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Cognitive and affective responses to natural scenes: Effects of low level visual properties on preference, cognitive load and eye-movements

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ABSTRACT

Research has shown that humans have a preference for images of nature over images of built environments, and that eye-movement behaviour and attention are significantly different across these categories. To build on these findings, we investigated the influence of low-level visual properties on scene preference, cognitive load, and eye-movements. In the present study, participants viewed a mixture of unaltered and altered photographs of nature and urban scenes to determine if low-level visual properties influenced responses to scenes. Altered versions included photographs with only low or mid-to-high visual spatial frequency information, and photographs where the phase or amplitude of visual spatial frequencies had been scrambled. We replicated past findings, demonstrating preference and longer fixation-time for nature scenes versus urban cities. We then demonstrated that the visual spatial frequencies and power spectra contained in images significantly influenced preference, cognitive load, and eye-movements, and can partially explain the restoration response to natural environments.

1. Introduction

Many studies have focused on exploring the beneficial properties of exposure to nature. These restorative effects of nature have been both widely studied and replicated in research laboratories across the world (see meta-analysis by McMahan & Estes, 2015). This focus on the beneficial properties of nature is partially motivated by the belief that exposure to nature has beneficial effects on individuals and populations, and the belief that decreased exposure to nature prompted by living in urban centers and large cities may result in increased mental illness, increased stress, and poorer health (Grinde & Patil, 2009; Gullone, 2000). Indeed, studies exploring workplace satisfaction and health have found that office spaces that afford views of nature (be they of plants or posters), result in improved job and life satisfaction, reduced stress and anger, and fewer sick-days compared to office spaces without such views (Bringslimark, Hartig, & Patil, 2007; Kweon, Ulrich, Walker, & Tassinary, 2008; Leather, Pyrgas, Beale, & Lawrence, 1998; Shibata & Suzuki, 2004). In this paper, the restorative effects of nature are replicated in controlled laboratory settings, and the mechanisms for restoration suggested by *Attention Restoration Theory* and *Psycho-evolutionary Theory* are examined from the perspective of human visual perception and visual reward systems. Potential visual mechanisms involved in restoration responses to natural environments are discussed and explored.

2. Literature review

2.1. Restorative effects of nature

The restorative effects of nature have been categorized into the three broad categories of improved cognitive function, improved affect, and reduction of physiological and cognitive stress (Berman, Jonides, & Kaplan, 2008; Gullone, 2000; Hartig, Mang, & Evans, 1991). Researchers have found consistent evidence that exposure to nature can improve attention and memory (Berman et al., 2008; Berto, 2005; Berto, Baroni, Zainaghi, & Bettella, 2010; Raanaas, Evensen, Rich, Sjøstrøm, & Patil, 2011), and both self-reported and physiological stress (De Kort, Meijnders, Sponselee, & IJsselsteijn, 2006; Jiang, Chang, & Sullivan, 2014; Valtchanov & Ellard, 2010; Van den Berg, Koole, & van der Wulp, 2003). The restorative effects of nature have been replicated using exposure to real nature (Berman et al., 2008; Bratman, Daily, Levy, & Gross,

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2015), exposure to videos of nature (De Kort et al., 2006; Van den Berg et al., 2003), and even using immersive virtual nature walks (Valtchanov, Barton, & Ellard, 2010). Nature exposure therapy has been found to be effective for clinical stress management (Villani & Riva, 2012), and stress and anxiety reduction for deployed military medics (Stetz et al., 2011). Nature posters and plants in hospital waiting rooms have been shown to reduce patient stress (Beukeboom, Langeveld, & Tanja-Dijkstra, 2012) and even perceptions of pain after undergoing painful bone marrow aspiration and biopsy (Lechtzin et al., 2010). From these studies, it is evident that exposure to nature reliably produces improvements in affect and reductions in both perceived and physiological stress, with the minimum requirement for the effects being brief viewing of nature scenes.

2.2. Theories of restoration

2.2.1. Attention Restoration Theory

Kaplan's *Attention Restoration Theory* (1995, 2001) has been widely cited and supported in the literature (Berman et al., 2008; Berto, Massaccesi, & Pasini, 2008; Berto et al., 2010; Taylor and Kuo, 2009) as an explanation for the observed restorative effects of nature. *Attention Restoration Theory* (*ART*) builds on the assumption that human cognitive capabilities evolved in natural environments (Hartig, Korpela, Evans & Garling, 1997). According to *ART*, interaction with inherently fascinating stimuli (e.g. waterfalls, sunsets) captures involuntary attention *modestly*, allowing it to wander freely while directed attention mechanisms replenish (Kaplan, 1995; 2001). Kaplan (1995; 2001) has named this *modest* capture of involuntary attention by pleasant stimuli *soft fascination*. This is made distinct from *hard fascination* where stimuli capture attention *dramatically* and do not allow attention to wander, requiring top-down resources to disengage from the stimuli (Kaplan, 1995; 2001).[1]

However, it is currently unclear what sort of mechanism drives *soft fascination*. The main problem lies in the vague definition of fascination used by Kaplan (2001, pp. 482), who stated that *fascination* is anything that contains patterns that hold one's attention effortlessly. Due to this definition, it is unclear why photos of nature scenes may prompt different amounts of *fascination* than photos of urban scenes. With an objective definition of what makes a scene fascinating (such as its complexity, symmetry, contrast, self-similarity, or patterns in visual spatial frequency), it may be possible for *ART* to better explain empirical results.

2.2.2. Psycho-evolutionary theory

A second theory intended to account for the restorative effects of nature has been proposed by Ulrich (1983). Similar to *Attention Restoration Theory*, Ulrich (1983)'s *Psycho-evolutionary Theory* is also based on the assumption that human physiology has evolved in a natural environment. Because of this, it also shares the assumption that brain and sensory systems are tuned to efficiently process natural content and are less efficient at processing urban or built environments, thus resulting in physiological and cognitive depletion when interacting with urban environments (Ulrich, 1983; Ulrich et al., 1991). Research by Rousselet, Thorpe, and Fabre-Thorpe (2004) using ERPs has found support for this assumption of "rapid processing of natural scenes" by providing evidence that individuals can accurately categorize natural scenes by content[2] with presentation times as low as 26 ms. However, unlike Kaplan (1995; 2001)'s *Attention Restoration Theory* where replenishment of directed attention is believed to be the source of restoration, Ulrich (1983)'s *Psycho-evolutionary Theory* proposes that there is an "*initial affective response*" to environments that drives restoration.

It is easy to see where *Attention Restoration Theory* and *Psycho-evolutionary Theory* overlap. Both theories suggest a bottom-up mechanism for restoration: *Attention Restoration Theory* recruits the concept of *soft fascination*, referring to patterns of visual information that capture involuntary attention *modestly*, while *Psycho-evolutionary Theory* proposes that there is an *initial affective response* to environments based on millions of years of evolution. If we consider the proposals made by *Attention Restoration Theory* and *Psycho-evolutionary Theory*, stating that sensory and cognitive systems evolved in natural settings, and that specific mechanisms may have evolved to favour survival, it is plausible that the underlying mechanism may be a reward system tuned to specific information in the environment that has evolutionarily been linked to survival and well-being. A tuned reward system could have motivated the pursuit of adaptive behaviour through endogenous rewards, manifesting itself as what Kaplan (1995; 2001) now calls "soft fascination" or what Ulrich (1983) refers to as an "*initial affective response*."

