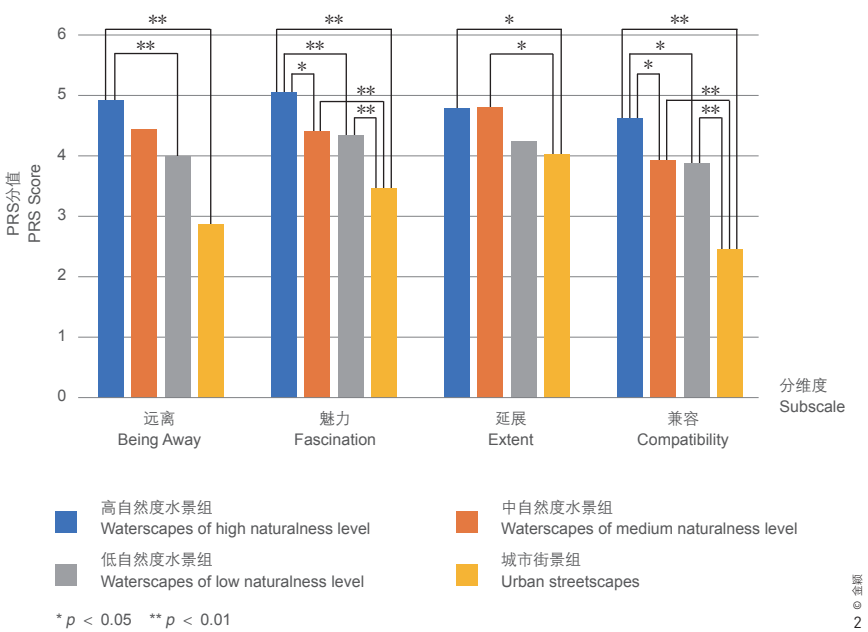
The LSD post hoc tests prove that the score of Group W3 is significantly higher than Group W2 (p = 0.033), and marginally higher than Group S (p = 0.058) in terms of attention restoration. As for clearing one's thoughts, Group S scores significantly lower than Group W1 (p = 0.005) and W3 (p = 0.010). Concerning relaxation and calmness, Group S scores significantly lower than W1 (p = 0.001), W2 (p = 0.022), and W3 (p = 0.003).

2. PRS结果及各维度均值分析
3. ROS结果及各维度均值分析

2. Analyses on mean value of each subscale in PRS
3. Analyses on mean value of each subscale in ROS

3.3 Working Memory Task Outcome

The repeated measures analyses of variance about the accuracy of running memory tasks show no significant main effects on naturalness or time point, and a



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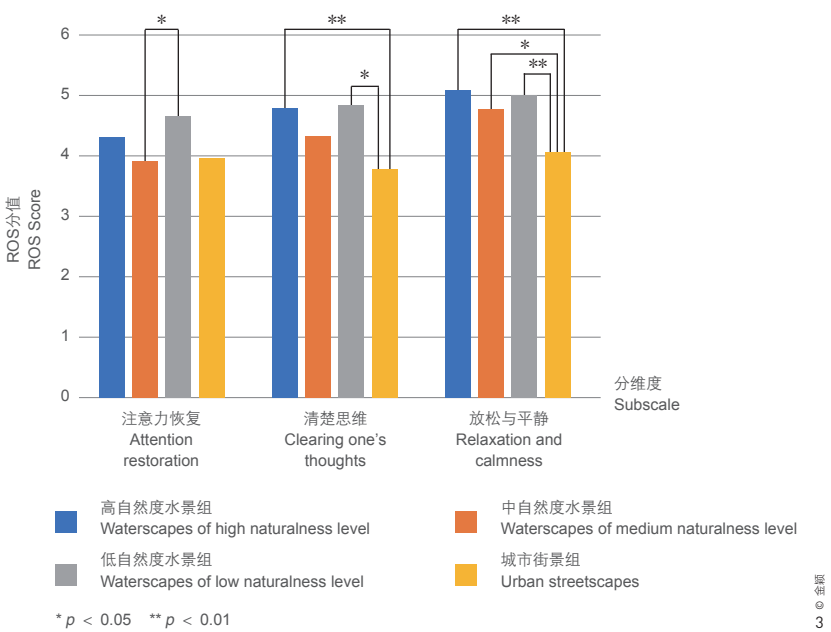

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表3：活动记忆正确率多变量检验[a]

Table 3: Multivariate test on running memory task accuracy[a]

