Journal of Environmental Psychology 101 (2025) 102506

Contents lists available at ScienceDirect

Journal of Environmental Psychology

journal homepage: www.elsevier.com/locate/jep

The green decision maker: Restoring decision making through exposure to environmental stimuli☆

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ARTICLE INFO

Handling editor: L. McCunn

Keywords:
Restorative environments
Cognitive restoration
Decision making
Decision strategies
Built environments

ABSTRACT

Exposure to natural environments or to their audiovisual representations has a restorative effect on attention and short-term memory. However, higher-level cognitive processes, such as decision making, have been overlooked. Additionally, studies have generally compared natural environments perceived to be restorative, such as woods, with built environments perceived to be nonrestorative, such as roads with traffic, paying less attention to built environments that could be restorative, such as libraries. We examined whether exposure to potentially restorative natural or built environments (vs. nonrestorative built environments) would improve the ability to apply decision rules to multi-attribute choices, an important aspect of decision-making competence. Fatigued participants completed parallel versions of the Applying Decision Rules task before and after being exposed to audiovisual representations of these environments. Performance improved after exposure to restorative natural environments, remained unchanged after exposure to restorative built environments, and deteriorated after exposure to nonrestorative built environments. Restorative effects were partially mediated by self-reported fatigue, but not mediated by changes in attention control, emotional state, or motivation. We discuss the theoretical and practical implications of our findings.

1. Introduction

Cognitive restoration refers to the improvement in cognitive performance of fatigued participants after exposure to natural environments such as woods, or their virtual representations in images and videos (Ohly et al., 2016; Stevenson et al., 2018). The principal aim of the study presented in this paper is to address two main limitations of research on cognitive restoration. First, this research has focused on attention and short-term memory, while overlooking theoretically and practically important higher-level cognitive domains such as decision making. Second, this research has tended to examine restorative effects of natural environments on cognitive performance, but not restorative effects of built environments such as libraries (e.g., Weber & Trojan, 2018). Therefore, we conducted a study aimed at overcoming these two limitations by examining the restorative capacity of natural and built environments to improve the ability to apply decision-making rules to multi-attribute choices. Below, we introduce cognitive restoration research and explain why it is important to overcome the two limitations we highlighted above. We then describe our study's methods and results, followed by the theoretical and practical implications of our findings.

1.1. Cognitive restoration research

Exposure to natural environments or to their virtual representations can improve emotional states (see McMahan & Estes, 2015), promote stress recovery (e.g., Berto, 2014; Hartig et al., 2003, 2014; Ulrich et al., 1991; Van Den Berg & Custers, 2011), and restore cognitive resources (e.g., Hartig et al., 1991; Kaplan & Kaplan, 1989). For example,

☆ The research project has been funded by the Friuli Venezia Giulia Region (assegni di ricerca 2020). Data are available from the corresponding author upon reasonable request. The authors thank Clara Miani and Mattia Mottica for their help in the selection of the stimuli, and Giovanna Sabbatini and Jessica Tirello for their help in data collection.

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https://doi.org/10.1016/j.jenvp.2024.102506
Received 18 October 2023; Received in revised form 23 October 2024; Accepted 8 December 2024
Available online 9 December 2024

participants who have become fatigued after completing a complex cognitive task tend to perform better on a subsequent cognitive task if they are exposed to natural environments or virtual representations thereof (Ohly et al., 2016; Stevenson et al., 2018).

Two meta-analyses (Ohly et al., 2016; Stevenson et al., 2018) examined the restorative effects of exposure to natural environments, such as parks, forests, wilderness areas, as compared to control built environments, such as city centers, residential areas, parking lots, on measures of cognitive performance. Improvement after exposure to natural environments was observed for working memory and cognitive flexibility, and less reliably for attentional control. However, according to Ohly et al. (2016), the size of the observed effects was of dubious practical significance, e.g., a mean of 0.39 additional digits recalled by participants on the Digit Span Forward task after exposure to real natural environments through outdoor activities or view from windows vs. the nonnatural control conditions, when the number of digits typically recalled on this task is 7 ± 2. Moreover, only one study included in the Stevenson et al.'s (2018) meta-analysis focused on higher-level cognitive skills (Chow & Lau, 2015). This study reported significantly better cognitive performance after viewing natural environments compared to built environments in logical reasoning ability as measured with the Graduate Record Exam (Chow & Lau, 2015).

The strong focus on attention-related tasks in the cognitive restoration literature can probably be explained by its linkage to the prominent Attention Restoration Theory (henceforth ART, Kaplan & Kaplan, 1989; Kaplan, 1995). According to this theory, environments differ in the degree to which they can stimulate perceptions of *being away* from everyday routine and hassles, *fascination* through effortless attention, *extent* including coherence and scope, and *compatibility* with personal interests. Natural environments are generally perceived to have these restorative features to a greater extent than built environments (Kaplan, 1995). According to ART, environments with greater restorative features can be explored effortlessly, without much involvement of directed attention (Kaplan, 1995). This would allow a fatigued person to recover directed attention resources, needed for completing subsequent cognitive tasks (see e.g., Berman et al., 2008). Thus, according to ART, restorative effects on cognition are mediated by the recovery of directed attention resources (Berman et al., 2008).

Another influential theory explaining restorative effects is the Stress Reduction Theory (SRT, Ulrich, 1983; Ulrich et al., 1991), which focuses on emotional aspects of restoration. According to SRT, individuals have an evolutionary disposition to react positively to natural environments populated with vegetation, water, and other features that foster survival and adaptation. Environments with these features elicit positive emotional reactions and reduce stress without the involvement of attention (Ulrich, 1983, 1984). Following this line of reasoning, cognitive restoration effects should be triggered by improved emotional states or by stress reduction, rather than by attention. Indeed, there is evidence that improvements in emotional states are associated with better motivation and cognitive performance (e.g., Brose et al., 2012, 2014; but see also Mitchell & Phillips, 2007). Thus, improved emotional states and related changes in motivation may act as potential mediators of restorative effects of environment exposure on cognitive performance. However, there is also evidence against the mediational role of emotional states (Stenfors et al., 2019). Additionally, restorative effects could be related to changes in interest or motivation to perform the task following environmental exposure (Joye & Dewitte, 2018; see also Silvia, 2008). Finally, participants' expectations about the positive effects of exposure to natural environments may have a role in explaining cognitive restoration effects, as suggested by the study of Antonelli et al. (2019) that highlighted an "anticipated placebo effect" in relation to stress reduction associated with forest bathing.

1.2. Effects of environment exposure on decision making: an overlooked domain

A main limitation of the cognitive restoration literature is that it has almost exclusively focused on attention or short-term memory. Higher-level cognitive processes, such as decision making, have been overlooked. Indeed, to the best of our knowledge, only a few studies examined restorative effects on two specific aspects of decision making: time discounting and risk taking.

First, a lab study on time discounting (Berry et al., 2014) found that participants exposed to images of natural (vs. built) environments were more likely to choose larger delayed monetary outcomes over smaller immediate monetary outcomes. Mediating constructs were not measured, but the authors speculated that participants who were exposed to natural environments experienced increased attention resources or slowed time perception rather than improved affect (Berry et al., 2014). Some evidence supporting a role for time perception was provided in subsequent work (Berry et al., 2015).

Second, a survey on risk taking conducted during to the COVID-19 pandemic found that access to natural environments such as gardens during home confinement was associated with greater likelihood of implementing COVID-19 related preventive measures even after accounting for socio-demographics and individual differences in impulsiveness (Panno et al., 2021). Although mediating constructs were not measured, the authors speculated that delay discounting and emotion regulation may have played a role.