2.2.3. Visual-reward mechanisms for restoration

The manner in which a visual reward mechanism can provide the missing piece in both Kaplan's (1995, 2001)'s *Attention Restoration Theory* and Ulrich's (1983) *Psycho-evolutionary Theory* has been suggested indirectly by research on scene preference. Functional neuroimaging (fMRI) studies have found that preferred scenes prompted a greater blood-oxygen level dependent (BOLD) response (i.e., "neural activation") in the ventral striatum (a part of the brain involved in conventional reward systems) and parahippocampal cortex (a region with a high-density of μ-opioid receptors that is involved in scene processing) in the ventral visual pathway (Biederman & Vessel, 2006; Yue, Vessel & Biederman, 2007). Opioid reward systems such as these have been linked to natural reinforcement, and regulation of pain, stress, and emotion (Merrer, Becker, Befort, & Kieffer, 2009). When reviewing the restorative effects of nature, there is a striking similarity between responses to nature scenes and activation of opioid reward systems: similar to other stimuli that can activate opioid reward systems (food and sex for example), viewing nature scenes has been shown to reduce perception of pain (Lechtzin et al., 2010), improve affect, and reduce physiological and perceived stress (Valtchanov & Ellard, 2010). From these studies, and a comprehensive review by Grinde and Patil (2009), it is evident that *visual* contact with nature is important in triggering the restorative response. Given that visual contact with nature has similar effects to activation of opioid reward systems (i.e., "restoration") and that opioid reward systems are present in the ventral visual stream (Yue, Vessel & Biederman, 2007), it can be hypothesized that there is a connection between the visual information processed by the ventral visual stream and the restorative response.

In order to understand how viewing nature scenes might be activating the ventral visual pathway and implicated reward systems (Biederman & Vessel, 2006; Yue, Vessel, & Biederman, 2007), it is important to consider how scenes are processed by the visual system. Following a rich history of research in visual neuroscience showing that individual neurons at many locations in the visual pathway are sharply tuned to specific visual spatial frequencies (DeValois & DeValois, 1988), Simoncelli and Olshausen (2001), and Geisler (2008), suggest that visual information is coded in the brain through statistical patterns of component visual spatial frequencies (SF). In simpler terms, component spatial frequencies can be

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[1] Kaplan (2001, pp. 482) defines fascination as "containing patterns that hold one's attention effortlessly."

[2] Individuals could categorize scenes based on whether animals were present or absent.

viewed as the building blocks of visual perception which are combined in the visual system to represent any visual object or scene. Knowing this, one can begin to understand recent neuroimaging research by Fintzi and Mahon (2014) that has demonstrated that the ventral visual pathway in question is sensitive to mid-to-high spatial frequency information (i.e., contours, lines and edges of shapes) as well as the identity of objects. Fintzi and Mahon (2014) decomposed visual images into their component spatial frequencies using a Fourier transform, which is a mathematical function that transforms the pixel information of images into component frequencies. Low spatial frequency and mid-to-high spatial frequency versions of the images were then created by using a Gaussian filter on the Fourier transform and then inverting it. This process muted all but the desired spatial frequencies, creating images that contained only specific spatial frequency information (Fintzi & Mahon, 2014). When participants were shown the images containing only specific spatial frequency information, the ventral visual stream showed a maximal fMRI BOLD response (“neural activation”) to images containing spatial frequencies with 4.75–9.14 cycles per degree of visual angle (c/d) (i.e., “mid-to-high” SF) (Fintzi & Mahon, 2014), providing evidence that the ventral visual stream is tuned to this limited spatial frequency range. The activation of the ventral visual reward systems by these frequencies could be what prompts the *soft fascination* discussed by Kaplan (1995; 2001)'s *Attention Restoration Theory* and the *initial affective response* discussed in Ulrich (1983)'s *Psychoevolutionary Theory*. Activation of such a visual reward mechanism could satisfy the criteria for both *soft fascination* (since visual information that is rewarding would capture attention *modestly*), and the *initial affective response* (since endogenous rewards would promote changes in affect). Given this, it is possible to hypothesize that there should be a relationship between the positive effects of viewing nature scenes and mid-to-high spatial frequencies of natural scenes.

2.3. Studying the effects of low level visual properties of environments on restoration

The first goal of the current research was to replicate the supporting evidence for *Attention Restoration Theory* (ART), found by Berto et al. (2008), and past literature suggesting that exposure to nature improves affect (Valtchanov & Ellard, 2010) by using a novel paradigm and novel stimuli. In their research on *ART*, Berto et al. (2008) demonstrated that eye travel distance and number of fixations are greater when viewing urban scenes compared to nature scenes. They related these differences in eye movement dynamics to Kaplan's hypothesized *soft fascination*.

The second goal of the current experiment was to build on these findings by including blink rates as a new measure of cognitive processing and attention, since blink rates have been found previously to be a measure of cognitive load: Blink rates have been found to increase when cognitive load increases (Bentivoglio et al., 1997; Cruz, Garcia, Pinto, & Cechetti, 2011; Siegle, Ichikawa, & Steinhauer, 2008; Stern, Walrath, & Goldstein, 1984).

The third goal of this experiment was to investigate the proposed notion that the restorative effects of nature may be partially driven by low level visual properties of scenes (Kardan et al., 2015; Valtchanov & Hancock, 2015) that prompt a *soft fascination* or *initial affective response*, potentially through activation of the ventral visual pathway. More specifically, the goal of the current study was to examine how visual spatial frequencies, which are the building blocks of human visual perception (Olshausen & Field, 1996; Simoncelli & Olshausen, 2001), may influence restoration. In order to explore how individuals respond to different parts of visual information present in scenes, methods of image manipulation previously used in studies on the visual system were used (Doi & Lewicki, 2005; Fintzi & Mahon, 2014; Mahon, Kumar, & Almeida, 2013). These image manipulations included visual spatial frequency isolation (low versus mid-to-high) and image degradation (phase and amplitude scrambling). Given these goals and previous literature, three main hypotheses were formed:

H1. A replication of Berto et al. (2008)'s findings was expected, such that the number of fixations and eye travel distance would be greater when viewing urban scenes compared to nature scenes. Average fixations times were hypothesized to show the inverse relationship since a greater number of fixations should result in less time per fixation. Nature scenes were also hypothesized to be rated as more pleasant than urban scenes, replicating previous findings in the restorative effects of nature literature (Valtchanov & Ellard, 2010).

H2. Blink rates were hypothesized to be lower when viewing nature scenes compared to urban scenes, given that viewing nature scenes is believed to reduce stress and restore attention while viewing urban scenes is believed to be stressful and result in a higher cognitive load (Berman et al., 2008; Valtchanov & Ellard, 2010).

H3. It was hypothesized that if low level visual properties, such as visual spatial frequencies, are differentially stimulating visual reward pathways and partially driving the restorative effect, removing broad ranges (e.g., mid-to-high frequencies or low frequencies) should influence measures of attention, cognitive load, and affect (i.e., eye-movement patterns, blink-rates and ratings of pleasantness.)

