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Master's thesis

How Natural Geometry Improves Cognition: The Curious Case of Fractal-Like Nature

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Are there deviations of the Master's thesis from the proposed plan?

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☒Yes, please explain below the deviations

The only deviation was that, due to unforeseen circumstances, the thesis took much longer to finalize than stated in the proposed plan.

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Abstract

This study aimed to evaluate whether fractal-like, compared to Euclidean, geometry has an effect on cognitive processes. While drawing from the Attention Restoration Theory and the reported relationship between restorative aspects of environments and nature we explored the possibility of cognitive benefits caused by fractal-like geometry without the existence of cognitive fatigue or attentional depletion. 72 (N) female and male participants were presented, in a within-subjects design, with three different experimental tasks, namely a Processing Fluency task, the Dot Probe Task (DPT) and the Affect Misattribution Procedure (AMP). The findings of this study support the hypotheses that observing natural fractal-like geometry, compared to natural non-fractal geometry, can capture attention but also improve speed and accuracy in cognitive processing of a visual task. On the other hand, no effects were observed by fractal qualities in human designed geometrical shapes and no evidence were produced on whether fractal geometric qualities influence implicit affective responses.

Introduction

From ancient times humans had a special relationship with nature compared to their urban environments. Natural environments have been utilized for a variety of instances or functions from simple sources of pleasure to supernatural nodes. Various cultures built dedicated places such as gardens and even national parks for relaxation and healing as they perceived nature to have such powers over humans (Williams, 2016). In today's world, societal issues have become more widely acknowledged and pertinent, such as the rise of depression, anxiety and other health problems. Following that, there is an explosion of interest from the scientific as well as the general community on the relation of nature with such conditions and the possible positive effects it may provide (Williams, 2016).

The focus of this study is to evaluate whether the geometric qualities in a perceived environment would have an effect on cognitive processes. In this part of the study we will firstly exhibit the relationship between nature and cognitive restoration and improvement. The Attention Restoration Theory (Kaplan, 1995) will be presented in order to delve into the dynamics of restorative aspects of environments. Then we will explore the concept of fractal geometry, compared to Euclidean geometry, and its relation to nature. Finally, we will present the research question and hypotheses tackled by this study.

Mental Fatigue and Environments

The relationship between our cognitive processes and the properties of our surrounding environment has been intriguing scientific research for more than half a century now. That does not mean that this topic is even close to be fully explored. Moreover, we see a growing interest in the last years from the general public regarding positive and restorative effects of nature against mental fatigue (Parker-Pope, 2008; Williams, 2016). Since 1892, James (as cited in Berto, 2005) postulated that, after observing specific natural elements, they can be engaged with in an effortless manner. Similarly, Kaplan (1995) considered that experiencing nature can effectively improve an individual's recovery from mental fatigue.

Mental fatigue is the diminishing of direct attention capacity and of the ability to manage distractions after a lot or heavy use of these mental resources (Berto, 2005). The replenishment of these resources is addressed as restoration. More specifically, restorative effects imply that exposure to "unthreatening" nature (e.g., parks, gardens, forests) appears to replenish cognitive resources and decrease negative affect and attentional depletion (Joye, et. al., 2013). Moreover, we can observe the existence and relative speed of the differing effects from urban and natural environments on one's physiology and emotional states from some studies (Berto, 2005). While other studies exhibit beneficial effects from natural environments on performance and a general negative effect from urban environments (Berto, 2005).

Nature and Restoration

A substantial number of publications support the view that natural environments have a greater restorative effect, are preferred over (implicit affective attitudes) and are perceived as more fluently processed than urban environments (Berto, 2005; Joye et. al., 2015). A study conducted by Tennessen and Cimprich (1995, as cited in Berto, 2005) examined restoration of mental depletion between university students and found that those students who's housing facilities had more "natural views" out their windows would exhibit higher restoration than those with less "natural views".

There are several findings from previous literature that support the restorative qualities of natural environments. According to Lee et al. (2015), observing a flowering green roof within a city scene would improve sustained attention. Children with fatigued attention saw improvement in speed towards an attention task and retained a more stable spatial working memory after a nature walk compared to an urban walk (Schutte, Torquati & Beattie, 2017). In addition, Chen, Lai & Wu (2011) come to the conclusion that nature environments can maintain the balance and improve the recovery of attentional resources.

Attention Restoration Theory

According to the Attention Restoration Theory (ART), the “typology” of an environment affects improvements or deteriorations in directed-attention abilities (Kaplan, 1995). More specifically, urban environments appear to require directed attention and thus increased levels of attentional resources, while natural environments hardly require directed attention and can be attended to in a rather fluent fashion. Nature, due to the fascinating qualities of its elements, is viewed as grabbing attention in a bottom-up fashion in such a way that does not hinder top-down directed-attention abilities (Berman, Jonides & Kaplan, 2008). Nature is relatively fluent to attend to while producing positive affect but also drawing attention (Joye et al., 2013). The terms ‘Restorative experiences’ or ‘Restorative environments’ are used to describe ‘soft fascination’ instances in which there is a reduction of the directed attention fatigue (Kaplan & Kaplan, 1989).Interestingly, restorative effects have been observed in some unthreatening urban settings as well (Joye et al., 2013). Such findings indicate that apart from specific properties that only pertain to nature, there might also be other common properties shared by both natural and urban environments that can make both environments restorative.

Attention

Attention is the most prominent quality within the Attention Restoration Theory paradigm as the name itself implies. ‘Directed attention’, ‘selective’ or ‘voluntary attention’ as was previously termed, has been contrasted with involuntary attention. Thus, directed attention is considered to be utilized when an important target of conscious focus does not in itself attract the attention, when it requires demanding mental activity or when there is a risk of possible distractions (Kaplan, 1995). Involuntary attention appears to be effortless and resistant to fatigue, while both types of attention seem to similarly be “inhibitory”, express “through suppression of competition” and when involuntary attention is applied directed attention should rest (Kaplan, 1995).

