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NATURAL FRACTALS AND FACIAL EMOTION RECOGNITION

by

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This document, submitted in partial fulfillment of the requirements for the degree from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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Nathaniel Pagel
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To my family; Shirley, James, Jeremy, Lila, Anna, and Kendall.

Thank you for all the love.

ABSTRACT

The psychological benefits that come from visually processing natural imagery have been widely studied. The components of natural imagery that provoke positive responses are not fully understood. This study uses a mixed design approach to identify if the acute exposure to statistical fractal imagery, of both a high-range or mid-range complexity, affects cognitive workload, physiological arousal, and gaze patterns in the recognition and identification of emotions through facial expressions. Participants were undergraduate students fulfilling a partial course requirement (N = 87). Eye-tracking metrics were used to compare exposure to fractal complexities. Participants were randomly assigned to either be exposed to a fractal of high-range complexity, mid-range complexity, or low-range complexity and a gray screen control. The fractal stimuli and emotion recognition tests were presented using Tobii Studio and Millisecond software shown on a computer monitor. The hypotheses surround the idea that the specific visual processing and physiological reactions elicited by fractals have measurable impacts on subsequent task performance.

Keywords: Fractal, natural fractal, fractal dimension, visual complexity, eye-tracking, emotion recognition, facial expression

Is the Recognition of Facial Expressions Modulated by Exposure to Fractal Imagery?

The COVID-19 pandemic and its various responses resulted in an exasperation of many psychological issues. Issues such as isolation, financial troubles, turbulent social interactions, and occupational frustrations were combined with the ongoing scarcity of access and availability of mental health resources. Transitioning to teletherapy and telehealth services has seen some much-needed success (Puspitasari et al., 2021), but the change has undoubtedly left many wanting (Turgoose et al., 2017). These varied effects continue to highlight the longstanding and persistent need for cost-effective and easily accessible therapeutic methodologies. This study attempts to look into one aspect of non-verbal information processing and perception to see if viewing natural fractals can have measurable changes in the recognition of positive emotions within facial expressions.

Facial expressions are a measurable emotional response as well as a means of social communication (Adolphs, 2002). They are a complex central component of body language, giving direct and indirect communication through a process that is both automatic and controlled (Shamay-Tsoory, 2011). Uncontrolled responses are of particular interest in psychological studies, as they can provide information on subconscious and deeply conditioned patterns, which are oftentimes difficult to study. The processing of facial expressions is unique, occurring in the fusiform face area (FFA) (Kanwisher et al. 1997), which is an unusually specialized region within both temporal lobes. While not entirely specialized (Schultz et al., 2003), the FFA is particular to certain tasks within a specific area, providing structurally neurological evidence that processing a facial expression is a complex and evolutionarily important task (Kanwisher & Yovel, 2006). Being able to readily identify facial expressions is critical to navigating and social settings, as is made salient through the differences in activation patterns that are seen within studies using face perception tasks those with autism: “…results revealed either abnormally weak or no activation in FG [fusiform gyrus] in autistic patients…” (Pierce et al., 2001). Proper activation of this region results in processing of social information, which provides the ability to understand more about interactions, intentions, expectations. Differences in processing occur contextually, with participants able to identify emotions more readily within stimuli that are congruent with what the participant is feeling (Niedenthal et al., 2000). Continuous flash suppression, which presents stimuli to one eye while eye while a high contrast mask is shown to the other, has shown that the emotional nature of the stimuli still affects subsequent assessments of facial expressions (Siegel et al., 2018). Some of the original experimenters to use this technique reported that the flash of one image suppresses the presentation of the other “ten times longer than that produced by binocular rivalry” (Tsuchiya & Koch, 2005). These studies show that there seems to be an effect during both concurrent and preceding stimuli presentations. Here, to objectively assess changes in unconscious emotional responses to the presented stimuli, facial expression analysis (FEA) has been used successfully (Moreno et al., 2020). There are also cultural differences in emotion recognition, Feng et al., in 2021, found that, among Eastern Europeans, the preceding emotional exposure impacted the interpretation of the next expression significantly more than Westerners. Facial expressions guide social behavior through providing visual feedback, giving insights into emotional and cognitive states. These studies show that how we interpret facial expressions is dependent upon what other information we include to create our perceptions, and an abnormally complex visual stimuli consumes a higher degree of cognitive processing power. In this study, the Autism Quotient (AQ) (Appendix C) and the Connectedness to Nature Scale (CNS), (Appendix D), will be used to investigate associations to the speed and accuracy of emotional recognition. Higher scores on the CNS mediate the positive effects of exposure to nature (Mayer, 2008). It is theorized here that the higher complexity fractal dimensions will interfere less with one's ability to perceive facial expressions accurately on those who score lower on the AQ and higher on the CNS.

A ubiquitous example of commonly complex stimuli are fractals. Fractals are a "geometric figure, each part of which has the same statistical characteristic as the whole" (Merriam-Webster, 2022). Fractals are a common method employed by nature to efficiently arrange matter. The visual components of fractal branching behavior are prevalent within nature, such as river deltas, lightning strikes, or cloud formations. Anatomically, branching fractals are found within bronchial tubes, the arterial tree of the kidney, the overall branching system of the arteries, or the internal neuronal structure of the cerebellum (with its wonderfully anachronistic nickname, Arbor Vitae). The characteristics of the branch archetype also mirror those of internal neural structures (Schröter et al., 2017). The internal structure of our brains is made up of neurons connecting to other neurons in complicated patterns, and nature chooses fractals to optimize the number of connections within neuronal space (Smith et al., 2021). With the average human brain consisting of 86 billion neurons, and the neuronal branching in the human brain existing in a 3-dimensional space, thousands of synaptic connections can connect to an individual neuron (Herculano-Houzel, 2009). Interestingly, the most common dimension of space that a neuron takes up, is close to the average natural fractal dimension of D = ~1.4 (Smith et al., 2021). The clearest operationalization of fractal complexity was put forth through a figure from Richard P. Taylor's review of experiments and literature concerning the geometry of architecture (Appendix E).