3. Method

3.1. Participants

Prior to recruitment, participants were pre-screened using a mass-testing questionnaire. Participants were required to speak and read English fluently (in order to understand instructions), and to have reported that they had normal 20/20 vision. A sample of fifty-five participants (27 male, 28 female) was recruited from the University of Waterloo SONA participant pool to participate in the study in exchange for course credit. Upon being recruited, participants were asked if they suffered from any visual disorders such as having a “lazy eye” or “crossed eyes” or “colour blindness.” None of the participants reported having any visual disorder or problem. This was done to ensure that they did not suffer from visual disorders that might influence eye-tracking.

3.2. Materials

The current experiment used a simple slide-show presentation of various types of images on an nVisor SX60 head-mounted display (HMD) that featured an Arrington monocular eye-tracker and 44 degrees of horizontal field of view (34° vertical field of view).

Images used in this study were collected from a free Internet computer wallpaper gallery that featured both natural and urban photography. All eight images were photographs from cities or natural scenery around the world. Selected photographs had similar perspectives for both natural and urban scene categories. For each category, there were two ground-level perspective photographs, one photograph with a perspective from a high vantage point, and one photograph with an aerial perspective. All images were converted to greyscale and cropped to the dimensions of

Fig. 1. Sample of nature (left) and urban (right) photographs used.

900 × 900 pixels using Adobe Photoshop Elements 10 (occupying approximately 30° field of view when presented on the HMD). All scenes were presented in greyscale in order to control for colour information. Past research by Codispoti, De Cesarei, and Ferrari (2012) using EEG/ERP techniques has validated this approach by demonstrating that colour information is not critical for processing of natural scenes. Similarly, Fintzi and Mahon (2014)'s neuro-imaging work has also shown that the ventral visual pathway responds to greyscale images. During pilot testing, it was confirmed that self-reported pleasantness of natural scenes was still higher than that of urban scenes in the absence of colour. Lastly, all images had their brightness levels and contrast balanced using the "Auto Levels" and "Auto Contrast" options in Adobe Photoshop Elements 10. To confirm that natural and urban scenes had similar brightness levels after the adjustment, Photoshop's histogram tool was used to measure the mean brightness of each photograph. The histograms revealed that the mean brightness levels were almost identical for natural and urban scenes in this experiment. Nature photographs had a mean brightness of 99.7 and urban scenes had a mean brightness of 100.1.[3] When displayed during the experiment, images were presented at their native resolution, such that pixels in the image matched pixels on the display in a 1:1 ratio. This was done to avoid image distortion that can be caused by scaling images. Sample photographs can be seen in Fig. 1.

Four "altered" versions of each image were created from the original images, as shown in Fig. 2, giving a total of five variations of each image. The first was a 1-dimensional phase scrambled version. The phase information of the image was scrambled by using a Fourier transform of the original image to separate the phase and amplitude of each component spatial frequency. The phase of the vertical visual spatial frequencies in the image was then scrambled and the Fourier transform was inverted to give the phase-scrambled image variant. This process eliminated all contours, lines, and edges of objects while retaining the approximate contrast of the scene. This can be seen in Fig. 2. The phase scrambled natural images had a mean brightness of 111.2 while the phase scrambled urban images had a similar mean brightness of 105.6. The phase scrambled images were included as a baseline comparison for spontaneous blink rates since they preserved the rough contrast of the scenes while eliminating all semantic content.

The second altered image type was a 1-dimensional amplitude scrambled version which preserved some contours but greatly degraded image quality as shown in Fig. 2. This image variant was created in a similar fashion to the phase-scrambled version, except the amplitudes of the vertical visual spatial frequencies in the image were scrambled instead of the phase information. Amplitude scrambled natural images had a mean brightness of 121.9 and while scrambled urban images had a mean brightness of 123.5. This image type was included for exploratory purposes to see if eye-movements and blink rates change when visual information is greatly degraded.

The third altered image type was a low spatial frequency version created by applying a Gaussian filter ($\sigma = 15$) to the original image, effectively eliminating middle and high spatial frequencies while maintaining overall contrast and shape of objects. The Gaussian

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[3] Note: Brightness is on a scale from 0 (pure black) to 255 (pure white).

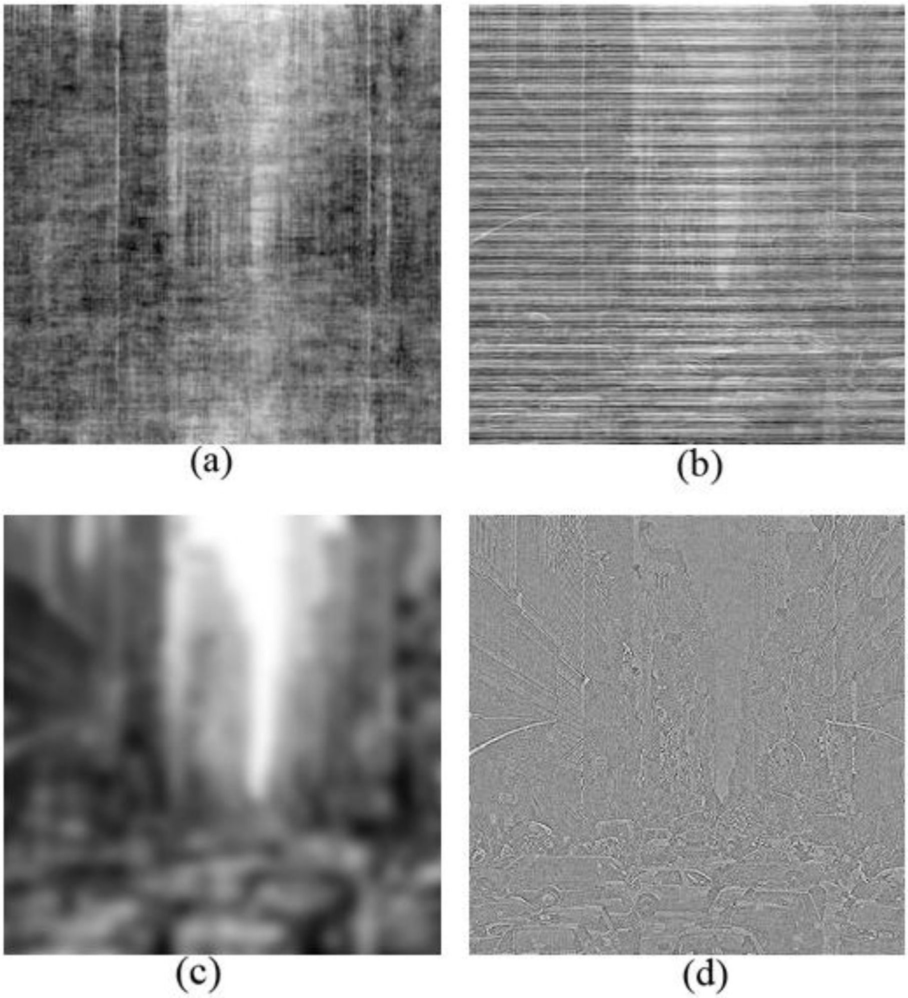

Fig. 2. Sample versions of the urban scene at the bottom right of Fig. 1: (a) phase scrambled in 1-dimension, (b) amplitude scrambled in 1-dimension, (c) low-spatial frequency, (d) "whitened" mid-to-high spatial frequency.

filtered images preserved the contrast and brightness of the original photographs: Filtered nature images had a mean brightness of 99.5 while filtered urban images had a mean brightness of 99.8. Fig. 3 shows how the Gaussian filtered images retain their low spatial frequencies but have greatly attenuated mid-to-high spatial frequencies for both natural and urban scenes. This image type was included to explore the effects of removing middle and high spatial frequencies on responses to the image.

