Research Paper

Observation of environments with different restorative potential results in differences in eye patron movements and pupillary size

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ABSTRACT

The Environmental Psychological Restoration (EPR) is the result of the recovery of an antecedent deficit (e.g. stress or attentional fatigue) culminating in a restorative environment exposure. Recent findings suggest that visual contact with nature is important in triggering restorative responses. We measure the behavioral evidence of visual exposure to restorative environments in an eye-tracking study. Eye movement patterns (fixations and pupil dilatation) were evaluated while a sample of participants ($n = 27$; 15 females and 12 males) viewed photographs with High Restorative Potential (HRP) or Low Restorative Potential (LRP). The eye patterns during the observation of LRP were distinct to those of the HRP environments. Eye movements related to LRP photographs were characterized by a greater number of fixations compared to those related to HRP. Fixation times predicted an inverse relation, with LRP settings having a significantly shorter time per fixation than HRP pictures. Differences on pupil diameter were found. A higher pupil size was found during the view of HRP vs. LRP environments. Our eye tracking study suggest that restorative environment observation is associated with reduced eye movement activity relative to low restorative potential environment perception, which may reflect a lower cognitive effort in processing natural scenes. Likewise, pupillary dilatation variations suggest a possible link between the affective valences of the settings and its restorative quality. Data results are confronted according to attention restoration theory on restorative environments.

1. Introduction

Currently, there is an emerging interest in identifying biological explanations that may clarify the link between physical features of the environment, the human functioning and wellbeing (Lambert et al., 2015). For this reason, the use of physiological and psychological measures is of relevance to have a better understanding of the link between the environment and human health. The concept of restoration involves the physiological and psychological processes of renovating capacities that have become reduced or depleted in meeting the demands of ordinary life (Hartig, 2011). The environmental context of psychological restoration has been studied from the research on restorative environments (Kaplan, 1995). According to the attention restoration theory-TRA (Kaplan, 1995), natural (restorative) environments can have a restorative effect on attention. Restorative environments must possess four factors to promote the restoration of

attentional fatigue: 1) being away (a distance, whether geographical or psychological, from stressful tasks, which allows people to escape from distractions), 2) fascination (an effortless curiosity about the surroundings which allows a person to distract from their quotidian tasks), 3) compatibility (the positive connection between what a person needs and desires and the environmental qualities) and 4) coherence (the sense that the structure, connectedness, and scope of the environment fit well together) (Hartig et al., 1997). Several findings suggest that visual experiences of nature are important in triggering restorative responses (Stevenson et al., 2019) in spite of this, there is a lack of systematic research about the characterization of visual patterns related to the view of restorative environments.

Eye tracking is a relatively novel approach in landscape architecture and environmental psychology (Nordh et al., 2013). An eye-tracking is a very useful tool to determine eye behavior (Ntouskos et al., 2013). It represents an objective, direct link between the stimuli and the