Natural fractals, also called statistical or random fractals, as compared to an exact or deterministic fractal, are commonly found in nature. Natural fractal designs still range widely in their complexity and in their levels of self-similarity; that is, the fractal's complexity is measured through the amount of the available dimensional space that the fractal takes up (1 = a straight line; 2 = a filled square; 3 = a filled cube). They are not infinite and perfect replications of themselves, as something like the Koch curve contains (Appendix J), but rather they introduce a component of chaos and randomness into their self-similarity formula. However, its complexity is limited by natural upper and lower scaling limits (Losa, 2009). There are multiple ways of assessing a fractal, but here we use the traditional box counting method, which breaks an image into increasingly smaller sections to observe changes that occur with changes of magnification and scale (Appendix I). Using a range of ~1.1 for low, ~1.5 and ~1.9 for highly complex, as an entire 2D image is filled at D = 2 and a straight line is D = 1. A growing body of literature is finding evidence for universal preferences for statistical fractals within the range of D = ~1.3 - 1.5 (Street et al. 2016; Robles et al., 2020; Taylor & Sprott, 2008; Taylor et al., 2011).

Using this mid-range complexity, studies have shown marked changes in EEG alpha and beta activation levels (Hagerhall et al., 2015). EEG studies that show changes in alpha activation levels are critically important to understanding what allows someone's attention to be at rest. Distinct fMRI activation patterns from mid-range fractal dimensions (e.g., dorsolateral parietal cortex, ventral visual stream, parahippocampal area, and the dorsolateral parietal cortex) have also been found (Taylor et al., 2011). Mitterschiffthaler et al., 2007, shows that the parahippocampal area is activated in response to emotional stimuli, making its activation by mid-range dimensional fractals markedly interesting; the activation could potentially impact emotive processing. Furthermore, a remarkable technical report from a 1986 NASA study by Wise, J.A.

and Rosenberg, E, out of the Space Human Factors Office, found that while undergoing three stress inducing mental tasks, the mid-range fractal complexity resulted in a stress reduction of 60% (as measured by electrodermal activity). These physiological changes mark a measurable difference in cognitive processing and cognitive processing fluency, or the perception of ease at which a cognitive process takes place (Oppenheimer, 2008), in response to fractal exposure of a specific dimensionality.

There seems to be replicable ease at which mid-range fractal complexities are processed (Aristizabal et al., 2021; Isherwood et al., 2017; Juliani et al., 2016; Spehar et al., 2003, 2015; Street et al., 2016; Taylor et al., 2005, 2017; Taylor & Spehar, 2016), leading to reductions in stress and arousal levels (Hagerhall et al., 2015). Mid-range dimensions are more common and seemingly more easily processed, potentially accessing the well-studied benefits of nature; viewing and experiencing nature has been linked to a marked reduction in stress, restoration of attentional capacities (Kaplan, 1995; Berman et al., 2008), speeder hospital recovery times (Ulrich, 1986). Past studies on the stress reducing experience of nature have investigated the calming effects that virtual forests, mountains, and streams have on prison populations (Nadkarni et al., 2021); the effects of a guided versus unguided navigation of natural settings, finding that self-directed navigation held significant positive effects (Reese et al., 2021); the positive effects that simultaneous walking and talking have on burnout, where nature was found to positively augment its effectiveness (van den Berg & Beute 2021); the separation between the color green and a natural setting, where simply exposing participants to the color green was not enough to find the restorative benefits that are found in natural settings (Michels et al., 2021). Furthermore, current research, albeit limited, has started to show little differences between navigating a real forest versus navigating that same forest within a virtual reality headset (Reese et al., 2021).

What are the characteristics of nature that provide these various beneficial effects, is it the underlying fractal dimension, and if so, are there upper and lower limits to its dimensionality?

In terms of eye movements, more complicated images induce longer fixations, durations, indicating a longer cognitive processing time, and if that duration is long enough (compared to a threshold), an uncertainty in what the subject is processing (Brunyé & Gardony, 2017). The theoretical constructs underlying the connection between eye movements and cognitive processing are twofold: One, the immediacy assumption, states that when someone looks at something, they automatically try to understand it. And two, the eye-mind assumption, that the eye will remain fixated on something until it is understood (Just & Carpenter, 1980). When processing an image, the eye combines saccades, smooth pursuits, vergences, and vestibulo-ocular movements as it moves between points of interest (Purves, et al., 2001). These movements create spatial patterns that can be analyzed and measured through eye-tracking recordings, as was done within Taylor et al., 2011. This study analyzed the fractal dimensions of the spatial patterns while viewing fractals of different complexities and found that, regardless of the dimension of the stimuli that was used, the eye repeatedly utilized the average complexity ($D = \sim 1.4$) typically found in nature to scan the image (Taylor et al., 2011). Is this simply a more effective search pattern? Is this the search pattern that is consistently used in emotion recognition? Search patterns have been exploited within clinical settings for their ability to enhance emotional processing.

To investigate this interesting combination of responses to specific visual stimuli, differing levels of fractal complexity were chosen. A medium dimensionality has been associated with indicators of lower levels of autonomic arousal, eye-movements that are both efficient and seemingly standardized, and EEG patterns of activity that signal alertness and focus. The purpose of the present study is to investigate whether manipulating the degree of fractal complexity, visually processed directly preceding the recognition task, increases the speed and accuracy of emotional recognition. As such, we hypothesize that this will facilitate the processing of emotional stimuli, while high levels of fractal complexity will interfere with processing of emotional stimuli.