Fascination

Fascination has been distinguished from directed attention in relation to nature within the literature (Berto, 2005). According to Kaplan (1995), one’s attention can be easily captured by nature due to “its intriguing objects and mesmerizing processes”. More specifically, he refers to ‘soft fascination’ in which attention is being captured with ease and might even end up facilitating cognitive processes. The typology of fascination varies and its sources are many, such as processes like gambling, size extremes of objects and settings, natural caves and wild animals. As briefly mentioned above, fascination can also be described along a ‘soft-hard’ dimension, with ‘hard’ including instances such as spectating a car race and ‘soft’ for instances such as having a walk in nature, while ‘softly fascinating’ objects, that are abundant in nature, are exemplified by clouds, snow and leaves (Kaplan, 1995).

Even though fascination is an integral part of the restorative experience, it does not mean that restoration requires fascination for it to occur since fascination is but one of the several parts of the model (Kaplan, 1995). Kaplan (1995) proposed more parts that constitute a restorative environment one of which is the notion of ‘getting away’, as in changing environments in a more conceptual way. A second quality is that the restorative environment needs to have extent, which means it has to be rich in stimuli and significant in scope but also coherent. Thirdly, such environments should be compatible with the observer’s “purposes and inclinations” where this fit, between one’s purposes and the environmental demands, provides comfort and fluency (Kaplan, 1995). Considering that fascination is thought to be intrinsic to the restorative qualities of nature, there is a reason to wonder why there is not a larger portion of research through an ART lens and the same applies for the effects of unthreatening natural environments on attention and affective valence (Joye et al., 2013).

Effort and Fluency

When examining these various processes of “directed attention” one can extract some general properties for this mechanism; these properties are that it is effortful, is important in gaining focus, can be controlled, can be affected by fatigue and can manage distractions (Kaplan, 1995). Thus, directed attention fatigue will be the outcome of any continuous cognitive effort. This appears reasonable when considered under an evolutionary perspective where being vigilant of one’s environment has been probably more crucial than focusing one’s attention long and hard on one specific target (Kaplan, 1995).

An inverse way to describe effort is fluency, which again is the subjective ease or difficulty one possesses when facing a task within a specific context. There are several types of fluency examined within the literature, such as ‘Retrieval Fluency’ that is based in memory retrieval, ‘Diagnostic Fluency’ pertaining diagnoses through deductive reasoning and fluency of higher order reasoning processes (Alter, & Oppenheimer, 2009). Reber, Schwarz, & Winkielman (2004) report that visual ‘Perceptual Fluency’, which is one’s “ease of identifying the physical identity of the stimulus", is highly researched by fluency researchers. In this research we utilize the more general term, related to perceptual fluency, of 'processing fluency' which describes the ease of processing "certain stimulus organization" (Joye & Van den Berg, 2011) and "stimulus meaning" (Reber, Schwarz, & Winkielman, 2004). According to the Perceptual Fluency Account (PFA) the affective responses that occur in restorative natural environments are due to fluent processing because of the lack of demand in cognitive resources in such environments (Joye & Van den Berg, 2011).

Interestingly, high fluency or ease is also considered within the literature to relate to positive affect due to possible familiarity with a stimulus rendering it unthreatening as well as the accuracy of stimulus recognition, processing and/or interpretation (Reber, Schwarz, & Winkielman, 2004; Joye & Van den Berg, 2011).

Affect

Ulrich (1983, as cited in Joye & Van den Berg, 2011) supports that individuals tend to get in an immediate but generalized affective response state when they are exposed to an environment or stimulus. Besides immediacy, these affective responses require minimal cognitive processing, occurs non-consciously and is considered to stem from prehistory as a survival aid in human evolution. Moreover, these responses can be brought forth by specific environmental characteristics such as "complexity", "gross cultural features" like symmetries, "depth and spatial cues", "even ground surface texture" and "absence of threats" (Joye & Van den Berg, 2011). When one is already in an anxious or stressful state, experiencing unthreatening natural scenes may reduce arousal and increase positive emotional states compared to urban environments and thus facilitate in a restorative experience (Joye & Van den Berg, 2011).

Similarly, Purcell, Peron and Berto (2001) considered a model of affective experience, such as preference, in relation to environments, where the type and intensity of this affective experience is dependent on the extent of deviations between the specific environment and the related schemas formulated within the observer. These schemas are considered to form by means of implicit learning after long-term experience of these environments (Purcell, Peron & Berto, 2001).

Fractals

An interesting property of visual environments, lately being placed under scientific scrutiny, is the mathematical concept of fractals. Inspired from the Latin adjective 'fractus', meaning 'broken', Mandelbrot coined the term 'fractal' to denote the idea of fragmentation but also that of irregularity in a specific type of geometry (Mandelbrot, 1982). Aside from their fragmented appearance, however, fractals enclose a variety of patterns. Fractals are more commonly described as geometrical shapes consisting of a self-similar pattern; that is, a pattern that contains smaller copies of itself at different scale levels. Consequently, fractals exhibit self-invariance, meaning that the fractal pattern looks the same no matter how much one zooms into it. This causes their boundaries to be infinitely complex as the copies contain even finer copies of the pattern (Taylor et al., 2005).

Fractal geometry was primarily linked to the mathematical description of natural forms such as coastlines. An aspect that was later observed in many natural phenomena. Hagerhall et. al. (2004) explored landscape preferences in relation to the fractal dimension of the scenes portrayed. In this paper, the fractal dimension is the quantification of the scale invariance which appears in natural patterns. They argued that an important aspect of the perception of fractals in nature is the perceived dimension. That is the dimension in relation to the observer. In light of this they deemed it to be ideal for judging the aesthetics of a pattern. As they argued, since nature "builds many of its patterns from fractals, the fractal dimension could be argued to identify the natural qualities, the naturalness of the pattern" (Hagerhall et. al. 2004). Since fractals are considered as an integral aspect of nature, the "geometry of fractals", as Purcell et. al. (2001) proposed, can be seen as the variable that underlies the restorative and preference relationship with natural scenes.

On the other hand, it is interesting to note, that as Shenker (1994) purported, fractals can be better perceived as a geometrical process instead of a geometrical object. This is because of their trait of "infinite complexity" because of their quality of invariance mentioned before. For this reason it was observed that natural objects cannot be true fractals but because of their finite nature can only be understood as "so-called fractal images" (Shenker, 1994). Indeed if one considers that in their true mathematical form fractals do have an 'extending towards infinity' quality nothing in nature could be described as fractal. Never the less, the fractal qualities of scale invariance and self-similarity can be found in natural and man-made objects or environments. So in this study we will use the term 'fractal-like' to denote those instances where these fractal qualities are present.