participant. In the present research we explore how eye tracking could be used as a tool in assessing links between restorative environments and vision. We used eye-tracking technology to ask whether visual perception differs between scenes that are highly restorative (HRP, e.g. natural settings) and scenes that are less restorative (LRP; e.g. urban settings without nature). With the eye tracker, gaze locations, the time length of fixations, pupil dilation, among others, can be measured (Duchowski, 2017). Cognitive process reflected in eye movement are dependent of the task and the stimulus presented (Duchowski, 2017). Fixations (looking at the same place for a while) and saccades (fast eye movements) indicate how people acquire information (Martinez-Conde et al., 2004). Eye fixations could be related to information extraction strategies. They are intimately involved with our ability to visually encode spatially distributed information and can help us to understand which image features capture our attention (Henderson, 2016). Studies on visual search have demonstrated that the eye movements in a visual search task are highly dependent on the organization of the search array with an increase in fixation duration and the number of fixations as the display becomes more complex (Vlaskamp and Hooge, 2006). A high number of fixations suggest difficulty in interpreting the fixated information (Ehmke and Wilson, 2007). And, longer fixation can signal deficits in saccade planning and execution. A longer duration of fixations has different interpretations: (a) more effortful cognitive processing and information extraction (Holmqvist et al., 2011), (b) greater interest and (c) deficits in saccade planning and execution (Leder et al., 2016). Emotional arousal has also been found to increase viewing duration for both pleasant and unpleasant scenes (Lang et al., 1993). As mentioned earlier, eye movements are related to attention, which have motivated studies of restoration theory to test eye tracking (Franěk et al., 2018; Nordh et al., 2013; Valtchanov and Ellard, 2015). Berto et al. (2008) refer to pattern fixation role as indicator of the amount of focused attention used to view nature vs. urban-industrial scenes. They considered eye movements as a way to measure attention during scene observation. The authors noted that eye movements related to low fascination photographs (e.g. urban zones) were characterized by a greater exploration and a greater number of fixations compared to those rated high on fascination (e.g. natural environments). According with Berto et al., a lower number of fixations for high fascination scenes indicates less cognitive effort during its viewing. Nordh et al. (2013) explore eye tracking behavior as a tool in assessing restorative components in small urban parks. The authors compare the number of fixations in restorative and non-restorative park photos. They found that more time the participants spent looking at nature components (e.g. grass) the more likely they were to give a high rating on restoration likelihood. Contrary to Berto et al. (2010), the authors didn't show significant differences in the mean number of fixations between the low vs. high restorative park. According to the authors, these outcomes are related presumably to the evaluation of only one scene type (e.g. small urban parks). In other study, Valtchanov and Ellard (2015) analyzed the impact that visual low-level properties have on the preference for scene photographs, ocular movements and cognitive load. As stimuli, the authors utilized both altered and unaltered photographs of natural and urban scenes in order to discover if low-level visual properties (vs. middle to high spatial frequency) influence responses to scenes. According to the findings of Valtchanov and Ellard (2015) there exists a higher preference and a longer fixation time for natural scenes in comparison to urban landscapes. The last suggests that visual low-level qualities of scenes may be an important factor involved in the restorative experience of natural scenes. In a more recent study, Franěk et al. (2018) analyze eye movements (numbers of fixations and total eye travel distance) during participants´ viewing of photographs of nature scenes, ordinary urban scenes and scenes from old cities of Czech Republic, Belgium, United States, England, Germany, the Netherlands, and Switzerland. The results show differences between eye movements while perceiving photographs of various levels of restorativeness with a higher number of fixations on the images of urban scenes than nature scenes. Consistent with Valtchanov and Ellard (2015), Franěk et al. (2018) identified longer mean durations of fixations while perceiving nature scenes than urban scenes, suggesting the fact that while viewing the nature scenes, the participants made a smaller number of eye fixations that were longer. The aforementioned studies suggest that viewing restorative environments is associated with reduced eye movement activities relative to perceiving environments with low restorative potential, which may reflect lower cognitive effort and presumably a different information extraction strategy during the visual processing of natural scenes (Berto et al., 2008; Dupont et al., 2016; Franěk et al., 2018). In accordance to the above, it is expected a replication of Berto et al. (2008), Valtchanov and Ellard (2015) and Franěk et al. (2018) findings, with the mean number of fixations would be higher when observing non-restorative urban scenes compared to the restorative scenes of nature. It was hypothesized that average fixation times would show an inverse relationship, i.e. the greater the number of fixations, the minor time per fixation (Valtchanov and Ellard, 2015). Broadly speaking, pupil size responds to three distinct type of stimuli: brightness, proximity of objects (pupil near response) and cognitive activity (Mathôt, 2018). Psychosensory pupil responses (which include sensory and psychological stimuli) indicate emotion (Partala and Surakka, 2003; Snowden et al., 2011), arousal (Bradley et al., 2008), stress (Henckens et al., 2009), pain (Ellermeier and Westphal, 1995), skin conductance (Bradley et al., 2008), cognitive load (Recarte et al., 2008) and even perceptual experiences and subjective interpretations (Laeng and Sulutvedt, 2014; Naber and Nakayama, 2013). In rest conditions, pupils are relatively small in size (Mathôt, 2018). Spontaneous fluctuations in pupil size or pupillary unrest are related to tiredness (Lowenstein et al., 1963) and correlated with changes in eye movement behavior. For example, in small pupils and under low arousing conditions, the oculomotor behavior tends to be guided by the salient proprieties of the environment, aversely when pupils are large, suggesting high arousal, behavior is directed to motivational interest of the environment (e.g. things that people like) (Mathôt, 2018). Although pupil diameter is primarily controlled by the sensory characteristics of a visual stimulus, including brightness, darkness, contrast, distance, etc. (Barbur, 2004) it is also modulated by psychological variables including interest (Demos et al., 2008), emotional arousal and mental effort (Bradley et al., 2008; Mathôt, 2018; Võ et al., 2008). This type of psychosensory pupil responses is an endogenous response with a highly variable size reflecting how mental effort and arousal evolve over time (Mathôt et al., 2015).

