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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.

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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

[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.

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