Hypotheses

Research Question 1

Does viewing a statistical fractal with an average high-range (D = ~1.9) complexity have a deleterious effect on the processing of facial expressions?

Hypothesis 1: Statistical fractal exposure of high-range complexity will increase the time it takes to identify the correct emotion from a facial expression.

Hypothesis 2: Statistical fractal exposure of high-range complexity will decrease the accuracy in identifying the correct emotion from a facial expression.

Hypothesis 3: Statistical fractal exposure of high-range complexity will increase the number of saccades, duration times, and fixation points, while changing the overall gaze pattern when identifying an emotion from a facial expression.

Research Question 2

Does viewing a statistical fractal with an average mid-range (D = ~1.4) complexity have a beneficial effect on the processing of facial expressions?

Hypothesis 4: Statistical fractal exposure of mid-range complexity will decrease the time it takes to identify the correct emotion from a facial expression.

Hypothesis 5: Statistical fractal exposure of mid-range complexity will increase the accuracy in identifying the correct emotion from a facial expression.

Hypothesis 6: Statistical fractal exposure of mid-range complexity will decrease the number of saccades, duration times, and fixation points, while changing the overall gaze pattern when identifying an emotion from a facial expression.

Research Question 3

Does viewing a statistical fractal with an average low-range (D = ~1.1) complexity have a beneficial effect on the processing of facial expressions?

Hypothesis 7: Statistical fractal exposure of low-range complexity will decrease the time it takes to identify the correct emotion from a facial expression.

Hypothesis 8: Statistical fractal exposure of low-range complexity will increase the accuracy in identifying the correct emotion from a facial expression.

Hypothesis 9: Statistical fractal exposure of low-range complexity will decrease the number of saccades, duration times, and fixation points, while changing the overall gaze pattern when identifying an emotion from a facial expression.

Methods

Participants

An apriori analysis was conducted prior to the study using GPower (Faul et al., 2007), for a paired sample t-test (power = .8), which suggested N = 27 per fractal group for a total of N = 87. All participants were above the age of 18, recruited through in-class notifications and fliers at the University of North Dakota, through the Department of Psychology, and granted research experience course credit requirement. Participants with photosensitivity were not included in this study.

Materials

Fractals

Fractals of low-range (1.05 – 1.2), mid-range (1.25-1.45), and high-range (1.55-1.85) complexities were photographed and processed to have their dimensionality confirmed using an ImageJ plugin, FracLac, and then presented using Tobii Studio software. The images were presented black and white, to remove any effects that color may have. The processing results in images that are outlines, controlling for a participant's ability to discern what natural imagery was photographed, which may contain emotional or meaningful content and produce undesired effects. The fractal and control presentations were limited to 60 seconds, which is the length of time that has been shown to be sufficient to detect significant changes (Hagerhall, 2005, Hagerhall et al., 2008). This length of time was also chosen to combat any forms of habituation and to ensure participant comfortability. An example of mid-range fractal stimuli is included within Appendix K.

Penn Emotion Recognition Test (ER-40)

The Penn Emotion Recognition Test (ER-40) is a standardized measure of a healthy individual's ability to identify emotions within facial expressions (Carter et al., 2009; Gur et al., 2002). The ER-40 is a subtest of a validated and reliable computerized measure, balanced for demographics (age, gender, ethnicity), from the University of Pennsylvania Computerized Neurocognitive Test Battery. As quickly and accurately as they can, participants were asked to identify the emotion (4 angry, 4 fearful, 4 happy, 4 sad, 4 neutral) from 40 images (20 male, 20 female).

Eye-tracking

The Tobii Eye-tracker X2 60hz Compact is a screen-based eye tracker that records eye movements through illumination of the pupil and retina (Tobii). The Tobii X2-60 has a sampling rate of 60 Hz and tracking accuracy of 0.5 degrees. Eye-tracking can capture changes in cognitive processing through changes in eye-movement measurements (fixations, durations, saccades). The Eye-tracker is connected to an external power source, which is connected to the recording laptop through a data cable. Data was processed and analyzed using the eye-tracker's company's native software, Tobii Studio.

Demographics Questionnaire

A background questionnaire will be administered that will gather demographic information: age, gender, education level, and time typically spent in nature each week. This will provide baseline demographics along with the participant's affinity towards natural environments.

Autism Spectrum Quotient

The Autism Spectrum Quotient (AQ) is a 50-item questionnaire that has been validated to measure the degree of the expression of autistic traits in adults of average intelligence (Baron-Cohen et al., 2001; Broadbent et al., 2013; Woodbury-Smith et al., 2005). The AQ is separated into 5 sections containing 10 questions each (i.e., communication, imagination, attention to detail, attention switching, social skills). Those that score highly on the AQ may have more difficulty in processing facial expressions. For general autistic phenotype identification, it is recommended to restrict consideration to social and communication scales (Bishop et al., 2004). The AQ is measured on a 4-point Likert scale from definitely disagree to definitely agree, with a suggested threshold score ranging from 32 (Baron-Cohen et al., 2001) to 26 for high functioning autism (Woodbury-Smith et al., 2005).

The Connectedness to Nature Scale

The Connectedness to Nature Scale is a 14-item questionnaire that measures an individual's unanimity and equality with the natural world, degree of familial relationship with plants and animals (Mayer et al., 2009; Mayer & Frantz, 2004; Perrin & Benassi, 2009). The scale is measured from 1 (strongly disagree to 7 (strongly agree) and has been validated within Western culture (Pasca et al., 2018).