In the context of restorative environments research, pupil size gives information about the restorative potential of the environment through the discernment of relaxation and arousal responses (Tveit et al., 2012). To date, pupil size studies on perception of restorative environments are scarce. Nordh et al. (2010) reported a negative correlation between pupil size and restoration likelihood considering a sample of small urban green spaces. The authors suggest the influence of pictures´ positive valence (e.g. a relaxing effect) associated with pupil constriction. By contrast, in the present study we show a sample of pictures with different affective and restorative valences: (a) highly restorative settings (high arousal and pleasure) (b) low restorative settings (low arousal and pleasure) (Martínez-Soto et al., 2014). If highly restorative environments tend to be more preferred than low restorative environments (van den Berg et al., 2003), then it is feasible to hypothesize differences between pupillary dilation variations in environments with HRP vs. LRP.

In sum, time held constant, the mean numbers of fixations within an image, the mean duration of all fixations, and pupil dilation in a free viewing of pictures (Wilming et al., 2017) with different restorative potential were considered.

2. Methods

2.1. Study 1. Preliminary study of image selection and stimulus development

This preliminary study was developed in order to match the pictures in terms of luminance and complexity (Snowden et al., 2011). Initially a sample of 33 photographs were selected from a previous study (Martínez-Soto et al., 2014). The values of average luminosity and its standard deviation were obtained using a standard image processing package (Photoshop). Those values are calculated in the histogram window by selecting show statistics and choosing the luminosity channel. As a result, a set of 26 pictures with similar ranges of luminance were obtained (mean luminance = 110.73; SD = 56.57). Complexity values were established in a single study with a sample of 14 students (age ranged from 18 to 21 years old). The participants were enrolled in the first year of various architecture courses. An 11-point unipolar Likert scale anchored at 0 "Simple" and 10 "Complex" was applied to test the scores of visual complexity (Chassy et al., 2015). The selected pictures were turned into a slide show with JAVA software designed in our lab. The subjects were placed at a distance of 50–70 cm from a 23″ flat-screen monitor with a high resolution (1920 × 1080 pixels). The photographic images had an actual size of 16 x 21 cm on a white background. After these activities, the participants read an introductory passage that indicated the approximate length of the evaluation and the objective of the research. The participants were then given instructions about the answering format for each of the visual complexity scale. Next, three practice exercises were performed to evaluate images representatives of low, middle and high visual complexity. After these trials, the participants began the main study. They were instructed to evaluate the images in terms of the content, not the quality, of the photograph shown. Each evaluation task began with the presentation of an image. After an answer was completed, the next image appeared again and then the response options; the process was the same for evaluating each of the 26 images. Each session lasted an average of 6 min. Results from this study was the collection of 18 pictures (HRP = 9; LRP = 9) with intermediate and similar ranges of complexity (mean complexity = 5.05; SD = .88, scale 0-10) and the elimination 8 photographs with extreme ratings of visual complexity. With these findings, the selected 18 pictures were comparable in luminance and visual complexity.

2.2. Study 2. Eye tracking study of visual exposure to restorative environment

A within-subjects experimental design was used in the current study. All participants viewed images of the two scene categories (HRP and LRP) presented in a random order.

2.3. Participants

Participant sample included 15 males and 12 females with age ranged from 16 to 23 years (M = 17.70; SD = 1.91). All of them were architecture students at Universidad Autónoma de Nuevo León and had normal visual acuity. They provided written informed consent in which they declared that they were voluntarily participating in the experiment and that they were informed about the experimental procedure. They agreed that recordings of their oculomotor behavior would be registered and used for scientific purposes only. They were allowed to withdraw from the experiment at any time.