The fourth altered image type was a middle to high spatial frequency "whitened" version. This image version was created in a

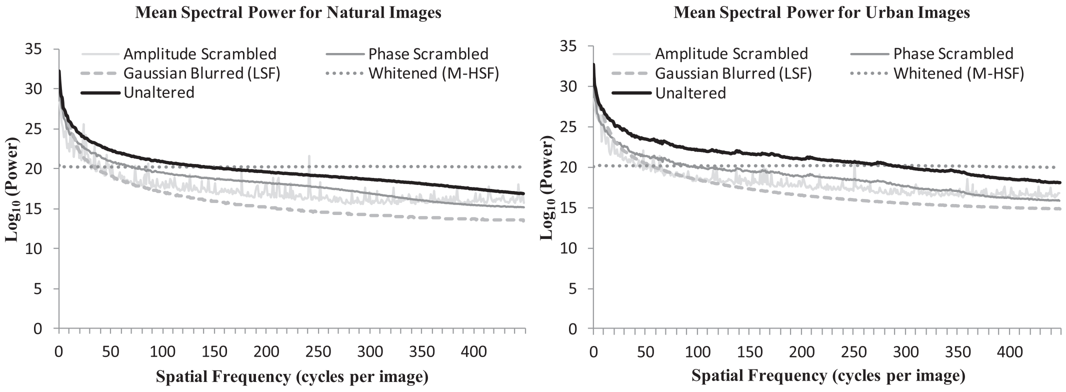

Fig. 3. Mean Spectral Power of Natural and Urban images. Here it can be seen that the Gaussian blur attenuated all mid-to-high spatial frequencies (SF) while leaving low SF intact. The image "whitening" procedure eliminated low SF while enhancing mid-to-high SF. This figure also shows how the image manipulations used in this study affected natural and urban images similarly across all spatial frequencies.

similar fashion to the amplitude scrambled variant, with the exception that all amplitudes of visual spatial frequencies were made equal to the average amplitude in the image instead of being scrambled. This flattened the amplitude of the visual spatial frequencies in a similar fashion to methods used by Joubert, Rousselet, Fabre-Thorpe, and Fize (2009), eliminating the majority of the low spatial frequencies. The process created an image that contains edge and contour information carried by middle-high spatial frequencies (Simoncelli & Olshausen, 2001), as shown in Fig. 2. The whitened natural images had a mean brightness of 113.7 and the whitened urban images had a similar mean brightness of 115.3. Fig. 3 shows how the "whitening" process greatly attenuated low spatial frequency information while enhancing mid-to-high spatial frequency information similarly for both natural and urban scenes. This image type was included in order to investigate the effects of removing low spatial frequencies and contrast on responses to the scene.

3.3. *Design*

A 5 (image type) × 2 (image order) mixed design was used in this experiment. All 5 image types were presented to all participants. Participants were randomly assigned to view the images in one of two image orders:

(1) Images were presented in random order with the condition that the image currently presented to the participant had to be the *least* discernible version of the scene that had not been already viewed. The original, unaltered version, of each scene was presented last.
(2) Images were presented in random order with the condition that the image currently presented to the participant had to be the *most* discernible version of the scene that had not been already viewed. This meant that participants always saw the unaltered version of each scene before seeing the altered (degraded) versions.

Fig. 2 shows a sample of altered image versions used from least discernible (a) to most discernible (d) of the bottom-right scene in Fig. 1. The unaltered image (bottom right of Fig. 1) was the most discernible. All 40 images (8 originals + 8 × 4 altered versions) were pilot tested using naive participants before this study was conducted to determine how much content could be identified in each image. Participants in the pilot study were asked to rate how well they could identify the types of objects in the scenes (e.g. trees, mountains, water, plants, buildings, windows, cars, etc). This data was used to determine presentation order.

3.4. *Procedure*

Individual participants were scheduled to come to the lab using the University of Waterloo's SONA online system. Upon their arrival, participants were greeted by the researcher, briefed on the procedure of the experiment, and given an information and consent form to read and sign. Upon agreeing to participate in the experiment, participants were fitted with the nVisor SX head-mounted-display and calibrated with the attached Arrington eye-tracker.[4] Participants were informed that they would see a variety of images that were urban, nature, or altered, each of which would be followed by two questions: The first question asked participants how pleasant they found the image to be, and the second question asked participants how well they could identify the types of objects in the image. Both questions were answered using a scale of 1–5.

Every trial started with a central fixation cross on a grey background, which functioned as a fixation trigger. Participants had to fixate on the fixation cross in the center of the screen for 150 ms before the trial would start. This was done to force all participants to fixate in the same place at the start of the trial to ensure consistency across participants.[5] Once the fixation trigger was fixated for 150 ms, the fixation cross and grey background disappeared and the image was presented. Images were presented in the center of the screen (occupying 30 degrees of visual angle) on a black background, one at a time, for fifteen seconds each. After the fifteen seconds, the screen shifted to a series of grey screens with the questions written on them. Participants responded to the questions using the number pad on the keyboard on a scale from 1 (low) to 5 (high).

4. Results

A mixed repeated-measures ANOVA was used to determine if the two different orders of stimulus presentation interacted with participants' responses to nature and urban stimuli across the five image types. No content (nature versus urban) by image type (unaltered, M-HSF, LSF, amplitude scrambled, and phase scrambled) by stimulus presentation order ("bottom-up" versus "top-down") interaction was found on fixation time, $F(4,212) = 1.38$, $p = 0.24$, n.s., number of fixations $F(4,212) = 1.01$, $p = 0.40$, n.s., eye travel distance, $F(4,212) = 0.83$, $p = 0.51$, n.s., blink rates, $F(4,212) = 1.74$, $p = 0.14$, n.s., or self-reported pleasantness responses to scenes, $F(4,212) = 0.93$, $p = 0.45$, n.s. This indicated that stimulus presentation order did not interact with participant responses to nature and urban images across the five image types. Since there were no significant differences between the stimuli orders, the data was pooled for the rest of the analyses.

4.1. *Manipulation check*

To check if the image manipulations affected natural and urban photographs equally in terms of semantic content, participants' self-reported responses on how well they could identify content in the scenes were analysed. The analysis was done using a series of paired-sample t-tests which compared participants' ability to identify content in natural versus urban scenes for each of the image variants. No significant differences in ability to recognize content were found between natural and urban scenes for the unaltered scenes, the mid-to-high spatial frequency variants, the low spatial frequency variants, and the phase-scrambled variants. The lack of significant differences indicated that the recognizable semantic content in these image variants did not differ between natural and urban scenes. However, for the amplitude scrambled image variants, participants reported being able to identify content significantly better for urban scenes than for natural scenes, $t(54) = 7.45$, $SE = 0.064$, $p < 0.001$, suggesting that urban semantic content is better preserved when the amplitude spectra were scrambled in the vertical dimension. Mean scores for identifiable content and standard deviations can be seen in Table 1.

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[4] An HMD was used because it allowed us to control for viewing distance and available field of view across participants, while also blocking out external visual stimuli that could be distractions or confounds.

[5] The first fixation was not included in analyses since it was forced via fixation trigger.

Table 1
Participants' ability to identify objects in the scene.