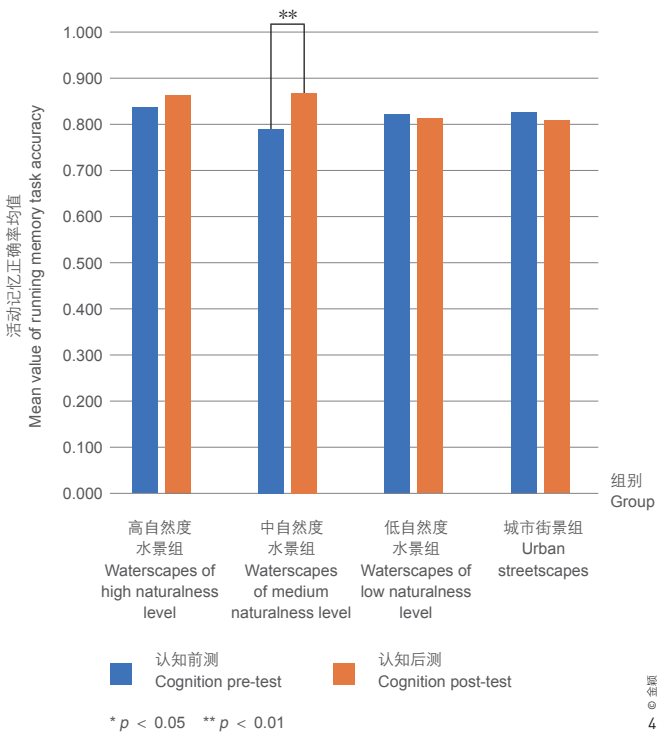
效应 Effect		值 Value	F	假设自由度 Degree of freedom for hypothesis	误差自由度 Degree of freedom for error	显著性 Significance	偏Eta平方 Partial eta squared
时间点 Time point	比莱轨迹 Pillai's trace	0.126	18.885[b]	1.000	131.000	0.000	0.126
	威尔克λ Wilks' lambda	0.874	18.885[b]	1.000	131.000	0.000	0.126
	霍特林轨迹 Hotelling's trace	0.144	18.885[b]	1.000	131.000	0.000	0.126
	罗伊最大根 Roy's largest root	0.144	18.885[b]	1.000	131.000	0.000	0.126
时间点×自然度 Time point × naturalness	比莱轨迹 Pillai's trace	0.018	0.784[b]	3.000	131.000	0.505	0.018
	威尔克λ Wilks' lambda	0.982	0.784[b]	3.000	131.000	0.505	0.018
	霍特林轨迹 Hotelling's trace	0.018	0.784[b]	3.000	131.000	0.505	0.018
	罗伊最大根 Roy's largest root	0.018	0.784[b]	3.000	131.000	0.505	0.018

注

a代表设计：截距；b代表精确统计。

NOTE

a means Designed intercept; b means Exact statistics.



4. 活动记忆正确率前后测均值图

4. Chart of mean value of running memory task accuracy in pre- and post-tests

3.3 工作记忆评价研究结果

重复测量方差分析结果显示：在活动记忆正确率方面，自然度主效应不显著，时间点主效应不显著，自然度×时间点交互作用显著（表3）。进一步的简单效应分析结果显示，中自然度水景组后测显著高于前测（$p=0.001$），这表明经过中自然度水景的干预，被试的活动记忆正确率显著上升（图4）。

在转换代价方面，自然度主效应不显著；时间点主效应显著；自然度×时间点交互作用不显著（表4）。进一步的简单效应分析结果显示，低自然度水景（$p=0.027$）和对照组（$p=0.001$）后测均值低于前测。转换代价越低说明转换功能越高，这一结果显示低自然度水景和对照组被试的转换功能经干预后有显著提高（图5）。

在Stroop冲突效应方面，自然度主效应不显著；时间点主效应不显著；自然度×时间点交互作用不显著（表5）。进一步的简单效应分析结果显示，高自然度水景组后测均值低于前测（$p=0.013$），这表明经过高自然度水景的干预，抑制功能得到了一定提升（图6）。

在Stroop基线正确率和Stroop冲突正确率方面，主效应和交互作用均不显著。这一结果可能说明5分钟的幻灯片干预任务不足以影响Stroop的正确率。

significant interactive effect between these two influences (Table 3). Further simple-effect analyses evidence that Group W2 scores significantly higher in post-tests than the pre-tests ($p = 0.001$), meaning that waterscapes of medium naturalness level can significantly promote the participants' working memory task accuracy (Fig. 4).