2.4. Measures, stimuli and procedure

The Restorative environments stimuli were taken from Study 1 and consisted of photographs with low (built settings without nature, n = 9; score average ≤ 3, mean = 2.63, SD = .78; scale 0 to 10) and high

restorative potential (natural scenes, n = 4 and some built urban environments with nature, n = 5; score average ≥ 6.5, mean = 7.25, SD = .74; scale 0 to 10). These pictures were rated by a Mexican sample of students considering the revised scale of Environmental Restoration Perception (ERP) (Martínez-Soto and Montero y López-Lena, 2010). The affective dimension of pleasure and arousal for these pictures were evaluated in the same study (Martínez-Soto et al., 2014), resulting in pictures of high arousal and pleasure for natural restorative environments (arousal M = 7.31, SD = 1.23; pleasure M = 5.16, SD = 2.27; scale 0 to 9) and low arousal and pleasure for non-restorative built environments (arousal M = 4.78, SD = 1.83; pleasure 3.62, SD = 1.37; scale 0 to 9). All the pictures were no familiar for the participants sample (Smith and Squire, 2008). The experiment was carried out on a PC computer Lenovo C540 touch running Windows 8.1, with a 1920 × 1080 pixel resolution screen and a diagonal of 23″ (50.5 × 28.4 cm). Eye movements were recorded binocularly using an unobtrusive Tobii Pro Glasses 2 eye tracker with a sampling rate of 50 Hz. The glasses are 18 × 16 × 5.5 cm and the recording unit where the glasses are connected with a cable is 13 × 8.5 × 2.5 cm. The eye-tracking recording unit was positioned behind the chair of the participant. During the experiment, the participant's position and distance to the screen was restricted by an unmovable chair, and no chin rest was used. The participants back was in contact with the chair during their observation of the photographs, and therefore their distance to the screen was around 60 cm. Upon arrival at the laboratory, each participant was seated in a small, sound-attenuated, dimly lit room. All the participants were tested individually. The experiment was carried out in a room with an ambient artificial light. After arriving at the laboratory, the subject completed a form asking for socio-demographic and other background data. Prior to entering the experiment, subjects received thorough instructions about the procedure and the tasks to perform. One single session began with the presentation of a screen and instructions: "Here you see a series of photographs, which you must observe freely. Avoid storing and judging any detail. This presentation is not a memory task, nor does it perform any work related to the particular content of the photographs". Following that procedure, every participant underwent an eye tracking calibration. While wearing the glasses, calibration consisted of asking the participants to fixate on the center of the Tobii calibration card, which contains a circle of 4.3 cm with a central point. The Software Tobii Pro Glasses Controller version 1.33.632 performs a quick calibration for each participant and allows to start and stop the recording of the observations. To ensure that the participants began exploring each image from the same point, every trial started with a fixation cross situated in the center of the screen on a white background. This slide functions as recovery slide and was presented to allow pupil size to return to baseline. The participants were asked to fixate on the fixation cross for 3 s before the image appeared. Each HRP/LRP image was displayed for 15 s. (see Fig. 1). All images were presented in color. HRP and LRP images were adjusted to the same resolution (150 pixels per inch) and dimensions (15.7 X 19 cm, actual size on the screen). Total time for the experiment, including calibration was 10–12 min.