Studies, focusing on the quantification of the visual complexity (D) dimension of fractals, (Taylor et al., 2005) found that higher complexity fractals (i.e. high internal repetition of visual information) are visually preferred (affective attitude) over lower, or very high, complexity fractals. High complexity fractals were also rated as more perceptually fluent than low complexity fractals (Joye et al, 2015). So, while some effects of fractal complexity are evident, the effects on cognitive processes of fractals versus non-fractals still need to be investigated. Extending this research, we will focus on the presence and absence of fractal-like geometry in a given visual stimulus by controlling as much as possible for the two significant qualities of fractals, namely self-similarity and scale invariance. It can be therefore considered that the fractal-like character of natural environments might lead to high perceptual fluency due to the organizational features of fractal objects, such as repetition of the same information at different scale levels, and therefore lead to an aesthetic preference, among others, towards those environments (Taylor et al., 2005; Joye et al., 2015).

Perceptual Fluency and Pattern Recognition

As briefly mentioned above qualities like symmetry, contrast and clarity, prototypicality and stimulus complexity positively affect processing fluency when they possess less information, for example symmetry when compared to asymmetry (Reber, Schwarz, & Winkielman, 2004). So one could draw a distinction between perceived intricacy and information overload of a stimulus. More specifically, an observer might consciously consider a stimulus as highly complex but in actuality the stimulus might be visually intricate but not informationally intricate, as we consider fractals to be. It is interesting to note that there is a substantial amount of research examining the effects of color on psychological functioning such as affect, cognition and behavior or its use as a "meaning-laden prime" (Lichtenfeld et. al., 2012). In order to avoid and confounding effects we avoided using color in this study.

"Instorative" Effect: Beyond Depletion and Restoration

Finally, studies on the restorative effects of natural environments on cognition, especially those considering ART, primarily utilize depleted attentional resources in order to investigate restoration, meaning that they examine participants with already depleted attention (Berman et al., 2008; Berto, 2005). Interestingly, fascination research supports that contact with nature can also produce an "instorative" or vitalizing effect that is independent from previous depletion (Ryan et al., 2010, as cited in Joye et al., 2013). Similarly, we examine "instorative" or positive cognitive effects of fractals without a depletion manipulation as we assume that the effects may occur independently from depletion (Joye et al., 2013).

The Current Study

The main research question that is tackled within this study is the following one: Are objects with fractal-like traits easier to process (processing fluency), attend to (directed attention) and perceived as more pleasant (positive affect) than their non-fractal counterparts? To answer these questions we formulated three hypotheses and tested all of them twice, once for natural objects and once for geometric shapes. The first hypothesis is that: (H1) Perceptual fluency is higher for fractals than non-fractals. We hypothesize this regarding accuracy for both (H1a) natural objects and (H1b) geometric shapes, but also for reaction speed for both objects (H1c) and shapes (H1d). The second hypothesis is: (H2) Directed attention spent is higher for fractal than non-fractal (H2a) natural objects and (H2b) geometric shapes. The third hypothesis is that: (H3) Positive affect is higher towards fractals than non-fractals for both (H3a) natural objects as well as (H3b) geometric shapes.

Method

Participants

The participants for this study (N = 72) consisted of 37 female and 35 male first year psychology bachelor students from the University of Groningen. Their ages ranged from 18 to 28 years of age (*M* = 20.61, *SD* = 1.85). Participants were recruited through convenience sampling means and were rewarded with one credit counting towards their bachelor program’s requirements.

Design and Procedure

The design of the study was set up as a within-subjects design where the independent variable was possession of fractal geometry with two levels; possessing elements of fractal geometry (fractal) and not possessing elements of fractal geometry (non-fractal). The dependent variables utilized in this study were mean accuracy performance scores and mean speed of correct response in milliseconds for Processing Fluency (cognitive effort) and speed in milliseconds for Directed Attention and Affect-Misattribution (implicit attitudes).

The study was carried out in research labs of the University of Groningen that possessed individual cubicles so that each participant would unobtrusively carry out the tasks on a personal computer. The design of the tasks as well as the performance by the participants was on the same computer program, E-Prime. Initially, participants filled in an informed consent guaranteeing anonymity and the ability to terminate the participation at will with no repercussions.

Furthermore, each participant completed the three different experimental tasks, namely a Processing Fluency task, the Affect Misattribution Procedure (AMP) and the Dot Probe Task (DPT). The presentation sequence (first, second and third) of the tasks was counterbalanced where different participants experienced different sequences in an ABC - BCA - CBA pattern as to avoid possible confounding from the sequence of task presented. For each of these three experimental tasks, there was a practice period of ten trials to assure participant understanding and basic competency. Furthermore, within each task, the presentation sequence of the trials was randomly selected for each participant. Participants then had to fill in information on their personal data such as age and gender. Finally, participants were debriefed and thanked.

Materials

Stimuli

The stimuli utilized for this study were comprised by the following. Firstly, sixty (60) real life images were collected via internet search into two categories, fractal and non-fractal nature, one for each level of the independent variable. These images were selected to satisfy several visual criteria. Most notably, they had to be images of real objects or scenes from a natural environment, such as plants, rivers and snowflakes. Moreover, they had to clearly possess or not fractal-like elements of geometry as defined in this study. Thus, objects exhibiting self-similarity and scale invariance were distinguished from objects that did not exhibit those properties. The images were coupled together to form similar thematic and visual dyads, such as fractal and non-fractal snowflake or fractal and non-fractal foliage (see Figure 1). Finally, all nature images had their color removed, thus being transformed into gray-scale, so as to avoid any possible effects of color on the variables at hand.

