The Natural Environment & Human Well-Being: Insights from Fractal Composition Analysis?

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Abstract

Some researchers have suggested that analysing the physical structure of environmental stimuli may provide insight regarding an underlying characteristic of nature that contributes to human functioning. Specifically, it has been proposed that visual scenes with particular fractal characteristics (i.e. mean fractal dimension, maximum fractal dimension) are preferred by humans and may enhance functioning. Moreover, these fractal characteristics appear to be particularly common in the natural environment. This suggests that the positive effects that are generally associated with exposure to nature may be at least partially explained by human response to the mathematical structure of the sensory stimulus. This study will investigate the hypothesis that fractal composition of images predicts human preference for (and benefits derived from) nature.

1. Introduction

The notion that exposure to the natural environment positively affects human well-being has been validated by studies showing measured cognitive, psychological, and physiological benefit. This article contains a brief review of the literature regarding human preference for natural environments, followed by a brief review of the literature regarding mathematical structure of stimuli. Then, preliminary results of an empirical study are presented. The study examines whether the mathematical properties of images may be predictors of human preference for those images. Further discussion of image analysis methods provides a theoretical link between these mathematical properties and human perception of the natural environment, and is followed by a more general review of restorative environment literature, with regard to this context. It is anticipated that use of the HarFA software will aid in timely completion of the experiments.

2. Human Preference for Natural Environments

Many studies have documented children's preference for natural green spaces. These studies show that children's favourite spaces are predominantly outdoors, in natural settings (eg. Department of the Environment, 1973; Korpela, 2002). A study by Sobel (1993) found that children generally preferred natural play spaces, when examining both British and Caribbean children. Lynch (1977) found that children universally appreciated vegetation, in an international study of the experience of growing up in cities. It has additionally been found that such natural settings, which are preferred by children, also have a beneficial effect on their well-being (Wells & Evans, 2003). This connection, between preference and well-being, will be discussed further, later in this article.

3. Mathematical Structure of Stimuli

Recent research has explored specific characteristics of the natural environment that may underlie its beneficial effect on humans. This work suggests mathematical explanations for the differing effects of natural and non-natural environments.

The work of Field (1987) demonstrates a possibility for statistically characterizing images that draws a general mathematical distinction between the visual environments of the natural and non-natural kind, with his finding that natural imagery possesses fractal-like properties. Taylor and his colleagues (Taylor, Micolich, & Jonas, 1999; Taylor 2002) also report fractal properties, as a way of characterizing natural imagery, and as a predictor for appeal of (preference for) some types of artwork.

Furthermore, Olhausen and Field (2000) suggest that such properties may provide insight into the human neurological systems associated with sensory processing. Hughes (2001) similarly suggests a relationship between the mathematical structure of preferred and beneficial stimuli, to neurological and physiological function. His work, addressing the structure of auditory stimuli, also suggests the importance of fractal like traits (i.e. scale invariant repetition and periodicity), and the prevalence of these traits in the natural environment (Gray, Krause, Atema, Payne, Krumhansl, & Baptista 2001).

These studies suggest that the beneficial effects that are generally associated with exposure to nature may be more specifically associated with the mathematical structure of the sensory stimulus. Furthermore, distinct (fractal) characteristics of the natural image may be reflected in the neurological function of the human sensory system, resulting in a physiological basis for differing responses to natural and artificial environments.

The psychological and cognitive effects, which are evident as natural environment responses, provide a means of testing the relationship between image structure and the human natural environment response. This study specifically examines a hypothesized relationship between image structure and preference of children, through the examination of the effects of image structure on preference ratings, for a series of greyscale images. The main hypothesis is that human preference rating for the images will be predicted by their image structure; that greater preference will be observed for those images that have the most natural statistical characteristics, independent of whether or not they are natural, non-natural, or computer generated.

4. Participants

The participants were children of similar socioeconomic status and geographical position (mean age of approximately 11). Data on personal background, physical activity, and daily exposure to nature were also collected.

