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Exposure to natural environments consistently improves visuospatial working memory performance

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ABSTRACT

Exposure to natural environments has shown to have a positive influence on executive mental functioning. In the present study, we investigated whether these nature-related cognitive benefits can extend to visuospatial working memory (WM), a cognitive function relatively underexplored on this topic. Participants performed a Change Localization task in three different experiments. On each trial, a sample array containing four colored shapes was briefly presented (100 ms) and followed, after a short delay (900 ms), by a similar test array that changed the color of one of the items, which participants had to identify. They completed this visuospatial WM task before and after exposure to images of either natural landscapes or urban settings, with both types being presented across two different sessions. Participants' WM performance systematically improved because of exposure to natural, but not to urban images, even when the aesthetic preference for natural and urban stimuli was controlled for.

1. Introduction

A wide variety of studies have found that interacting with nature has a positive impact on health, reducing stress and anxiety levels (Miller et al., 1992), increasing subjective wellbeing, or even improving pain control in hospital patients (McMahan & Estes, 2015). This impact has also been observed at a psychological level, particularly in cognitive tasks involving attentional control processes (e.g., Jenkin et al., 2018; Lin et al., 2014). These benefits are not limited to actual immersion in nature (e.g., walking through a green area) but can also be observed after brief exposures (e.g., less than 10 min) to nature-related stimuli (Berman et al., 2008; Berto, 2005; Beute & de Kort, 2014; Gamble et al., 2014).

Many of these investigations have been conducted within the framework of the Attention Restoration Theory (ART; Kaplan, 1995; Kaplan & Berman, 2010). This theory uses the distinction made by William James (1892) between a type of attention that is conscious and intentionally directed by the individual, and an involuntary attention that is automatically captured by striking or relevant stimuli. Efforts made throughout the day to maintain focus on our intentional behaviors would cause the depletion of the limited resources of directed attention, subjectively perceived as mental fatigue. This would not be the case with involuntary attention, which would not demand limited resources. According to Kaplan and Berman (2010), contexts that provide a feeling of *being away*, *extent* (i.e., expansive enough to occupy the mind), *compatibility* with a person's purpose, and a mild "state of amazement" (which they call *soft fascination*) can promote recovery from fatigue. In their view, natural settings very often embody these features and have, therefore, the ability to restore directed attention. Conversely, urban contexts usually would produce a *hard fascination*, engaging both involuntary and directed attention too intensely, thus impeding recovery.

The definition of directed attention used by Kaplan and Berman (2010) conceptualizes it as one that the individual directs towards stimuli of their choice and that makes use of frontal and parietal cognitive control networks (e.g., Braver et al., 2021; Corbetta et al.,

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2008). It makes sense that directed attention would share characteristics, and even neural circuits, with some executive functions, such as inhibitory control, or working memory (Stevenson et al., 2018).

An alternative, though not mutually exclusive, explanation comes from Stress Reduction Theory (SRT; Ulrich, 1983). This theory postulates that perception of several "safety" indicators (such as water and food availability) usually present in natural environments would cause a reduction in stress levels and an improvement in mood, which then translates into an improvement in cognitive performance. Evidence that supports this possibility could be the reduction of skin conductance response and heart rate (Laumann et al., 2003) or the reduction of cortisol levels and enhancement of positive affect (Bratman et al., 2015) as a consequence of nature interventions.

Although both theories have been objects of different lines of criticism (e.g., Joye & Dewitte, 2018), numerous studies consistently demonstrate that interacting with certain natural environments (in comparison to urban contexts) produces positive effects not only at the affective level, but also at the cognitive one, especially in working memory, cognitive flexibility, and attentional control tasks (see the meta-analysis by Stevenson et al., 2018, for a review).

Regarding working memory (WM), there is now a large body of evidence for a close association between WM and selective attention (e.g., De Fockert, 2013). A lower availability of WM resources, either due to aging (e.g., Mayas et al., 2012; Noguera et al., 2019), low WM capacity (e.g., Megías et al., 2020, 2021; Ortells et al., 2016), or performing a high load task (e.g., De Fockert et al., 2010; Heyman et al., 2015; Ortells et al., 2017), would interfere with both inhibitory and facilitatory attention processes (e.g., Fernández et al., 2021; Ortells et al., 2017, 2018).

A possible explanation for this close interrelationship between WM and selective attention is given by the executive attentional control model of working memory capacity (WMC) developed by Engle (2002, 2018; see also Burgoyne & Engle, 2020). This model proposes the existence of a domain-general attentional control ability necessary for activation of any task-relevant mental representations, as well as blocking access to potentially task-irrelevant distracting information. According to this model, interaction with nature might be beneficial for WM by directly improving this domain-general attentional mechanism.

1.1. Influence of nature interventions on verbal vs. visuospatial WM

It is important to note, however, that most research showing improved WM performance associated with nature interventions has almost exclusively used verbal tasks, such as complex operation span (e.g., OSPAN, Bratman et al., 2015) or backwards digit span-DSB (e.g., Berman et al., 2008; Lin et al., 2014; Van Hedger et al., 2018). These tasks seem to reflect domain-general executive or attentional control processes, as they require focusing on relevant information and inhibiting distracting information (to prevent the secondary task to interfere with the primary task in the case of OSPAN; to successfully process, manipulate and update sequences in DSB; and to prevent proactive interference in both). It is now well-accepted that WM tasks not only measure storage capacity, but also a common central construct of directed (executive) attention (Burgoyne & Engle, 2020). Hence, given the numerous findings reporting a positive impact of nature on *verbal* WM, it would be reasonable to expect similar cognitive benefits in *visuospatial* WM. To our knowledge, however, only two studies so far have explored the cognitive benefits of nature experience in *visuospatial* WM, with divergent and somewhat inconsistent findings.

In one study, Schutte et al. (2017) required both preschool (4- to 5-years old) and school-aged (7- to 8-years old) children to perform different attention and WM tasks after walking along urban streets in one session, and after a nature walk in another session. The spatial WM task used by Schutte et al. consisted of remembering the position of a target that appeared on a computer screen either 40° to the right or 20° to the left of midline after a variable delay (retention interval, during which a distractor item could appear in a nearby location. Performance in the spatial WM task was better following a nature walk than an urban walk. But this difference was only significant for preschoolers (particularly boys), not for school-aged children, and the reasons for these age differences are unknown.

In another study by Bratman et al. (2015), two groups of young adults completed a series of verbal (e.g., OSPAN) and visuospatial WM tasks before and after a 50-min walk in either a natural or an urban environment. To assess visuospatial WM, they used a variant of the Change Detection task-CDT (e.g., Luck & Vogel, 1997). On each trial, a memory array consisting of either 4 or 8 colored squares is presented for a brief time, with participants being asked to hold as many squares as possible in mind. After a short retention interval, one probe item is presented on a test array and participants judge whether the item changed color. Results showed that, compared to the urban group, the nature group performed better after their walk. Yet, the observed cognitive impact of nature was only reliable in the complex verbal OSPAN task, not in the CDT, thus suggesting null cognitive benefits of nature experience in visuospatial WM.

However, several observations are pertinent here. First, although the Environment*Time interaction did not reach statistical significance ($p = .15$) for the CDT, the nature group also had a numerically greater improvement after walking (K After = 3.14; K Before = 2.73) than the urban participants (K After = 3.12; K Before = 3.04; see also Fig. 3B, pp. 47, from Bratman et al., 2015). Second, and even more relevant, in Bratman et al.'s study the memory arrays consisted of either 4 or 8-items. It is unclear why Bratman et al. only analyzed participants' performance from the 8-items condition to calculate the WM capacity measure (see Bratman et al., 2015, pp. 45), rather than assessing averaged performance across both the 4-item and 8-item conditions. There is behavioral and electrophysiological evidence that when participants are required to hold more than 4 items in a CDT, their accuracy performance can decline notably, especially in lower capacity individuals (e.g., Fukuda et al., 2015). Based on these findings, the results by Bratman et al. (2015) in the 8-item condition should be interpreted carefully as they might be constrained by our limited capacity for large sets of relevant stimuli (e.g., Fukuda et al., 2015; see also Cowan, 2001).