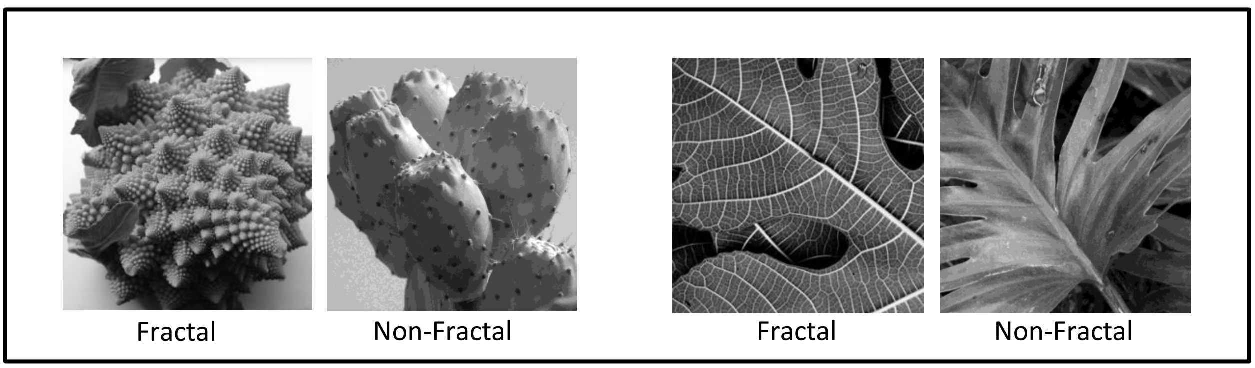

Figure 1. Examples of stimuli used under the nature images condition. This figure illustrates two dyads of fractal and non-fractal nature.

In addition, sixty (60) images of geometric shapes were also grouped into fractal and non-fractal shapes with similar conditions as above. The images in the fractal geometric shapes condition consisted mostly of traditional geometric fractals, such as the Sierpinski Triangle and the Koch Snowflake (Mandelbrot, 1982). Each of the images for the non-fractal geometric shapes condition were designed or selected to match an image of the fractal geometry condition. The goal was to maintain some qualities as similar as possible between the images of each pair in order to control for possible confounding variables. These qualities were general shape, size, line thickness and relative complexity. All geometric images were set in black and white color (see Figure 2).

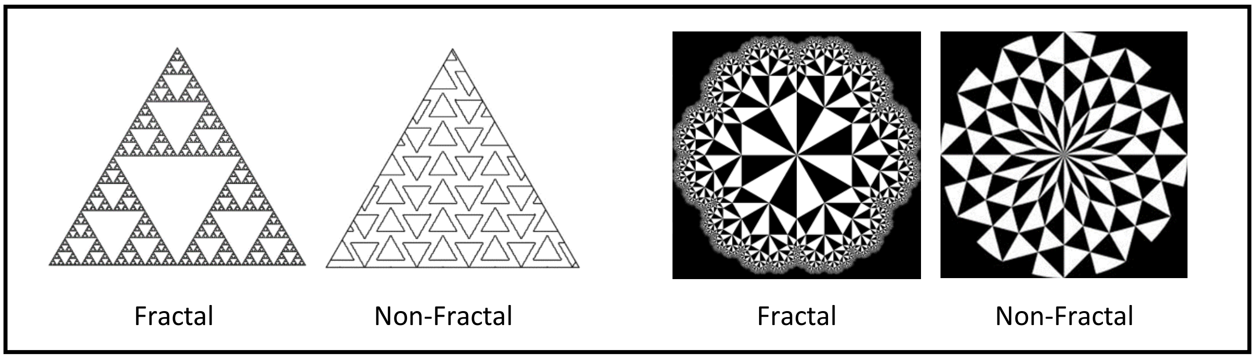

Figure 2. Examples of stimuli used under the geometric shapes condition. This figure illustrates two dyads of fractal and non-fractal geometric shapes.

The secondary materials used for the experimental tasks, such as the "noise" image, used in the affect misattribution task, and the cognitive puzzle, used in the Processing Fluency task, were made with Photoshop and Windows Paint software respectively. In addition, a selection of real life pictures of neutral objects, such as cars and bikes, were used for the practice trials. The entire study was executed using the E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA).

Tasks

Processing-fluency task. A cognitively effortful task was designed and used to measure processing fluency similarly to previous studies (Joye et al., 2013; Joye et al. 2015). The task would first display (prime) a target stimulus (fractal or non-fractal), and then present a "puzzle" to be solved. More specifically, the puzzle comprised of a configuration of squares and triangles of varying color which participants had to evaluate as correct or incorrect by pressing the appropriate key (see Figure 3).

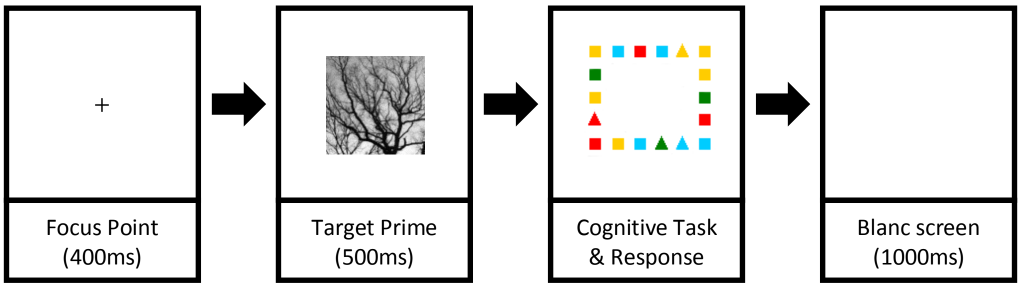

Figure 3. Processing Fluency Task flowchart. This figure illustrates the process of the task in steps.

Participants were instructed that the configuration was correct when it satisfied three specific conditions. More specifically, (a) there had to be exactly four triangles present (b) two of which had to be adjacent (c) while each triangle had to be a different color. Any violation of these conditions would result in an incorrect configuration (see Figure 4). There were nine "puzzles" for each of the four combinations of experimental conditions (fractal, non-fractal, natural images, geometrical shapes) making it thirty six trials for each participant in total.

