Nonlinear Dynamics, Psychology, and Life Sciences, Vol. 19, No. 1, pp. 1-12.
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Human Physiological Benefits of Viewing Nature: EEG Responses to Exact and Statistical Fractal Patterns

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Abstract: *Psychological and physiological benefits of viewing nature have been extensively studied for some time. More recently it has been suggested that some of these positive effects can be explained by nature's fractal properties. Virtually all studies on human responses to fractals have used stimuli that represent the specific form of fractal geometry found in nature, i.e. statistical fractals, as opposed to fractal patterns which repeat exactly at different scales. This raises the question of whether human responses like preference and relaxation are being driven by fractal geometry in general or by the specific form of fractal geometry found in nature. In this study we consider both types of fractals (statistical and exact) and morph one type into the other. Based on the Koch curve, nine visual stimuli were produced in which curves of three different fractal dimensions evolve gradually from an exact to a statistical fractal. The patterns were shown for one minute each to thirty-five subjects while qEEG was continuously recorded. The results showed that the responses to statistical and exact fractals differ, and that the natural form of the fractal is important for inducing alpha responses, an indicator of a wakefully relaxed state and internalized attention.*

Key Words: attention restoration theory, restorative environments, landscape preference, nature, biophilia

INTRODUCTION

The psychological and physiological benefits of viewing natural scenery is an issue that has generated great interest both theoretically and empirically, particularly in the field of environmental psychology. The societal relevance of such research can also broadly be seen in the light of an increase in stress related diseases. The research on connections between nature's effect on human health and well-being has, of course, a much broader scope than the perception of nature and natural elements. Yet, there are

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specific and central theoretical statements being made concerning the visual information in nature and its connection to human functioning that are of high relevance to this study. In the much cited Attention Restoration Theory, ART (Kaplan, 1995), nature is pointed to as a particularly good candidate for restoring the ability to focus and inhibit distractions. The theory deals with information processing and the human capacity to direct attention. When a person concentrates on a task like reading, distracting competing stimuli have to be suppressed. This requires effort and our capacity to direct attention will decrease with prolonged use. As a consequence, we will experience difficulties both in performing cognitive tasks and in mastering human relations. However, the ART theory claims the capacity for directed attention can be restored when engaging in a different type of attention, labelled "fascination" in the ART theory. This type of attention is effortless and our capacity to engage in it is not limited.

Nature is argued to particularly foster this type of attention as nature is full of fascinating phenomena that hold the attention without effort while at the same time also leaving "ample opportunity for thinking about other things" (Kaplan, 1995, p. 174). In other words, this describes a situation where the visual environment is attended to but where simultaneously much of the attention can be directed inward. Interestingly, but little discussed, this also points to the dual role the natural visual environment seems to play in such a situation, where it could be both a stimuli that one is actively looking at and a background that allows for attention to be directed inward.

Much of the environmental psychology studies on the topic of landscape preferences and restorative environments refer to nature in broad terms. Comparatively little effort has been directed to elaborating on the concept of nature and what makes its visual pattern unique for restoration purposes. However, it has been suggested that nature's effect on attention restoration could be explained by nature's fractal properties (Hagerhall, 2005; Joye, 2007; Joye & van den Berg, 2011; Purcell, Peron, & Berto, 2001).