As noted, there is now broad evidence that performance on verbal (complex span) WM tasks reflects the involvement of general-domain executive attention processes. Participants showing high WM capacity scores (relative to low-capacity individuals) perform more efficiently across a broad range of selective attention tasks (e.g., Stroop, Negative Priming) that do not require maintaining large amounts of information (e.g., Hutchison, 2007; Hutchison et al., 2013; Maldonado et al., 2018; Megías et al., 2020, 2021; Ortells et al., 2016). From an ART framework, one could plausibly consider that interacting with several environments (natural stimuli) would have a positive impact on controlled attention processes that increase participants' performance on those WM span tasks. But this might not be the case with respect to the *visual arrays* tasks, such as the CDT used by Bratman et al. (2015), thus explaining the null cognitive impact of nature experience reported in the latter task. In fact, performance in the visual arrays tasks has been traditionally interpreted as a fairly pure measure of visual memory storage capacity (e.g., Luck & Vogel, 1997) thought to mainly reflect the number of items stored in visual WM (with k values reaching asymptotic values around 3 or 4; Cowan, 2001).

1.2. Attention control processes in selective vs. nonselective visual WM tasks

Over the last decade, however, evidence has accumulated that behavioral (k scores) and ERP (contralateral delay activity-CDA) measures of visual arrays performance reflect individual differences in controlled attentional processing (e.g., Adam et al., 2015; Fukuda et al., 2015; Martin et al., 2021).

This is particularly true for *selective* visual array tasks, in which participants have to focus on only a subset of the items presented in the target array, with the remaining elements being treated as to-be-ignored distractors. In these tasks, WM capacity measures (e.g., k scores; CDA) are determined, at least in part, by individuals' ability to filter task-irrelevant distractors (e.g., Li et al., 2017; Vogel et al., 2005).

Furthermore, several behavioral and ERP findings demonstrate that performance in *nonselective* visual arrays also reflect a contribution of attention control processes by reducing external and internal interference (e.g., Adam et al., 2015; Fukuda et al., 2015; Robison & Brewer, 2022; Shipstead & Engle, 2013; Shipstead et al., 2015). For example, Shipstead and Engle (2013) reported that performance variability in a conventional visual CDT reflected proactive interference effects from previous trials and participants' WM capacity (k) scores were enhanced by increasing the interval between trials. In addition, Adam et al. (2015) found that the degree of attentional engagement on a trial-by-trial basis during a nonselective CDT reliably predicted individual differences in performance. These findings suggest that controlled processes for goal-maintenance and preventing lapses of attention can also determine performance on nonselective visual arrays.

Lastly, correlations between participants' WM capacity (k) scores in nonselective visual arrays, and behavioral and ERP measures of performance in selective attention tasks (i.e., Stroop) have been found (e.g., Fernández et al., 2021; Shipstead et al., 2015). This is the case of several recent studies that used a nonselective variant of the CDT, known as the Change Localization task (CLT) to assess participants' visual WM capacity. For example, Fernández et al. (2021) reported behavioral and ERP evidence that high- and low-capacity individuals showed differences when implementing strategic (expectancy-based) attentional processes.

1.3. The current study

Considering that nonselective visual WM tasks (i.e., no distractor filtering) seem to involve directed (executive) attention processes as well, the main goal of the present research is to test if exposure to nature-related (vs. urban) environments could reliably improve performance on them, as found in verbal WM tasks.

To this end, we ran three experiments in which participants performed a nonselective CLT before and after being exposed to images depicting natural and urban environments. Both kinds of stimuli were manipulated within-participants in all experiments. The main difference between the three studies was related to the degree of aesthetic preference induced by natural and urban images.

A common finding in the attentional restoration literature is that nature-related stimuli are much more preferred by participants (i.e., a higher degree of likability) than are urban stimuli. In Experiment 1, we included a post-experiment preference rating task for the natural and urban image sets and correlated this with performance. In Experiment 2, we presented a subset of the images that had induced similar preference ratings across participants in Experiment 1. In Experiment 3 we used a series of preference-equated subsets of natural and urban scenes recently created by Meidenbauer et al. (2020). These experiments allow us to investigate whether being exposed to natural (relative to urban) stimuli could improve participants' capacity WM scores (k) in our CLT, as well as whether aesthetic preference plays a role in the potential cognitive benefits of nature.

2. Experiment 1. natural environments and visuospatial working memory

Participants performed a CLT (Fernández et al., 2021; Ortells et al., 2018), in which no distracting information is presented either on the memory array or during the retention interval (unlike the visual WM task used by Schutte et al., 2017). In a CLT, unlike the standard CDT, a color *change* is present on every trial. On each trial, participants are presented with a brief array of four colored circles that they are asked to remember. Memory for these items is tested 1 s later with a test array that is identical to the original memory array except that one circle has changed its color. Participants have to localize that change by selecting it manually on the test array.

Some of the features of the CLT are that: (a) it takes less than 10 min to administer; (b) its execution does not require any kind of specialized knowledge (e.g., vocabulary or mathematical skill); and (c) unlike the complex WM span tasks, it does not require any kind of task-switching. Despite its apparent simplicity compared to other WM capacity tasks used in the literature (e.g., complex span tasks), the CLT yields highly reliable results (e.g., test-retest reliability; Johnson et al., 2013), and has produced significant correlations with more complex cognitive processes (e.g., Castillo et al., 2020, 2021, 2023), reliably predicting the capacity to implement both facilitatory and inhibitory attentional control strategies (e.g., Fernández et al., 2021; Noguera et al., 2019).

Participants performed this CLT before and after being exposed to different sets of images depicting both natural and urban environments, with both types of images presented to the same participants across two different experimental sessions. To the extent that the exposure to certain types of nature-related images improves WM performance more than viewing urban images, we expected to find a reliable interaction between image type (natural vs. urban) and time of WM task (before vs. after being exposed to the images). Thus, participants' performance in our CLT (as indexed by k capacity scores) should increase after viewing nature-related images, as compared to urban settings.

3. Materials and method

3.1. Participants

Forty undergraduate students (27 women) from the University of Almería (age range = 19–46 years; $M = 22.6$, $SD = 4.96$) received course credit for their participation in the experiment. All participants were native Spanish speakers with normal or corrected-to-normal vision. This sample size was larger than that of previous studies addressing the impact of nature interventions on memory and executive attention tasks (e.g., Berman et al., 2008, $n = 38$; Berto, 2005, $n = 32$; Bourrier et al., 2018, $n = 30$; Bratman et al., 2015, $n = 30$; Gamble et al., 2014; $n = 30$; Van Hedger et al., 2018, $n = 32$). We additionally conducted an a priori power analysis with G*Power (Faul et al., 2007) based on the assumption of a medium-large size effect by nature experience reported in literature (e.g., Berto, 2005, $d = 0.58$; Berman et al., 2008, $d = 0.44$; Bratman et al., 2015, $d = 0.67$; Gamble et al., 2014, $d = 0.76$; Van Hedger et al., 2018, $d = 0.71$). With an alpha = .05, and a statistical power of .90, a minimum sample size of twenty-nine participants would be required to detect a medium effect size ($d \approx 0.63$).

All participants realized two consecutive experimental sessions (being exposed in each session to different sets of natural vs. urban images) with 5–7 days between the two sessions. This and the remaining experiments were conducted in compliance with the Helsinki Declaration and the ethical protocols of the Code of Good Practices in Research from the University of Almería. Participants were informed of the details of the study and signed an informed consent before inclusion, with the protocol being approved by the Bioethics Committee in Human Research from the University of Almería.