Image variant	Environment type	Mean score (SD)
Phase scrambled	Nature	1.20 (0.38)
	Urban	1.19 (0.29)
Amplitude scrambled	Nature	2.63 (0.83)
	Urban	3.21 (0.91)
Low spatial frequency	Nature	2.60 (0.87)
	Urban	2.50 (0.93)
Mid-to-high spatial frequency	Nature	3.93 (0.70)
	Urban	3.92 (0.77)
Unaltered photograph	Nature	4.81 (0.40)
	Urban	4.85 (0.55)

Note. Scores are on a scale from 1 to 5, where 1 = none, and 5 = very high.

4.2. Replication of past fixation behaviour and perceived pleasantness

In order to examine if Berto et al. (2008)'s findings were replicated in this experiment, preliminary analysis was restricted to participants' eye-movement for the unaltered versions of the images, since Berto et al. (2008) used unaltered images in their study. The first fixations of participants were not included in the analysis since the fixation trigger was in the center of the screen, causing all first fixations to be at that location. To test hypothesis 1, a repeated-measures ANOVA was used to analyse fixation time, number of fixations, eye travel distance, and self-reported pleasantness for unaltered nature and urban images.

4.2.1. Fixation behaviour for unaltered images

As predicted, there were significantly more fixations for urban scenes (M = 34.6) than for nature scenes (M = 31.8), F(1,54) = 34.62, MSE = 6.47, $\eta_p^2 = 0.39$, p < 0.001. Fixation times had the predicted inverse relationship, with urban scenes having a significantly shorter time per fixation (M = 0.33 s) than nature scenes (M = 0.38 s), F(1,54) = 23.14, MSE = 0.003, $\eta_p^2 = 0.30$, p < 0.001. Next, eye travel distance was quantified similarly to Berto et al. (2008). For each participant and each image, the sum of the Euclidean distances between fixations was calculated in image pixels. This gave a measure of the total distance each participant's eyes travelled for each image. Surprisingly, eye travel distance was not found to be different between viewings of nature and urban scenes, F(1,54) = 0.004, p = 0.95, n.s., suggesting that the eye travel difference found by Berto et al. (2008) may be dependent on the stimuli or paradigm used, and is thus not a reliable measure compared to the number of fixations. The replication of differences in fixation behaviour with moderate effect sizes presented here support this notion. Overall, these results agree with Berto et al. (2008)'s previous findings that suggest there are changes in visual attention when looking at nature versus urban scenes.

4.2.2. Self-reported pleasantness for unaltered images

Based on the well-documented effects of exposure to nature, viewing nature scenes was hypothesized to be significantly more pleasant than viewing urban scenes. Analysis focused on the unaltered images using a repeated-measures ANOVA. As expected, there was a robust main effect; nature scenes were rated as significantly more pleasant (M = 4.48 out of 5) than urban scenes (M = 3.77 out of 5), F(1,54) = 37.4, MSE = 0.368, $\eta_p^2 = 0.41$, p < 0.001. This can be seen in Fig. 4 (left).

4.3. Blink rates as a measure of cognitive load

Blink rates were hypothesized to be lower when viewing nature scenes compared to urban scenes, indicating a more relaxed state since exposure to nature was expected to 'restore' individuals and reduce stress and cognitive load (Berman et al., 2008; Valtchanov et al., 2010). Preliminary analysis was done on blink-rates for the unaltered images in order to see if there were indeed differences in blink rates when viewing nature versus urban scenes. Hypothesis 2 was supported: A repeated-measures ANOVA revealed that participants blinked significantly less often when viewing nature scenes (M = 23.9 blinks per minute) compared to urban scenes (M = 25.5 blinks per minute), F(1,54) = 16.4, MSE = 4.15, $\eta_p^2 = 0.23$, p < 0.001. This effect can be seen in Fig. 5 (left).

While there was support for the hypothesis that viewing urban scenes relative to viewing nature scenes would result in higher blink rates due to increased cognitive load, it was unclear whether viewing urban scenes *increased* blink rates or whether viewing nature scenes *decreased* blink rates relative to baseline. To address this ambiguity, blink rates when viewing unaltered versions of urban and nature scenes were compared to blink patterns for the 1-dimensional phase-scrambled images which were used as a baseline.

A baseline check was first conducted: Blink rates and self-reported pleasantness for phase-scrambled natural and urban scenes were compared using a repeated-measures ANOVA. Blink rates for the phase-scrambled images of natural and urban scenes were not significantly different, F(1,54) = 0.07, p = 0.80, n.s. However, phase-scrambled images of nature were reported as being significantly more pleasant (M = 1.82) than phase-scrambled images of urban scenes (M = 1.62), F(1,54) = 14.18, MSE = 0.08, $\eta_p^2 = 0.21$, p < 0.001. This indicated that even though preference for nature was preserved in phase-scrambled image variants, blink-rates were not different, thus the images could be used as a baseline for blink rates as intended.

A set of paired-samples t-tests revealed that blink rates for urban scenes were significantly higher than baseline (M = 24.8), t(54) = 27.3, p < 0.001, while blink rates for nature scenes did not differ from baseline, t(54) = 1.36, p = 1.36, n.s. These results indicated that viewing urban scenes *increased* blink rates and cognitive load.

4.4. Effects of low level visual properties

A two (environment type: nature vs. urban) by four (image variant: unaltered, mid-to-high spatial frequency, low spatial frequency, and amplitude scrambled) repeated measures ANOVA was conducted to examine if low level visual properties of environments influenced pleasantness and visual attention.[6]

4.4.1. Fixation time

The omnibus repeated measures ANOVA revealed that there was a significant main effect of environment type on fixation time. Fixations for nature scenes were significantly longer across image variants, F(1,54) = 9.75, MSE = 0.015, $\eta_p^2 = 0.15$, p = 0.003. There was also a significant main effect of image variant on fixation time, F(3,162) = 17.04, MSE = 0.034, $\eta_p^2 = 0.240$, p < 0.001. However, there was no interaction effect on fixation time, F(3,162) = 0.170, n.s.

Simple effects were explored using a polynomial contrast to determine how the image variants affected fixation time. The polynomial contrast revealed a significant linear trend, F(1,54) = 26.09, MSE = 1.664, $\eta_p^2 = 0.326$, p < 0.001, suggesting that fixation times were shorter for unaltered image variants compared

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[6] The phase-scrambled variants of the scenes were not included in this analysis since they contained no recognizable content and served as a random-noise baseline comparison image.