Procedure

Participants were informed that they are participating in a study regarding processing fluency, stress levels, and nature. All participants were given a consent form to complete prior to their participation. The study took place in Columbia Hall at the University of North Dakota. Participants were asked to complete the demographics questions and behavioral measures. The participants were calibrated with the Tobii Eye-tracker X2 60hz Compact within Tobii Studio, the calibration consisted of the participant following a red-dot as it moved across 9 calibration points on the laptop (1920 x 1080). The eye-tracker estimated the geometric characteristics of the participant's eyes to ensure accurate gaze calculations (Tobii Technology Manual, 2014). Each calibration was checked for limited errors within each calibration point, resulting in zero points recommended for recalibration. Each calibration grid was also manually checked for precision through having the subjects view the coordinate grid locations on the monitor, provided within Tobii Studio. Depending on random assignment, participants were shown either a fractal of a high level of complexity, a mid-level of complexity on one visit, and a gray screen control on the other. To control for order effects, each participant was randomly assigned to receive either the fractal or the control first. To control for practice effects, each session was separated by at least two weeks. The stimulus presentation lasted for 60 seconds. The participants took the Penn Emotion Recognition Test immediately after the stimulus presentation, with the first face appearing after the fractal stimulus ended. As quickly and accurately as they can, using a laptop trackpad, participants identified the emotion (4 angry, 4 fearful, 4 happy, 4 sad, 4 neutral) from 40 images (20 male, 20 female) that appeared in the center of the screen, from a list that appeared on the right-hand side of the screen. Upon completion, participants were thanked for their time and energy, and then dismissed.

Results

Demographics

Of the 87 participants recruited for the study, 81 (93.1%) completed both study visits, the remaining 6 (.069%) did not attend the second visit. Of the 87 participants recruited for the study, 76 (87.3%) completed 100% of the survey. 79% of the participants were Female (*n* = 64), 11.1% were Male (*n* = 9). 35.8% were Conservative (*n* = 29), 21% were Liberal (*n* = 17) 18.5% were Independent (*n* = 15), and 13.6% were Other (*n* = 11). 64% were white, 2.5% were Black (*n* = 2), 2.5% were American Indian or Alaska Native (*n* = 2), 2.5% were Asian (*n* = 2), and 3.7% were Other (*n* = 3). 86.4% of participants had completed some college (*n* = 70), and 3.7% had completed a four-year degree (*n* = 3). 70.4% of participants make less than $10,000 annually, 38.3% (*n* = 57) made between $10,000 and 19,999 annually (*n* = 10), 3.7% made between $20,000 and 29,999 (*n* = 3) annually, and 1.2% made between 30,000 and 39,999 (*n* = 1) annually. 90.1% of the were within 18-24 (*n* = 73) years of age. Eight participants completed both study visits, but did not complete 100% of the survey, and were therefore not included in the demographics. The full listing of demographic characteristics is included in Appendix A.

Penn Emotion Recognition Task (ER-40)

Reaction Time

A paired-samples t-test was used for each group to determine whether there was a statistically significant mean difference between the reaction time to correctly identify an emotion when participants were exposed to a fractal compared to control.

For high complexity fractals, two outliers were detected that were more than 1.5 box-lengths from the edge of the box in a boxplot. After inspection, these values were deemed not to be extreme, and they were kept in the analysis. The assumption of normality of differences was violated, as assessed by Shapiro-Wilk's test (p = <.001) and violated as assessed by Kolmogorov-Smirnov's Test (p = <.001). As the paired sample t-test is robust to violations of normality (Fradette et al., 2003; Posten, 1979; Rasch & Guiard, 2004; Wiedermann & von Eye, 2013), the following analysis can be reported. Participants did not decrease in time it took to identify emotions after the medium complexity fractal (M = 2085.574 milliseconds, SD = 307.931) as opposed to the control condition (M = 2174.481 seconds, SD = 709.544), a statistically insignificant mean decrease of -88.907, 95% CI [-334.632, 156.817], t(26) = -.744, p > .05, d = -0.143.

The mean difference was not statistically significantly different from zero. Therefore, we fail to reject the null hypothesis and reject the alternative hypothesis for RQ1: Hypothesis 1. See Graph 1 within Appendix B for a clustered bar chart comparison of Reaction Time means by fractal group.

For medium complexity fractals, four outliers were detected that were more than 1.5 box-lengths from the edge of the box in a boxplot. After inspection, these values were deemed not to be extreme, and they were kept in the analysis. The assumption of normality of differences was violated, as assessed by Shapiro-Wilk's test (p = <.001), and by Kolmogorov-Smirnov’s test (p = <.001). As the paired sample t-test is robust to violations of normality (Fradette et al., 2003; Posten, 1979; Rasch & Guiard, 2004; Wiedermann & von Eye, 2013), the following analysis can be reported. Participants did not significantly decrease in the time it took to identify emotions after the medium complexity fractal (M = 2361.870 milliseconds, SD = 888.999) as opposed to the control condition (M = 2191.759 milliseconds, SD = 1112.403), a statistically insignificant mean increase of 170.111, 95% CI [-379.640, 719.862], t(26) = .636, p > .05, d = 0.122.

The mean difference was not statistically significantly different from zero. Therefore, we fail to reject the null hypothesis and reject the alternative hypothesis for RQ2: Hypothesis 4. See Graph 1 within Appendix B for a clustered bar chart comparison of Reaction Time means by fractal group.

For low complexity fractals, no outliers were detected that were more than 1.5 box-lengths from the edge of the box in a boxplot. The assumption of normality of differences was violated, as assessed by Shapiro-Wilk's test (p = .200) but was not violated as assessed by Kolmogorov-Smirnov’s Test (p = .958). Participants did not decrease in the time it took to correctly identify emotions after the low complexity fractal (M = 2045.333 milliseconds, SD = 386.687) as opposed to the control condition (M = 2361.870 milliseconds, SD = 272.616), a statistically insignificant mean increase of 43.259, 95% CI [-197.63, 111.119], t(26) = .121, p > .05, d = -0.111.