3.2. Apparatus and stimuli

The experiment was run on a PC using E-Prime 2.0 software (Psychology Software Tools, 1996–2002). The stimuli were presented on a 17-inch TFT monitor at a viewing distance of approximately 60 cm. The stimuli in the CLT consisted of four colored circles about 0.96° horizontally and 0.96° vertically presented on a gray (RGB values 60, 60, 50) background screen. The four circles were randomly selected from a set of nine colors with the following RGB values: Black (0, 0, 0), Blue (0, 0, 255), Cyan (0, 255, 255), Green (0, 255, 0), Magenta (255, 0, 255), Orange (255, 113, 0), Red (255, 0, 0), Yellow (255, 255, 0) and White (255, 255, 255). The colors of the four circles were not repeated on the same screen and each one appeared randomly in one quadrant of the screen with a minimum and maximum distance respective to the central fixation point of 3.36° and 4.80° visual angle, respectively. The distance between fixation and the closest stimulus is 3.36° and between fixation and the furthest is 6.24°. The distance between the closest stimuli in adjacent quadrants is 3.82° and between the furthest stimuli is 8.58°. Participants' responses were collected by using a mouse.

A total of 100 color photos were used as environmental stimuli: 50 urban photos taken at the city center of Almería (Spain), and 50 natural pictures taken at the Cabo de Gata-Níjar natural park and Tabernas desert (natural areas in the province of Almería). All photos were taken during spring with clear skies or partly cloudy skies and are available in https://osf.io/f7ncr/. As in previous studies examining the cognitive impact of picture viewing (e.g., Berman et al., 2008; Berto, 2005; Beute & de Kort, 2014), the nature images contained scenes of mountains, hills, coasts, vegetation, and stretches of grass, whereas the urban photos represented characteristic elements of cities such as asphalt, cars, and buildings. No humans were present in the foreground of any of the pictures (see also Berto, 2005; Beute & de Kort, 2014; see Fig. 1).

3.3. Procedure

Each participant attended two different experimental sessions (distributed over a week). In each session, the CLT was carried out twice, before and after being exposed to a set of 50 photographs presented consecutively (see Fig. 2).

Each trial in the CLT started with a fixation point (+) in the center of the screen that remained on the screen throughout the whole trial. After 1000 ms, a sample array displaying four differently colored circles (randomly distributed in the four quadrants of the screen) was presented for 150 ms. After a 900 ms black screen (retention interval), a test array was displayed, which was identical to the sample array except that one circle had changed its color, and participants had to indicate the location of the change using the mouse. Participants were informed that their reaction time was not measured and that they always had to choose one circle, even if they were not sure about their answer. Once the answer was recorded, a black screen appeared for 1500 ms followed by the next trial (see Fig. 3). Participants performed eight practice trials followed by two experimental blocks of 32 trials per block, with a break interval between them. The total time to complete the task was around 5–6 min.

For each participant, the proportion of correct responses for both experimental blocks were combined and transformed to a *K*-index, based on the Pashler-Cowan equation (see Cowan et al., 2005; Pashler, 1988). As each stimulus array contains four circles and each test array always contains a circle that changed color (i.e., there are no false alarms), the proportion of correct responses was multiplied by four (equaling the number of circles per trial) to obtain the *K*-Index as the dependent variable. This equals the mean number of colored circles a participant can memorize in the task, with $K = 1$ or 25% being chance level, and $K = 4$ representing 100% of correct responses.

Each participant carried out two consecutive experimental sessions 5–7 days apart. On each session, they performed the CLT twice: before and after being exposed to a set of 50 consecutive photographs. In one session, the photos depicted nature-related environment contexts. In the other experimental session, all the images depicted urban scenes. The presentation order of both kinds of images in the two sessions was counterbalanced across participants.

Each photograph from each image-set was presented on screen for 6 s. Afterwards, participants were asked to rate its aesthetic value ("*how much did you like this photograph*) with a 3-point scale that indicated the level of disliking/liking that it produced. It ranged from 1 "*I barely or did not like it*" to 3 "*I liked it a lot*" (for similar aesthetic preference judgments of natural and urban images, see Berto, 2005 or Van Hedger et al., 2018). After rating the image, a new image was shown successively until all 50 pictures were presented (see Fig. 4).

4. Results and discussion

First, the inter-rater reliability for the preference ratings of the pictures was analyzed by means of the Cronbach's alpha coefficient, as recommended by Hallgren (2012). Both the natural pictures and the urban photos had $\alpha = 0.96$, which can be considered as "excellent" following the rules of thumb of George and Mallery (2003). Second, we conducted a repeated-measures analysis of variance (ANOVA) on our dependent variable (K index) with Context (natural vs. urban) and Time of WM task (before vs. after image viewing) as within-participants factors. There was a significant main effect of task Time ($F(1, 39) = 11.55$, $p = .002$, $\eta^2 = 0.23$), indicating improved performance from pre-exposure ($K = 3.30$) to post-exposure ($K = 3.41$) to photographs (i.e., a practice effect; see Table 1A), and a Time*Context interaction ($F(1, 39) = 9.35$, $p = .004$, $\eta^2 = 0.19$; see also Table 2). Follow-up tests revealed that CLT performance was reliably better after viewing nature

Fig. 1. Examples of photographs used in Experiment 1 (top row: natural contexts; bottom row: urban contexts).

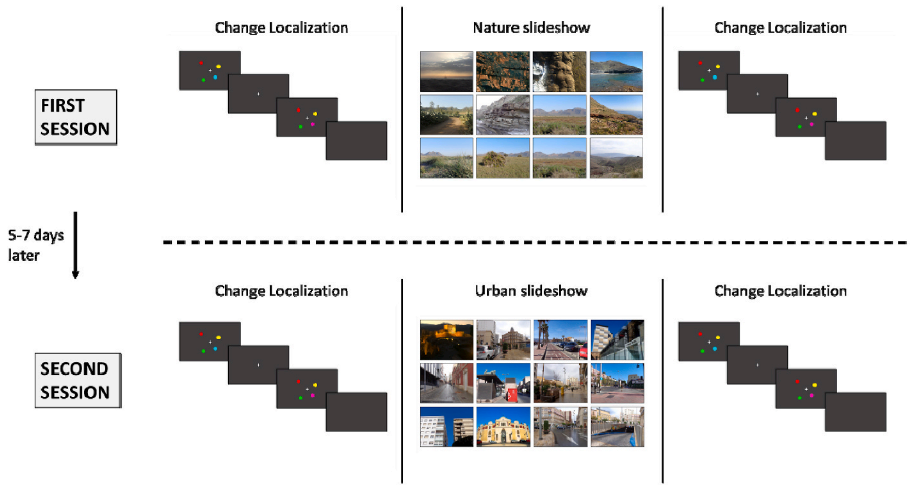

Fig. 2. Graphic summary of the procedure followed in Experiments 1, 2 and 3 (the slideshow content was counterbalanced across sessions).

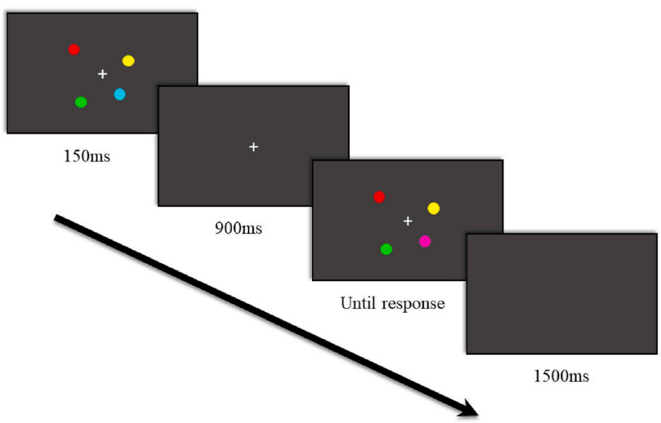

Fig. 3. Sequence of events in the Change Localization task.