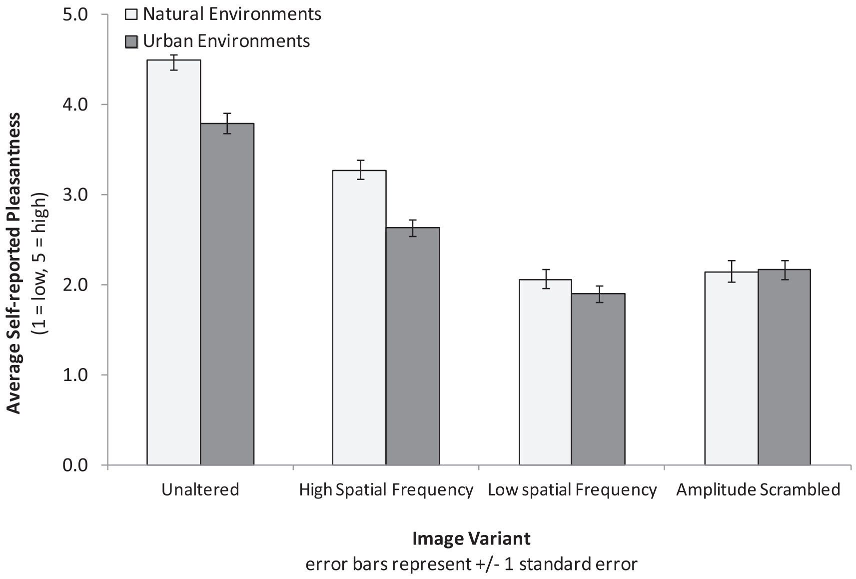

Fig. 4. Self-reported pleasantness for natural and urban scenes for each of the four image variants. Here it can be seen that natural environments are significantly more pleasant than urban environments for the unaltered and high spatial frequency image variants. The effect disappears when high spatial frequencies are removed, or have their power spectrum scrambled, as seen by responses to the low spatial frequency and amplitude scrambled image variants.

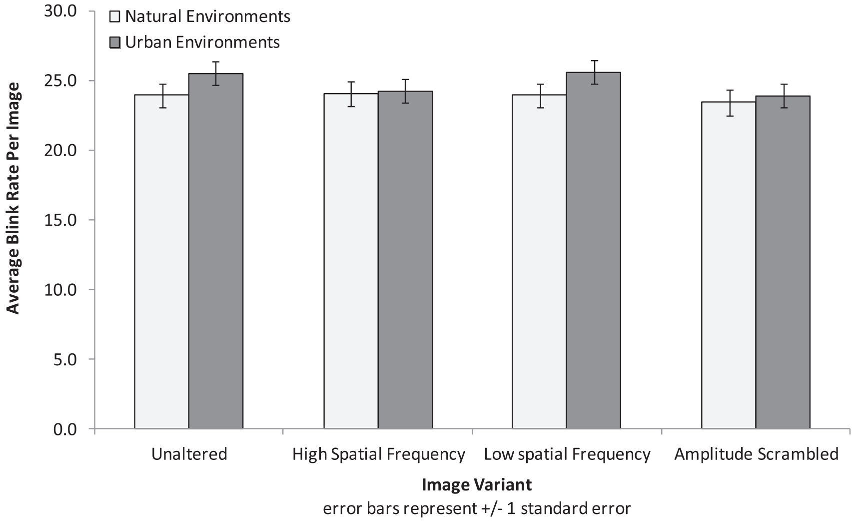

Fig. 5. Average number of blinks for natural and urban scenes for each of the four image variants. Here it can be seen that natural environments are prompt significantly fewer blinks (and thus lower cognitive load) than urban environments for the unaltered and low spatial frequency image variants. The effect disappears when low spatial frequencies are removed, or have their power spectrum scrambled, as seen by responses to the high spatial frequency and amplitude scrambled image variants.

to the high-spatial frequency image variants, which had lower fixation times in comparison to the low-spatial frequency image variants and amplitude scrambled variants.

4.4.2. *Number of fixations*

As with fixation time, the omnibus repeated measures ANOVA revealed that there was a significant main effect of environment type on the number of fixations. There were significantly fewer fixations for nature scenes across image variants, $F(1,54) = 56.74$, $MSE = 8.80$, $\eta_p^2 = 0.512$, $p < 0.001$. There was also a significant main effect of the different image variants on the number of fixations, $F(3,162) = 58.50$, $MSE = 16.30$, $\eta_p^2 = 0.520$, $p < 0.001$. Lastly, there was a trending environment type by image variant interaction effect on number of fixations $F(3,162) = 2.47$, $MSE = 5.70$, $\eta_p^2 = 0.044$, $p = 0.06$.

Simple effects were explored using a polynomial contrast to determine how the image variants affected the number of fixations. The polynomial contrast revealed a significant linear trend, $F(1,54) = 96.60$, $\eta_p^2 = 0.641$, $p < 0.001$, suggesting that there were more fixations for unaltered image variants compared to the high-spatial frequency image variants, which had a higher number of fixations in comparison to the low-spatial frequency image variants and amplitude scrambled variants.

4.4.3. *Self-reported pleasantness*

Similar to the observed effects for number of fixations, the omnibus analysis revealed that there was a significant main effect of environment type on self-reported pleasantness across the different image variants, $F(1,54) = 37.6$, $MSE = 0.504$, $\eta_p^2 = 0.41$, $p < 0.001$, where natural scenes were reported as being more pleasant than urban scenes. There was also a significant main effect of the different image variants on self-reported pleasantness of scenes, $F(3,162) = 204.22$, $MSE = 0.527$, $\eta_p^2 = 0.79$, $p < 0.001$, indicating that self-reported pleasantness was different across image variants. Lastly, there was also a significant environment type by image variant interaction effect on self-reported pleasantness, $F(3,162) = 28.23$, $MSE = 0.110$, $\eta_p^2 = 0.343$, $p < 0.001$, suggesting manipulations of low-level visual properties of scenes influenced responses to nature and urban environments differently.

Simple effects were examined using a Tukey HSD post-hoc test with $q(8, 162) = 4.29$ in order to determine how responses to the nature and urban environments differed across image variants. The analysis revealed that the unaltered image variants of both urban and nature scenes were more pleasant than all other variants. Natural environments with only high spatial frequency information were significantly more pleasant than natural scenes with only low spatial frequencies, and those with their amplitude (power) spectrum scrambled in one dimension. Similarly, urban environments with only high spatial frequency information were more pleasant than their low-spatial frequency variants and their amplitude (power) spectrum scrambled variants. Natural environments were significantly more pleasant than urban environments across the unaltered and high-spatial frequency variants, but were not significantly different across the low spatial frequency and amplitude (power) spectrum scrambled variants. These effects can be seen in Fig. 4.

Taken together, these results suggest that natural scenes are more pleasant than urban scenes only when their spatial frequency amplitude (power) spectra are intact, or when high spatial frequencies are present. Scrambling the amplitude (power) spectra, or removing high spatial frequencies (as done to create the low-spatial frequency only variants), attenuated differences in reported pleasantness between natural and urban environments to the point where they became statistically non-significant. The removal of low spatial frequencies (as done to create the high-spatial frequency variants) significantly lowered the overall reported pleasantness, but did so similarly across both natural and urban scenes. This suggested that low spatial frequency information is similarly important for the pleasantness of both natural and urban scenes as seen in Fig. 4.

4.4.4. *Blink rates (cognitive load)*

Similar to the observed main effects on self-reported pleasantness and number of fixations, a significant main effect of environment type on blink rates was found. Blink rates were lower for nature scenes across image variants, $F(1,54) = 14.74$, $MSE = 7.17$, $\eta_p^2 = 0.21$, $p < 0.001$, suggesting that they required a lower overall cognitive load. There was also a significant main effect of the different image variants on blink rates, $F(3,162) = 3.06$, $MSE = 9.87$, $\eta_p^2 = 0.54$, $p = 0.03$. Lastly, there was also a significant environment type by image variant interaction effect on blink rates, $F(3,162) = 4.0$, $MSE = 3.76$, $\eta_p^2 = 0.070$, $p = 0.009$.