However, decision-making competence refers to a variety of judgment and decision-making skills, including appropriate risk perception and time discounting and many others (see e.g., Bruine de Bruin et al., 2007, 2012; Del Missier et al., 2015; Finucane & Guillon, 2010; Parker & Fischhoff, 2005; Strough et al., 2015). In our study, we focused on the ability to apply decision-making rules to multi-attribute choices as assessed by the Applying Decision Rules task (Parker & Fischhoff, 2005; see section 1.4). Applying Decision Rules is one of the six performance-based tasks in the Adult Decision-Making Competence battery (ADMC; Bruine de Bruin et al., 2007). The ability to apply decision-making rules is an essential skill for making real-world choices between options, such as products, services, foods, or activities, which vary along multiple attributes (e.g., Payne & Bettman, 2004; Payne et al., 1993).

In the original Applying Decision Rules task, participants are asked to apply specific decision-making rules to choose between DVD players that vary along attributes like picture quality, sound quality, programming options, and so on. For example, the "elimination by aspects" decision rule (Payne et al., 1993; Tversky, 1972), involves the sequential elimination of options until only one option is left in the choice set. In the Applying Decision Rules task, the first step of applying "elimination by aspects" is to select those DVD players with the best ratings for picture quality. From those DVD players, participants are subsequently asked to select the ones with the best ratings for sound quality. If more than one DVD player is left in the choice set, they may then choose the one with the best rating for programming options. Thus, the application of this elimination-by-aspects rule requires attention focusing, mental comparisons, temporary maintenance and updating of the choice set.

The Applying Decision Rules task is theoretically grounded in research on multi-attribute choice, which examines the decision rules that people apply under different circumstances (e.g., Payne & Bettman, 2004; Payne et al., 1993). It also evaluates the quality of resulting choices as defined by criteria of rationality (e.g., Keeney & Raiffa, 1993; Raiffa et al., 2003). Applying decision rules to multi-attribute choices involves sequentially applying goal-directed mental operations and requires decision makers to focus on goal-relevant information, inhibit irrelevant information, combine, update or integrate information, and remember the options that are still considered in the current choice set (Bettman et al., 1990; Parker & Fischhoff, 2005; Payne & Bettman, 2004; Payne et al., 1993; Riedl et al., 2008). Some of these cognitive operations, like attention focusing and inhibition, information updating or integration, and information maintenance are also relevant for performing other high-level tasks in problem solving (e.g., Brand-Gruwel et al., 2005; Florean et al., 2024), multiple-cue judgment (e.g., Hoffmann et al., 2014; Juslin et al., 2008), and reasoning (e.g., Capon et al., 2003; De Neys & Verschueren, 2006; Stanovich & West, 2000).

Performance on Applying Decision Rules has been associated with measures of working memory (Del Missier et al., 2013; Rosi et al., 2019), executive functioning (Del Missier et al., 2010, 2012; Parker & Fischhoff, 2005), and fluid intelligence (Bruine de Bruin et al., 2007, 2012; Del Missier et al., 2013). Moreover, cross-sectional studies have suggested that performance on Applying Decision Rules declines with age, and this decline is partially mediated by fluid intelligence (Bruine de Bruin et al., 2012) and working memory (Del Missier et al., 2013; Rosi et al., 2019), even when controlling for processing speed and sensory functioning (Del Missier et al., 2017). Like the performance of the overall ADMC, performance on Applying Decision Rules task also has practical importance, as seen in correlations with the avoidance of negative life outcomes stemming from bad decisions, as reported on the Decision Outcome Inventory (Bruine de Bruin et al., 2007).

Given its cognitive underpinnings and its theoretical and practical relevance, the Applying Decision Rules tasks thus seems to be particularly suitable for testing restorative effects in decision making. Moreover, Applying Decision Rules appears to have the characteristics of tasks for which performance is likely to be restored by exposure to natural environments or stimuli (Stevenson et al., 2018). Indeed, such tasks tend to be "1) high in cognitive demand, requiring the maintenance of several processes simultaneously; 2) related to the control of attention towards both internal and external goal relevant stimuli; and 3) related to the suppression of internal distractors, such as goal-irrelevant thoughts, as well as external distractors, such as goal-irrelevant stimuli." (Stevenson et al., 2018, p. 265). Thus, in our study, we aimed to examine restorative effects in the ability to apply decision rules to multi-attribute choices as measured by the Applying Decision Rules task.

1.3. *Cognitive restoration effects after exposure to built environments: an underinvestigated issue*

Another main limitation of the cognitive restoration literature is that participants have been mainly exposed to potentially restorative natural environments such as woods or potentially nonrestorative built environments such as industrial areas and roads with traffic, while potentially restorative built environments such as libraries and museums have been mostly excluded (see Joye & Dewitte, 2018). However, studies on perceived restorativeness have found that people think of some built environments as having restorative potential (for a review, see Weber & Trojan, 2018). For example, Stragà et al. (2023) asked participants to rate multiple images of 12 types of natural environments and 12 types of built environments along several restorative dimensions (i.e., ART dimensions of being-away, fascination, compatibility, and coherence, plus perceived safety and opportunity for reflection). A cluster analysis across these ratings revealed that natural environments could be clustered into hospitable natural environments (woods, rivers, lakes, seaside, lawns, mountains) and harsh natural environments (deserts, savannahs, iced landscapes, caves, volcanos, lagoons). Additionally, built environments could be clustered into hospitable built environments (museums, libraries, oldtowns, residential areas with terraced houses, home interiors and urban parks), functional built environments (commercial areas, downtowns and airport interiors), and harsh built environments (roads with traffic, industrial areas and residential areas with condos/apartment buildings). The five clusters differed on ratings of overall perceived restorativeness, with hospitable natural environments being rated as the most restorative, hospitable built environments being rated as the second most restorative, and harsh built environments being rated as the least restorative (Stragà et al., 2023). Other studies provided converging evidence on the restorative potential of museums (e.g., Kaplan et al., 1993), recreational destinations (e.g., Scopelliti & Giuliani, 2004; Staats et al., 2016), historic sites (e.g., Scopelliti et al., 2019), well-designed neighborhoods (e.g., Karmanov & Hamel, 2008), and urban greenery (e.g., Carrus et al., 2013). Thus, there is a need to study whether potentially restorative built environments may actually provide cognitive restoration, helping fatigued people to improve their cognitive performance.

1.4. *Aims and hypotheses of the study*

The first aim of our study was to examine restoration effects on the ability to apply decision rules to multi-attribute choices, which is a cognitively demanding decision-making skill and a theoretically and practically relevant aspect of decision-making competence (Bruine de Bruin et al., 2007, 2012). The second aim of our study was to investigate the actual restorative effects of exposure to built environments that people perceive as restorative (Stragà et al., 2023; Weber & Trojan, 2018) in addition to potentially restorative natural environments, as compared nonrestorative built environments.

Specifically, we hypothesized that fatigued participants would show a significant restoration of Applying Decision Rules performance after exposure to potentially restorative natural environments (H1), and after exposure to potentially restorative built environments (H2), but not after exposure to potentially nonrestorative built environments (H3). Additionally, we conducted auxiliary mediation analysis to examine whether the hypothesized restorative effects were at least partially mediated by fatigue recovery. Such analysis can help to understand the extent to which any effects of environmental exposure on improved cognitive performance reflect restorative effects on fatigue, suggesting underlying restorative processes (Joye & Dewitte, 2018; Stevenson et al., 2018). We also tested whether the expected restorative effects of environmental exposure were mediated by attention control (Kaplan, 1995; Kaplan & Kaplan, 1989), emotional state (Ulrich, 1983; Ulrich et al., 1991), motivation (Joye & Dewitte, 2018; Strough et al., 2015), or by participants' perceived attention and cognitive abilities, potentially reflecting their expectancies on the effects of the environmental exposure (Antonelli et al., 2019).