Since the 1970s many of nature's patterns have been shown to be fractal (Mandelbrot, 1982). In contrast to the smoothness of artificial lines, fractals consist of patterns that recur on finer and finer scales, building scale-invariant shapes of immense complexity. An important parameter for quantifying a fractal pattern's visual complexity is the fractal dimension, *D*. This parameter describes how the patterns occurring at different magnifications combine to build the resulting fractal shape (Mandelbrot, 1982). For Euclidean shapes, dimension is described by familiar integer values – for a smooth line (containing no fractal structure) *D* has a value of 1, whilst for a completely filled area (again containing no fractal structure) its value is 2. However, the repeating patterns of a fractal line cause the line to begin to occupy space. As a consequence, its *D* value lies between 1 and 2. By increasing the amount of fine structure in the fractal mix of repeating patterns, the *D* value moves closer to 2 (Taylor & Sprott, 2008). Thus, for fractals described by a low *D* value, the small content of fine structure builds a very smooth, sparse shape. However, for fractals with a *D* value closer to two, the larger content of fine structure builds a shape full of intricate, detailed structure (Taylor & Sprott, 2008). Previous studies had noted that fractals with *D* ~ 1.3 are the most prevalent in natural scenery (Aks & Sprott, 1996) and perception studies show that *D* ~ 1.3 - 1.5 fractals are also perceived to be the most natural in appearance (Hagerhall, 2005). Intriguingly, perception studies investigating visual preference reveal that fractals with *D* values below 1.5 have a significantly higher appeal than higher *D* fractals, with this preference peaking in the range 1.3-1.5 (Aks & Sprott, 1996; Hagerhall, 2005; Hagerhall, Purcell, & Taylor, 2004; Spehar, Clifford, Newell, & Taylor, 2003; Taylor, Spehar, van Donkelaar, & Hagerhall, 2011).

To investigate whether these visual responses affect the physiological condition of the observer, skin conductance was used to measure subjects' physiological response to the stress of mental work (Taylor, 2006). During continuous exposure to a fractal image, each participant performed a sequence of mental tasks designed to induce physiological stress. Each task period was separated by a recovery period, thus creating a sequence of alternating high and low stress periods. The results showed that the mental tasks induced the smallest rise in stress when the observer was observing a fractal pattern with a *D* value of 1.4 (Taylor, 2006).

In a recent study (Hagerhall et al., 2008), this was taken one step further by using quantitative electroencephalography (qEEG) to investigate the physiological response of viewing fractal patterns with different fractal dimension. The study results showed significant differences in brain activity for different fractal dimensions. Furthermore, patterns with fractal dimension, *D*, had the highest alpha frequency activity in the frontal brain areas (F3F4). Alpha is considered to show a wakefully relaxed state and it is a characteristic commonly found in the EEG of a person sitting with closed eyes and attention directed inward. The traditional idea that alpha activity reflects general cortical idling (Adrian & Matthews, 1934) and reduced information processing (Pfurtscheller, 2001) has in recent years been complemented by ideas that increased alpha may be an indicator of active inhibition of non-task relevant areas or processes (Cooper, Croft, Dominey, Burgess, & Gruzelier, 2003; Klimesch, Sauseng, & Hanslmayr, 2007), a sign of top down processes and internal attentional control (Klimesch et al., 2007). An increase in alpha activity could therefore be seen as an indicator that the person is trying to suppress competing information (Ward, 2003). Studies have shown that alpha activity is higher when the attention is directed inward on mental imagery than when attention is directed towards external information intake tasks (Cooper et al., 2003; Ward, 2003). This relation between alpha activity and internalized attention has also been found in studies on meditation (Aftanas & Golocheikine, 2001).

Whereas all fractals exhibit repetition of patterns at increasingly fine scales, fractals can be grouped into two categories based on the manner in which the patterns repeat. For fractals found throughout natural scenery (e.g. clouds, mountains, coastlines, rivers, etc.), the statistical qualities of the patterns repeat at different size scales. In contrast, the patterns of mathematically generated 'exact' fractals repeat exactly at different scales. Consequently, whereas exact fractals look precisely the same at increasingly fine scales, 'statistical' fractals simply look similar at different scales (Fairbanks & Taylor, 2011).

Virtually all perception studies on fractal patterns have used statistical fractals, with the exception of a study by Pickover (1995, p. 206). This raises the question of whether the human responses (preference and relaxation) seen so far in several studies are being driven by fractal geometry in general or by the specific form of fractal geometry found in nature, i.e., statistical fractals. To answer this question, we conduct the first study in which we consider both types of fractals and morph one type (the artificial exact variety) into the other (the statistical natural variety). We hypothesize that the human responses will be driven by the types of fractals found commonly in nature, and so we expected that: (a) Alpha responses would be maximal for the statistical fractals compared to the exact fractals, and (b) that the alpha responses would be maximal for *D* values in the region of 1.3-1.5. All previous experiments on statistical fractals have found the responses (preferences) to be highest for *D* below 1.5. For this reason the stimuli of this experiment are focused on *D* values in the low to mid-range.