2.5. Data analyses

Data analyses were considered according to the sequence of the eye positions during the time of photograph exploration (Duchowski, 2017; Stevenson et al., 2019; Valtchanov and Ellard, 2015). The scores were calculated for each participant and were subsequently averaged across images of each category. The mean numbers of fixations, the mean duration of all fixations, and pupil dilation were calculated for all the HRP and LRP pictures. We established the difference in pupil size compared to a baseline period (Mathôt et al., 2018) where pupil diameter was recorded for 50 Hz for 3000 ms prior to picture onset. Our measurements refer to the pupil diameter (in millimeters). To avoid the idiosyncratic influences on the oculomotor parameters here we
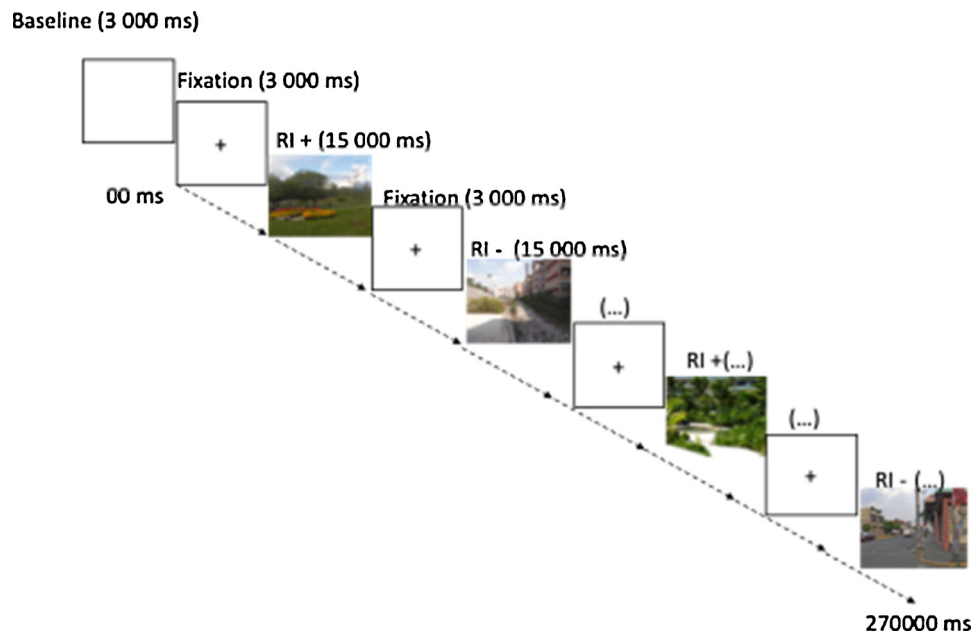
Fig. 1. Schematic representation of the experimental paradigm. Note: RI Restorative images with (+) high restorative environments (*n* = 9) and (-) low restorative environments (*n* = 9).

developed a within-subjects experimental design. Because we were not concerned with individual differences in eye movements, we chose to use photographs as the unit of analysis in order to see whether variability due to category was more powerful than variability due to particular photograph (Berto et al., 2008). Thus, paired samples t-tests were conducted to compare the total number of fixations, average duration of fixations and pupil size across the two environments for the same subjects. This approach has been utilized in previous studies (e.g. Nordh et al., 2013). The same analytic procedure was applied for baseline measures of pupil size. Correspondingly, the *t* values are reported according the standard requirements of presentation for paired sample t test (Field, 2013). As complement to the visual analysis heat maps and gaze plots were illustrated for representative cases. Heat maps were obtained through the Tobii Pro Glasses Analyzer Software. The event detector used to create the heat maps in the mentioned software is Tobii I-VT (Fixation). The background images are 800×600 px and the heat map is calculated with a 50 px radius (Fig. 3).

3. Results

3.1. Number of fixations

The mean number of fixations and fixation durations was calculated for each participant and averaged across images of each category. As predicted, a series of paired-sample t-tests shows that there were significantly more fixations for low restorative scenes (*M* = 30.65, *MSE* = .48) than for high restorative scenes (*M* = 27.88, *MSE* = .79), *t* (8) = 2.44, p < .05, *r* = .65. Fixation times had an inverse relationship; LRP settings had a significantly shorter time per fixation, as predicted (*M* = .47 s, *MSE* = .03) than HRP scenes (*M* = .64 s, *MSE* = .07), *t* (8) = -2.22, *p* = .05, *r* = .61.

3.2. Pupil size

Our data suggest that pupil size was successfully manipulated during the experiment. A paired *t*-test revealed the difference between pupillary diameters in response to the passive view of HRP vs LRP environments *t*(8) = -2.33, *p* < .05, *r* = .39. Higher measures of pupil dilatation were related to the view of HRP vs. LRP environments (see

Table 1

Means (Standard Error) for dependent (pupil size) measures at task viewing.

Measure	Picture content	
	HRP	LRP
Base line pupil size[a]	HRP	LRP
4.04 (.85)	4.28 (.41)	4.21 (.38)

Note: [a] Pre-stimulus baseline pupil size average of 3000 ms.

Table 2

Mean Baseline-Corrected HRP and LRP pictures pupil response average over post image onset.