2. Method

2.1. *Participants*

One-hundred and twenty-five undergraduate students were recruited to participate in the study. Those who did not complete the study ($n = 3$) or did not follow the instructions ($n = 1$) were excluded from the final sample, which included 121 participants (75% female, age: $M = 20.69$, $SD = 3.09$). An a-priori power analysis conducted using G*Power 3 (Faul et al., 2007) indicated that a sample size of 120 was needed to uncover significant effects with medium effect size (f = 0.25; Cohen, 1988) $\alpha = .05$, $1\text{-}\beta = 0.80$, in a 2 (pre-test vs. post-test) x 3 (conditions) mixed design. The study was approved by the Ethical Committee of the University of Trieste, and students provided their informed consent prior to participating.

2.2. *Experimental design and procedure*

Participants were randomly assigned to one of three environmental exposure conditions: potentially restorative natural environments ($n = 39$), potentially restorative built environments ($n = 41$), or potentially nonrestorative built environments ($n = 41$), following Stragà et al.'s (2023) classification of environments. Henceforth, we will refer to those as restorative natural environments, restorative built environments, and nonrestorative built environments.

The experimental procedure included the following stages: pre-baseline task, baseline measurement, fatigue induction, pre-exposure measurement, randomly assigned environmental exposure, post-exposure measurement, and control questionnaires (see Table 1). The entire procedure lasted about 1 h and half.

All participants completed a simple pre-baseline task, which involved choosing between pairs of abstract paintings. This task aims to reduce individual differences in anxiety, boredom, and so on (see e.g., Jennings et al., 1992; Piferi et al., 2000).

During the baseline measurement stage, participants were asked to complete demographic information as well as baseline measures of their self-reported emotional state, attention, fatigue, cognitive abilities, and motivation.

During the fatigue induction stage, participants completed a short version Raven's Advanced Progressive Matrices (Raven & Court, 1998) consisting of 24 trials for about 20 min. This task is cognitively demanding, requiring reasoning abilities, working memory, and visuospatial skills (Carpenter et al., 1990). Each item presented participants with a 3 x 3 matrix containing abstract figures on a computer screen. Each matrix had a missing element and participants had to choose one of eight elements to complete the overall pattern. Participants had a maximum of 70 s to provide an answer to each item. Otherwise, their answer was counted as incorrect, and the next item appeared.

During the pre-exposure measurement stage, participants first completed two cognitive tasks, Antisaccade (attention control) and Applying Decision Rules (decision making), in random order. Next, participants reported again on their emotional state, attention, fatigue, cognitive abilities, and motivation.

In the environmental exposure stage, participants were shown videos of their randomly assigned *restorative natural environments*, *restorative built environments*, or *nonrestorative built environments* (see section 2.3.1). Participants were asked to watch the video while imaging being in the presented environments.

In the post-exposure measurement stage, participants reported one more time on their emotional state, attention, fatigue, cognitive abilities, and motivation. These self-report measures assessed the effects of environmental exposures and were therefore completed before the Applying Decision Rules and Antisaccade tasks, to avoid any influence of these two cognitive tasks on participants' evaluations. Then, participants completed a parallel version of the Applying Decision Rules task and the Antisaccade task, in the same order than in the pre-exposure stage. The Antisaccade task was performed with analogous items presented in a different random order than in the pre-exposure stage. Applying Decision Rules versions in the pre-exposure and post-exposure were counterbalanced. Finally, participants filled in the short version of the Perceived Restorativeness Scale (PRS) and other control measures.

2.3. Independent and dependent variables

2.3.1. Independent variable: environmental exposure

Participants were randomly assigned to viewing 10-min videos of either restorative natural environments, restorative built environments, or nonrestorative built environments. The restorative natural environments were woods, rivers, lakes, and seaside. The restorative built ones were museums, libraries, oldtowns, and residential areas with terraced houses. Finally, the nonrestorative built environments were residential areas with condos/apartment buildings, industrial areas, roads with traffic, and commercial areas.[1] Each video included three images for each of its four environments, for a total of 12 images (see Fig. 1 and Supplementary materials Fig SM1-SM3). Each image was shown for 50 s. In a previous work (Stragà et al., 2023), participants rated the images of restorative natural environments we used as more restorative than the ones of restorative built environments, and the images of restorative built environments as more restorative than the ones of nonrestorative built environments. Images were presented with consistent sounds (e.g., bird song with image of woods, footsteps and soft chattering with image of museum, traffic sounds with image of road), because sound can play a role in restorative experiences (e.g., Alvarsson et al., 2010).

2.3.2. Dependent variable: Applying Decision Rules (decision making)

Applying Decision Rules. The Applying Decision Rules task was adapted from the Adult Decision-Making Competence battery (Bruine de Bruin et al., 2007) to assess participants' ability to apply decision rules to multi-attribute choices. In the original task, participants were presented with five DVD players, which had varying ratings across multiple dimensions (e.g., picture quality, sound quality, programming options). Each of ten items then asked participants to apply specific decision rules to select DVD players, including elimination by aspects, satisficing, lexicographic, and equal weights rules (see Payne et al., 1993). Based on a pilot test, we created two new parallel 14-item versions of this task that were similar in difficulty (for details see Supplementary materials, section 2). The two new versions included additional decision rules such as weighted additive, least important minimum heuristic, and additive difference rules (see Riedl et al., 2008). Because the purchase of a DVD player is outdated, the two new versions presented choices between apartments to rent or movies to rent. As in the original version, the price was the same across all presented options, to remove its influence on participants' responses. An example item is presented in Fig. 2 (for all the items see Supplementary materials, section 2, Table SM1). Cronbach's alpha across the 14 items was 0.62 for the movie version and 0.56 for the apartment version in our pre-test, which was in line for the Cronbach's alpha for the original version (0.59). Each participant received one version of the Applying Decision Rules task in the pre-exposure stage and the other in the post-exposure stage, in random order. The overall score of the task reflected the proportion of responses that showed the correct application of prescribed rules, as in the original Applying Decision Rules Task (Bruine de Bruin et al., 2007).

2.3.3. Potential mediators: attention control, emotional state, motivation, perceived attention and cognitive abilities

Antisaccade (attention control). We used the Antisaccade task (Hutchison, 2007; Kane et al., 2001), because it is deemed to be a better measure of attention control than the traditional Stroop and flanker tasks (Draheim et al., 2021, Cronbach's $\alpha = .92$; see also Draheim et al., 2023). Following previous work (Draheim et al., 2021), each trial started by displaying a fixation point in the center of the screen for a randomly determined time period of 2000–3000 ms. After a sound that lasted 300 ms, an asterisk appeared on the left or on the right of the fixation point. The letter Q or the letter O then appeared in the position opposite to the asterisk, but as masked after 500 ms by the symbols "##". Participants were asked to identify the target letter and provide an answer pressing the letter Q or O on the keyboard. After giving the answer, feedback was provided about whether their answer was correct. In the two administrations of the task, 72 equivalent trials were presented in different random orders. Participants received one administration of the task in the pre-exposure stage, and another in the post-exposure stage. The overall score across items reflected the proportion of correctly identified targets.

Self-reported emotional state. Participants' emotional state was assessed through items adapted from the Zuckerman Inventory of Personal Reactions (ZIPERS, Zuckerman, 1977) and the Emotional dimension of the Restoration scale (Han, 2003). Participants rated, on a scale from −3 to +3 how much they felt tense-relaxed, agitated-calm, angry-peaceful, worried-carefree, fearful-confident; inactive-active, depressed-elated, sad-happy, tired-rested, exhausted-energetic. The same items were presented in the baseline, pre-exposure, and post-exposure stages. Respectively, Cronbach's α was 0.85, 0.85, and

[1] Considering that the harsh built cluster detected in Stragà et al. (2023) included only three types of environments and we needed a fourth one for the present study, we added commercial areas because such type of environment received on average the lowest perceived restorativeness ratings among functional built environments.

Table 1
Stages of the experimental procedure.