MATERIAL AND METHODS

Stimuli

The fractal stimuli used in this study are based on the Koch curve, a traditional fractal pattern dating back to 1904. A triangular 'seed pattern' is repeated at many size scales in order to establish the scale-invariant properties of the fractal pattern. The angle within the triangle determines the fractal dimension that charts the scale-invariance. The original and most commonly used Koch curve uses an equilateral triangle and this generates a curve with a fractal dimension of $D = 1.26$. By adjusting the angle it is possible to obtain curves with *D* values lying between 1 and 2.

If all of the triangles have the same orientation (e.g. pointing upward) then this produces an 'exact' fractal, as shown in the top row of the presentation of experimental stimuli in Fig. 1. However, it is possible to adjust the relative numbers of upward and downward pointing triangles and we introduce the parameter *P* to quantify these numbers. For example, in the top row of Fig. 1, $P = 0$. In the middle row, $P = 0.25$ indicating that 25% of the triangles now pointing downward. The third row corresponds to $P = 0.5$, meaning that 50% of the triangles are pointing downward. In each case, the spatial positioning of the upward and downward triangles is random. A consequence of introducing this randomization is that the pattern loses the exact repetition at different size scales – instead, only the statistical characteristics of the pattern repeat and so we obtain a 'statistical' fractal.

Crucially, this introduction of randomness does not affect the fractal properties of the pattern. In particular, the *D* value remains constant. Thus every column of Fig. 1 show a gradual evolution from an exact to statistical fractal, all charted by the same *D* value.

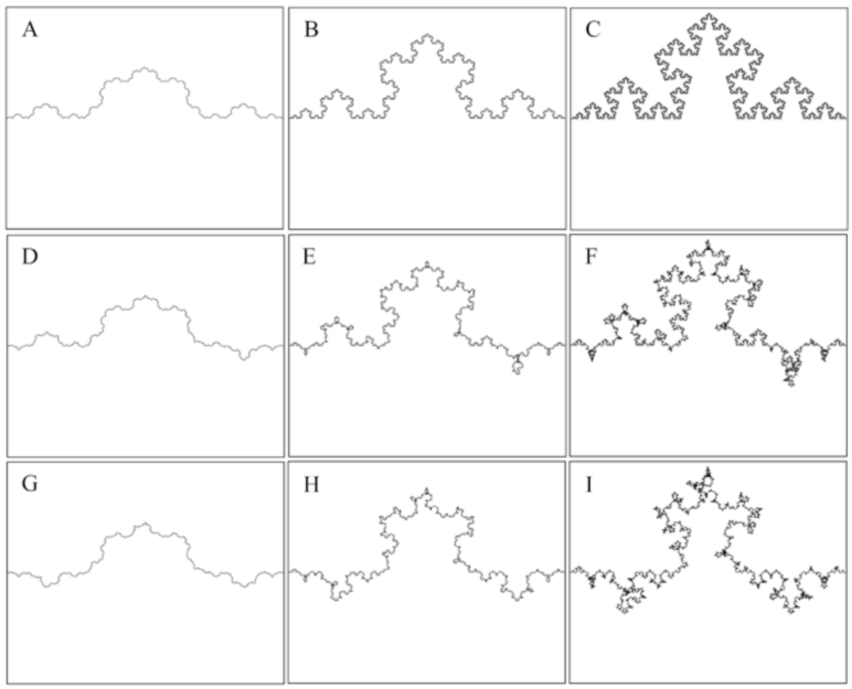

Fig. 1. The nine stimuli used in the study, combining three levels of randomness (*P*) and three fractal dimensions (*D*).Panel A: P0.00 D1.1; Panel B: P0.00 D 1.3; Panel C: P0.00 D 1.5; Panel D: P.0.25 D 1.1; Panel E: P.025 D1.3; Panel F: P0.25 D 1.5; Panel G: P 0.50 D 1.1; Panel H: P 0.50 D 1.3; Panel I: P 0.50 D1.5.