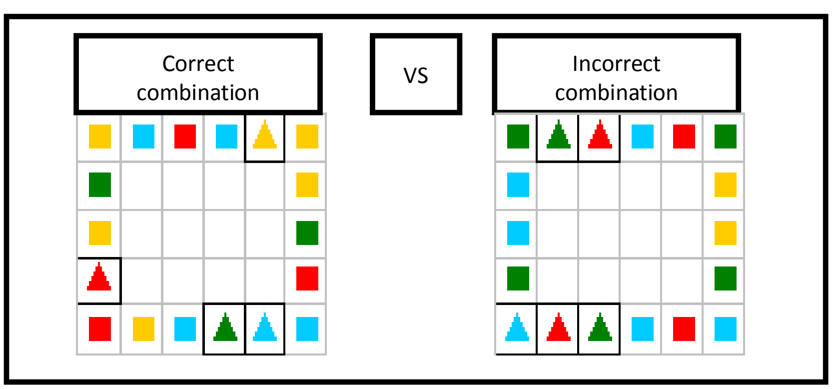

Figure 4. Examples of correct and incorrect instances of shape combinations for the cognitively effortful task.

Moreover, participants were asked to respond as fast and as accurate as possible since mean accuracy scores and mean reaction times of correct responses, measured in milliseconds, in this task were operationally defined as indicators of processing fluency.

The Dot Probe Task (DBT). The Dot Probe Task (Halkiopoulos, 1981; Joye et al., 2013) was used to effectively assess directed attention. In this task, two competing stimuli would appear side by side on the screen for a short period of time, thus serving as primes. For two thirds of the trials (66%), immediately after the primes, a probe (dot) would appear in the position of one of the two stimuli (see Figure 5). In sum, six item pairs were presented for each of the four experimental conditions thus having twenty four trials for each participant. Participants were asked to indicate the presence and location (left or right) of the probe, by pressing the appropriate key, as quickly and as accurately as possible. For this task, both mean reaction time of correct responses and mean accuracy scores were measured as distinct dependent variables; with fast reaction times and high accuracy as indicators of directed attentional bias towards one of the two competing conditions, fractal or non-fractal.

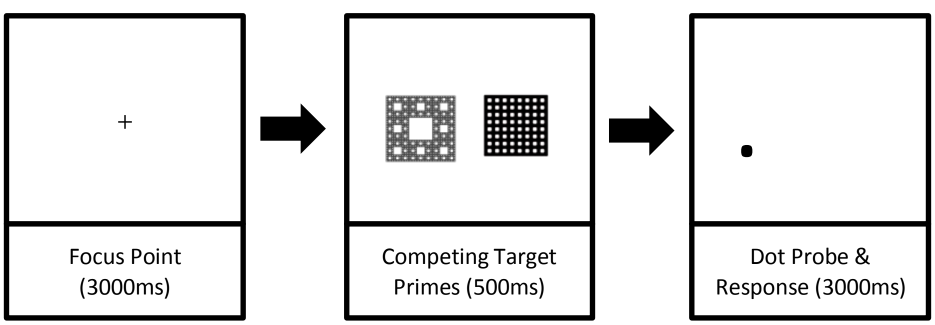

Figure 5. Dot Probe Task flowchart. This figure illustrates the task step by step.

The Affect Misattribution Procedure (AMP). To measure implicit affect (attitudes) we employed the Affect Misattribution Procedure (Payne et al., 2005; Joye et al., 2013), which is an implicit measure of affective responses. The target stimulus appeared for a short amount of time serving as a prime. Immediately after, a neutral stimulus was presented which the participants were asked to evaluate (see Figure 6). More specifically, participants were asked to evaluate the neutral stimulus as “less” or “more pleasing than average” by pressing the “Z” or “M” key of the keyboard. Participants were thus expected to misattribute feelings they experience for the target prime on to the neutral stimulus. This task presented nine (9) items for each of the four (4) experimental conditions resulting in thirty six (36) trials for each participant. The neutral stimuli comprised of black Chinese characters (logograms) on a white background as they are considered as neutral towards a non-Chinese speaking audience. The dependent variable for this task was calculated by adding the positive and negative evaluations for each category (e.g. fractal nature) into two distinct scores. The negative score would be then subtracted from the positive score for each category thus resulting to an affect score, on a semantic differential scale, ranging from -9 to +9 with positive scores indicating positive affect and negative score indicating negative affect. The scores towards the extremes indicate stronger negative or positive affect while the ones in the middle near zero a more neutral one.

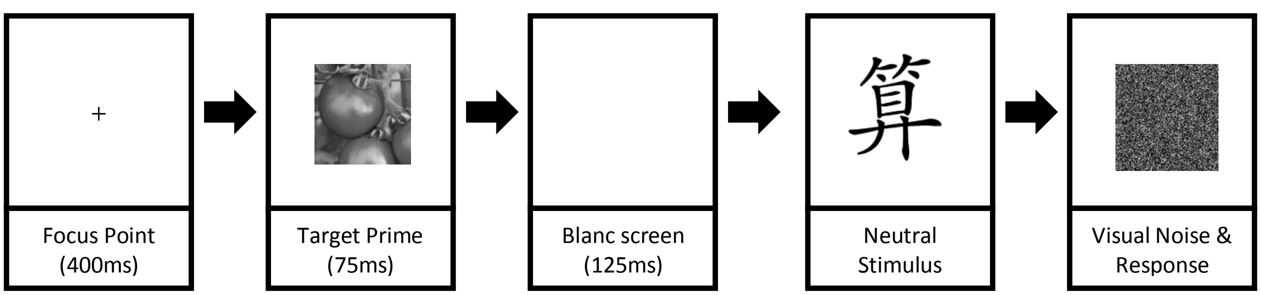

Figure 6. Affect Misattribution Task flowchart. This figure illustrates every step of the task.

Results

Premises

We used an alpha level of .05 for all statistical tests. Cohen's d was used as an indication of effect size (Cohen, 1988), where effect sizes over .20 are deemed as small, over .50 as medium and over .80 as large. Each hypothesis has been tested separately for the two distinct experimental conditions, one of images of nature and one of images of geometrical shapes. In addition, processing fluency (hypothesis 1) was tested under two different measurements, accuracy of responses and reaction time of correct responses.