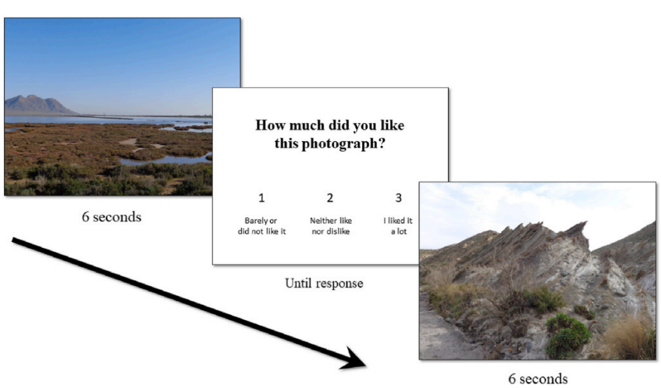

Fig. 4. Sequence of events during the photography slideshow phase.

photographs (t (39) = 5.043, p < .001; d = 0.56), with these cognitive benefits being found in most participants (75%; see Fig. 5A). However, task performance was similar before and after being exposed to urban images (t (39) = 0.997; p = .325; d = 0.14; see Table 2). Additional analyses revealed that there were no main effects or interactions associated with photograph-viewing order (i.e., viewing nature images first or second).

The present results replicate and extend several prior findings where simply viewing images of natural landscapes (as compared to viewing urban images) can have a beneficial effect on memory and attention

Table 1

Results from the (A) ANOVA on Context (Nature vs. Urban) by Time of WM task (Before vs. After viewing the images) effects, and from (B) ANCOVA on Context (Nature vs. Urban) by Task Time (Before vs. After) by Preference rating (covariate) effects for Experiment 1. Bold = Statistically significant (p < .05).

Source	Sum of Squares	*df*	Mean square	*F*	*p*	partial η^2
A)						
Context	.004	1	.004	.053	.820	.001
Error (Context)	2.678	39	.069			
Time	.515	1	.515	11.553	**.002**	.229
Error (Time)	1.740	39	.045			
Context*Time	.193	1	.193	9.354	**.004**	.193
Error (Context*Time)	.806	39	.021			
B)						
Context	.104	1	.104	1.536	.223	.039
Context*Preference	.107	1	.107	1.576	.217	.040
Error (Context)	2.571	38	.068			
Time	.263	1	.263	5.936	**.020**	.135
Time*Preference	.057	1	.057	1.286	.264	.033
Error (Time)	1.683	38	.044			
Context*Time	.060	1	.060	2.852	.099	.070
Context*Time*Preference	.005	1	.005	.237	.629	.006
Error (Context*Time)	.801	38	.021			

Table 2

Average performance (K index) of participants in the Change Localization task as a function of Context (Nature vs. Urban) and the Time of WM task (Before vs. After viewing the images) in Experiment 1. Bold = Statistically significant (p < .05).

				Confidence interval (95%)	
Context	Time of WM task	M	SD	Lower bound	Upper bound
Natural	**Before**	3.27	.33	3.17	3.37
	After	**3.45**	.33	3.34	3.56
Urban	**Before**	3.33	.32	3.23	3.43
	After	3.37	.33	3.27	3.48

control processes (e.g., Berman et al., 2008; Berto, 2005). But, unlike previous work, we found a nature-related performance advantage on a relatively simple visuospatial WM task.

On the other hand, there is evidence that nature-related stimuli tend to be aesthetically preferred to urban stimuli (e.g., Bratman et al., 2015; Kardan et al., 2015; Stenfors et al., 2019; Van Hedger et al., 2018). Consistent with these findings, we found that participants' ratings of aesthetic preference given to natural images (M = 2.39, SD = 0.28) were

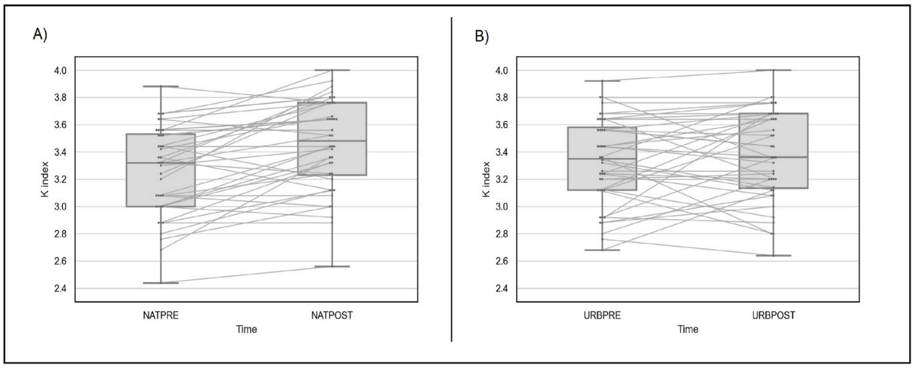

Fig. 5. Boxplots of Change Localization performance (k scores) for each participant in Experiment 1 before vs. after viewing natural (A) and urban (B) images.

significantly higher [t (39) = 13.84; $p < .001$; $d = 2.45$] than those for urban images ($M = 1.71$, $SD = 0.27$). This raises the possibility that nature-related cognitive benefits in our visual WM task could be driven by the greater subjective preference towards natural stimuli (see, for example, the SRT by Ulrich, 1983; to see the distribution of participants' preference, see Fig. 6).

To explore this possibility more directly, we conducted a further analysis of covariance (ANCOVA) in which, for each participant, we calculated an average preference score for natural over urban stimuli (with positive vs. negative scores reflecting, respectively, a preference for natural vs. urban images). This preference score was used as a continuous covariate, along with Context (natural vs. urban) and task Time (before vs. after) as within-subject factors. The ANCOVA results (see Table 1B) showed that image preference did not interact with either Context or Time (all p's > 0.26), and the three-way Preference*Context*Time interaction was not reliable ($F < 1$). The results of further correlational analyses also showed a lack of correlation between preference and WM performance after viewing both natural (r (40) = −0.007, $p > .96$) and urban images (r (40) = −0.12, $p > .44$), thus replicating what was found in previous literature.

Overall, that result pattern suggests that participants' preference judgements towards natural photographs were not predictive for the improved performance in the visual WM task after viewing them. Yet, it remains unclear whether greater cognitive benefits by nature exposure could also be observed when participants were presented with nature and urban images that would induce a similar degree of subjective satisfaction. Our next experiment was conducted to address this possibility.

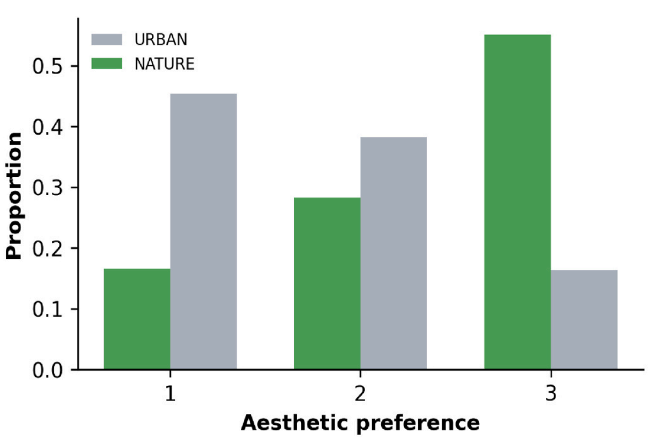

Fig. 6. Proportion of choice of every preference option (from 1 to 3) for each image set in Experiment 1 (urban: gray; natural: green). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

5. Experiment 2. controlling for individual aesthetic preferences

The main goal of this experiment was to investigate whether exposure to natural environments could improve performance in a WM task, even when the overall aesthetic preference for the presented natural and urban images is judged to be similar. To this end, from the overall set of photographs used in Experiment 1, two sub-sets of natural and urban images to which participants had given very similar aesthetic preference ratings were selected. Participants viewed both sets of images through two consecutive experimental sessions and performed a CLT in a procedure similar to the one followed for Experiment 1.