Subjects

Subjects who came to participate were first interviewed concerning medication, neurological dysfunctions and incidences of unconsciousness. They were then tested for handedness, visual acuity and colour deficiency. All subjects were right handed. No conditions were found that would disqualify any subjects from participating. EEG recordings were obtained from forty subjects. Five subjects had to be completely discarded from the sample later on due to technical errors or subjects' physiological conditions (sleepiness and muscle tensions). Hence, the basis for the analyses in the study is a sample of thirty-five subjects, comprising seventeen males and eighteen females in good health with ages ranging from 20 to 66 years (M = 46.2, Md = 49, SD = 14.6). However, for some positions, further reduction of subjects was made in the analyses due to artefacts in the EEG signal (mostly due to eye movements). The study was carried out in accordance with relevant institutional and national ethical regulations concerning experiments with human subjects.

Procedure

The experiment took place in a laboratory room without windows and with grey walls. The lighting in the room was controlled for and kept constant at 0.5 - 0.8 lux for all sessions. Subjects were seated at a table in the middle of the room with a 19 inch LCD screen placed 70 cm in front of them. The picture size of the screen was 37 by 29.5 cm and the resolution was set to 1280x1024 pixels. The qEEG recording equipment (a Nervus Digital EEG Recorder) was placed in an adjacent control room, where the experimenter could follow the experiment and monitor the recording that was made continuously throughout the whole experiment.

The positioning of the electrodes was based on the nasion, vertex, inion, and preauricular points and corresponded to the international 10-20 system. The equipment used had manually attached electrodes, which provides very good reliability but they are more time consuming to apply than a cap. Hence, in this study a limited number of electrode positions were included. The choice of positions to include was guided by the aim of investigating the more generalised cortical arousal (Küller & Wetterberg, 1993). Although of interest, occipital positions were not included since the responses to the direct visual stimulation was not central to the hypothesis. The set up used unipolar recordings and silver electrodes (10 mm) placed on both hemispheres frontally (F3, F4), parietally (P3, P4) and temporally (T5, T6), together with a centrally placed reference electrode (Cz). A clip attached to the subject's left ear lobe grounded the recording system electrically. The individual signal impedance was set at <10 kW.

Each stimulus was shown for a period of 60 seconds, followed by a 30 seconds exposure of a neutral grey image, before the next stimuli appeared. Exposure times were chosen based on the experience from similar experiments (Hagerhall et al., 2008). Four presentation orders were used for the stimuli, both *P* and *D* increasing, both *P* and *D* decreasing, *P* decreasing and *D* increasing and last an order with *P* increasing and *D* decreasing.

The EEG recordings were checked for anomalies and artefacts by two researchers experienced in this procedure. This procedure included a visual check using a low cut filter at 0.5 Hz and a high cut filter at 30 Hz, followed by a check for every subject of the mean values for the 60 second exposures of the stimuli for all frequencies (delta 2.25 – 3 Hz, theta 4.5 – 6 Hz, alpha 9 – 12 Hz and beta 18 – 24 Hz). Lastly, a comparison was made between the visual check and the check of the means. Since the focus of this study is effects on alpha the data for the other frequencies are not reported on or discussed further in this article.

Analysis

The data were mainly treated by analysis of variance (repeated measures design), including both within-group (fractal dimension *D*, level of randomness *P*) and between-group (order) variances. Polynomial contrasts were used to test for tendencies. Based on the nine stimuli, combined means and standard deviations were computed (Guilford, 1950) for the three levels of randomness and the three fractal dimensions.

RESULTS

The results, displayed in Fig. 2, show that alpha increased with *P* at all positions. In other words, alpha power increases as we gradually evolve from the exact fractal to the statistical fractal, which confirms our hypothesis that the natural form of the fractal is important for inducing alpha responses. The results were significant at all positions (main effect of *P* on alpha, F3F4 $F(2, 66) = 3.82$, $p < .05$; P3P4 $F(2, 66) = 3.26$, $p < .05$; T5T6 $F(2, 68) = 3.53$, $p < .05$).