1 Baseline Measurement	2 Fatigue induction	3 Pre-exposure measurement	4 Environment exposure	5 Post-exposure measurement	6 Control questionnaires
Demographics ***Self-report measures:*** - Emotional state - Attention - Fatigue - Cognitive abilities - Motivation	Raven's Advanced Progressive Matrices	***Cognitive tasks:*** - Antisaccade (attention control) - Applying Decision Rules (decision-making) ***Self-report measures:*** - Emotional state - Attention - Fatigue - Cognitive abilities - Motivation	**Randomly assigned to:** - Restorative natural - Restorative built - Nonrestorative built	***Self-report measures:*** - Emotional state - Attention - Fatigue - Cognitive abilities - Motivation ***Cognitive tasks:*** - Antisaccade (attention control) - Applying Decision Rules (decision-making)	- Perceived Restorativeness Scale - Other control measures

Note: The order of administering Antisaccade (attention control) and Applying Decision Rules (decision making) was counterbalanced between participants as the two versions of Applying Decision Rules.

Fig. 1. Examples of presented images in each environmental exposure condition.

Cristina wants to exclude apartments with a score in "natural light" equal to or less than 2, so she discards apartments with scores in "natural light" equal to or less than 2. Then, if there is more than one apartment left, she discards those with scores in "safety of the area" equal to or less than 2. If there is more than one apartment left, she discards those with scores in "conditions of the apartment" equal to or less than 3.

Characteristics

	Quietness of the apartment	Conditions of the apartment	Natural light	Safety of the area	Services of the area	Monthly rent
A	3	5	3	4	2	500 €
B	4	3	4	3	2	500 €
C	3	4	2	4	3	500 €
D	5	3	1	5	2	500 €
E	1	4	4	2	4	500 €

Which of the apartments would Cristina prefer?

Fig. 2. Example item from the Applying Decision Rules task.

0.90 for those stages. The overall score reflected the average rating across the 10 items, with higher values indicating a better emotional state.

Self-reported motivation. Participants received three statements adapted from the engagement subscale of the Short Stress State questionnaire (Helton & Näswall, 2015). They indicated their agreement with the statements on a scale ranging from 1 (*not at all agree*) to 7 (*totally agree*): "I am committed to attaining my performance goals in the next tasks", "I want to succeed in the assigned tasks", and "I am motivated to do the assigned tasks." These items were administered in the baseline stage, pre-exposure stage, and post-exposure stage, yielding Cronbach's α of respectively, 0.84, 0.92, and 0.94. The overall score reflected the average rating across items, with higher values indicating stronger motivation.

Self-reported attention. Participants received the cognitive dimension sub-scale of the Han's Restoration scale (Han, 2003). They indicated the extent to which they felt inattentive-attentive, distracted-concentrated, bored-interested, on a scale from −3 to 3. These items appeared in the baseline, pre-exposure, and post-exposure stages, yielding, respectively, a Cronbach's α of 0.84, 0.89, and 0.88. The overall score reflected the average rating across items, with higher scores indicating better self-reported attention.

Self-reported cognitive abilities. Six statements were adapted from Hartig and Staats (2006) to ask participants how much they agree with: "I feel capable of performing complex tasks", "I feel capable of making great cognitive efforts", "I would be able to make a well balanced decision", "I would be able to concentrate", "I would be able to foresee the implications of a complex situation", "I would be able to pay attention to a long lecture." Responses were provided on a scale ranging from 1 (*not at all agree*) to 7 (*totally agree*). The measure appeared in the baseline stage, pre-exposure stage, and post-exposure stage, yielding, respectively a Cronbach's α of 0.89, 0.93, and 0.94. The overall score reflected the average rating across measures, with higher values indicating better self-reported cognitive abilities.

2.3.4. *Self-reported fatigue, Perceived Restorativeness Scale, and other control measures*

Self-reported fatigue. Participants were asked to indicate how much they agree with two items: "I feel mentally fatigued", and "I feel physically fatigued." Responses were provided on a response scale ranging from 1 (*not at all agree*) to 7 (*totally agree*). The fatigue items were administered in the baseline stage, pre-exposure stage, and post-exposure stage, yielding correlations of 0.45 ($p < .001$), 0.41 ($p < .001$) and 0.57 ($p < .001$). The overall score reflected the average rating across items, with a higher score indicating a higher level of self-reported fatigue.

Perceived Restorativeness Scale. We used a short version of the Perceived Restorativeness Scale (Hartig, Kaiser, & Bowler, 1997; Hartig, Korpela, et al., 1997), with one item measuring each relevant dimension: Being-away: "Being in the places shown in the video would be an escape experience", Fascination: "The places shown in the video are fascinating", Coherence: "In the places shown in the video everything seems to have a proper place", and Compatibility: "In the places shown in the video I could do things I like." The items were administered as part of the control questionnaires in the final stage of the experimental procedure. Participants answered on a scale ranging from 1 (*not at all agree*) to 7 (*totally agree*). Cronbach's α was 0.80 across the four items. The overall score was the average rating across these items with higher values reflecting greater perceived restorativeness.

Other control measures. We asked participants to evaluate three statements about the perceived immersion and realism of the stimuli: "Different sounds seemed to come from different distances," "The images and sounds surrounded me, creating an immersive experience", and "The video produced a sense of realism, of being inside the place.". We also asked participants to what extent they found the video to be boring and relaxing. Responses for all these items were provided on a scale from 1 (*not at all*) *agree* to 7 (*totally agree*). These measures were collected as part of the control questionnaires in the final stage of the experimental procedure.

2.4. *Data analyses*

2.4.1. *Manipulation checks*

To examine whether fatigue induction was effective, seen in participants reporting higher fatigue ratings in the pre-exposure measurement than in the baseline measurement, we conducted a 2 (measurement stage: baseline vs. pre-exposure) x 3 (environmental exposure condition: restorative natural vs. restorative built vs. nonrestorative built) mixed ANOVA on fatigue ratings. We also verified, though a one-way ANOVA and associated post-hoc tests, whether the restorative natural environments were perceived as more restorative than the other two environments, and whether the restorative built environments were perceived as more restorative than the nonrestorative built environments.

2.4.2. Test of main hypotheses

To test our main hypotheses regarding improvement in performance after exposure to potentially restorative natural environments (H1) and after exposure to potentially restorative built environments (H2), but not after exposure to potentially nonrestorative environments (H3), we conducted a 2 (measurement stage: pre-exposure vs. post-exposure) x 3 (environmental exposure condition: restorative natural vs. restorative built vs. nonrestorative built) mixed ANOVA on Applying Decision Rules scores, followed by paired t-tests of pre-exposure and post-exposure measurements of Applying Decision Rules within each environmental exposure condition.

2.4.3. Mediation analyses with latent change score models

We tested whether fatigue recovery, attention control (Antisaccade), and self-report measures of emotional state, motivation, attention, and cognitive abilities mediated the relationship between exposure to environmental stimuli and cognitive restoration. We first assessed whether there was a significant difference in the potential mediator variables between the pre- and the post-exposure stage and between the environmental exposure conditions. Specifically, we conducted 2 (measurement stage: pre-exposure vs. post-exposure) x 3 (environmental exposure condition: restorative natural vs. restorative built vs. nonrestorative built) mixed ANOVAs for each potential mediator. If we found a significant interaction between measurement stage and environmental exposure condition on a potential mediator, and the interaction was consistent with the one observed for Applying Decision Rules as shown by post-hoc tests, we proceeded to the following analysis of indirect effects.

To test for mediation, we used Latent Change Score modeling, which is especially suitable for testing whether change in a variable explains change in another variable and to test mediation effects with repeated measures (see Selig & Preacher, 2009). This procedure avoids methodological problems with mediation analyses on difference scores (Matusik et al., 2021), and it has been already employed in environmental and social psychology studies (see Inoue et al., 2023; Yeo et al., 2020). Latent Change Score models specify change in a variable between two different time points as a distinct latent construct (see Kievit et al., 2018; McArdle, 2009), allowing to test simultaneously the effect of change over time and whether such change is dependent on the initial scores of the variable at the pre-exposure stage.