With regard to shifting cost, there established significant main effects on time point but not on naturalness, nor significant interactive effect between these two influences (Table 4). Further simple-effect analyses show that the post-tests of both Group W3 ($p = 0.027$) and Group S ($p = 0.001$) score lower in the pre-tests. The lower the shifting cost, the better the shifting performance. The results suggest that stimuli for Group W3 and S significantly improved the participants' shifting function (Fig. 5).

In terms of the Stroop effect, there showed no significant main effect on naturalness or the time point, nor significant interactive effect between these two factors (Table 5). Further simple-effect analyses show that Group W1 scores lower in post-tests than in pre-tests ($p = 0.013$), suggesting that waterscapes of high naturalness level facilitated the inhibition function (Fig. 6).

As regards the accuracy rate of baseline and conflict phases in Stroop tasks, neither significant main effect nor significant interactive effect is displayed, indicating that a 5-minute-PowerPoint stimulation may be not enough to affect the accuracy rate of Stroop task.

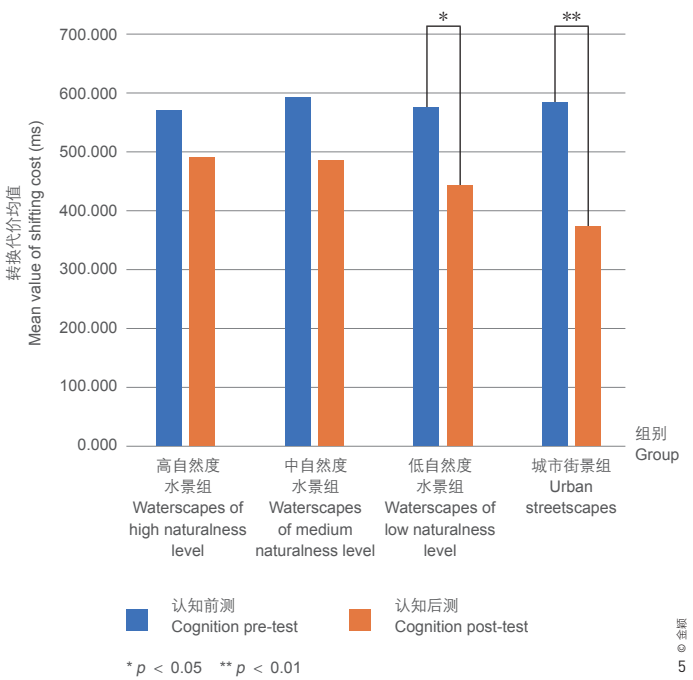
表4：转换代价多变量检验[a]

Table 4: Multivariate test on shifting cost[a]

效应 Effect		值 Value	F	假设自由度 Degree of freedom for hypothesis	误差自由度 Degree of freedom for error	显著性 Significance	偏Eta平方 Partial eta squared
时间点 Time point	比莱轨迹 Pillai's trace	0.016	2.178[b]	1.000	131.000	0.136	0.017
	威尔克λ Wilks' lambda	0.984	2.178[b]	1.000	131.000	0.136	0.017
	霍特林轨迹 Hotelling's trace	0.017	2.178[b]	1.000	131.000	0.136	0.017
	罗伊最大根 Roy's largest root	0.017	2.178[b]	1.000	131.000	0.136	0.017
时间点×自然度 Time point × naturalness	比莱轨迹 Pillai's trace	0.035	1.606[b]	3.000	131.000	0.022	0.071
	威尔克λ Wilks' lambda	0.965	1.606[b]	3.000	131.000	0.022	0.071
	霍特林轨迹 Hotelling's trace	0.037	1.606[b]	3.000	131.000	0.022	0.071
	罗伊最大根 Roy's largest root	0.037	1.606[b]	3.000	131.000	0.022	0.071

注
a代表设计：截距；b代表精确统计。

NOTE
a means Designed intercept; b means Exact statistics.