The results concerning alpha in relation to *D* show some differences between the positions; see Fig. 2. In the frontal positions the highest alpha, as expected, occurs at $D = 1.3$, the *D* value most prevalent in nature. However, the effect of *D* on alpha was not significant for F3F4 ($F(2, 66) = 1.40$, $p > .10$). In the parietal and temporal positions alpha is the highest at the lower value of $D = 1.1$, and at these positions the effect of *D* on alpha was significant (main effect of *D* on alpha at P3P4, $F(2, 66) = 3.19$, $p < .05$, and at T5T6, $F(2, 68) = 3.21$, $p < .05$). Whereas all alpha results are consistent with the previous experiments, that responses should peak below $D = 1.5$, the *D* value of the peak seems to depend on the brain region.

Interaction effects between *P* and *D* were found. As shown in Fig. 2 there is a pattern where alpha responses for the mid-levels of *D* and *P* seem to come close to each other while for the lower and higher levels of *D* and *P* alpha responses go in opposite directions. The interaction effect was significant at T5T6 (linear linear $F(1, 34) = 5.11$, $p < .05$), and marginally significant at P3P4 (linear linear $F(1, 33) = 3.79$, $p < .10$).

Lastly, it is worth pointing to the hemispheric differences frontally. There was a significantly greater frontal alpha activity in the left hemisphere ($F(1, 33) = 6.13$, $p < .05$). There was also a marginally significant interaction effect of *D* and hemisphere frontally (linear linear $F(1,33) = 3.08$ $p < .10$). No significant effects were found in relation to gender or age.

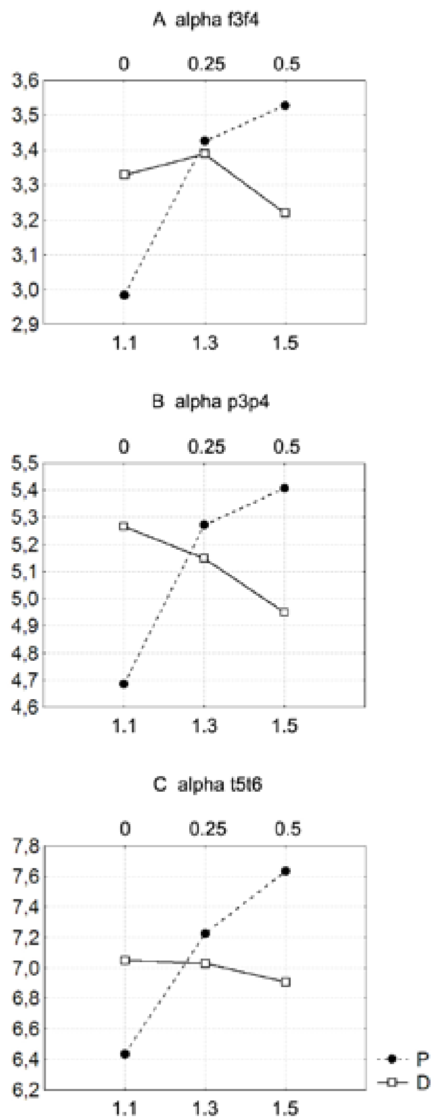

Fig. 2. Plot of main results and interactions. Combined means in μV on the y-axis, for the three levels of randomness (P) and the three fractal dimensions (D) on the x-axis. Dotted line represents P, continuous line represents D. Panel A: alpha F3F4; Panel B: alpha P3P4; Panel C: alpha T5T6.

DISCUSSION

The study confirmed our hypotheses in that alpha response was found to be largest for fractals found in nature, i.e. statistical fractals (incorporating high randomness) and mid to low fractal dimension. In natural scenery, statistical fractals are common because of nature's integration of randomness with the underlying fractal scaling properties. For example, the edges of clouds and coastlines are statistical fractals. The randomness adds some variation to the repeating pattern that might be very important for how the pattern is perceived and evaluated in relation to preference, interest, complexity etc. This variation might also be important in deciding if the pattern is interesting enough to hold the attention for a longer time. In the Attention Restoration Theory (Kaplan, 1995), the desired state for restoration is one where the attention is held but in a way that leaves space for the person to 'go into themselves' to think about other things. It could be argued then that what makes nature so suitable for attention restoration is the mix of variation and predictability in its visual patterns. In line with this thinking, an exact fractal might be too predictable while a statistical natural fractal pattern might have a more optimal mix of order and variation that is effortless to attend to but is still interesting enough to hold the attention.