Participants in the present experiment were required to rate the aesthetic value of each viewed photograph using a 5-point scale (instead of the 3-point scale used in Experiment 1), from 1 "*I do not like it*" to 5 "*I love it*". This broader range to evaluate each one of the photos could result in more specific and discriminative rating scores, allowing a more precise measure of the level of "liking/disliking" produced by each image.

If the nature-related cognitive benefits in Experiment 1 were mainly due to greater preference towards natural environments, we would expect that viewing similarly-preferred natural and urban images would produce similar effects on WM performance. Conversely, if the cognitive enhancements associated with nature interventions were not driven by changes in the degree of aesthetic preference, we would expect that participants' CLT performance should again be better after being exposed to natural photos than after viewing urban scenes.

6. Materials and method

6.1. Participants

Forty undergraduate students (26 women) from the University of Almería participated in this experiment, with ages between 18 and 46 years (*mean age* = 22.6; *SD* = 4.96), all of them with normal or corrected-to-normal vision and receiving course credit for their collaboration. All the participants completed two experimental sessions 5–7 days apart.

6.2. Apparatus, stimuli, and procedure

Fifteen natural and fifteen urban images were selected from the stimulus set used in Experiment 1 by calculating a total score for each image from their ratings in Experiment 1. Because natural images were generally preferred, many of the urban images were rated lower than all the nature images. Therefore, we chose the 15 urban images with the *highest* score and matched these one-by-one in similarity to the nature images, giving a total set of 15 natural and 15 urban images (Figs. 7 and 8). Finally, to ensure natural and urban images had a similar degree of aesthetic preference, we verified that the overall rating scores for both natural ($M = 2.178$; $SD = 0.30$) and urban images ($M = 2.195$; $SD =$

Fig. 7. Natural landscapes photographs used in Experiment 2. Taken in Cabo de Gata (Almería).

Fig. 8. Urban landscapes photographs used in Experiment 2. Taken in Almería's urban center.

0.31) were not statistically different ($t < 1$).

Given that our intention was to achieve the same task duration as Experiment 1 (i.e., 6 min; see also Berman et al., 2008; Berto, 2005), but less pictures were used, participants viewed the same 15-image set twice, across two consecutive blocks. Each image was thus shown for 12 s in total.

7. Results and discussion

Regarding inter-rater reliability for preference ratings of pictures, the Cronbach's alpha coefficient was adequate (George & Mallery, 2003) for both natural ($\alpha = 0.95$), and urban photos ($\alpha = 0.97$). As in Experiment 1, the results of a preliminary analysis showed that the order in which participants viewed images (nature picture first vs. urban first) had no significant effect.

The repeated measures ANOVA on K index with Context (urban vs. natural) and Time of WM task (before vs. after image viewing) as within-participants factors, showed a significant interaction between the two factors (F (1, 39) = 6.70; p = .01; η^2 = 0.15; see Table 3A). Follow-up tests revealed improved performance after (relative to before) viewing natural images (t (39) = 2.72, p = .01, d = 0.21; see Table 4). Yet, such a cognitive benefit was not observed with urban images (t (39) = 0.88; p = .386; d = 0.07), thus replicating the results from Experiment 1.

Although the selected natural and urban images were judged by participants in Experiment 1 as inducing a similar overall degree of subjective satisfaction, we found that preference ratings (using a 5-points scale) in the present experiment were again reliably higher [t (39) = 6.61; p < .001; d = 1.16] for natural (M = 3.41; SD = 0.67) than for urban (M = 2.70; SD = 0.55) photographs (see Fig. 10). Consequently, we could not completely rule out that improved performance in the CLT after viewing natural images may, at least partly, result from greater subjective satisfaction (preference) that these produce in participants, relative to urban images. It is noteworthy, however, that the effect size between natural and urban was much smaller than in Experiment 1 (d = 2.47 vs. d = 1.06).

Accordingly, we conducted an ANCOVA similar to Experiment 1,

Table 3
Results from the (A) ANOVA on Context (Nature vs. Urban) by Time of WM task (Before vs. After viewing the images) effects, and from (B) ANCOVA on Context (Nature vs. Urban) by Task Time (Before vs. After) by Preference rating (covariate) effects for Experiment 2. Bold = Statistically significant ($p < .05$).

A)

Source	Sum of Squares	*df*	Mean square	*F*	*p*	partial η^2
Context	.276	1	.276	2.549	.118	.061
Error (Context)	4.216	39	.108			
Time	.046	1	.046	1.670	.204	.041
Error (Time)	1.080	39	.028			
Context*Time	.174	1	.174	6.698	**.013**	.147
Error (Context*Time)	1.015	39	.026			

B)

Source	Sum of Squares	*df*	Mean square	*F*	*p*	partial η^2
Context	.060	1	.060	.543	.466	.014
Context*Preference	.025	1	.025	.230	.634	.006
Error (Context)	4.190	38	.110			
Time	4.732E-06	1	4.732E-06	.000	.990	.000
Time*Preference	.040	1	.040	1.466	.233	.037
Error (Time)	1.040	38	.027			
Context*Time	.134	1	.134	5.098	**.030**	.118
Context*Time*Preference	.012	1	.012	.459	.502	.012
Error (Context*Time)	1.002	38	.026			

Table 4
Average performance (K index) of participants in the Change Localization task as a function of Context (Nature vs. Urban) and the Time of WM task (Before vs. After viewing the images) in Experiment 2. Bold = Statistically significant ($p < .05$).

				Confidence interval (95%)	
Context	Time of WM task	M	SD	Lower bound	Upper bound
Natural	**Before**	3.28	.48	3.12	3.43
	After	**3.38**	.38	3.25	3.50
Urban	**Before**	3.26	.47	3.10	3.42
	After	3.23	.47	3.08	3.38

using participants' preference as a continuous covariate along with Context (natural vs. urban) and task Time (before vs. after) as within-subject factors (see Table 3B). Image preference did not reliably interact with either Context or Time (all p's > 0.24). More relevant was the lack of a reliable three-way interaction between Preference, Context, and Time ($F < 1$), whereas Context*Time interaction remained still significant (F (1, 38) = 5.098; $p = .030$; $\eta2 = 0.12$). The results of additional correlational analyses revealed again no reliable relation between participants' preference ratings and WM performance after viewing either nature (r (40) = −0.17, $p > .29$) or urban images (r (40) = 0.015, $p > .93$).

We conducted a mixed ANOVA treating Experiment (Exp 1 vs. Exp 2) as a between-participants factor, to see if our attempts to equalize images in Experiment 2 could have reduced the effects found compared to Experiment 1. There was a significant main effect of Time [F (1, 78) = 12.4; $p < .0001$; $\eta^2 = 0.13$], such that WM performance was better after ($K = 3.35$) than before ($K = 3.28$) image exposure (i.e., a task practice effect). The interaction between Context and Time was also significant [F (1, 78) = 15.74, $p < .0001$; $\eta^2 = 0.17$], showing again an improved CLT performance from pre- ($K = 3.27$) to post-exposure ($K = 3.41$) of nature photographs, but no improvement in WM performance following urban images (Pre-exposure = 3.29; Post-exposure = 3.30). Moreover, the cognitive benefits by nature stimuli did not reliably differ across both experiments, as revealed by the lack of a three-way interaction Experiment*Context* Time ($F < 1$).

8. Experiment 3. preference-equated stimuli from Meidenbauer et al. (2020)

In Experiments 1 and 2, we found that WM performance reliably improved after exposure to nature images. These cognitive benefits did not reliably correlate with aesthetic preference (e.g., "liking") judgments (Ulrich, 1983) given by participants to natural scenes, as shown by the lack of a reliable three-way Context*Time*Preference interaction. Other previous studies had demonstrated that affective and cognitive benefits of nature can be dissociable by not finding any correlation between aesthetic preference ratings given to environments and the behavioral improvements found (Berman et al., 2008; Stenfors et al., 2019; Van Hedger et al., 2018). These findings could be explained by Attention Restoration Theory-ART (Kaplan, 1995; Kaplan & Berman, 2010), which proposes a mechanism of cognitive restoration that would be independent and unrelated to aesthetic preference for certain environments.