The mean difference was not statistically significantly different from zero. Therefore, we fail to reject the null hypothesis and reject the alternative hypothesis for RQ3: Hypothesis 7. See Graph 1 within Appendix B for a clustered bar chart comparison of Reaction Time means by fractal group.

Emotions Correctly Identified

A paired-samples t-test was used for each group to determine whether there was a statistically significant mean difference between the number of correct emotions identified when participants were exposed to a fractal as compared to control.

For high complexity fractals, no outliers were detected that were more than 1.5 box-lengths from the edge of the box in a boxplot. The assumption of normality of differences was not violated, as assessed by Shapiro-Wilk's test ($p = .778$) and by Kolmogorov-Smirnov's Test ($p = .200$). Participants did not decrease in the amount of correctly identified emotions after the high complexity fractal ($M = 33.704$, $SD = 2.958$) as opposed to the control condition ($M = 33.926$, $SD = 2.999$), a statistically insignificant mean decrease of -0.592, 95% CI [-1.749, .564], $t(26) = -1.053$, $p > .05$, $d = 0.20$.

The mean difference was not statistically significantly different from zero. Therefore, we fail to reject the null hypothesis and reject the alternative hypothesis for RQ1: Hypothesis 2. See Table 2 within Appendix A for descriptive statistics, and also Graph 2 within Appendix B for a clustered bar chart comparison of Emotions Correctly Identified means by fractal group.

For medium complexity fractals, no outliers were detected that were more than 1.5 box-lengths from the edge of the box in a boxplot. The assumption of normality of differences was not violated, as assessed by Shapiro-Wilk's test ($p = .198$) and by Kolmogorov-Smirnov's Test ($p = .200$). Participants did not increase in the amount of correctly identified emotions after the mid complexity fractal (M = 34.482, SD = 2.694) as opposed to the control condition (M =34.666, SD = 2.402), a statistically insignificant mean increase of 0.485, 95% CI [-.691, 1.645], t(26) = .851, p > .05, d = 0. 0.16.

The mean difference was not statistically significantly different from zero. Therefore, we fail to reject the null hypothesis and reject the alternative hypothesis for RQ2: Hypothesis 5. See Table 2 within Appendix A for descriptive statistics, and also Graph 2 within Appendix B for a clustered bar chart comparison of Emotions Correctly Identified means by fractal group.

For low complexity fractals, no outliers were detected that were more than 1.5 box-lengths from the edge of the box in a boxplot. The assumption of normality of differences was not violated, as assessed by Shapiro-Wilk's test (p = .401) and Kolmogorov-Smirnov’s Test (p = .200). Participants did not increase in the amount of correctly identified emotions after the low complexity fractal (M = 34.407, SD = 2.635) as opposed to the control condition (M = 34.888, SD = 2.309), a statistically insignificant mean decrease of 0.485, 95% CI [-1.477, .514], t(26) = -.994, p > .05, d = 0.195.

The mean difference was not statistically significantly different from zero. Therefore, we fail to reject the null hypothesis and reject the alternative hypothesis for RQ3: Hypothesis 8. See Table 2 within Appendix A for descriptive statistics, and also Graph 2 within Appendix B for a clustered bar chart comparison of Emotions Correctly Identified means by fractal group.

Multivariate Analysis

A one-way multivariate analysis of variance was run to determine the effect of fractal complexity on the number of correctly identified emotions, as compared to the control condition. The five emotions (fear, anger, sadness, happiness, and neutral) were treated as continuous dependent variables that measured each participant's level of emotion identification. Each fractal complexity was used as one level within the independent variable (low, mid, high). To compare the effects of fractal complexity to the control condition, the difference was calculated between the number of each emotion that was correctly identified during the control condition and the corresponding fractal condition.

Preliminary assumption checking revealed that data was not normally distributed, as assessed by a significant Shapiro-Wilk test for each group within each emotion ($p < .05$). There were several univariate outliers, as assessed by boxplot, however there were no multivariate outliers as assessed by Mahalanobis distance ($p > .001$), and all observations were included in the analysis. There were limited linear relationships between the emotions, and this is expected to result in a loss of statistical power, as assessed by scatterplot. There was no multicollinearity as assessed by scatterplot, and there was no homogeneity of variance-covariance matrices, as assessed by Box's M test ($p = .020$).

The differences between the groups of fractal complexities on the combined dependent variables was not statistically significant, F (10, 150) = 1.668, $p =.093$; Pillai’s Trace = .200; partial $\eta2 = .100$. While Roy's Largest Root showed significance F (5, 75) = .206, $p = .014$; partial $\eta2 = .171$ it is not generally not advised to interpret this as meaningful significance while the other multivariate statistics did not find significance (Olson, 1976).

Therefore, we fail to reject the null hypothesis and reject the alternative hypothesis for RQ1, 2, 3: Hypotheses 2, 5, and 8, respectively. See Table 9 within Appendix A for descriptive statistics, Table 10 for the Multivariate Test, and also Graph 5 within Appendix B for a clustered bar chart comparison.

Eye-Tracking

Visit Duration

Visit duration is defined as the sum of the amount of time each participant spent within the active area of interest, the faces of the ER-40. A paired-samples t-test was used for each group to determine whether there was a statistically significant mean difference between the number of seconds spent viewing the ER-40 faces when participants were exposed to a fractal as compared to control.

For high complexity fractals, two outliers were detected that were more than 1.5 box-lengths from the edge of the box in a boxplot. Upon inspection, they were removed from the analysis. The assumption of the normality of differences was violated as assessed by Shapiro-Wilk's test (p = <.001) and by Kolmogorov-Smirnov's Test (p = .018). As the paired sample t-test is robust to violations of normality (Fradette et al., 2003; Posten, 1979; Rasch & Guiard, 2004; Wiedermann & von Eye, 2013), the following analysis can be reported. Participants did not increase in the overall duration of fixations when identifying emotions after the high complexity fractal (M = 60.682 seconds, SD = 17.973) as opposed to the control condition (M =68.188 seconds, SD = 36.290), a statistically insignificant mean increase of 7.505 seconds, 95% CI [-21.129, 6.119], t(15) = -1.174, p > .05, d = -0.294. Of the 27 paired recordings used for this analysis, due to internal eye-tracker malfunction or a lack of sufficient gaze pattern threshold, (*n* = 12) did not meet the minimum criteria for eye-tracking analysis.