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5. 转换代价前后测均值图
5. Chart of mean value of shifting cost in pre- and post-tests

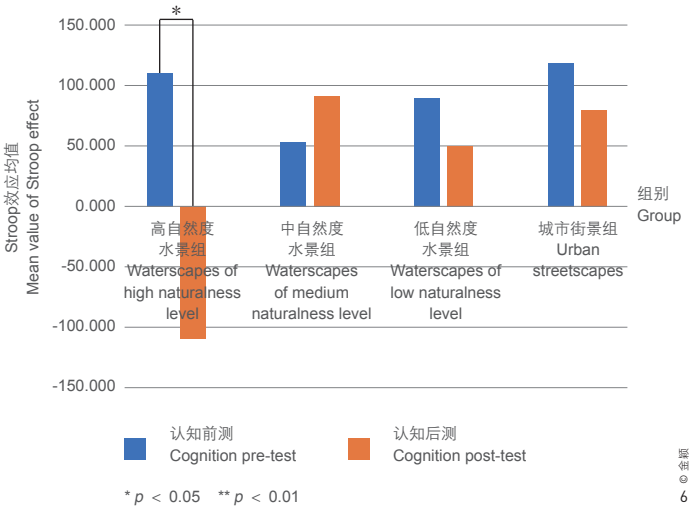
表5：Stroop效应多变量检验[a]

Table 5: Multivariate test on Stroop effect[a]

效应 Effect		值 Value	F	假设自由度 Degree of freedom for hypothesis	误差自由度 Degree of freedom for error	显著性 Significance	偏Eta平方 Partial eta squared
时间点 Time point	比莱轨迹 Pillai's trace	0.017	2.246[b]	1.000	131.000	0.142	0.016
	威尔克λ Wilks' lambda	0.983	2.246[b]	1.000	131.000	0.142	0.016
	霍特林轨迹 Hotelling's trace	0.017	2.246[b]	1.000	131.000	0.142	0.016
	罗伊最大根 Roy's largest root	0.017	2.246[b]	1.000	131.000	0.142	0.016
时间点×自然度 Time point × naturalness	比莱轨迹 Pillai's trace	0.071	3.322[b]	3.000	131.000	0.191	0.035
	威尔克λ Wilks' lambda	0.929	3.322[b]	3.000	131.000	0.191	0.035
	霍特林轨迹 Hotelling's trace	0.076	3.322[b]	3.000	131.000	0.191	0.035
	罗伊最大根 Roy's largest root	0.076	3.322[b]	3.000	131.000	0.191	0.035

注
a代表设计：截距；b代表精确统计。

NOTE
a means Designed intercept; b means Exact statistics.



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6. Stroop效应前后测均值图
6. Chart of mean value of Stroop effect in pre- and post-tests

4 讨论

4.1 PRS和ROS分析

4.1.1 PRS分析

量表中远离与延展维度结果类似，表明人们明显能够感觉到高自然度水景相对于城市街景更具有远离性和延展性，中自然度水景也具备一定的远离性和延展性，但低自然度水景与城市街景在这两个属性方面并未见显著差异。或许是因为高自然度水景与人们日常生活场景之间的差异最大，且其内容和结构能够占据大脑足够多的空间[11]，因此展现出高远离性和延展性；而中、低自然度水景在这两方面的表现相对较弱。

量表中魅力与兼容维度结果类似，所有实验组数据均高于对照组，说明魅力与兼容或为不同自然度水平水景共有的特征。究其原因，或许在于水景作为自然环境的一种类型，其本身即能展现出魅力[11]；同时水景能够提供特定的活动内容、契合人们的使用需求，因而展示出兼容的特性。这一结果可与艾哈迈德·赫米等人的研究结果相互印证[27][28]。

综合来看，高自然度水景似乎在主观恢复力方面表现最为突出——在远离维度显著高于低自然度水景，延展维度显著优于对照组，魅力和兼容维度显著高于中、低自然度水景。相对于城市街景，中自然度水景可以使人们产生明显的远离感和延展感，而低自然度水景则不能。这意味着在三种自然度水平的水景中，高自然度水景的主观恢复力效果最好，其次是中自然度水景，最后是低自然度水景。

4.1.2 ROS分析

在注意力恢复维度，低自然度水景显著优于中自然度水景和城市街景；在清楚思维维度，高和低自然度水景都显著优于城市街景；在放松与平静维度，所有水景都显著优于城市街景，这与西蒙·格拉西尼等人的研究结果相一致[15]。

相较于其他自然度水平水景，低自然度水景综合表现最优：其三项维度均明显优于对照组，在注意力恢复维度甚至显著优于中自然度水景。综合表现次优的是高自然度水景，在清楚思维和放松与平静两个维度均显著优于对照组。

4.1.3 PRS和ROS的比较分析

比较分析PRS和ROS的实验结果，发现高自然度水景在PRS四个维度的表现都最突出，这可能意味着高自然度水平很好地契合了注意力恢

4 Discussions

4.1 Analyses of PRS and ROS Results

4.1.1 PRS Result Analysis

In PRS, the results of Being Away and Extent are comparable: both can be better perceived by participants in waterscapes of high naturalness level than in urban streetscapes; waterscapes of medium naturalness level can arouse these two senses to some extent; there is no significant difference between waterscapes of low naturalness level and urban streetscapes. The above results could be explained by the fact that waterscapes of high naturalness level are least seen in people's daily scenarios, and are environments with contents and structures of sufficient scope to engage the mind[11]. In contrast, the effect of waterscapes of medium and low naturalness level are less obvious.