5. Independent Variables

The images were either photographs of the natural environment, the non-natural (manmade) environment, or computer generated patterns. The images were intentionally difficult to recognize (the participants were told beforehand that they were “just patterns”). There were six examples in each category, representing a range of image structure within each category. The image structure characteristics used are statistical measures obtained through brightness (intensity) analysis, fractal dimension analysis, and wavelet analysis.

6. Dependent Variable

Preference ratings were obtained, according to a five point Likert scale, for all nineteen images, through one-on-one verbal interviews.

7. Image analysis

The fractal dimension values, used in this study, were obtained through an adaptation of the traditional “box counting” method. Traditional box counting yields a fractal dimension score that characterizes the properties of, for instance, the black area of a binary (black & white) image. The adapted method used in this study instead characterizes the properties of the border (i.e. between the black and white).

Since the box counting method relies on binary (black and white) data, non-binary images must be converted through a technique known as thresholding. In this process, a threshold must be predetermined, as the intensity value (brightness) above which is essentially converted to white, and below which is converted to black, yielding a binary image. Since the images used in this study were greyscale (non-binary) images with content across the complete range of intensity (brightness), fractal dimension values were obtained across the entire range of threshold values for each image, resulting in a fractal spectrum, with fractal dimension as a function of threshold value. It is characteristics of this spectrum that this study is concerned with; the mean, variance, and maximum of this spectrum was calculated for each image used in this study.

The software used to perform the fractal analyses was HarFA, made available by Image Science Fundamentals (Zmeškal, O., Nežádal, M., & Buchnícek, M., 1999).

Overall intensity (brightness) characteristics were also analysed, for each image. Mean intensity and intensity variance were calculated from the intensity histogram of each image. The composite intensity histograms for the images in all three categories showed similar statistical characteristics. Generally speaking, all images tended towards a relatively normal frequency distribution of intensity.

8. Preliminary Results

Significant correlation was found between mean preference rating and mean fractal dimension ($p = 0.049$). Significant correlation was found between mean preference rating and maximum fractal dimension ($p = 0.014$).

9. Discussion

The findings of this study may support the notion that preference for nature may be more specifically associated with the mathematical structure of the sensory stimulus. Further study should include specific measures of cognitive functioning employed in previous restorative environment studies, along with measures of personal affect and physiological stress.

There is prior evidence of a relationship between preference and the cognitive and physiological benefits. Many studies show the cognitive and physiological benefit of exposure to natural environment, in addition to psychological benefit described above (Ulrich et al 1990, 1991; Parsons et al 1998, Driver, 1976; Knopf, 1987; Schroeder, 1989). A study of unstressed subjects (Ulrich, 1981), that showed an effect of more positively toned emotional states, for exposure to nature scenes, also showed broadly consistent recordings of brain electrical activity of the subjects, suggesting that the individuals were more "wakefully relaxed" during exposure to nature (Ulrich, 1981). Additionally, it has been shown that surgical patients in rooms with windows looking out on a natural scene showed benefits, including shorter postoperative hospital stays, and requiring fewer potent analgesics, as opposed to patients in similar rooms, but with windows facing a brick building wall (Ulrich 1984). A study by Wells showed that cognitive functioning in children, following a move to a different home, was higher for those whose new homes had greater levels of nature nearby (Wells, 2000). Likewise, studies have shown both immediate and durational effects of exposure to the natural environment on cognitive functioning (Hartig, Mang, & Evans, 1991, Driver, 1976; Knopf, 1987; Schroeder, 1989)

It has additionally been found that coherent autonomic response (e.g. skin conductance) to specific environmental stimuli can occur in the absence of recognition or conscious awareness of the elements (Ohman, 1986; Ohman et al., 1989). "Other studies have found that well defined emotional responses to stimuli (assessed by facial electromyography) can occur so rapidly that it is difficult to reconcile with a purely 'controlled' cognitive response perspective on humanenvironment interactions (Dimberg, 1990; Ulrich, 1991)." These findings eliminate the suggestion that people may be conditioned, through cultural influences, to develop positive associations with nature (e.g. Tuan, 1974), as a sole mechanism in restorative environment theory.