Yet, most previous work that measured preference and showed a robust impact of nature on attentionally demanding cognitive tasks (e.g., working memory; inhibitory control) has found that nature-related stimuli (e.g., images, soundscapes) are also systematically rated as more attractive than urban stimuli, suggesting a potential role of aesthetic preferences. One could thus wonder whether there is something unique to cognitive benefits of nature stimuli over and above individuals' preference for them.

In a recent study, Meidenbauer et al. (2020) found that affective benefits induced by nature interactions were mainly result of being exposed to highly preferred stimuli. When nature scenes were compared to equally-preferred urban images, the authors failed to find evidence for an additional affective benefit of nature. These findings suggest that nature improves affective states because it is usually a highly preferred environment.

On the basis of these results, a stronger test of whether preference plays a role in the *cognitive* benefits of nature would be to compare objective performance on our visual WM task before and after exposure to preference-equated nature and urban images. This was already attempted in Experiment 2, however, *post-hoc* analysis showed that images were not perceived as equal in likability in that sample. The goal of Experiment 3 is, therefore, to account for aesthetic preference on the beneficial cognitive effects that natural images seem to produce (compared to urban ones) using previously-normed images equated on aesthetic preference.

To this end, we used a series of preference-equated sets of natural and urban scenes recently developed by Meidenbauer et al. (2020). These images were rated by a much larger sample ($n = 401$) than those used in our Experiment 2 ($n = 40$) and have shown adequate inter-rater reliability throughout their study. Following the same procedure as of Experiments 1 and 2, participants performed the CLT before and after being visually exposed to both types of images (across different experimental sessions).

If nature has a positive effect on a cognitive WM task that is not simply due to preference, then exposure to natural environments should elicit larger positive cognitive changes (i.e., higher *K* score) than preference-equated urban environments. Conversely, if context-type is less important than aesthetic preferences, then a similar cognitive impact should be produced by preference-equated image sets, so that participants' performance in our WM task should be significantly increased after exposure to both kinds of pictures.

9. Materials and method

9.1. Participants

Forty undergraduate students (30 women) from the University of Almería who had not taken part in Experiments 1 or 2 participated in this experiment, with ages between 18 and 43 years (mean age = 20.85; *SD* = 3.85). All participants had normal or corrected-to-normal vision and received course credits for their participation. All participants completed two experimental sessions, with 5–7 days between the two sessions (just like in the first two experiments).

9.2. Apparatus, stimuli, and procedure

The procedure was the same as the one used in Experiments 1 and 2, with participants being exposed to two different sets of images in two different sessions and performing CLT before and after visualizing them. The main difference with the first two studies is that the set of contextual images was comprised of forty-five natural and forty-five preference-equated urban images selected from Meidenbauer et al. (2020). In their study, a total of 375 images (including both natural and urban types) were rated by their aesthetic preference. By matching images of both kinds based on their ratings, two pairs of sets were obtained (a high aesthetic value set and a low aesthetic value set). For the present experiment, the High Aesthetic Value set or 'HA' was used, which included preference-matched natural and urban images. Because the set included 45 natural images and 45 urban images, each image was displayed for 8 s, so that the total length of environmental exposure remained at a total of 6 min (as in Experiments 1 and 2).

10. Results and discussion

Inter-rater reliability analysis for the preference ratings of the pictures showed an adequate Cronbach's alpha coefficient for both the natural (α = 0.88) and urban (α = 0.90) images (George & Mallery, 2003). As in Experiments 1 and 2, the results of a preliminary analysis revealed no significant main effect or interaction associated with image-viewing order. The repeated measures ANOVA on *K* index with Time of WM task (pre-vs. post image exposure) and Context (urban vs. natural) and as within-participants factors. showed a significant main effect of task Time ($F(1, 39) = 6.38$; $p = .016$; $\eta^2 = 0.14$). As observed in Experiments 1 and 2, participants' WM performance reliably improved from pre-exposure (*K* = 3.29) to post-exposure (*K* = 3.34) of photographs (see Table 5A). But this time, the task Time*Context interaction did not reach significance ($F < 1$).

Also using preference-equated natural and urban images, Meidenbauer et al. (2020) found no reliable Context*Time interaction. Note, however, that in their study, exposure to environment images with high aesthetic value produced a similar and reliable impact on affective changes, regardless of image category (natural vs. urban). But this was not the case in Experiment 3. Despite the lack of interaction, we conducted an exploratory post-hoc analysis in which we found that natural environments produced a significant improvement in WM performance ($t(39) = 2.06$, $p = .046$, $d = 0.19$; see Table 6), as observed in our previous experiments. In contrast, WM performance did not significantly improve after viewing urban pictures ($t(39) = 1.20$, $p = .24$, $d = 0.12$; see also Fig. 9), despite a marginally-significant trend ($t(39) = 1.95$, $p = .058$, $d = 0.37$) for preferring the urban (*M* = 3.23; *SD* = 0.63) over natural images (*M* = 3.00; *SD* = 0.56) among our participants (see also Fig. 11). This result hints at the same pattern found in Experiments 1 and 2, that is, cognitive benefits for natural environments and lack thereof for urban ones.

A further ANCOVA similar to those conducted in our previous experiments (see Table 5B), showed only a significant main effect of Time [$F(1, 38) = 6.46$, $p = .015$, $\eta^2 = 0.15$]. As in Experiments 1 and 2, the results of correlational analyses again revealed that participants' preference ratings did not reliably correlate with their performance in the WM task after being exposed to either nature ($r(40) = 0.267$, $p = .096$) or urban images ($r(40) = -0.151$, $p = .35$).

11. Global results

In a further attempt to explore a potential role of aesthetic preference in the differential WM benefits induced by natural vs. urban images, we conducted a global ANCOVA including preference ratings from the 120 participants in our three experiments. The Context*Time interaction remained significant once again ($F(1, 118) = 5.242$, $p = .024$, $\eta^2 = 0.43$), showing that the only reliable enhancement in CLT was produced by natural scenes (Pre K = 3.28; Post-exposure K = 3.39; $t(119) = 5.65$, $p < .001$, $d = 0.30$), but not by urban pictures (Pre = 3.29; Post-exposure = 3.31; $t(119) = 0.79$; $p = .43$). It appears then, that the inclusion of participants' preference ratings does not explain away the differential effects by natural and urban environments. At least to some degree, aesthetic preference is not a necessary condition to get visual WM

Table 5

Results from the (A) ANOVA on Context (Nature vs. Urban) by Time of WM task (Before vs. After viewing the images) effects, and from (B) ANCOVA on Context (Nature vs. Urban) by Task Time (Before vs. After) by Preference rating (covariate) effects for Experiment 3. Bold = Statistically significant ($p < .05$).

A)

Source	Sum of Squares	*df*	Mean square	*F*	*p*	partial η^2
Context	.000	1	.000	.003	.890	.000
Error (Context)	1.616	39	.041			
Time	.113	1	.113	6.384	**.016**	.141
Error (Time)	.693	39	.018			
Context*Time	.006	1	.006	.140	.710	.006
Error (Context*Time)	1.015	39	.026			

B)

Source	Sum of Squares	*df*	Mean square	*F*	*p*	partial η^2
Context	.002	1	.002	.058	.812	.002
Context*Preference	.021	1	.021	.510	.480	.013
Error (Context)	1.594	38	.042			
Time	.117	1	.117	6.461	**.015**	.145
Time*Preference	.004	1	.004	.237	.629	.006
Error (Time)	.689	38	.018			
Context*Time	.021	1	.021	.859	.360	.022
Context*Time * Preference	.073	1	.073	2.947	.094	.072
Error (Context*Time)	.942	38	.025			

Table 6

Average performance (K index) of participants in the Change Localization task as a function of Context (Nature vs. Urban) and the Time of WM task (Before vs. After viewing the images) in Experiment 3. Bold = Statistically significant ($p < .05$).