The results showed greater frontal alpha power in the left hemisphere. In a recent review (Harmon-Jones, Gable, & Peterson, 2010) it was suggested that hemispheric asymmetry in the frontal cortex is connected to motivational direction rather than as previously thought to affective valence. The authors argue that lower activity (i.e. greater alpha power) in the left than right hemisphere is connected to withdrawal motivation, i.e. a tendency to move attention away from the stimuli. However, the authors also emphasize that further studies are needed to separate withdrawal from for instance inhibition, which has similarly been connected to frontal areas, and which is of relevance to the issue of attention restoration in this paper.

Withdrawal and approach motivations can furthermore be of different strengths, and this has been found important for the understanding of how emotions of the same valence affect attention. Gable and Harmon-Jones (2008) have shown that positive affects with low approach motivation (such as amusement or joy) broadened the attention while positive affects with high approach motivation (such as desire or enthusiasm) narrow the attention. They further speculate that similar intensity effects could apply to withdrawal motivations in negative affect, i.e. "low – withdrawal-motivated negative affect may cause broadening, whereas high-withdrawal-motivated negative affect may cause reduction in breadth" (p. 481). As we conclude, this would mean that a similar effect on attention, i.e. a broader attention, could be the result of both a positive approach motivation and a negative withdrawal motivation as long as those are of low intensity. It is interesting then to note that restorative environments research has so far mainly included common human influenced nature types (like parks and urban forests) and not dramatic or wild nature (like deserts, polar areas or rain forests). The restorative effect of common nature, and of mid *D* fractal patterns, might be due to the fact that they are affecting us in moderate ways and that they act as a suitable visual environment allowing for behaviors involving broader attention.

The degree of randomness seemed to be more important than the fractal dimension, in that it was only the degree of randomness that affected frontal alpha significantly. For the parietal and temporal areas both randomness and fractal dimension had a significant effect on alpha. Interaction effects between degree of randomness and fractal dimension could be observed for alpha in the temporal and parietal areas.

We hypothesised that alpha activity would increase with randomness and fractal dimension in the patterns. The results proved the relationship to be more complicated. Randomness and fractal dimension seemed to have opposite effects on alpha activity in the parietal and temporal areas, with alpha increasing with randomness and decreasing with fractal dimension. Concerning the frontal area, alpha increased with randomness while the fractal dimension $D = 1.3$ had the highest alpha although not significant, that might be due to the fact that there were no higher D than 1.5. However, the result point in the same direction as in the study by Hagerhall and colleagues (2008), who found the highest frontal alpha activity for the pattern with $D = 1.3$.

The results and conclusions of this study must be considered as encouraging since significant and consistent results, in line with the hypotheses, could be obtained already with these relatively simple visual stimuli. The stimuli used are one dimensional line fractals and we expect even bigger responses will be likely from fractals that spread across a two dimensional plane. We believe the results point to the fact that human response to these patterns, and the parameters randomness and fractal dimension, have some fundamental base and is important to investigate further.

ACKNOWLEDGMENTS

The study was supported by The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (FORMAS), and The Crafoord Foundation. We gratefully acknowledge the assistance of Jan Janssens and Tord Lundgren and the cooperation of all the subjects who took part in the study.

REFERENCES

Adrian, E. D., & Matthews, B. H. C. (1934). The berger rhythm: Potential changes from the occipital lobes in man. *Brain, 57,* 355-385.

Aftanas, L. I., & Golocheikine, S. A. (2001). Human anterior and frontal midline theta and lower alpha reflect emotionally positive state and internalized attention: high-resolution EEG investigation of meditation. *Neuroscience Letters, 310,* 57-60.

Aks, D. J., & Sprott, J. C. (1996). Quantifying aesthetic preference for chaotic patterns.

Empirical Studies of the Arts, 14, 1-16.

Cooper, N. R., Croft, R. J., Dominey, S. J. J., Burgess, A. P., & Gruzelier, J. H. (2003). Paradox lost? Exploring the role of alpha oscillations during externally vs. internally directed attention and the implications for idling and inhibition hypotheses. *International Journal of Psychophysiology, 47*, 65-74.