The results in Fascination and Compatibility show that both factors are rated the lowest in the control group, suggesting that waterscapes across varied naturalness levels all have the properties of fascination and compatibility. It could be that fascination was an inherent characteristic of waterscapes, as a type of natural environments[11]. Moreover, waterscapes can combine with specific programs and activities to meet people's various use demands. Such results are consistent with the findings of Ahmed Hemi et al.[27][28]

In general, waterscapes of high naturalness level perform the best subjective restoration, performing significantly better than waterscapes of low naturalness level in terms of Being Away, than urban streetscapes in respect of Extension, than waterscapes of low and medium naturalness level in Fascination and Compatibility. As for Being Away and Extent, waterscapes of medium naturalness level work significantly better than that of low naturalness level and urban streetscapes. That is to say, waterscapes of high naturalness level can lead to the best subjective restoration outcome, followed by the waterscapes of medium and low naturalness level.

4.1.2 ROS Result Analysis

Waterscapes of low naturalness level perform significantly better than waterscapes of medium naturalness level and urban streetscapes in terms of attention restoration; both waterscapes of high and low naturalness level perform significantly better than urban streetscapes in terms of clearing one's thoughts; and all waterscapes perform significantly better than urban streetscapes in terms of relaxation and calmness. The results are consistent with the findings of Simone Grassini et al.[15]

Among the waterscapes groups, waterscapes of low naturalness level excel in all three subscales, performing significantly better than urban streetscape and even than waterscapes of medium level in attention restoration. Waterscapes of high naturalness level were rated second, performing significantly better than urban streetscapes in clearing one's thoughts and relaxation and calmness.

4.1.3 Comparative Analysis of PRS and ROS Results

The PRS results show that waterscapes of high naturalness level ranked the first in all four subscales of PRS, suggesting that the environments of high naturalness level

复理论的环境属性；但从ROS评价结果来看，高自然度水景的恢复结果并不如预期突出，尤其是在注意力恢复方面，甚至不如低自然度水景。如果仅从量表的总分来分析，本实验结果并不支持“主观恢复力高导致恢复结果好”的结论。深入分析量表的各个指标，远离、魅力、兼容的属性似乎与放松与平静的结果更加匹配。对于注意力恢复的结果，高、中自然度水景组与对照组之间均未见显著差异。

4.2 工作记忆评价指标分析

从不同自然度水平来看，高自然度水景组的Stroop冲突效应后测均值显著小于前测，即Stroop冲突反应时与基线反应时之差显著减小，说明高自然度水景的干预缓解被试的Stroop冲突效应，对于抑制功能的提升有积极影响。或许是由于高自然度水景可以使人获得更多放松、平静的体验，使大脑的休息更加充分，进而提高了抑制功能。中自然度水景干预对于活动记忆正确率的提高效果显著，说明中自然度水景显著提高了中央执行系统的刷新功能。低自然度水景和城市街景干预显著降低了转换代价，或可说明通过这两种环境的干预，转换功能显著提升。

上述结果与本实验ROS评价分析中低自然度水景在注意力恢复维度得分最高的结果相互印证。值得注意的是，对照组的转换代价也显著下降，说明城市街景这类人工建成环境与低自然度水景存在某些相同的特征，使得转换功能一直处于激活状态。

除此之外，工作记忆的其他指标并没有表现出干预导致的显著影响。从Stroop冲突效应的均值图分析，经中自然度水景干预后，Stroop冲突展现出上升的趋势，与此前注意力网络功能有一定下降的研究结果相呼应[4]（图6）。

对于PRS、ROS和工作记忆测评的实验结果，其原因可能在于三者都与改善认知的内在机制有关。PRS和ROS都基于注意力恢复理论而编制，注意力恢复理论强调自然环境可以使人从注意力疲劳状态中恢复，而工作记忆有可能通过认知训练促进发展[2]。