In particular, an unobserved latent variable representing change (Δ_Y), is included to the model. Paths from the observed variable at the pre-exposure stage ($Y_{pre\text{-}exposure}$) to the observed variable at post-exposure stage ($Y_{post\text{-}exposure}$), as well as path form the latent variable (Δ_Y) to observed variable at post-exposure stage ($Y_{post\text{-}exposure}$) need to be fixed at 1, to mimic a subtraction (i.e., $Y_{post\text{-}exposure} = Y_{pre\text{-}exposure}*1 + \Delta*1$). Therefore, the latent change variable (Δ_Y) represents the score of $Y_{post\text{-}exposure}$ that is not equal to $Y_{pre\text{-}exposure}$. Then, the path from the observed score at pre-exposure stage ($Y_{pre\text{-}exposure}$) to the latent change variable (Δ_Y) is estimated, so that the coefficient represents the effect of the observed variable at pre-exposure stage on the change in that variable. The test of mediation effects in our design, in which both the mediator and the dependent variable were measured at two time points, requires us to specify a latent change variable for the mediator ($\Delta_{Mediator}$) and another latent change variable for the dependent variable (namely, the Applying Decision Rules performance, $\Delta_{Applying\ Decision\ Rules}$) following the above-mentioned procedure (see Fig. 3).

In this model, the path from the observed score in the pre-exposure stage to the corresponding latent change score represents the effect of the initial score on the magnitude of change. Indeed, the model includes a path from the pre-exposure measurement of the dependent variable to its latent change variable (pre-exposure Applying Decision Rules → $\Delta_{Applying\ Decision\ Rules}$), and a path from the pre-exposure measurement of the mediator to its latent change variable (pre-exposure mediator → $\Delta_{Mediatior}$). Crossed paths inform about the influence of one variable at pre-exposure on the change of the other variable (see Kievit et al., 2018): from the pre-exposure measurement of the dependent variable to the latent change variable of the mediator (pre-exposure Applying Decision Rules → $\Delta_{Mediator}$) and from the pre-exposure measurement of the mediator to the latent change variable of the dependent variable (pre--exposure mediator → $\Delta_{Applying\ Decision\ Rules}$).

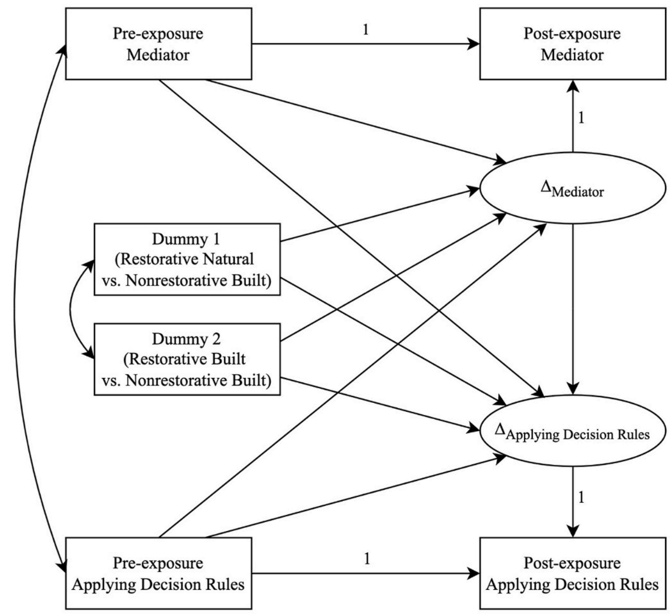

Fig. 3. Abstract structure of the latent change score model for mediation.

The model includes two dummy coded variables to represent restorative natural and built environmental exposure conditions (vs. nonrestorative built): Dummy 1 (restorative natural = 1, restorative built = 0, nonrestorative built = 0) and Dummy 2 (restorative natural = 0, restorative built = 1, nonrestorative built = 0). The dummy predictors are supposed to predict both latent change scores (Dummy 1 → $\Delta_{Mediator}$; Dummy 1 → $\Delta_{Applying\ Decision\ Rules}$; Dummy 2→ $\Delta_{Mediator}$; Dummy 2→ $\Delta_{Applying\ Decision\ Rrules}$). Finally, the latent change score variable related to the mediator is supposed to predict the latent change score of the dependent variable (i.e., $\Delta_{Mediator}$ → $\Delta_{Applying\ Decision\ Rules}$).

In our study, the indirect effects from the two dummy coded variables to changes in Applying Decision Rules performance through changes in the mediator (Dummy 1 → $\Delta_{Mediator}$ → $\Delta_{Applying\ Decision\ Rules}$ and Dummy 2 → $\Delta_{Mediator}$ → $\Delta_{Applying\ Decision\ Rules}$) were assessed estimating 95% confidence intervals using a bootstrapping procedure with the percentile method (10,000 samples). Models were estimated with the maximum likelihood method of the IBM SPSS AMOS 21 package (Arbuckle, 2012).

3. Results

3.1. Manipulation checks

The ANOVA comparing baseline and pre-exposure fatigue ratings confirmed that participants felt significantly more fatigued after the fatigue induction stage ($M = 3.86$, $SD = 1.32$) than at the baseline stage ($M = 3.45$, $SD = 1.35$), $F(1, 118) = 13.00$, $p < .001$, $\eta_p^2 = .10$, with no differences between environment exposure conditions, main effect: $F(2, 118) = 0.48$, $p = .62$, $\eta_p^2 = .01$; interaction: $F(2,118) = 1.38$, $p = .26$, $\eta_p^2 = .02$; for further analysis on the effectiveness of fatigue induction see Supplementary materials, section 3.1.

The ANOVA on the Perceived Restorativeness Scale score highlighted a significant effect of the environmental exposure condition, $F(2, 118) = 131.71$, $p < .001$, $\eta_p^2 = .69$. As expected, restorative natural environments were perceived as more restorative ($M = 5.76$, $SD = 0.82$) than both restorative built environments ($M = 5.12$, $SD = 0.92$, $t(118) = 3.22$, $p = .002$) and nonrestorative built environments ($M = 2.74$, $SD = 0.90$), $t(118) = 15.31$, $p = < 0.001$, with a significant difference in perceived restorativeness between the latter two, $t(118) = 12.25$, $p < .001$. There were no significant differences between environmental exposure conditions in terms of the immersion, $F(2, 118) = 2.34$, $p = .10$, $\eta_p^2 = .04$, and realism, $F(2,118) = 1.59$, $p = .21$, $\eta_p^2 = .03$, of the audiovisual materials, while nonrestorative environments were perceived as more boring, $F(2, 118) = 15.91$, $p < .001$, $\eta_p^2 = .21$, and less relaxing, $F(2,118) = 26.21$, $p < .001$, $\eta_p^2 = .31$, than restorative ones (see Supplementary materials, section 3.2).

3.2. Applying Decision Rules (decision making)

A significant interaction between measurement stage and environmental exposure condition emerged in the ANOVA on Applying Decision Rules performance, $F(2, 118) = 5.28$, $p = .01$, $\eta_p^2 = .08$, with no main effect of measurement stage, $F(1, 118) = 0.40$, $p = .53$, $\eta_p^2 = .00$, nor of condition, $F(2, 118) = 0.18$, $p = .84$, $\eta_p^2 = .00$ (see Fig. 4).

Post hoc tests (see Table 2 for descriptive statistics) showed that, in comparison with the pre-exposure measurement, which did not significantly differ between conditions, $ts < 1.23$, $ps > 0.22$, participants performed better after being exposed to the restorative natural environments, $t(118) = 2.06$, $p = .04$, supporting H1. However, participants performed similarly on Applying Decision Rules before and after being exposed to the restorative built environments, $t(118) = 1.25$, $p = .21$, suggesting no support for H2. Moreover, participants performed worse after being exposed to the nonrestorative built environments rather than before, $t(118) = 2.26$, $p = .03$, suggesting some support for H3 in that nonrestorative built environments did not promote restoration.