Context	Time of WM task	M	SD	Confidence interval (95%) Lower bound	Upper bound
Natural	**Before**	3.28	.34	3.18	3.40
	After	**3.35**	.34	3.24	3.46
Urban	**Before**	3.30	.35	3.18	3.41
	After	3.34	.36	3.22	3.45

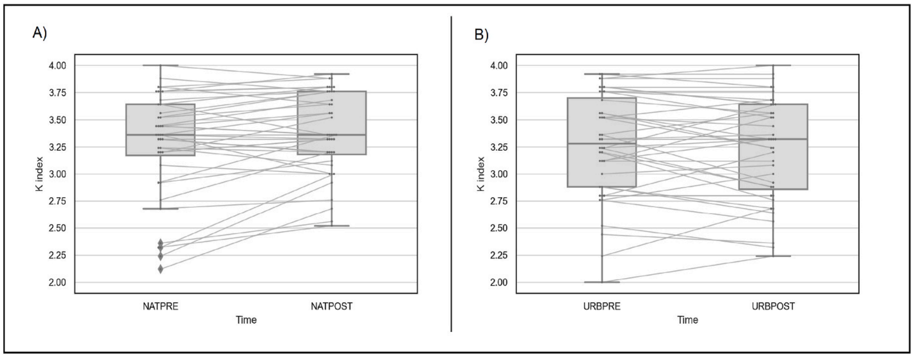

Fig. 9. Boxplots of Change Localization performance (k scores) for each participant in Experiment 2 before vs. after viewing natural (A) and urban (B) images.

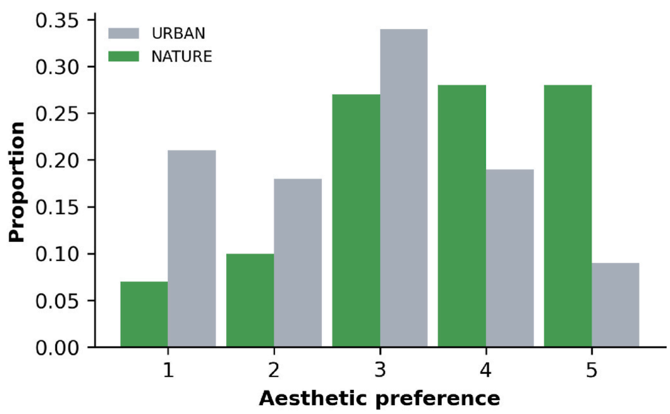

Fig. 10. Proportion of choice of every preference option (from 1 to 5) for each image set in Experiment 2 (urban: gray; natural: green). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

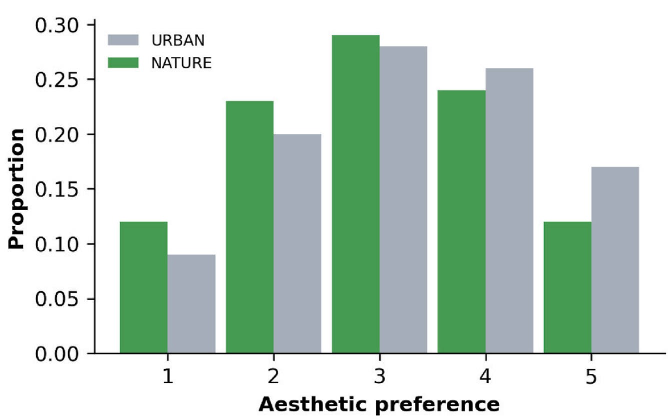

Fig. 11. Proportion of choice of every preference option (from 1 to 5) for each image set in Experiment 3 (urban: gray; natural: green). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

benefits in our research.

12. General discussion

There is now a robust body of evidence that interaction with natural environments is beneficial to cognitive performance, in particular on attentionally demanding tasks that require, for example, cognitive flexibility, inhibitory control or working memory (see Stevenson et al., 2018). This latter finding is well explained by the executive attention account of WM capacity, which states that its performance largely relies in the executive attention system to actively maintain task-relevant information and minimize external and internal sources of interferences (Burgoyne & Engle, 2020; Engle, 2018).

Previous research reporting a positive impact of nature experience in WM, however, has generally used tasks that require participants to retain and process *verbal* stimuli, such as letters or digits (e.g., Berman et al., 2008; Bourrier et al., 2018; Bratman et al., 2015; Van Hedger et al., 2018). Even though visual arrays such as Change Localization tasks (CLT) have been considered relatively stable measures of storage capacity in the past (e.g., Luck & Vogel, 1997; see also Fukuda et al., 2010), the results of numerous studies demonstrate that individual differences in *ability* to *control attention* are also important for differential performance in visual array tasks, even if they do not contain a selective attentional filtering component (Fernández et al., 2021; Gold et al., 2003; Ortells et al., 2018). For that reason, the fact that only two studies using visual WM tasks have been published to date (with inconsistent results) is insufficient.

The main goal of the present research was to determine whether exposure to certain types of environmental contexts (e.g., natural) could have consistent beneficial effects on a nonselective visuospatial WM task. For this purpose, we used a Change Localization task (or CLT), which can be considered a simplified version of the CDT used by Bratman et al. (2015), as noted in the Introduction. However, unlike Bratman et al.' s task, in our WM task, the memory arrays always consisted of 4 colored items.

Our results showed that participants in all three experiments consistently improved performance in the CLT after being exposed to nature photographs, compared to before. Several prior studies had shown evidence that behavioral and electrophysiological measures of participants' performance in verbal and visual WM tasks can be reliably enhanced by different kinds of experimental manipulations (e.g., inter-trial interval; extensive practice; filtering distractor training) aimed to affect attention-controlled processing (e.g., Borella et al., 2010; Carretti, Borella, Zavagnin, & Beni, 2013; Fukuda et al., 2015; Li et al., 2017; Shipstead & Engle, 2013; Xu et al., 2018).

The results of the present study extend those findings in showing reliable improvement in a nonselective visual arrays task after participants were briefly exposed to environmental pictures. The observed benefits in WM performance are likely short-lived after the brief exposures (less than 10 min) used in our experiments but they are comparable in magnitude (especially in the case of Experiment 1, $d = 0.56$), to the effects obtained from other interventions that have been found to boost executive function performance such as acute exercise (*average* $d = 0.25$; see Smith et al., 2010 for a review) or meditation (*average* $d = 0.30$; see Fox et al., 2014 for a review).

At the same time, as certain studies show, the observed cognitive improvements could be even greater by interacting with nature physically (e.g., Gatersleben & Andrews, 2013) or virtually (e.g., Mostajeran et al., 2023). Given the important role that WM and executive attention play in other higher-order cognitive abilities, such as language comprehension, thought, problem solving, or navigational memory (e.g., Castillo, 2021; 2023), there are several relevant questions to address through future research. For example, (i) to what extent longer exposures to environment images might induce longer-term effects in visual WM; (ii) whether the effects could transfer to untrained abilities; (iii) whether the effects of nature interventions could be modulated by individual differences in executive control (or WM) capacity, and (iv) whether these effects could more greatly benefit individuals attentionally fatigued such as older adults, or some clinical populations (e.g., Berman et al., 2012).

Perhaps the higher K scores obtained in CLT after being exposed to nature images could reflect a more focused attentional engagement (and/or fewer lapses of attention) across trials in our WM task. Consistent with this, a previous study by Adam et al. (2015) using a nonselective CDT reported that trial-by-trial performance variations were mainly due to graded fluctuations in attention control in WM. But note that the whole-report procedure used by Adam et al. (2015) to examine different levels of attentional engagement included a relatively high number of trials (150, 300, and 450 trials in Experiments 1a, 1b, and 2, respectively). Our CLT had, however, a much lower number of trials (64), and our task procedure did not allow us to track for fluctuations in performance on a trial-by-trial basis. Whether being exposed to nature-related stimuli could induce better attentional engagement and fewer lapses of attention in performing our WM task remains a further interesting issue for future research.