The mean difference was not statistically significantly different from zero. Therefore, we fail to reject the null hypothesis and reject the alternative hypothesis for RQ1: Hypothesis 3. See Graph 3 within Appendix B for a clustered bar chart comparison of Visit Duration means by fractal group.

For medium complexity fractals, one outlier was detected that was more than 1.5 box-lengths from the edge of the box in a boxplot and was removed from the analysis. The assumption of normality of differences was not violated, as assessed by Shapiro-Wilk's test (p = .183) and by Kolmogorov-Smirnov's Test (p = .189). Participants did not decrease in the overall duration of fixations when identifying emotions after the medium complexity fractal (M = 54.627 seconds, SD = 13.726) as opposed to the control condition (M = 50.705 seconds, SD =14.287), a statistically insignificant mean decrease of 3.921 seconds, 95% CI [-1.656, 9.499], t(10) = -1.567, p > .05, d = 0.472. Of the 27 paired recordings used for this analysis, due to internal eye-tracker malfunction or a lack of sufficient gaze pattern threshold, (*n* = 17) did not meet the minimum criteria for eye-tracking analysis.

The mean difference was not statistically significantly different from zero. Therefore, we fail to reject the null hypothesis and reject the alternative hypothesis for RQ2: Hypothesis 6. See Graph 3 within Appendix B for a clustered bar chart comparison of Visit Duration means by fractal group.

For low complexity fractals, three outliers were detected that were more than 1.5 box-lengths from the edge of the box in a boxplot and were removed from the analysis. The assumption of normality of differences was violated as assessed by Shapiro-Wilk's test (p = .044) and not violated as assessed by Kolmogorov-Smirnov's Test (p = .136). As the paired sample t-test is robust to violations of normality (Fradette et al., 2003; Posten, 1979; Rasch & Guiard, 2004; Wiedermann & von Eye, 2013), the following analysis can be reported. Participants did not decrease in the overall duration of fixations when identifying emotions after the low complexity fractal (M = 61.669 seconds, SD = 21.211) as opposed to the control condition (M = 61.5371 seconds, SD = 11.578), a statistically insignificant mean decrease of .132 seconds, 95%

CI [-8.593, 8.857], t(23) = .031, p > .05, d = 0.006. Of the 27 paired recordings used for this analysis, due to internal eye-tracker malfunction or a lack of sufficient gaze pattern threshold, (*n* = 4) did not meet the minimum criteria for eye-tracking analysis

The mean difference was not statistically significantly different from zero. Therefore, we fail to reject the null hypothesis and reject the alternative hypothesis for RQ3: Hypothesis 9. See Graph 3 within Appendix B for a clustered bar chart comparison of Visit Duration means by fractal group.

Visit Count

Visit count is defined as the sum of the number of uninterrupted visits to the Area of Interest (AOI), the ER-40 faces, such that a visit is the time interval between the first fixation and the end of the last fixation. A paired-samples t-test was used for each group to determine whether there was a statistically significant mean difference between the number of seconds spent viewing the ER-40 faces when participants were exposed to a fractal as compared to control.

For high complexity fractals, four outliers were detected that were more than 1.5 box-lengths from the edge of the box in a boxplot. The assumption of normality of differences was not violated, as assessed by Shapiro-Wilk's test (p = <.001) and by Kolmogorov-Smirnov’s Test (p = <.001). As the paired sample t-test is robust to violations of normality (Fradette et al., 2003; Posten, 1979; Rasch & Guiard, 2004; Wiedermann & von Eye, 2013), the following analysis can be reported. Participants did not increase in the number of visits to the AOI after the high complexity fractal (M = 75.277 visits, SD = 23.333) as opposed to the control condition (M =63.888 visits, SD = 33.730), a statistically insignificant mean decrease of 11.3888, 95% CI [-.834, 23.611], t(17) = 1.966, p > .05, d = .443. Of the 27 paired recordings used for this analysis, due to internal eye-tracker malfunction or a lack of sufficient gaze pattern threshold, (n = 10) did not meet the minimum criteria for eye-tracking analysis.

The mean difference was not statistically significantly different from zero. Therefore, we fail to reject the null hypothesis and reject the alternative hypothesis for RQ1: Hypothesis 3. See Graph 4 within Appendix B for a clustered bar chart comparison of Visit Count means by fractal group.

For medium complexity fractals, two outliers were detected that were more than 1.5 box-lengths from the edge of the box in a boxplot. The assumption of normality of differences was not violated, as assessed by Shapiro-Wilk's test (p = <.001) and by Kolmogorov-Smirnov’s Test (p = <.001). As the paired sample t-test is robust to violations of normality (Fradette et al., 2003; Posten, 1979; Rasch & Guiard, 2004; Wiedermann & von Eye, 2013), the following analysis can be reported. Participants did not significantly decrease in the number of visits to the AOI after the medium complexity fractal (M = 53.882 visits, SD = 43.876) as opposed to the control condition (M = 58.941 visits, SD = 28.889), a statistically insignificant mean increase of 5.058, 95% CI [-36.584, 26.467], t(16) = -1.053, p > .05, d = -0.083. Of the 27 paired recordings used for this analysis, due to internal eye-tracker malfunction or a lack of sufficient gaze pattern threshold, (n = 11) did not meet the minimum criteria for eye-tracking analysis.