Furthermore, when controlling for pre-exposure Applying Decision Rules performance in an ANCOVA, $F(1,117) = 48.69$, $p < .001$, $\eta_p^2 = .29$, post-exposure Applying Decision Rules performance significantly differed between environmental exposure conditions, $F(2,117) = 4.38$, $p = .01$, $\eta_p^2 = .07$. Compared to participants in the non-restorative condition, participants in the restorative natural condition, $t(117) = 2.83$, $p = .01$, and in the restorative built condition, $t(117) = 2.16$, $p = .03$, performed better in the post-exposure phase, with no difference between the two restorative conditions, $t(117) = 0.70$, $p = .49$ (for descriptive statistics see Table 2).

3.3. Potential mediators

3.3.1. Self-reported fatigue

The ANOVA on self-reported fatigue detected a significant main effect of the measurement stage, $F(1, 118) = 14.28$, $p < .001$, $\eta_p^2 = .11$, qualified by a significant interaction between measurement stage and environmental exposure condition, $F(2, 118) = 3.16$, $p = .046$, $\eta_p^2 = .05$, while the main effect of the environmental exposure condition was not significant, $F(2, 118) = 1.04$, $p = .36$, $\eta_p^2 = .02$. Post hoc comparisons showed that, while participants in the nonrestorative built condition did not recover from fatigue after environment exposure, $t(118) = 0.14$, $p = .89$, participants exposed to restorative natural environments reported less fatigue, $t(118) = 3.16$, $p = .002$, as did participants exposed to the restorative built environments, $t(118) = 3.22$, $p = .002$ (Table 2).

Given these results, we estimated a Latent Change Score Model (Fig. 5) to test the possible mediating role of self-reported fatigue, finding that fatigue partially mediated the effects of environmental exposure on Applying Decision Rules performance. The model had very good fit indices: $\chi^2 (4) = 2.68$, $p = .61$, $\chi^2/df = 0.67$, SRMR = 0.03, CFI = 1.00, RMSEA = 0.00 (cut-off values: $\chi2$ nonsignificant, $\chi2/df \leq 3$, SRMR $\leq$0.09, RMSEA $\leq$0.05, CFI $\geq$0.95; see Iacobucci, 2010).

Importantly, both Dummy 1, $\beta = -0.23$, $z = 2.51$, $p = .01$, and Dummy 2, $\beta = -0.27$, $z = 2.90$, $p = .004$, predicted $\Delta_{Fatigue}$, showing that the restorative natural and built conditions, with respect to the nonrestorative built condition, promoted fatigue recovery. $\Delta_{Fatigue}$, in turn,

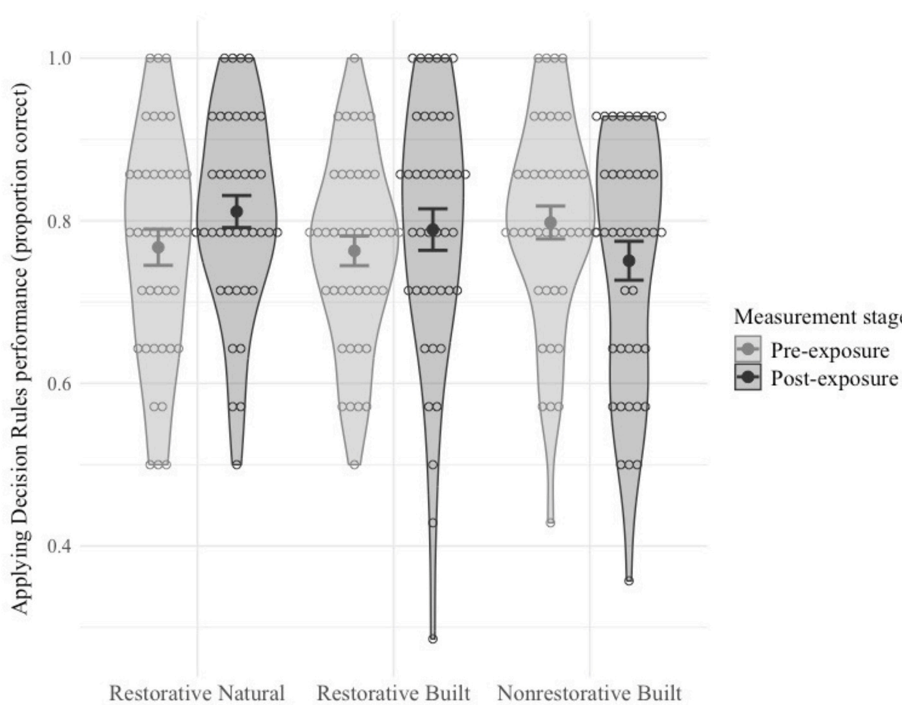

Fig. 4. *Violin and dot plots of performance on Applying Decision Rules task (proportion correct) by measurement stage and environmental exposure condition.*
Note. Filled dots with error bars represent mean performance (proportion correct) on the Applying Decision Rules task for each measurement stage and environmental exposure condition. Errors bars represent standard errors. Empty dots represent individual Applying Decision Rules scores. Associated statistical tests are reported in section 3.2.

Table 2
Descriptive statistics by measurement stage and environment exposure condition.

	Measurement Stage	Environment Exposure Condition					
		Restorative natural		Restorative built		Nonrestorative built	
		M	SD	M	SD	M	SD
Applying Decision Rules (decision-making)	Pre-exposure	0.77	0.14	0.76	0.12	0.80	0.13
	Post-exposure	0.81	0.12	0.79	0.16	0.75	0.15
Self-reported fatigue	Pre-exposure	3.97	1.31	3.73	1.44	3.87	1.23
	Post-exposure	3.41	1.46	3.17	1.68	3.84	1.14
Antisaccade (Attention control)	Pre-exposure	0.77	0.12	0.76	0.14	0.78	0.13
	Post-exposure	0.84	0.11	0.84	0.14	0.84	0.13
Self-reported emotional state	Pre-exposure	0.43	0.89	0.70	1.04	0.43	0.75
	Post-exposure	0.82	1.00	0.96	1.01	0.38	0.84
Self-reported motivation	Pre-exposure	5.26	1.31	5.15	1.40	5.33	1.16
	Post-exposure	5.26	1.40	5.26	1.62	5.15	1.28
Self-reported attention	Pre-exposure	0.71	1.58	0.72	1.39	0.86	1.17
	Post-exposure	0.39	1.44	0.70	1.31	0.22	1.14
Self-reported cognitive abilities	Pre-exposure	3.84	1.29	4.00	1.47	4.07	1.33
	Post-exposure	3.87	1.30	3.95	1.43	4.08	1.29

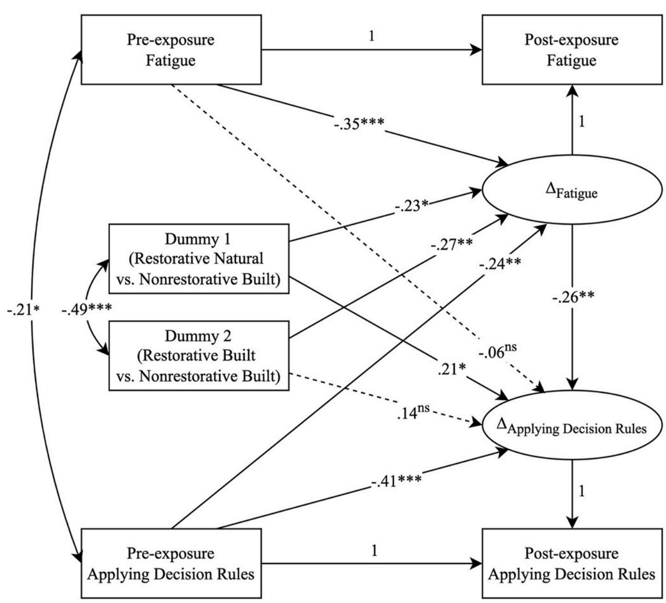

Fig. 5. *Latent change score model with fatigue change score as a mediator of the effect of environmental exposure condition on change in Applying Decision Rules performance.*
Note. Numbers close to the arrows are standardized coefficients. Dashed arrows represent nonsignificant effects (p ≥ .05). Significance levels are as follows: ns nonsignificant, *p < .05, **p < .01, ***p < .001.