Missing data

Participants were excluded from the analyses by using a pairwise deletion method in order to deal with missing data and outlying cases. In all three tasks, missing data were considered missing completely at random (MCAR) and missing by design. Out of the seventy-two participants, two were excluded from the perceptual fluency task due to poor performance in all conditions, perhaps because of insufficient understanding of the task. Nine participants were excluded from the attention task (DPT) because of poor performance on the task. Notably, absence of correct responses would produce missing scores for the reaction time measurement as it is based on the reaction time of correct responses. Finally, for the affective response task (AMP) three participants were excluded from the analysis as preliminary analysis deemed them outliers.

Processing Fluency

In order to test hypothesis H1a, a paired-samples t-test was conducted to examine differences between images of fractal and non-fractal nature on performance in a processing fluency task. There was a statistically significant difference between the scores in fractal nature (M=8.41, SD=.77) and non-fractal nature (M=7.66, SD=1.17) conditions; $t(69)$= 5.188, p<.05;

d=.62. Effect size analysis exhibited a large effect (d = .62) for this test. The findings indicate that participants solved the puzzle more accurately in the fractal nature condition than the non-fractal nature condition (See Figure 7).

In order to test hypothesis H1b, a paired-samples t-test was conducted to examine differences between fractal and non-fractal geometric shapes on performance in the processing fluency task. There was no statistically significant difference between the scores in fractal geometric shape (*M*=7.61, *SD*=1.32) and non-fractal geometric shape (*M*=7.57, *SD*=1.16) conditions; $t(69)= .255$, $p>.05$; $d=.03$. The findings indicate that participants solved the puzzle in similar accuracy rates for both the fractal nature and the non-fractal nature conditions (See Figure 8).

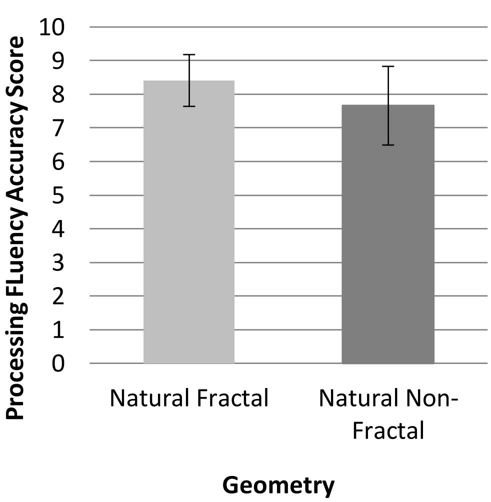

Figure 7. Processing Fluency task mean accuracy for fractal and non-fractal nature images (H1a).

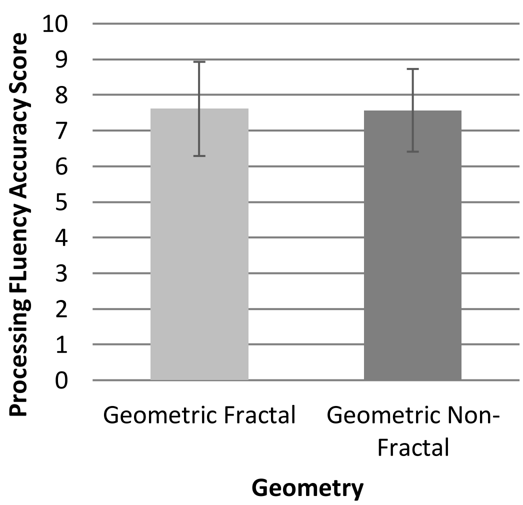

Figure 8. Processing Fluency task mean accuracy for fractal and non-fractal geometric shapes (H1b).

In order to test hypothesis H1c, a paired-samples t-test was conducted to examine differences between images of fractal and non-fractal nature on reaction times (performance speed) of correct responses in the processing fluency task. There was a statistically significant difference between the scores in fractal nature (*M*=2611.04, *SD*=799.24) and non-fractal nature (*M*=2721.61, *SD*=824.03) conditions; *t*(69)= -1.997, *p*=.05; *d*=.24. Effect size analysis exhibited a small effect (d = .24) for this test. The findings indicate that participants solved the puzzle faster in the fractal nature condition that the non-fractal nature condition (See Figure 9).

In order to test hypothesis H1d, a paired-samples t-test was conducted to examine differences between fractal and non-fractal geometric shapes on reactions times (performance speed) of correct responses in a processing fluency task. There was no statistically significant difference between the scores in fractal geometric shape (*M*=2785.08, *SD*=932.28) and non-fractal geometric shape (*M*=2707.80, *SD*=823.74) conditions; *t*(69)= 1.385, *p*>.05; *d*=.17. The findings indicate that participants solved the puzzle in a similar speed for both the fractal and the non-fractal geometric shape conditions (See Figure 10).

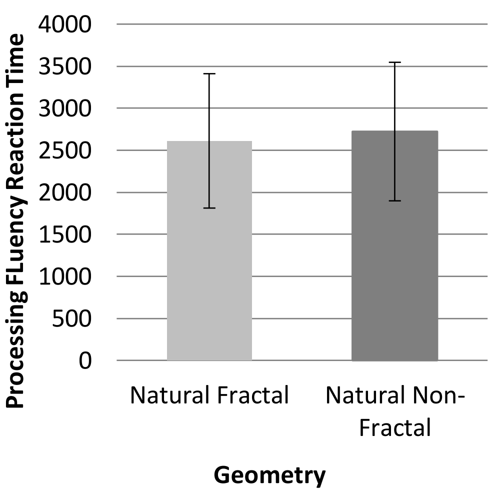

Figure 9. Processing Fluency reaction times for fractal and non-fractal nature images (H1c).

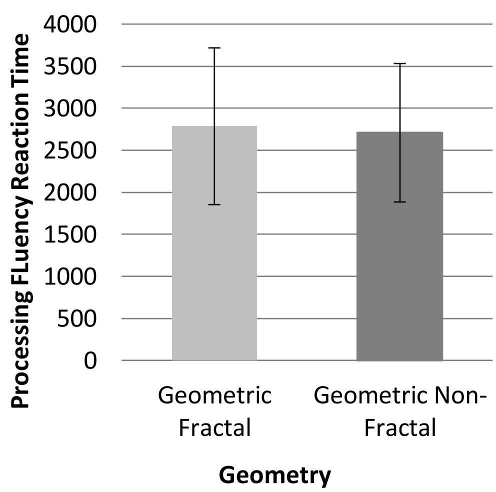

Figure 10. Processing Fluency task reaction times for fractal and non-fractal geometric shapes (H1d).