4.3 不同自然度水景的特点及其对设计使用的参考

经过在线问卷调查得出的不同自然度的水景照片组中，除低自然度水景组不包括海域外，每组都包括了所有的水景类型，但不同类型的

might well meet with the subjective restoration properties of attention restoration theory. However, the ROS results evidence that the restoration outcomes of waterscapes of high naturalness level are not as satisfactory as expected, especially in terms of attention restoration (Group W1 scored even lower than Group W3). According merely to the total score of both scales, the results of this experiment does not prove that “high subjective restoration leads to good restoration outcomes.” In-depth analyses of each item lead to the conclusion that the shown correlations between naturalness level and restoration in Being Away, Fascination, and Compatibility seem to be in line with the shown correlation between naturalness level and relaxation and calmness. In addition, group comparisons show that there is no significant difference among the experiment groups and the control group in terms of attention restoration.

4.2 Analyses of Working Memory Indicators

Concerning the variety of naturalness levels, participants in Group W1 generally performed significantly better in the post-test than pre-test during the conflict phase of Stroop task, i.e. the difference of reaction time between the conflict phase and baseline was narrowed, meaning that waterscapes of high naturalness alleviated the Stroop effect, helping enhance the inhibition function. Such progress could be achieved through senses of relaxation and calmness aroused by waterscapes of high naturalness level and allow for better mind relax. Waterscapes of medium naturalness level significantly boosted running memory task accuracy, suggesting that they can improve the updating function of central executive system. Waterscapes of low naturalness level and urban streetscapes significantly reduced the shifting cost, possibly because they can reinforce the shifting function.

The results above are consistent with the ROS results on waterscapes of low naturalness level, as they performed the best in terms of attention restoration. It is worth noting that urban streetscapes also caused a significant plummet in shifting cost, indicating that artificially built urban streetscapes share some similarities with waterscapes of low naturalness level, which keep the shifting function activated.

Apart from that, the stimuli show no significant impact on working memory measured by other indicators. According to the chart of mean value graph of Stroop effect in pre- and post-tests, waterscapes of low naturalness level bring an upturn in the effect, which is consistent with previous results of declining attention networks[4] (Fig. 6).

The research results of PRS, ROS, and working memory tasks possibly because they all can somehow impact the internal mechanism of cognition enhancement. Both PRS and ROS are developed on attention restoration theory, which points out that the natural environment can support recovery from attention fatigue and working memory can be improved by training[2].

4.3 Characteristics of Waterscapes of Varied Naturalness Levels and Related Design Suggestions

Sorted by the online survey, although the low-naturalness rank of waterscape

水景在不同自然度水平中占比不同。高自然度水景组中，海域、池塘湖泊、溪流河流、瀑布跌水、湿地占比较高；中自然度组与高自然度组水景相比，海域占比有所下降；低自然度组中喷雾喷泉占比较高，也包含沟渠、瀑布跌水、溪流河流、池塘湖泊。

高自然度水景组驳岸曲折自然，有完全自然的石、滩、土驳岸；周边以山、植物、天空等自然元素主；有岛、峡谷等内容。其中大部分都没有人工构筑物，但也有两张例外——一张照片中，喷雾将驳岸上的建筑与照片观看者隔离开；另一张照片中建筑物本身体量很小，并且在周边山水的夹持下存在感更弱。中自然度组照片中人工砌筑、修建的痕迹明显增加，包括建筑、亭、桥等元素，石质驳岸人工砌筑痕迹明显，但驳岸线形以曲线为主，岸边栽有植被。低自然度组中绝大多数水景边界为人工建造的几何形态，并多配以规则式种植。

如前所述，高自然度水景展示出更加全面的主观恢复力及显著的恢复性结果，且对中央执行系统的抑制功能有显著的提升。因此，若以恢复注意力水平、清楚思维、放松平静等为主要建设或使用目的，可优先选择高自然度水景；若注重注意力恢复水平的促进及转换功能提升，可优先选择低自然度的水景。

以上实验材料制备过程及实验结果中所体现出的不同自然度水平水景的特点，可以为相关水景观设计和使用提供参考。

4.4 不足与未来展望

对于实验材料，实验采用PowerPoint放映照片的方式，相对于视频、虚拟现实、真实环境而言，环境表达的真实性有待提高。未来可以考虑采用其他可增加实验生态效度的研究方法。有研究指出，距离水体过近可能会引起恐惧的心理[29]，这种空间属性在本研究中并未得到体现。5分钟的总干预时间虽然建立在既有实证研究基础上[19]，但也有研究采用了如10分钟、20分钟的更长干预时间[30][31]。本次实验中多项指标并未出现显著差异，也可能是干预时间较短的原因所致。