In order to determine if blink-rates followed a similar pattern to self-reported pleasantness, simple effects were examined using four paired-samples t-tests with a Bonferroni correction for multiple comparisons. The four paired-samples t-tests compared nature versus urban environments for the four main image variants (unaltered, high spatial frequency, low spatial frequency, and scrambled amplitude spectrum) at the corrected alpha level of 0.0125. The analysis revealed that blink rates were lower for nature scenes when viewing the unaltered scenes, $t(54) = 4.05$, $SE = 0.388$, $p < 0.001$, and when viewing the low spatial frequency variants, $t(54) = 3.60$, $SE = 0.458$, $p = 0.001$. However, there were no differences in blink rates for nature and urban scenes when viewing high-spatial frequency variants of images, $t(54) = 0.55$, $p = 0.58$, n.s., or when viewing the scrambled amplitude (power) spectrum variants $t(54) = 1.19$, $p = 0.24$, n.s. These results suggest that the observed differences in cognitive load when viewing nature and urban scenes may be dependent on the power spectrum and low spatial frequency information in environments. This pattern of results can be seen in Fig. 5.

Overall, the results supported the hypothesis that low level visual properties, such as visual spatial frequency, influence measures of visual attention, cognitive load, and affect (i.e., eye-movement patterns, blink-rates and ratings of pleasantness).

4.4.5. *Relationship between eye movements and blink rates*

To better understand how blink rates change with fixation time and fixation duration, a partial correlation controlling for participants was conducted. Data from all image variants was included in the analysis. There was a significant positive correlation between the number of fixations and blink rates, $r(547) = 0.39$, $p < 0.001$, and a significant negative correlation between average fixation durations and blink rates, $r(547) = -0.37$, $p < 0.001$. Next, we repeated the partial correlation analysis but controlled for image type in the analysis. The correlations were similar, with a positive correlation for number of fixations and blink rates, $r(546) = 0.41$, $p < 0.001$, and a negative correlation for average fixation duration and blink-rates $r(546) = -0.38$, $p < 0.001$. Overall, this analysis revealed that higher blink rates (cognitive load) were significantly related to a higher number of fixations and lower average fixation durations, regardless of the image variant. This was consistent with previous research by Berto et al. (2008) which suggests that increased fixations when viewing a scene indicates that the scene is being viewed with more effort.

It is important to note that, as stated in the previous results, blink rates can be experimentally decoupled from the number of fixations and fixation durations. This is evident from the lack of an environment type by image variant interaction on the number of fixations and average fixation time, and the presence of an interaction effect on blink rates. This indicates that while there is a moderate correlation between blink rates and eye-movement behaviours, they are not measuring the same construct (e.g., visual attention).

5. Discussion

In the current study, there were three main goals. The first goal was to replicate the supporting evidence for *Attention Restoration Theory* (ART), found by Berto et al. (2008), and past literature showing that exposure to nature improves affect (Valtchanov & Ellard, 2010) using a new paradigm and new experimental stimuli. The current study successfully replicated some of the findings by Berto et al. (2008), supporting *Attention Restoration Theory*. There were significantly more fixations when participants viewed urban scenes compared to nature scenes. However, effects on eye travel distance when viewing urban versus nature scenes reported by Berto et al. (2008) were not replicated, suggesting that the measure may be less reliable than the number of fixations. This finding serves as a reminder that there is a need for the replication and expansion of the currently observed restorative effects of nature using novel paradigms and stimuli. Through replication across different paradigms and stimuli, it is possible to determine which effects of exposure to nature are more robust. Lastly, the current study successfully replicated past research, suggesting that viewing nature scenes resulted in significantly higher positive affect compared to viewing urban scenes (De Kort et al., 2006; Ulrich et al., 1991; Valtchanov et al., 2010; Van den Berg et al., 2003).

The second goal of the current experiment was to build on these findings by including blink rates as a measure of cognitive processing and stress in order to test predictions made by *Attention Restoration Theory*, which suggests that urban environments increase cognitive load and deplete cognitive resources. Previously, higher blink rates have been linked with higher cognitive load (Bentivoglio et al., 1997; Siegle et al., 2008; Stern et al., 1984) and higher anxiety (Cruz et al., 2011). Given that blink rates have been previously found to increase when cognitive load increases (Bentivoglio et al., 1997; Cruz et al., 2011; Siegle et al., 2008; Stern et al., 1984), this was a logical measure to test *Attention Restoration Theory*. Results from the current experiment suggested that viewing urban scenes *increased* blink rates and cognitive load compared to viewing scrambled images and natural images. This provides the first empirical evidence that blink-rates (and cognitive load) are higher when viewing images of urban environments as suggested by *Attention Restoration Theory*, and suggests that blink-rates could be used as a possible psychophysiological measure of restoration.

The third goal of this study was to determine whether the restorative effects of nature may be partially driven by low level visual properties of scenes that prompt a *soft fascination* or *initial affective response*, potentially through the activation of the ventral visual pathway. The present study used methods of image manipulation previously used in studies on the visual system (Doi & Lewicki, 2005; Fintzi & Mahon, 2014; Mahon et al., 2013). The results from this novel approach to examining the restorative effects of nature supported the hypothesis that the low level visual properties of scenes may play a role in the restorative response to viewing natural scenes versus urban scenes. The results suggested three novel findings:

The first finding was that removing mid-to-high spatial frequencies resulted in the greatest reduction of reported pleasantness of the scenes. This suggested that mid-to-high spatial frequencies of scenes are the most pertinent for positive affective responses. It should be noted that we did not directly measure activation of the ventral visual system in the current study, so we cannot directly speak to the link between mid-to-high spatial frequencies and its activation. Instead, we note that the results from the current study are consistent with the theoretical link between the ventral visual pathway, which is tuned to mid-to-high visual spatial frequencies (Fintzi & Mahon, 2014), and affective responses to scenes (Biederman & Vessel, 2006; Taylor, Spehar, Van Donkelaar, & Hagerhall, 2011; Yue, Vessel & Biederman, 2007). Further neuroimaging research is required to confirm the theoretical link between the restorative effects of nature and activation of the ventral visual pathway.

The second finding was that nature scenes were judged more pleasant compared to urban scenes only when the mid-to-high visual spatial frequencies of the environments were intact: Scrambling the amplitude (power) spectrum of the spatial frequencies in the visual scene, or removing the mid-to-high frequencies, resulted in nature and urban scenes being similarly preferred. This finding converged with the previous finding, suggesting that the higher pleasantness ratings of nature scenes, as compared to urban scenes, may be driven preferentially by information contained in mid-to-high spatial frequencies. Once mid-to-high spatial frequencies were altered, nature scenes were no longer considered more pleasant than urban scenes.

The third main finding was that cognitive load and stress, as measured by blink rates, appeared to be influenced by low visual spatial frequencies, in contrast to the reported pleasantness of the environments. Urban environments prompted higher cognitive load than nature scenes only when low-spatial frequencies were intact. When the low visual spatial frequencies were altered (through removal or scrambling of the power spectrum), differences in cognitive load between natural and urban environments were not statistically significant. Taken with the previous two results, this finding suggests that the higher cognitive load and stress associated with urban environments may be dissociable from the positive affective response to natural environments.