was related with $\Delta_{\text{Applying Decision Rules}}$, β = −0.26, *z* = 2.96, *p* = .003, so that fatigue worsening was associated with a lower improvement in Applying Decision Rules scores. In other words, the restorative conditions promoted recovery from fatigue, that, in turn, resulted in a better Applying Decision Rules performance. The indirect effect of environmental exposure condition on Applying Decision Rules improvement through changes in fatigue was confirmed by the 95% bootstrap confidence intervals not including zero (Dummy 1: 95%CI [0.007, 0.150]; Dummy 2: 95%CI [0.009, 0.166]). Moreover, the direct effect on $\Delta_{\text{Applying Decision Rules}}$ of Dummy 1 was significant, β = 0.21, *z* = 2.25, *p* = .02, while the direct effect of Dummy 2 was not, β = 0.14, *z* = 1.48, *p* = .14, showing that changes in fatigue partially mediated the effect of environment exposure on changes in Applying Decision Rules performance. This means that being exposed to videos depicting restorative natural and restorative built environments, as opposed to nonrestorative built environments, promoted fatigue recovery, and this was related to an improvement (or not worsening) of Applying Decision Rules scores. Therefore, we can conclude that the observed effects of environment exposure on decision making were actually restorative.

In addition, the Latent Change Model showed that higher pre-exposure Applying Decision Rules scores were associated with a reduced Applying Decision Rules improvement ($\Delta_{\text{Applying Decision Rules}}$), β = −0.41, *z* = 4.86, *p* < .001, probably because scoring higher in Applying Decision Rules at pre-exposure left less room for later improvement. Similarly, higher pre-exposure fatigue score resulted in less fatigue worsening (Δ_{fatigue}), β = −0.35, *z* = 4.23, *p* < .001, probably because higher pre-exposure fatigue levels left less room for a later enhancement of fatigue. Pre-exposure Applying Decision Rules scores predicted Δ_{fatigue}, β = −0.24, *z* = 2.86, *p* = .004, so that higher pre-exposure Applying Decision Rules scores resulted in less fatigue worsening. Pre-exposure fatigue score did not directly predict $\Delta_{\text{Applying Decision Rules}}$, β = −0.06, *z* = 0.64, *p* = .52.

3.3.2. Antisaccade (attention control)

The ANOVA on the Antisaccade score showed only a main effect of measurement stage, $F(1, 118) = 80.83$, $p < .001$, $\eta_p^2 = .41$, with participants performing better after video exposure (*M* = 0.84, *SD* = 0.13) than before (*M* = 0.77, *SD* = 0.13). We found no significant effects of the environmental exposure condition, $F(2, 118) = 0.02$, $p = .98$, $\eta_p^2 = .00$, or of the interaction, $F(2, 118) = 0.28$, $p = .76$, $\eta_p^2 = .00$. Thus, only a general improvement, compatible with a learning effect, was observed. These findings suggest that changes in attention control did not mediate the observed effect of environmental exposure condition on Applying Decision Rules performance.

3.3.3. Self-reported emotional state

The ANOVA on self-reported emotional state detected the main effect of the measurement stage, $F(1, 118) = 9.97$, $p = .002$, $\eta_p^2 = .08$, but not the main effect of the environmental exposure condition, $F(2, 118) = 2.53$, $p = .08$, $\eta_p^2 = .04$. The measurement stage by condition interaction was significant, $F(2, 118) = 4.17$, $p = .02$, $\eta_p^2 = .07$. Post hoc comparisons showed an improvement in the emotional state after exposure to the restorative natural condition (0.82 vs. 0.43), $t(118) = 3.46$, $p < .001$, and to the restorative built condition (0.96 vs. 0.70), $t(118) = 2.41$, $p = .02$, but not to the nonrestorative built condition (0.38 vs. 0.43), $t(118) = 0.45$, $p = .66$. However, in a latent change score mediation model like the one in Fig. 3, the latent change score for emotional state did not predict the latent change score related to Applying Decision Rules, β =

0.08, $z = 0.93$, $p = .35$ (see Supplementary materials section 3.3). Thus, the emotional state did not mediate the effect of environment exposure of decision-making performance. A latent change score model including both self-reported fatigue and emotional state as mediators confirmed that only fatigue was a significant mediator of the effect of environment exposure on decision-making performance (see Supplementary materials section 3.4).

3.3.4. Self-reported motivation

The ANOVA on self-reported motivation did not detect significant effects related with the measurement stage and the environmental exposure condition ($Fs < 1.37$, $ps > 0.25$). Thus, motivation did not mediate the effect of environmental exposure condition on Applying Decision Rules performance.

3.3.5. Self-reported attention and cognitive abilities

Only a main effect of measurement stage was detected by the ANOVA on self-reported attention, $F(1, 118) = 8.29$, $p = .005$, $\eta_p^2 = .07$. Participants reported to be less attentive after video exposure ($M = 0.44$, $SD = 1.31$) than before ($M = 0.77$, $SD = 1.38$), irrespective of the environmental exposure condition (main effect: $F(2, 118) = 0.26$, $p = .77$, $\eta_p^2 = .00$; interaction: $F(2, 118) = 2.50$, $p = .09$, $\eta_p^2 = .04$). For self-reported cognitive abilities, there were no significant effects of measurement stage, $F(1, 118) = 0.003$, $p = .96$, $\eta_p^2 = .00$, environmental exposure condition, $F(2, 118) = 0.31$, $p = .73$, $\eta_p^2 = .01$, or of the interaction, $F(2, 118) = 0.07$, $p = .93$, $\eta_p^2 = .00$. These results suggest that neither self-reported attention nor self-reported cognitive abilities mediated the effect of environmental exposure condition on Applying Decision Rules performance.

4. Discussion

Our study aimed to make two contributions to the cognitive restoration literature. First, we examined the restorative effects of exposure to natural environments (woods, rivers, lakes, and seaside) on complex decision-making, specifically the ability to apply decision-making rules in a multi-attribute choice context. This core aspect of decision-making is important within the context of decision-making competence (Bruine de Bruin et al., 2007; Parker & Fischhoff, 2005) and for its role in decision-making theories (e.g., Payne & Bettman, 2004; Payne et al., 1993). Second, we examined the restorative effects of specific built environments (museums, libraries, oldtowns, and residential areas with terraced houses), which are perceived as potentially restorative (Stragà et al., 2023; Weber & Trojan, 2018), but have been previously overlooked by studies of cognitive restoration.

We found that natural environments (woods, rivers, lakes, seaside) did indeed have positive effects on the ability to apply decision rules to multi-attribute choices. However, potentially restorative built environments (museums, libraries, oldtowns, and residential areas with terraced houses) had no effect on the ability to apply decision rules. Moreover, potentially nonrestorative built environments (roads with traffic, residential areas with condos/apartment buildings, industrial areas, commercial areas) had detrimental effects on the ability to apply decision rules. The observed effects of environmental exposure on decision making was partially mediated by fatigue recovery, thus showing that the effect was, at least in part, truly restorative (see Stevenson et al., 2018).

4.1. Theoretical implications

4.1.1. Potential explanations of the observed restoration effect in decision making

In our study, we found that recovery from fatigue is a partial mediator of restorative effects on decision-making. Indeed, exposure to restorative natural and built environments, as opposed to nonrestorative built environments, promoted recovery from fatigue, leading to improved decision-making performance. This finding suggests that the effect of environmental exposure on cognitive performance is, at least in part, truly restorative. That is, environmental exposure seems to increase performance due to recovery from fatigue rather than increasing performance irrespective of the pre-exposure fatigue level (cf. Joye & Dewitte, 2018).