Attention

In order to test hypothesis H2a, a paired-samples t-test was conducted to examine differences between images of fractal and non-fractal nature on reaction times of correct responses in a directed attention task. There was a marginal statistically significant difference between the scores in fractal nature (*M*=395.84, *SD*=55.29) and non-fractal nature (*M*=384.61, *SD*=51.63) conditions; *t*(62)= 1.949, *p*=.056; d=.25. Effect size analysis exhibited a small effect (d = .25) for this test. The findings indicate that participants performed somewhat slower in the attention task under the fractal nature condition than the non-fractal nature condition (See Figure 11).

In order to test hypothesis H2b, a paired-samples t-test was conducted to examine differences between fractal and non-fractal geometric shapes on performance speed (reaction times) of correct responses in a directed attention task. There was no statistically significant difference between the scores in fractal geometric shape (*M*=388.66, *SD*=47.75) and non-fractal geometric shape (*M*=393.77, *SD*=54.40) conditions; *t*(62)= -1.014, *p*>.05; d=.13. The findings indicate that participants performed at similar speeds in the attention task for both the fractal and the non-fractal geometric shape conditions (See Figure 12).

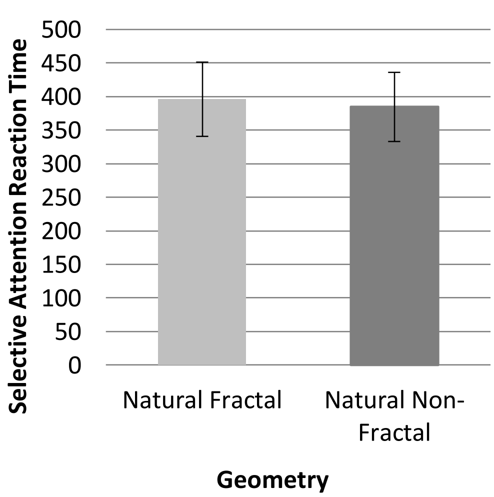

Figure 11. Dot Probe Task mean reaction times for fractal and non-fractal nature images (H2a).

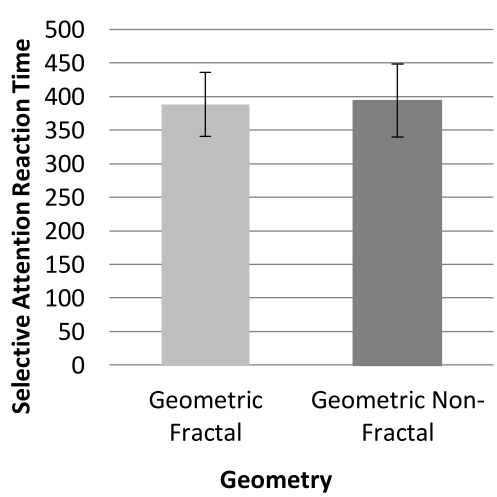

Figure 12. Dot Probe Task mean reaction times for fractal and non-fractal geometric shapes (H2b).

Affect

In order to test hypothesis (H3a), a paired-samples t-test was conducted to examine differences in elicited affect between images of fractal and non-fractal nature obtained by performance in the affect misattribution task. There was no statistically significant difference between the preference scores in fractal nature (*M*=1.12, *SD*=3.25) and non-fractal nature (*M*=.97, *SD*=3.26) conditions; *t*(68)=.277, *p*>.05; d=.07. The findings indicate that participants provided similar valuations in the affect misattribution task for both the fractal and the non-fractal nature conditions (See Figure 13).

In order to test hypothesis (H3b), a paired-samples t-test was conducted to examine differences in preference between fractal and non-fractal geometric shapes from performance in an affect misattribution task. There was no statistically significant difference between the scores in fractal geometric (*M*=.91, *SD*=3.56) and non-fractal geometric shape (*M*=1.12, *SD*=3.31) conditions; *t*(68)= -.431, *p*>.05; d=.11. The findings indicate that participants provided similar valuations in the implicit association test for both the fractal and the non-fractal geometric shape conditions (See Figure 14).

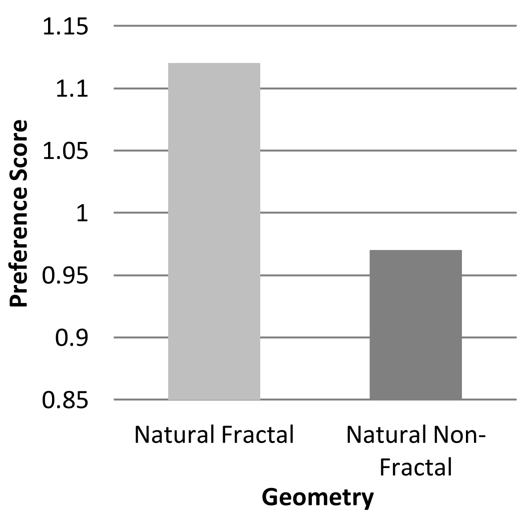

Figure 13. Affect Misattribution Procedure preference scores for fractal and non-fractal nature images (H3a).

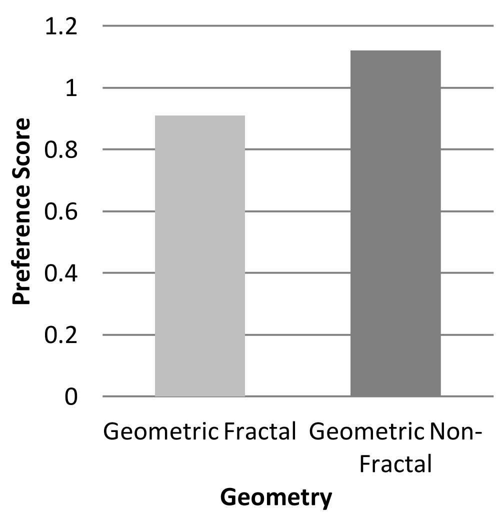

Figure 14. Affect Misattribution Procedure preference scores for fractal and non-fractal geometric shapes (H3b).