从研究结果来看，低自然度水景并不具备远离性和延展性，这一结果可能与被试个体对于自然度的界定相关。西尔维娅·科拉多等人的研究结果显示，生活在城市、山区和农业区的孩子们对于自然意象的理解完全不同[32]。本研究未对被试的生活背景进行调查分析，未来应该将

pictures did not include seas, the other two ranks covered all waterscape categories, the proportion of each varies though. In the high-naturalness rank, categories of seas, ponds/lakes, streams/rivers, waterfalls, and wetlands account for a large ratio. In the medium-naturalness rank, the share of seas is smaller. In the low-naturalness rank, fountains/sprays account for a larger proportion, with other categories such as ditches, waterfalls, streams/rivers, and ponds/lakes.

In the high-naturalness rank, there are entirely natural shallows or winding rock or mud banks, surrounded by natural elements such as mountains, vegetation, and sky, whereas islands and canyons are also seen in some of the pictures. Pictures in this rank present no artificial structures with two exceptions: in one picture, the structures on the bank were screened by mist; in the other, the structure in a humble size is overwhelmed by its surrounding mountains and waterscape. Both structures in the pictures are insignificant to the viewers. In the medium-naturalness rank, artificial structures (e.g. buildings, pavilions, and bridges) are more visible, especially the curving stone revetments with riparian vegetation. Most waterscapes in the low-naturalness rank are restricted with artificial geometrical boundaries and with regular plantings.

In this research, waterscapes of high naturalness level show more comprehensive subjective restoration and significant restoration outcomes, and a stronger effect to the inhibition function of central executive system. In design practice, waterscapes of high naturalness level are recommended for the projects that attempt to improve visitors' attention restoration, clearing one's thoughts, and relaxation and calmness, while waterscapes of low naturalness level are advised for projects that support improving visitors' attention restoration and shifting function.

The characteristics of waterscapes of varied naturalness levels summarized upon the online survey and the results of the experiment can be used as references for related waterscape usage and design practice.

4.4 Limitations and Prospects

In this research, the stimuli are PowerPoint slides presenting static pictures, thus less effective in ecological validity than videos, virtual reality, and authentic environments. This can be alleviated through adopting new research methods in the future. Existing studies evidence that getting too close to water bodies can cause fear[29], which is not supported by this research. In addition, although a 5-minute stimulation was found effective in previous empirical research[19], there are also experiment cases that adopted longer stimuli duration such as 10 and 20 minutes[30][31]. The shorter stimuli duration in this research might lead to the insignificant differences in several indicators.

The research results suggest that waterscapes of low naturalness level cannot arouse senses of being away and extent, possibly resulting from the participants' preference on naturalness. A research by Silvia Corrado et al. proved that there is a significant differentiation among children's conceptualizations of the natural world who live in different places (urban, rural mountain range, and rural agricultural)[32]. Hence, the participants' life experience and their familiarity with the waterscapes

被试的生活经验、对实验材料的熟悉程度等因素纳入实验考量之中。另外，主观恢复力与恢复性结果之间的不一致，可能是由量表的中文表达产生的理解偏差，或者量表不适用于这种自然度不同但内容高度相似的实验材料所致。

在本实验中，对照组场景内容是城市街道，如果替换成兼具功能与艺术性的建筑作品，实验结果在兼容维度是否会有差异也值得在未来做进一步的深入探讨。同样地，针对低自然度水景对注意力恢复效果最好的研究结果，以及由此引发的自然度与注意力恢复结果之间相关性的问题，仍然需要更多研究进行深入探索。

从机制的角度分析，注意力恢复理论认为，自然环境是诱导个体注意力从定向注意到不定向注意转变的有效方式[11]。定向注意力的恢复或许是工作记忆指标提高的原因之一，但这尚不能解释为何不同自然度水平的水景会对中央执行系统的不同功能产生差异化的影响，其内在的联系机制还有待更加深入的研究。

水景本身除了视觉特征外，还有听觉、嗅觉、触觉等丰富的感官属性。以听觉为例，丹尼尔·帕顿等人通过对16种水声采样，探索了声学参数与人体舒适度的关系，发现谐波相关的信息与偏好有关，而瀑布式、喷射式喷泉的声音使人感到厌恶[33]。这些除视觉之外的其他感官信息可能会对人的感知体验造成较大影响。本研究仅从视觉感知的角度分析了水景对人所产生的认知效益，未来中可针对水景的多种感官属性及其所引发的行为展开进一步研究。