Target duration (ms)	15000
HRP	0.24
LRP	0.17
Difference	0.07
p value	< .05

Table 1). These differences were comparable with the baseline measures in HRP *t*(8) = -4.56, *p* < .05 and LRP *t* (8) = -3.45, *p* < .05 (Tables 1 and 2).

Fig. 2a and b shows a heats maps of two scenarios representative of HRP and LRP environments, while 3a and 3b exhibit the same environments within gaze plots.

4. Discussion

The main objective of this study was to determine if two classes of scenes, HRP (natural and built environments with nature) and LRP (built environments without nature), differ in visual perception (processing information through eye fixations) and autonomic arousal responses (pupil size). Eye-tracking technology was utilized in order to discover differences between the visual perception of scenes that are highly restorative (e.g. natural landscapes) and scenes that are less restorative (e.g. urban environments with no natural elements). Eye tracker studies on visual processing on restorative environments typically departs from eye movements dynamics to test the attentional response proposed by the attention restoration theory (Kaplan, 1995).
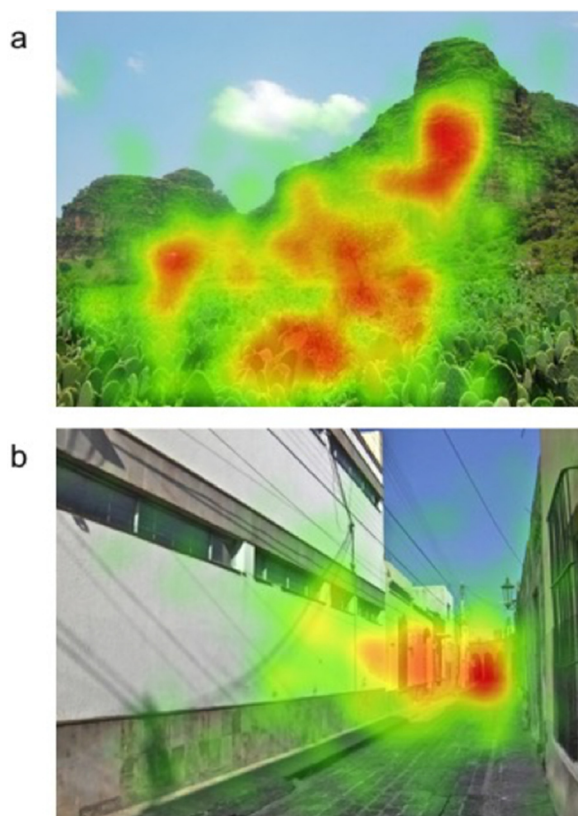
Fig. 2. Two of the 18 Photographs used in the experiment representing the high and low restorative potential. a) The high restorative potential scene depicts a natural Mexican environment with cacti; while b) the low restorative potential shows an urban scene of a narrow street. As can be seen in the heat maps that show the absolute count of fixations, the last appear very concentrated in the urban scene, meanwhile, they are disperse in the natural scene.

Fig. 3. A gaze plot of fixations realized by one of the 27 participants. The size of the circle in the gaze plots is proportional to the duration of the fixation. a) HRP image in the background and b) LRP image in the background.