Discussion

The aim of this study was to examine whether fractal qualities in the geometry of the environment can affect cognitive functions. More specifically, we looked into three functions namely processing fluency, directed attention and positive affect. The hypotheses stated that viewing images with fractal-like geometry would improve accuracy and / or speed as well as a positive emotional state within the give tasks compared to images without fractal-like geometry.

The first hypothesis which stated that (H1) Processing fluency would improve for fractals than non-fractals was mostly supported by the data. More specifically, when participants observed fractal-like natural objects they performed both better (H1a) and faster (H1c) in the processing fluency task than when they observed natural objects without fractal-like qualities. The same effect though did not occur between fractal and non-fractal images of geometrical shapes (H1b & H1d). Thus we observed an effect when comparing, for example, a cauliflower to a tomato but not when comparing the Shierpinski Triangle, an actual mathematical fractal, to a collection of triangles (See Figure 2). If 'fractality' was the only factor we would expect that when the stimuli are black and white line drawings we would observe the same positive effect, if not even more because of the inclusion of 'truer' fractal shapes compared to the fractal-like shapes we find in nature. Perhaps fractal qualities in nature appear to the observer as more 'natural', meaning they are a part of the perceived experience of nature as integral parts from an experiential as well as an evolutionary perspective.

The results for the second hypothesis had a similar pattern with the first. When considering that (H2) directed attention spent would be higher for fractal than non-fractal (H2a) natural objects and (H2b) geometric shapes, the data supported this with a marginally statistical significance for the difference between fractal-like and Euclidean geometry only regarding natural objects and not geometric shapes. The assumption was that fractals would be more attention grabbing but once more that was not the case for the designed geometric shapes. Similarly to processing fluency above, the naturalness itself of an image could have an effect on attentional processes such as fasciation and that there is an important difference on how individuals interact with a natural environment compared to an artificial one.

Finally, the third hypothesis postulated that (H3) positive affect would increase towards fractals than non-fractals for both (H3a) natural objects as well as (H3b) geometric shapes but the data did not produce any statistically significant results. So we did not observe the existence or not of fractal qualities to be able to determine ones implicit affective state neither positively or negatively. There is an assumption for why this experimental procedure did not produce any results regarding the quality of the materials used as the neutral stimulus which is discussed more in depth below in the Limitations section.

Implications and applications of the findings

In this study we observed that indeed fractal-like qualities in nature can have some beneficial effect in involuntary attention as well as the ease with which one processes a visual scene. On the other hand there were no findings to support similar effects between designed geometrical shapes and fractals. Perhaps this occurred because of the innate familiarity we as humans have with natural environments. Moreover, the geometrical shapes that were utilized in both fractal and non-fractal conditions were in essence simple two dimensional designs that perhaps lacked the fascinating qualities that nature, architecture or art possess. More specifically, the stimuli used might be too simplistic, underwhelming and unfamiliar to elicit strong responses from the participants.

The findings from this study do support previous research in the claims that nonthreatening nature is beneficial to one's psychological processes and that objects with more fractal-like qualities have a greater effect compared to those with less or none. Thus, we propose that, when considering the effects of an environment in architecture, education or urban planning, a greater emphasis should be given to more diverse fractal-like natural objects or scenes.

Limitations and Future Research

After the completion of the whole procedure some participants gave feedback in regards to how they perceived the tests and how they tackled them. Considering the Affect Misattribution Procedure a few participants reported that they observed themselves coming up with various rules for what constituted a 'more or less pleasing than average' stimulus. For example, they would consider jagged edges or steeper angles within a Chinese character as more negative than positive. This might imply that participants truly focused on the Chinese character and found a way to discriminate between them through an arbitrary trait which could be unrelated with the target stimulus (prime) they would previously see. Under the assumption that this may have happened to an important percentage of the sample that did not report it, perhaps the Affect Misattribution Procedure was not implemented correctly or the neutral stimuli selected, i.e. Chinese characters, were not the appropriate in being perceived as neutral. It would be interesting to re-examine this test under these conditions but with a different material as a neutral stimulus.

Further limitations of this study may be more commonplace but still remain important. One such limitation is the relatively small sample size (N = 72), which although sufficient for adequate statistical power could be quite larger. Similarly, this study could benefit from a larger amount and a greater array of the visual stimuli used as materials. More images presented to the participants for each condition would increase the data points and thus give us a clearer and more robust picture of differences between conditions.

Thus, future research could vastly improve upon this study if, besides recruiting more participants ad materials, it would discover ad utilize a more appropriate means of examining the affective response elicited by fractal geometry. Either by use of more appropriate materials as neutral stimuli in the Affect Misattribution Procedure or by using a different experimental task altogether it would be worthwhile to re-examine the existence of possible effects. Furthermore, future research could explore concepts that have not been fully explored by previous research. An interesting path would be to examine the geometric structure of a whole composition of objects and whether such an environment would affect cognition in a meaningful way. More specifically, how would the coexistence of non-fractal objects with fractal-like objects, both natural and artificial, within the same scene influence individuals depleted, or not, cognitive state. This could provide us with a different perspective of mental fatigue and restoration as well as unconditioned perception and attention in a complete and continual environment.

Conclusions

The fact remains that fractals are a mathematical idea that can only be expressed partially in reality, never the less, nature possesses some level of qualities such as self-similarity and scale invariance that are the basis of fractal geometry. The ability of nature to fascinate, inspire, sooth and revitalize is undeniable and so the question is becoming more and more pertinent (Berto, 2005; Joye et. al., 2015; Schutte, Torquati & Beattie, 2017): What are the characteristics of nature that benefit us and how do they work?

Based on the findings of this study we observe that natural fractal-like geometry appears to moderately improve both speed and accuracy in cognitive processing of a visual task, which is a relatively novel finding within the literature (Joye et. al., 2015). Moreover, we observe a small effect of fractal nature on holding visual attention while, on the other hand, none of these effects are identified for fractal qualities in human designed geometrical shapes. Finally, we were unable to procure any evidence on whether fractal geometric qualities influence implicit affective responses. As mentioned in the previous section, future research could shed light into the reasons behind the lack of such effects. More importantly, it could expand our understanding towards the benefits of nature, geometry and their combination in a world that appears increasingly in need of it but also more able to grasp and utilize this valuable knowledge.

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