The mean difference was not statistically significantly different from zero. Therefore, we fail to reject the null hypothesis and reject the alternative hypothesis for RQ2: Hypothesis 6. See Graph 4 within Appendix B for a clustered bar chart comparison of Visit Count means by fractal group.

For low complexity fractals, three outliers were detected that were more than 1.5 box-lengths from the edge of the box in a boxplot and were removed from the analysis. The assumption of normality of differences was violated as assessed by Shapiro-Wilk's test (p = .044) and not violated as assessed by Kolmogorov-Smirnov's Test (p = .136). As the paired sample t-test is robust to violations of normality (Fradette et al., 2003; Posten, 1979; Rasch & Guiard, 2004; Wiedermann & von Eye, 2013), the following analysis can be reported. Participants did not decrease in the overall number of visits to the AOI when identifying emotions after the low complexity fractal (M = 61.669 visits, SD = 21.211) as opposed to the control condition (M = 61.5371 visits, SD = 11.578), a statistically insignificant mean decrease of .132 seconds, 95% CI [-8.593, 8.857], t(23) = .031, p > .05, d = 0.006. Of the 27 paired recordings used for this analysis, due to internal eye-tracker malfunction or a lack of sufficient gaze pattern threshold, (*n* = 4) did not meet the minimum criteria for eye-tracking analysis.

The mean difference was not statistically significantly different from zero. Therefore, we fail to reject the null hypothesis and reject the alternative hypothesis for RQ3: Hypothesis 9. See Graph 4 within Appendix B for a clustered bar chart comparison of Visit Count means by fractal group.

Behavioral Surveys

Autism Quotient

The Autism Quotient (AQ) measure found a minimum score of 5, a maximum score of 34, a Mean of 19.562 and a SD of 5.817. A Pearson's correlation was run to assess the relationship between the AQ and the Fractal ER-40 score, Visit Count, Visit Duration, and Reaction Time. The AQ did not significantly correlate with the Fractal ER-40 score, Visit Count, or Reaction Time. The AQ was significantly correlated with Visit Duration.

Preliminary analyses showed the relationship to be linear between the AQ and Visit Duration variables to be normally distributed, as assessed by Shapiro-Wilk's test (p > .05) and

Kolmongorov-Smirnov (p>.05). There was one outlier that was removed upon visual inspection. After removing the single outlier, the correlation between AQ and Visit Duration was no longer significant (p = .575). See Table 3 within Appendix A for the full correlation table.

Connectedness to Nature Scale

The Connectedness to Nature Scale (CNS) measure found a minimum score of 1.93, a maximum score of 4.43, a Mean of 3.423, and SD of .479. A Pearson's correlation was run to assess the relationship between the CNS and the Fractal ER-40 score, Visit Count, Visit Duration, or Reaction Time. The CNS did not significantly correlate with the Fractal ER-40 score, Visit Count, Visit Duration, or Reaction Time. See Table 4 within Appendix A for the full correlation table.

Discussion

The current study aimed at impacting the identification of emotions through the short-term exposure to low, medium, and high levels of self-similar natural geometry. Also, to advance a more specific conception within the literature that proposes a “fractal fluency model”, in which humans have evolved to process specific levels of the natural environment more efficiently. This model indicates that there is a profound relationship between processing fractal stimuli and the brain and has repeatedly been investigated for its various benefits (Aristizabal et al., 2021; Hagerhall et al., 2015; Isherwood et al., 2017; Juliani et al., 2016; Spehar et al., 2003, 2015; Street et al., 2016; Taylor et al., 2005, 2017; Taylor & Spehar, 2016), but to date no study had attempted to identify the limitations of this model using short exposure periods as well exposure that came before the various measures and tasks.

It was expected that the higher levels of complexity in fractals will significantly increase reaction time to correctly identify facial expressions, as the visual information will be more challenging to process cognitively. This was expected to be reversed when participants are exposed to mid or low-range fractal complexities. The typical fixations and durations for identifying facial expressions were expected to be affected by the preceding level of processing difficulty, extending the fluency in the processing of mid or low-range statistical fractals and the difficulty in processing the high-range complexities.

This study found no significant effects from the prior short-term exposure to various fractal complexities on subsequent emotion identification tasks. The participants ER-40 scores (as measured by the number of correctly identified emotions) and reaction times (as measured as the time between the presentation of the stimulus to the participant clicking on the associated emotion) were not significantly impaired by high levels of fractals, nor were they significantly benefited by medium or low range of fractal complexities. This conclusion was further supported by the additional analysis using the one-way MANOVA, which typically results in greater statistical power among correlated dependent variables, compared to individual ANOVAS (Cole et al., 1994). This analysis utilized the difference between the number of correctly identified emotions within the participant’s fractal group and their control session but did not find significant associations between these differences. This shows that the impact of short-term exposure to natural examples of complex, self-similar, geometry, does not extend after the cessation of the fractal exposure.

Additionally, this study found no significant eye-tracking differences within groups that were produced through the prior short-term exposure to any level of fractal complexity. The total amount of time spent viewing the AOIs (the ER-40 faces) did not significantly differ between the low fractal complexity, medium fractal complexity, and the high fractal complexity. This finding gives objective physiological evidence for a lack of change in how long each participant took to investigate the faces before choosing an emotion. This evidence directly supports the lack of significant difference found within overall reaction times. The number of fixation-based visits to the AOIs did not differ significantly between the low fractal complexity, medium fractal complexity, and high fractal complexity. Combined with fixation duration, and the reaction time, this is further objective physiological evidence to support the lack of subsequent impact that natural fractals of any complexity have on this specific emotion identification task.