It remains unclear, however, whether nature could have certain unique features responsible for the observed benefits, or whether they are mainly caused by the preference for such environments.

The Attention Restoration Theory-ART (Kaplan & Berman, 2010) does not explicitly reference how individual preferences for certain environments could influence cognitive restoration. Stress Reduction Theory (SRT, e.g., Ulrich, 1983), however, states that the first response when encountering a new environment would be to make an (automatic) affective evaluation of it, leading to primary reactions such as evaluations of safety and liking. Only if those evaluations are positive, restorative mechanisms would occur. From this view, it would be expected that positive evaluations of environments would predict their restorative potential on affective and cognitive function.

Most participants in Experiments 1 and 2 (39 and 36 out of 40, respectively) rated natural scenes as more attractive than urban ones (see histograms of preference ratings for nature and urban images depicted on Figs. 6 and 10), a common result in attentional restoration literature (e.g., Berman et al., 2008; Bratman et al., 2015; Van Hedger et al., 2018). A *preference-based account* (e.g., SRT) of cognitive change could predict the Time*Context interaction found in these two experiments, so that only nature-related, but not urban, stimuli induced reliable improvements in WM performance.

Yet, several observations seem relevant here. First, participants' preference ratings did not reliably correlate with cognitive benefits in any of our experiments, as usually found in literature (e.g., Berman et al., 2008, 2012; Stenfors et al., 2019; Van Hedger et al., 2018). Second, the Time*Context interaction was still reliable in Experiments 1 and 2 when aesthetic preference was included as a covariate (trending in Experiment 1; statistically significant in Experiment 2, and also for the combined analysis). Likewise, in the global ANCOVA including the data from all three experiments, the Time*Context interaction remained again significant, such that the only reliable WM enhancement was observed for natural, but not for urban images across experiments. Apparently, therefore, aesthetic preference would be not a necessary condition to get visual WM benefits.

Lastly, the results from Experiment 3 would be also difficult to explain by a preference-based account. Specifically, almost two-thirds of participants (27 out of 40) in this experiment preferred urban pictures over natural (see preference scores for both image sets depicted on Fig. 11). One could argue that the novelty and potential interest of the pictures used in Experiment 3 could have driven the preference for urban pictures over natural ones, as these pictures show places from North America and our participants were from (University of) Almeria, southern Spain. Indeed, comparing the ratings of urban settings between experiments (after transforming all scores from Experiment 1 to a five-point scale), the urban pictures that obtained higher mean scores were those of Experiment 3 (Experiment 1 = 2.85; Experiment 2 = 2.70; Experiment 3 = 3.23). Despite this advantage in aesthetic preference for urban over natural scenes in Experiment 3, urban exposure did not increase WM performance in the exploratory post-hoc analysis conducted (p = .24). In clear contrast, nature exposure reliably improved WM performance, as observed in our previous experiments.

Overall, our results do not provide enough information to draw definitive conclusions about the role of aesthetic preference in cognitive benefits from natural stimuli. And it is even possible that urban environments could cause cognitive enhancement if, according to ART, they fulfilled the "restorative requirements" (see for example, Berto et al., 2010). For that reason, we believe that an interesting approach for a future study could be using low and highly preferred urban and natural images, which would allow for a more precise dissociation of the effects from each environment and from each level of preference.

12.1. Limitations and future research lines

It is worth stressing that some factors were not controlled in the natural and urban images used in our research, such as the time of day, weather, or the relative presence of "aquatic" elements (e.g., rivers, lakes, coasts). Note, for example, that none of the urban photographs in Experiments 1 and 2, and only an 8% of the urban images presented in Experiment 3, contained water. In sharp contrast, the proportion of aquatic elements in the nature photographs was much higher in every experiment (Experiment 1 = 54%; Experiment 2 = 47%; Experiment 3 = 18%). We cannot discard the influence of this unbalanced representation of water in natural and urban images in our results (particularly in the first two experiments).

Using self-report measures, some studies have shown that both natural and urban scenes containing water are associated with higher preferences, greater positive affect, and higher perceived restorativeness than images without water (e.g., White et al., 2010). An interesting matter for future research concerns whether the presence of water or other elements normally inherent in nature, such as the type of vegetation or the usual curved forms of the landscape, could be critical to improving cognitive performance (for a description of other visual features common in natural environments, see Meidenbauer et al., 2020).

Additionally, in the present research, we did not assess participant emotional state (e.g., Positive and Negative Affect Schedule – PANAS; Watson et al., 1988) to account for emotional or affective changes (e.g., increases in positive emotions; decreases in negative emotions) from exposure to natural environments. Nevertheless, studies using these types of questionnaires have consistently shown that emotional changes associated to nature experience do not underlie the observed cognitive improvements (e.g., Berman et al., 2008; Crossan & Salmoni, 2019; Jenkin et al., 2018; Van Hedger et al., 2018).

As some researchers suggest, interaction with nature does not always provide positive effects. Under certain conditions, natural environments generate stress, negative emotions, and are associated with poorer cognitive performance (e.g., Gatersleben & Andrews, 2013). Finding what types of natural environments can induce more beneficial effects (Pearson & Craig, 2014) or the optimal duration of exposure or interaction with a natural environment are issues that must be addressed in future research on this topic.

It should be noted that in all our experiments there was notable between-participant variability in the size (and direction) of cognitive benefits supposedly induced by image exposure (see Figs. 5, 9 and 12). It remains unclear to what extent such between-subjects variability in

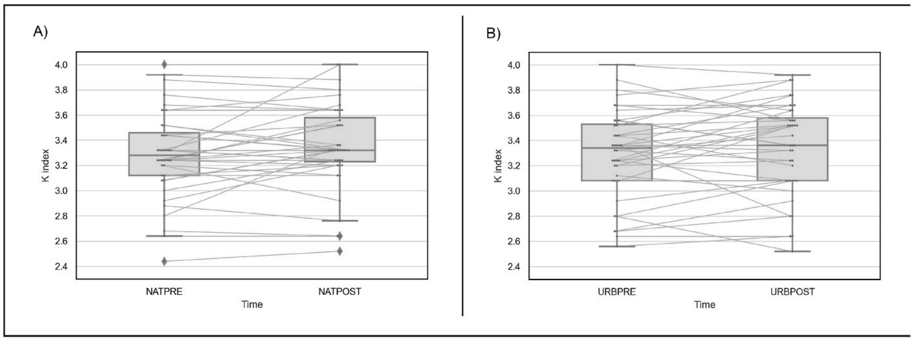

Fig. 12. *Boxplots of Change Localization performance (*k *scores) for each participant in Experiment 3 before vs. after viewing natural (A) and urban (B) images.*

cognitive restoration effects could be attributable to trait and/or state individual differences. In a recent study, Schertz et al. (2022) reported that individuals who scored higher on trait reflection attained larger benefits from interacting with nature. Individual differences in executive control capacities could also modulate the impact of nature exposure in our WM task. This is another question that deserves future investigation.

13. Conclusions

Using Change Localization task, the present experiments provide consistent evidence that visuospatial WM can be reliably enhanced after exposure to visual images of natural environments. Previous studies had showed that it was possible to improve performance in WM tasks that involved *verbal* information, but the present findings are novel in demonstrating beneficial effects in a nonselective WM task that requires the retention and processing of *visuospatial* information, even when there are no distracting elements in the task. Another question that tried to be addressed was whether individual preferences for certain environments may have modulated the effects found, but no definite answer was found and further research is needed to identify the role of this variable.

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Ethics statement

The local ethical committee has reviewed and approved the present studies and they fulfill the requirements of the European Communities Council Directive 2001/20/EC. Participants provided a written informed consent to participate in this study.

Author contributions

F. Javier González-Espinar:Conceptualization, Formal Analysis, Investigation, Writing – Original Draft, Writing – Review & Editing.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2023.102138.

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