Assuming that eye-movement analysis can reveal attentional and cognitive processes during image perception (see Holmqvist et al., 2011) eye dynamics has been evaluated through measures of fixations, eye travel distance, saccades and blink rates (Berto et al., 2008; Franěk et al., 2018; Nordh et al., 2013; Valtchanov and Ellard, 2015) (Fig. 3). They are developed through within-subjects experimental designs with adult samples of students of psychology and related areas. Recognizing that cognitive process reflected in eye movement are dependent of the task and the stimulus presented (Duchowski, 2017; Yarbus, 1967) and hence different patterns of eye movements over the same scene can emerge depending on the task (Navalparkkam and Itti, 2005), most parameters used on eye movements are captured in a screen based eye-tracking and using a free viewing modality (without task) which in part, ensures some consistence in the results obtained. Different levels of content´s variability has characterized the environmental exposure of restorative environments. From single (e.g. urban parks; Nordh et al., 2013), dichotomic (e.g. city vs. nature scenarios; Valtchanov and Ellard, 2015) and intermediate levels of comparisons (nature vs. built environments vs. architectural environments; Franěk et al., 2018) has been utilized. In order to rate the variability of the environmental conditions, both psychological (e.g. perceived restoration) and physical measures related with the perceived qualities has been implemented. In a whole, these methodological issues reveal that urban non restorative settings exhibit a greater number of fixations contrasting with nature restorative settings. Likewise, as measure of interest (Holmqvist et al., 2011), times of eye fixation´s tend to be more for natural than for built settings. These consistencies have suggested the existence of visual changes in attention when looking restorative and non-restorative scenes. Translating such outcomes to the TRA (Kaplan, 1995), its
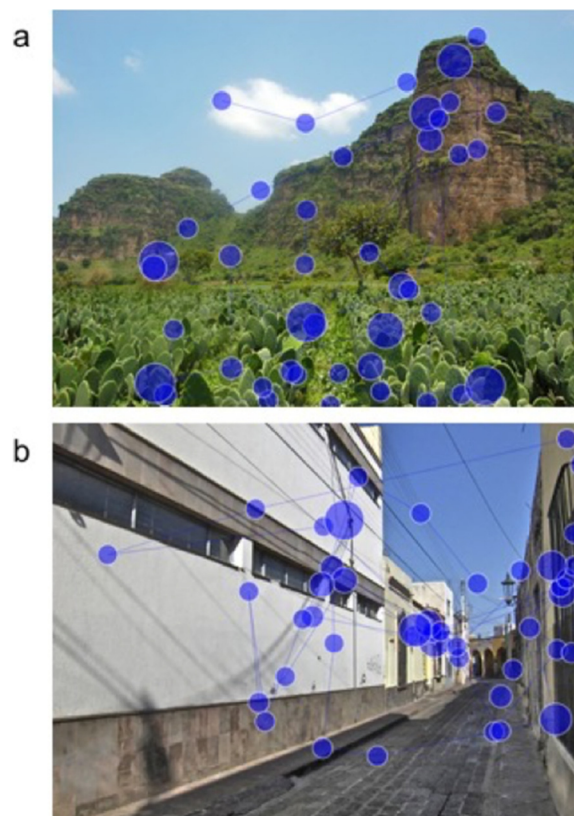
theoretical implications suggest that the visual experiences with built environments involve a more demanding and overloading attention than nature environments, whose physical and psychological perceived qualities engage a greater interest and less cognitive effort.

Here we develop a within-subjects experimental design into an eye tracking study that considers a screen based and a free modality viewing of a robust sample of previously rated pictures of restorative and non-restorative photographs in a sample of Mexican architectural students. Considering the eye movements as indicators of the amount of focused attention used to view nature vs. urban-industrial scenes, our findings ratify visual differences on patterns of fixation (frequency and time) during the view of environments with different restorative potential. In accordance with previous findings (Berto et al., 2008; Franěk et al., 2018; Valtchanov and Ellard, 2015), it was identified a higher number of fixations on the LRP vs. HRP pictures.

Following the notion that eye movements can be considered an indicator of the type of attention engaged when viewing a scene (Berto et al., 2008), our results suggest that HRP scenes were viewed with more effort and difficulty in interpreting the fixated information (Ehmke and Wilson, 2007). Although this asseveration deserves more attention through its correlation with other behavioral or stimulus property data (Kootstra et al., 2011), other sources of empirical data refers that pictures of urbanization tend to be positively associated with higher visual complexity (Dupont et al., 2016; Kaplan and Kaplan, 1989) which in turn are often associated with a higher number of visual fixations (Dupont et al., 2016; Parkhurst et al., 2002). Thus, it seems that the visual processing of built environments requires greater cognitive effort that the processing of nature related environments (Vedder et al., 2015), which in part explain some the mental fatigue effects associated with the exposure to some non-restorative city environments. With respect to our information extraction strategy related to the view of natural restorative vs. the built non restorative settings, it

must take into account that the landscape type and photograph properties could have some influence on the resources to extract the information. For example, a lower number of fixations in homogeneous landscapes may imply that this landscape type is explored less intensively (Goldberg and Kotval, 1999) compared to more heterogeneous landscapes due to their simpler characteristic (Dupont and Van Eetvelde, 2014). Furthermore, consistent with previous studies in the area (Franěk et al., 2018; Valtchanov and Ellard, 2015) it was revealed longer means of fixations while perceiving HRP vs. LRP environments. Longer fixations on an object may be interpreted as a greater interest in or liking of the objects (Calvo and Lang, 2004; Leder et al., 2016; Nummenmaa et al., 2006) which in turn could be related to greater environmental preference toward nature based restorative environments (van den Berg et al., 2003). Likewise, emotional arousal has a key role in the picture viewing duration (Lang et al., 1993), which in part agrees with an earlier description of the affective valence HRP vs LRP photographs (Martínez-Soto et al., 2014).