Despite the importance of this finding, it is not yet clear by what mechanisms environmental exposure promotes recovery from fatigue and what resources are restored. Indeed, we tested several potential explanations of the cognitive restoration effect we observed in the domain of decision making but were unable to identify any. Our analyses suggested that the restorative effect was not mediated by attention control, or self-reports of emotional state, motivation, attention, and cognitive abilities. While it has been speculated that these factors could be potential mediators of cognitive restoration effects, few studies have conducted actual mediation tests (see Joye & Dewitte, 2018).

Although we did not measure working memory in our study, it could potentially be a mediator of the restorative effects of environment exposure we found on decision-making performance (e.g., González-Espinar et al., 2023; Stenfors et al., 2019). Previous research has suggested that working memory is more likely than attention control to be affected by environmental exposure manipulations (Bratman et al., 2015; González-Espinar et al., 2023; Ohly et al., 2016; Stenfors et al., 2019; Stevenson et al., 2018), even if the two are related (e.g., Burgoyne et al., 2023; Draheim et al., 2021; Engle, 2002). Moreover, working memory is relevant to complex decision making, including performance on the Applying Decision Rules task (e.g., Del Missier et al., 2013, 2017) and other cognitively demanding judgment and decision-making tasks (e.g., De Neys & Verschueren, 2006; Dougherty & Hunter, 2003).

Thus, it is possible that the restoration or depletion of working memory resources in different environmental exposure conditions may have played a role in the effects we observed in decision-making performance. From existing findings, it may be hypothesized that restorative effects concern not only the attention control functions of working memory but also, or especially, its updating and maintenance functions (see also Bratman et al., 2015; Stenfors et al., 2019). This would explain the higher sensitivity of tasks like Backwards Digit Span, Operation Span, or Applying Decision Rules to restorative effects vs. 'purer' attention control tasks like the Antisaccade, given that the former tasks but not the latter require maintaining and updating information in working memory. If this potential explanation were correct, we should observe stronger restorative effects in cognitive tasks posing significant demands on both the attentional and the maintenance and updating functions of working memory than in tasks involving the attentional component only.

Additionally, it is also possible that the observed restorative effect was driven by evaluative conditioning, which, according to the Conditioned Restoration Theory (CRT, Egner et al., 2020), results from relaxation experienced during leisure activities becoming associated with natural environments. Subsequent exposure to natural environments or their audiovisual representations would then trigger relaxation and stress reduction, which would have positive cognitive consequences. According to CRT (e.g., Egner et al., 2020), as well as SRT (e.g., Ulrich, 1983; Ulrich et al., 1991), positive emotional states and stress reduction accompany exposure to natural environments. But our study found no association between change in self-reported emotional states and change in decision-making performance. Future studies may need to conduct psychophysiological measurements that more directly assess stress reduction as a potential mediator of restoration effects in decision making (Ulrich et al., 1991).

Another potential explanation of the observed restorative effects of environment exposure we found on decision-making performance is revitalization (Ryan et al., 2010). We did, indeed, find that exposure to natural environments facilitated recovery from fatigue, which may have made participants feel revitalized. However, one would expect this revitalization to be related with changes in motivation and emotional states, but these changes were not observed or did not explain the restoration effects on decision making. Future studies may need to test revitalization as a potential mediator of cognitive restoration effects using vitality scales (Ryan et al., 2010).

4.1.2. Potentially restorative built environments

As noted, we found no increase in Applying Decision Rules performance after exposure to built environments that participants in previous research (Stragà et al., 2023) had indicated as potentially restorative (museums, libraries, oldtowns, residential areas with terraced houses). Specifically, previous research (Stragà et al., 2023) found that participants rated these potentially restorative built environments as more restorative than potentially nonrestorative built environments (residential areas with condos/apartment buildings, industrial areas, roads with traffic, and commercial areas), and as less restorative than potentially restorative natural ones (woods, rivers, lakes, and seaside). Our study found that exposure to these potentially restorative built environments did not improve or decrease performance on Applying Decision Rules, even though it did reduce self-reported fatigue and improve self-reported emotional state. Thus, the effectiveness of potentially restorative built environments fell in-between the restorative natural environments, which improved performance, and the nonrestorative built environments, which reduced performance. Future studies should examine whether longer immersion into actual built environments deemed as restorative, instead of a short exposure to their audiovisual representations, is more effective for producing cognitive restoration (see also Stevenson et al., 2018).

4.2. Practical implications

Our findings show that cognitive restoration effects can be observed in the ability to apply multi-attribute decision rules, an aspect of decision making that has both theoretical and practical importance (Bruine de Bruin et al., 2007; Parker & Fischhoff, 2005). Indeed, performance on the Applying Decision Rules task has been associated with the avoidance of negative decision outcomes in real life (Bruine de Bruin et al., 2007). The task itself reflects real-world choices between multiple options that differ along multiple features, such as products, services, apartments, or jobs.

Moreover, we observed that decision-making performance in this task benefits from environmental exposure partly through recovery from fatigue. Thus, a practical implication of our work is that decision makers who feel fatigue when facing multi-attribute choices may be able to perform better after exposure to restorative natural environments. Therefore, people who face demanding choices in their personal and professional lives may benefit most from the positive effects of environmental exposure.

4.3. Limitations and future research

As any study, ours had limitations that future research could address. First, as noted above, our study did not include measures of working memory, psychophysiological variables, or revitalization, which future research could explore as potential mediators.

Second, as also noted above, our study briefly exposed participants to audiovisual representations of environments, which may not be as effective as longer immersion into actual environments (Stevenson et al., 2018). Third, due to presenting multiple environments in each environmental exposure condition (as in Berto, 2005; Hicks et al., 2020) to avoid boredom, we were unable to determine which specific environment drove the observed cognitive restoration effects.

Fourth, the internal consistency of Applying Decision Rules versions we used could be improved, and multiple measures for attention control may be employed (e.g., Burgoyne et al., 2023; Draheim et al., 2021, 2023).

A fifth limitation pertains to our undergraduate student sample. Although students are commonly sampled for research on restoration, the external validity of our findings needs to be strengthened by replicating the study with other populations. However, young adults report high level of stress and worry (e.g., Stone et al., 2010), and thus the investigation of restorative effects in this segment of the population is valuable.

A final limitation is that we investigated a single, although important, aspect of decision-making competence: the ability to apply decision rules to multi-attribute choices. Future research may focus on other aspects of decision-making competence that also have theoretical and practical importance such as the ability to be appropriately confident given one's knowledge and the ability to avoid being affected by how the same decision problem is described or 'framed' (Bruine de Bruin et al., 2007; Del Missier et al., 2017).

5. Conclusion

In our study, we examined whether exposure to potentially restorative natural or built environments (vs. potentially nonrestorative built environments) would improve the ability to apply decision-making rules. Performance improved after exposure to potentially restorative natural environments, remained unchanged after exposure to potentially restorative built ones, and deteriorated after exposure to potentially nonrestorative built ones. The restorative effect was partially mediated by self-reported fatigue, suggesting that it was truly restorative. However, none of the mediators we considered (attention control, self-reported emotional state, motivation, attention, and cognitive abilities) could explain the underlying processes for the cognitive restoration effect. Participants' emotional state improved after exposure to potentially restorative environments, either natural or built. Our study expands existing knowledge of cognitive restoration related to environmental exposure by considering an important but previously unexamined aspect of decision-making competence and a wider range of built environments as compared to previous studies.

CRediT authorship contribution statement

Marta Stragà: Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Data curation, Conceptualization. **Timo Mäntylä:** Writing – original draft, Supervision, Conceptualization. **Wändi Bruine de Bruin:** Writing – review & editing, Writing – original draft, Supervision, Methodology. **Irene Florean:** Writing – review & editing, Writing – original draft, Methodology. **Diego Zambon:** Writing – original draft, Methodology. **Fabio Del Missier:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Funding acquisition, Conceptualization.

Declarations of interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2024.102506.

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