Fairbanks, M. S., & Taylor, R. P. (2011). Measuring the scaling properties of temporal and spatial patterns: From the human eye to the foraging albatross. In S. J. Guastello & R. A. M. Gregson (Eds.), *Nonlinear Dynamical Systems Analysis for the Behavioral Sciences Using Real Data* (pp. 341–366). Boca Raton, FL: CRC Press/Taylor and Francis.

Gable, P. A., & Harmon-Jones, E. (2008). Approach-motivated positive affect reduces breadth of attention: Research article. *Psychological Science, 19*, 476-482.

Guilford, J. P. (1950). *Fundamental Statistics in Psychology and Education* (2nd revised ed.). New York: McGraw-Hill.

Hagerhall, C. M. (2005). Fractal dimension as a tool for defining and measuring naturalness. In A.Martens & A. G. Keul (Eds.), *Designing social innovation - Planning, building, evaluating* (pp. 75-82). Cambridge, MA: Hogrefe & Huber.

Hagerhall, C. M., Laike, T., Taylor, R. P., Küller, M., Küller, R., & Martin, T. P. (2008). Investigations of human EEG response to viewing fractal patterns. *Perception, 37*, 1488-1494.

Hagerhall, C. M., Purcell, T., & Taylor, R. (2004). Fractal dimension of landscape silhouette outlines as a predictor of landscape preference. *Journal of Environmental Psychology, 24*, 247-255.

Harmon-Jones, E., Gable, P. A., & Peterson, C. K. (2010). The role of asymmetric frontal cortical activity in emotion-related phenomena: A review and update. *Biological Psychology, 84*, 451-462.

Joye, Y. (2007). Architectural lessons from environmental psychology: The case of biophilic architecture. *Review of General Psychology, 11*, 305-328.

Joye, Y., & van den Berg, A. (2011). Is love for green in our genes? A critical analysis of evolutionary assumptions in restorative environments research. *Urban Forestry and Urban Greening, 10*, 261-268.

Kaplan, S. (1995). The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology, 15*, 169-182.

Klimesch, W., Sauseng, P., & Hanslmayr, S. (2007). EEG alpha oscillations: The inhibition-timing hypothesis. *Brain Research Reviews, 53*, 63-88.

Küller, R., & Wetterberg, L. (1993). Melatonin,cortisol,EEG, ECG and subjective comfort in healthy humans: Impact of two fluorescent lamp types at two light intensities. *Lighting Research and Technology, 25*, 71-81.

Mandelbrot, B. B. (1982). *The fractal geometry of nature*. San Francisco: W.H. Freeman. Pfurtscheller, G. (2001). Functional brain imaging based on ERD/ERS. *Vision Research, 41*, 1257-1260.

Pfurtscheller, G. (2001). Functional brain imaging based on ERD/ERS. *Vision Research 41*, 1257-1260.

Pickover, C. (1995). *Keys to infinity*. New York: Wiley.

Purcell, T., Peron, E., & Berto, R. (2001). Why do preferences differ between scene types? *Environment and Behavior, 33*, 93-106.

Spehar, B., Clifford, C. W. G., Newell, B. R., & Taylor, R. P. (2003). Universal aesthetic of fractals. *Computers and Graphics (Pergamon), 27*, 813-820.

Taylor, R. P. (2006). Reduction of physiological stress using fractal art and architecture. *Leonardo, 39*, 245-251.

Taylor, R. P., Spehar, B., van Donkelaar, P., & Hagerhall, C. M. (2011). Perceptual and physiological responses to Jackson Pollock's fractals. *Frontiers in Human Neuroscience, 5:60*(JUNE). doi: 10.3389/fnhum.2011.00060

Taylor, R. P., & Sprott, J. C. (2008). Biophilic fractals and the visual journey of organic screen-savers. *Nonlinear Dynamics, Psychology, and Life Sciences, 12*, 117-129.

Ward, L. M. (2003). Synchronous neural oscillations and cognitive processes. *Trends in Cognitive Sciences, 7*, 553-559.