5 结论

本研究发现，相较于城市街景，人们对任何自然度的水景都给予了更高的魅力和兼容性评价，并且认为其能够产生较好的放松与平静作用；高、中自然度水景具有显著的远离性与延展性；高自然度水景还能够显著提高中央执行系统的抑制功能；中自然度水景对于中央执行系统的刷新功能提升效果最优；低自然度水景对于注意力恢复有良好的效果，有助于中央执行系统转换功能的提升。这意味着，在理论上，高、中自然度水景相对于低自然度水景具备更高的主观恢复性力；从恢复结果及对工作记忆的影响来看，各自然度水景在不同的认知指标上存在不同的优势。

in the experiment was not studied in this research, which should be taken into consideration in the future. Furthermore, the inconsistency between waterscape qualities and the corresponding outcomes of subjective restoration might be caused by the participants' comprehension deviation on the Chinese version of scales, or due to the scales' imperfect in measuring experiment materials of highly similar contents, which present varied naturalness levels though.

In this research, the stimuli for control group is featured with urban streetscapes. Whether its replacement by quality architectural works would lead to a different result on compatibility needs further investigation. The findings that waterscapes of low naturalness level provided a better attention restoration outcome and the correlation between naturalness and attention restoration outcomes need to be further verified or explored.

According to attention restoration theory, natural environment can be supportive of rendering one's use of directed attention to involuntary attention[11], which could be one of the reasons for enhanced working memory. Nonetheless, this shared quality of all waterscapes cannot well explain the effect variety among varied naturalness levels on different functions of central executive system. Further research is expected on the correlations between naturalness and working memory.

In addition to the visual perception, waterscapes can be perceived through other senses such as auditory, olfactory, and tactile senses. For example, Daniel Parton et al. explored what acoustic parameters are related to human comfort with 16 water sound samples of very different acoustic characteristics. They found that information related to harmonics is behind the preferences, and the sound of fountains with large waterfalls or jets produced a marked acoustic aversion to humans[33], marked a significant role that sensory perceptions other than visual could play in an individual's cognition. Although this research presses on cognitive benefits of waterscapes from visual perception only, efforts in multi-sensory perception of waterscapes and related behaviors are expected in future studies.

5 Conclusions

In this research, it is concluded that waterscapes across naturalness levels can bring about senses of fascination, compatibility, and relaxation and calmness better than urban streetscapes. Waterscapes of high and medium naturalness levels have evidenced their qualities of being away and extent, and the former can also significantly enhance the inhibition function while the latter work the best to improve the updating function of central executive system. Waterscapes of low naturalness level can contribute to attention restoration and boost the shifting function of central executive system. Thus, theoretically, waterscapes of high and medium naturalness levels demonstrate a better quality of subjective restoration than those of low naturalness level. As for the restoration outcomes and their impacts on working memory, waterscapes of varied naturalness levels would have differentiated influence on different aspects of cognition accordingly.

对于不同自然度水景所产生的认知效益特点的认识，有助于指导景观实践的资源利用、资金投入等方面，也对人们以不同目的游览水景提供了参考。相对于无水景的城市人工建成环境，水景具有更高的认知效益，在资金、生态等条件允许的情况下，应考虑建设水景。在设计实践中，可以通过构筑物、水体边界形态、植被等方面体现水景的自然度水平，并且以其差异化的认知效益判断适宜建设和使用的水景类型：以高主观恢复力、增强中央执行系统抑制功能为目的时，可优先选择高自然度水景；以较高主观恢复力、增强中央执行系统刷新功能为目的时，可优先选择中自然度水景；以注重提高注意力恢复水平，提高中央执行系统转换功能为目的时，可优先选择低自然度水平水景。**LAF**

The findings on cognitive benefits of waterscapes of varied naturalness levels can provide references to the resource allocation and investment in landscape practice, as well as guide visitors' usage of waterscapes. Waterscapes are recommended in urban and landscape design practice for the productive cognitive benefits, if financial and ecological conditions permit. Waterscapes of varied naturalness can be created through the design of landscape elements such as artificial structures, waterfront forms, and vegetation. In terms of cognitive benefits, waterscapes of high naturalness level are conducive to high subjective restoration and enhanced inhibition function of central executive system; waterscapes of medium naturalness level can lead to a relatively high subjective restoration and improved updating function of central executive system; and waterscapes of low naturalness level can bring about a better attention restoration and better performance on shifting function of central executive system. **LAF**

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