This set of findings suggests that there may be two difference mechanisms working in concert to produce the widely replicated restorative effects of natural environments. It is possible that attention and affective mechanisms of restoration that are seemingly consistent in their restorative response to natural environments could be responding to different elements of visual stimuli. More specifically, the affective restoration mechanism appears to be mostly responding to mid-to-high spatial frequencies, while the cognitive/attention mechanism appears to be more strongly influenced by low spatial frequencies within environments.

If one considers both Kaplan's *Attention Restoration Theory* (Kaplan, 1995; 2001), and Ulrich's *Psycho-evolutionary Theory* (Ulrich, 1983; Ulrich et al., 1991) as being valid theories of restoration mechanisms with empirical support, the results from the current experiment suggest that the two *different* mechanisms proposed by these theories are indeed dissociable and present, even if they are potentially working together to produce what researchers have documented as the restorative effects of nature (Berman et al., 2008; Valtchanov & Ellard, 2010). More specifically, the current results suggest that the changes in cognitive load and attention associated with *hard fascination* and *soft fascination* theorized by *Attention Restoration Theory* (Kaplan, 1995; 2001) may be influenced by the low visual spatial frequencies in environments, while the *initial affective response* theorized by *Psycho-evolutionary Theory* (Ulrich, 1983; Ulrich et al., 1991) may be influenced by the mid-to-high spatial frequencies in environments.

There has been some past contention between *Attention Restoration Theory* and *Psycho-evolutionary Theory* about the order of events leading to restoration, with the former theorizing that changes in cognitive resources lead to changes in affect (Kaplan, 1995; 2001), and the latter theorizing that changes in affect lead to changes in attention and cognitive resources (Ulrich, 1983). The current results can help put this contention to rest: nature scenes were found to be more pleasant than urban scenes without any differences in cognitive load when only high spatial frequencies were present, while urban scenes were found to have a higher cognitive load than nature scenes in the absence of differences in reported pleasantness when only low spatial frequencies were present. This suggests that cognitive resource/attention and affect systems may function independently when an individual is exposed to natural and urban environments. The mechanisms of *fascination* from *Attention Restoration Theory* and the *initial affective response* from *Psycho-evolutionary Theory* appear to be working independently in the present study. As such, it may be more accurate to suggest that *fascination* and the *initial affective responses* to environments may be working simultaneously to produce restoration, rather than affect or attention being the primary source. It is important to note that this dissociation was not anticipated or hypothesized since *Attention Restoration Theory* (Kaplan, 1995; 2001) and *Psycho-evolutionary Theory* (Ulrich, 1983; Ulrich et al., 1991) both suggest that the cognitive and affective responses are inter-dependent. Consequently, the current study hypothesized that both types of responses were tied to the visual reward systems in the ventral visual pathway (Biederman & Vessel, 2006; Taylor et al., 2011; Yue, Vessel & Biederman, 2007) and mid-to-high spatial frequencies (Fintzi & Mahon, 2014). More research is required to examine the implications of the observed dissociation between affective and cognitive mechanisms of restoration. It is possible that attention restoration mechanisms and affective restoration mechanisms may be feeding into each other, amplifying the restorative effects when both are present.

While the current study is first to look at how restorative mechanisms may be influenced by visual spatial frequencies in environments, the results are not surprising when considering research on human visual perception. A recent study by Melmer, Amirshahi, Koch, Denzler, and Redies (2013) explored the Fourier statistics of images with low and high aesthetic appeal: By analysing cross-cultural artworks, Melmer et al. (2013) demonstrate similar spectral features (such as scale invariance in the Fourier domain) across all cultures, and suggest that the specific perceptual mechanisms for aesthetic judgement may be common amongst people across different cultures. This idea is consistent with the meta-analysis by McMahan and Estes (2015) which looked at studies showing the restorative effects of nature across the world. Furthermore, recent research by Valtchanov and Hancock (2015), provides further evidence that environmental preference and restoration may be automatic and influenced by visual spatial frequencies. They were able to automatically and accurately predict participants' emotional response (positive, neutral, or negative) to different environments using an algorithm that analysed the visual spatial frequencies of visual scenes. They even tested their algorithm "in the wild" by incorporating it into a smart phone camera app that allowed participants to analyse any location and environment by simply using their smart phones' cameras. Given the wide replication of the positive effects of natural environments (McMahan & Estes, 2015), and researchers' ability to algorithmically model restoration responses (Kardan et al., 2015; Valtchanov & Hancock, 2015), it is logical that the underlying mechanism should be biologically based and mostly consistent across individuals around the world.

5.1. Study limitations

Even though the effects found in the current study were statistically significant and relatively strong, there are several factors that should be considered when interpreting our results:

Firstly, the participants in the current study were all healthy psychology undergraduate students which made them relatively homogenous in terms of education and age. Given this, the results from the current research may not generalize to other populations since university undergraduates are not necessarily representative of the general population. As a result, it is possible that the effects reported in this study are smaller for heterogeneous populations. This may be especially relevant for populations that include older adults who could have deficits in visual acuity and contrast sensitivity. However, since the current work argues that the restorative effects of nature may be driven by a biological mechanism, it is expected that the reported effects would still exist for other populations, even if they are potentially attenuated by other factors. More research examining how the effects reported in the current study replicate, or change, for different populations is required.

Secondly, the current study could not administer a cognitive performance metric due to the length of the study. The potential confound of participant fatigue caused by extending the study session and incorporating a cognitive task was deemed to be a greater limitation than the current study design which relied on blink rates as an indirect measure of cognitive load. Without a cognitive performance metric, the claims of the current research are weakened. It is important to note that the image variants used in the current study were made highly similar in terms of features that may affect blink-rates, such as brightness and spatial frequency proportions across the natural and urban categories. Given the rigour of the current study, it is unlikely that the observed differences in blink-rates when viewing natural versus urban scenes were confounded by image features. In order to make a stronger argument than the current study, future research examining how low-level visual features may influence cognitive load would benefit from including multiple converging and explicit metrics of cognitive load.

Lastly, the current study used a limited number of natural and urban environments due to the large number of image variants required for exploring the effects of low level visual properties. This means that not all environment types are represented in the image set and that the effects observed in the current study may be different for other environment types, such as deserts and oceans. We wish to note that in a pilot version of this study, the number of natural and urban environments (along with their image variants) was doubled. This lead to participant fatigue, and loss of eye-tracking calibration, requiring the final iteration of the study to use fewer stimuli. Future research could use a larger environment set size by excluding some of the image variants, or by conducting a between-subjects study.

6. Implications for future research and conclusion

The current study replicates past research on the restorative effects of nature, and then builds on this research by suggesting a novel measure of restoration and cognitive load using blink-rates. The current study further builds on past research by examining how mechanisms for *fascination* and the *initial affective responses* to natural environments from *Attention Restoration Theory* and *Psycho-evolutionary Theory* may be functioning through known visual perception and endogenous reward systems. In demonstrating that cognitive and affective responses to environments can be dissociated through the use of visual spatial frequency filters (low versus mid-to-high), we propose that *Psycho-evolutionary Theory* and *Attention Restoration Theory* are describing two distinct restoration mechanisms that are working in tandem to produce what researchers have come to observe as the restorative effects of natural environments. This empirical dissociation between the cognitive and affective responses to environments provides a new direction for future research to explore, suggesting that it may be possible to have environments that are cognitively restorative, environments that are emotionally restorative, and environments that promote both cognitive and emotional restoration. Further research is required to determine what specific visual spatial frequencies are most strongly associated with cognitive and affective responses to environments.

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