Additionally, to the typical pattern of eye fixation used at the eye tracker study of restorative environments, we have added the measure of pupillary size. To date, the status of this measure is exploratory, with only study (task-based view) referred in the research area (Nordh et al., 2010).

Through the use of the same restorative pictures and its affective valences (low vs. high arousal and pleasure) our data shows a possible connection between the affective quality of the settings, restorative responses and pupil size. As antecedent, Nordh et al. (2010) documented a relation between pupil size and judgements on restoration likelihood (a behavioral method to evaluate the restorative quality of a picture). From the view of only one environmental category of pocket parks (small urban green spaces) the authors document an inverse relationship between pupilar size and the potential of the environment to induce a restorative response. The authors found that higher values on restoration likelihood were associated with lower pupil size. These changes were attributed to the relaxing effects of the restorative images. Contrary to Nordh et al. (2010) our data sustain a reverse pattern of association. Controlling for the arousal values and the pleasant and unpleasant valences for the HRP and LRP pictures, here we show that relative to LRP, higher pupil size was associated during the view of HRP environments. Differences in pupil size could be considered according to the picture's emotional arousal and hedonic valence established previously (Martínez-Soto et al., 2014; Mathôt, 2018). The aforementioned is coherent with the fact that pupil dilatation revealed the emotional valence related to the affective processing of restorative settings (Partala and Surakka, 2003). As such, it could be considered that the relation between hedonic valence and pupil size is mediated by the emotional arousal of the pictures (Bradley et al., 2008; Mathôt, 2018). Because the exploratory and descriptive nature of the research on pupil responses, further studies need to be developed in order to replicate and expand the psychosensory pupil responses revealed through the view of restorative environments (Lang et al., 1993; Niu et al., 2012).

The effects discovered in this study were statistically significant and relatively strong. Nevertheless, there are some factors that should be remarked. Participants were undergraduate architecture students with good health (e.g. without deficits in visual acuity). For this reason, our current results may not be generalized to other populations (see Lee et al., 2015) thus opening the possibility that the effects reported in this study could result to be smaller in a heterogeneous population. In spite of these, a meta-analysis based on previous studies indicate that the environmental evaluations made by student and non-student groups do not differ significantly (Stamps, 2016). Further studies could determine if the effects reported in this study could be replicated, or if they change for different populations. Because the promising use of eye tracking in architecture and environmental psychology, future studies on psychological restoration could examine the environmental influences on affect and cognition examined through the use of eye tracking

technologies (Nordh et al., 2013; Stevenson et al., 2019).

The present research characterizes the visual patterns related to the view of static restorative environments and hence complement the psychological research on psychological restoration. From a methodological point of view, our present study replicates previous results obtained with similar designs and different restorative stimuli on student samples. Further studies could consider the examination of eye movements in an immersive situation while walking on restorative environments, for example looking for the measure of natural viewing behavior. This approach could enhance the ecological validity and document the environments visual proprieties that are relevant to the optimal human functioning and wellbeing.

Author contributions

JM-S, FAB and LAFS designed the experiment, JM-S and LAFS acquired all the data, JM-S, LAFS and LGS analyzed the data, LG-S coded software, JM-S and FAB wrote the main manuscript text, and LAFS and LG-S prepared all figures. All authors reviewed the manuscript.

Ethics

All participants signed and informed consent form adhering to the principles expressed in the Declaration of Helsinki and authorized by the Bioethics Committee of the Neurobiology Institute [Comité de Bioética del Instituto de Neurobiología].

Conflict of interest

The authors declare no competing interests.

Data availability statement

All data will be available from the corresponding author.

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