Theoretical bases for the positive psychophysiological effect of the natural environment have been widely published – most notably, Attention Restoration Theory (Kaplan & Kaplan 1989) and the affective (rather than cognitive) response model (Ulrich 1983) - both relying on the notion of fascination. However, neither model explicitly addresses the basis for fascination itself (i.e. the characteristics of a fascinative stimulus). Assumptions that have addressed this basis include: it is the complexity of the natural environment that contributes to its ability to fascinate (Kaplan & Kaplan 1989), and that the human species is genetically predisposed to respond, with “fascination,” to the form and structure of the natural environment (Ulrich 1983).

Perspectives on such an evolutionary basis for the nature response often draw on the intuitive notion that humans’ long term evolution in natural environments must have resulted in some physiological and perhaps psychological ‘adaptation’ to natural, as opposed to urban, physical settings. Central to this argument is the position that humans have an unlearned predisposition to respond positively to natural content (e.g. vegetation, water) and to configurations characteristic of settings that were favorable to survival or ongoing well-being during evolution (e.g. Stainbrook, 1968; Appleton, 1975; Driver & Greene, 1977; Kaplan & Kaplan, 1989; Ulrich 1983; Orians, 1986).

The evolutionary perspective has been furthered by speculation that natural content may be processed with relative ease and efficiency because the brain and sensory systems evolved in 6 (11)

natural environments, in a parallel manner (Wohlwill, 1983; Hughes 2001). Because this evolutionary tuning is lacking for urban or built environments, encounters with such settings place greater demands on processing resources, and may overload the individual or require more coping or adaptation effort (Stainbrook, 1968).

In summation, it seems possible that there exists a human response to repetition and periodicity, found within the natural environment in the form of visual stimuli. Additionally, perhaps due to the corresponding structure of the somatosensory cortex, as well as physiological function (Hughes 2001, Ivanov 1999), these naturally structured stimuli “resonate well” with the human mind and body, showing measurable effects.

The results of this study suggest that there may be elemental characteristics of the natural environment that produce, for instance, the fascination response, and that quantitatively distinguish it from the built environment. This does not necessarily imply the ability to separate such a characteristic from the natural environment and effectively reproduce it within the artificial, built environment; a proposition carries extremely powerful philosophical implications.

Towards a Physiological Basis

Previous studies on this topic have not taken into account the variability of thresholding conditions that can greatly affect the fractal dimension value obtained, for images with information over the entire range of intensity, as is commonly processed by the human eye (Olhausen & Field, 2000).

It is not surprising that intensity (brightness) characteristics did not show as a predictor for preference. Physiological aspects of the human visual system indicate a wide range of sensitivity to light intensity (with a more localized, focused sensitivity to color). The vast dynamic intensity range of natural images is managed by the human eye through adjustment of the iris, which controls the total amount of light admitted to the eye, and with neurons in the retina that do not directly register light intensity. Rather, they encode contrast, as a measure of the fluctuations in intensity relative to the mean level. This widely accepted contrast sensitive excitatory and inhibitory receptive field model of the human visual system suggests the relevance of a method of analyzing images according to threshold borders.

In research on image encoding, Olhausen and Field (2000) have suggested that image compression algorithms may provide insight into the neurological processes that take place with human vision. They propose that nature has thus found solutions that are near to optimal in efficiently encoding images of the visual environment; that the visual system has organized itself to represent efficiently the sorts of images it normally takes in, which we call natural scenes.

A clue to human neurological function may be rooted in the postulations of Horace Barlow (University of Cambridge), nearly 40 years ago - that the nervous system might be able to form representations of the underlying causes of images (Olhausen & Field, 2000). Therefore, a model for sensory function may involve fractal algorithms that probabilistically identify stimulus structures without providing a one-to-one representation. That is to say that with human image processing, we process a mathematical compression of a visual image when we see things – allowing neural resources to be specifically directed at elements in the visual field, as desired, while maintaining a low cost understanding of the ambient environment.

10. References

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