The behavioral measures utilized, the Autism Quotient (AQ) and the Connectedness to Nature Scale (CNS), were both proposed to be able to be impactful on individuals who scored low on the ER-40. In that, if an individual's score was low on the ER-40, this would have been correlated with a higher score on the AQ. Or, if the individual scored highly on the ER-40, this would have also been correlated with a higher CNS score. Upon removal of a single outlier, both behavioral measures did not correlate significantly with the eye-tracking metrics, nor the ER-40 score.

This study allowed more evidence to be gathered towards the investigation of the subsequent impacts of processing of a range of self-similar geometry, found novel limitations of the fractal fluency model that included the lack of significant effects on this study's measures when the fractal is shown for a short period of time, and a lack of significant effects on this study's measures when the fractal is shown prior to the performance task or physiological measure.

Limitations and Future Directions

The findings from this study are not without limitations. First, the ER-40 test proved to provide substantial ceiling effects, in that the test itself did not provide enough of a challenge to the participants. This limited the ability to detect any impact that the fractal complexities may have had. Next, physiological measures had been planned to be incorporated which included electroencephalography (EEG) heart rate variability, galvanic skin response, and skin temperature. Due to limitations within software acquisition, and a researcher error that left the EEG sample rate at too slow of a frequency for analysis, only the eye-tracking was able to be included. Additionally, the sample of participants being recruited from undergraduate psychology courses at the University of North Dakota was homogeneous on many demographic characteristics (e.g., gender, ethnicity, age). Next, this group of participants did not score highly on the Autism Quotient (M = 19.516) well below the typical cut off score of 32 (Baron-Cohen et al., 2001) to 26 for high-functioning autism (Woodbury-Smith et al., 2005), indicating normal levels of social engagement and emotion identification, and may have contributed to why significant differences within both the ER-40 scores and eye-tracking metrics were not found. Next, there were connection issues concerning the eye-tracker, which resulted in a decreased sample size for data analysis. While there were no statistically significant differences between ER-40 scores, this decreased sample size limits the interpretability of the results from the physiological measure. Next, within the one-way MANOVA, the difference scores for each emotion were not highly associated, if associated at all, which violates one of the statistical assumptions and functionally reduced the ability for the analysis to detect any significant differences. Next, while the short-exposure window proved to be useful in maintaining the participants attention on the fractal, this may have limited any effects that processing the fractal may have had on subsequent performance and physiological measures. Finally, future studies should prioritize fractal exposure that is concurrent with performance tasks and physiological measures.

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Appendix A – Tables

Table 1

Demographic Characteristics of Participants

Characteristic	n	%	
Age			
18-24	73	90.1	
Did not respond		8	9.9
Religion			
Christian	32	39.5	
Catholic	18	22.2	
Jewish	1	1.2	
Traditionalist/Folk/Spiritualist		3	3.7
Atheist	5	6.2	
Agnostic	4	4.9	
Nothing in particular	5	6.2	
Don't Know	5	6.2	
Did not respond		8	9.9
Gender			
Male	9	11.1	
Female	64	79.0	

Did not respond		8	9.9
Political			
Conservative	29	35.8	
Liberal	17	21.0	
Independent	15	18.5	
Other	11	13.6	
Did not respond		9	11.1
Education			
Some College	67	82.7	
2-year degree	3	3.7	
4-year degree	3	3.7	
Did not respond		8	9.9
Ethnicity			
White	64	79.0	
Black of African American	2	2.5	
American Indian or Alaska Native	2	2.5	
Asian	2	2.5	
Other	3	3.7	
Did not respond		8	9.9

Income			
Less than $10,000	57	70.4	
$10,000 - $19,999	10	12.3	
$20,000 - 29,999	3	3.7	
$30,000 - 39,999	1	1.2	
Did not respond		10	12.3

Table 2

ER-40 Descriptive Statistics

Statistics

Group			Tx Score	Control Score
Low	N	Valid	27	27
		Missing	0	0
	Mean		34.4074	34.8889
	Median		35.0000	34.0000
	Std. Deviation		2.63496	2.30940
	Range		10.00	8.00
	Minimum		29.00	31.00
	Maximum		39.00	39.00
Mid	N	Valid	27	27
		Missing	0	0
	Mean		34.1481	33.6667
	Median		35.0000	34.0000
	Std. Deviation		2.69906	2.77350
	Range		12.00	13.00
	Minimum		26.00	25.00
	Maximum		38.00	38.00
High	N	Valid	27	27
		Missing	0	0

Mean	34.1481	34.7407
Median	34.0000	35.0000
Std. Deviation	2.93131	2.33028
Range	12.00	8.00
Minimum	27.00	30.00
Maximum	39.00	38.00

Table 2. Descriptive statistics of the Penn Emotion Recognition Task (ER-40).

Table 3

AQ Descriptive Statistics

AQ

N	Valid	73
	Missing	8
Mean		19.5616
Median		19.0000
Std. Deviation		5.81661
Range		29.00
Minimum		5.00
Maximum		34.00

Table 3. Descriptive statistics of the Autism Quotient

Table 4

CNS Descriptive Statistics

CNS

N	Valid	72
	Missing	9
Mean		3.4236
Median		3.3929
Std. Deviation		.47988
Range		2.50
Minimum		1.93
Maximum		4.43

Table 4. Descriptive Statistics for the Connectedness to Nature Scale

Table 5

Reaction Time Descriptive Statistics

Group		N	Minimum	Maximum	Mean	Std. Deviation
Low	Fractal	27	1453.00	3180.00	2045.3333	386.38731
	Control	27	1670.00	2677.00	2088.5926	272.61621
	Valid N (listwise)	27				
Mid	Fractal	27	1367.00	5093.00	2361.8704	888.99964
	Control	27	1486.00	7435.00	2191.7593	1112.40306
	Valid N (listwise)	27				
High	Fractal	27	1447.50	2821.50	2085.5741	307.93102
	Control	27	1670.00	4642.00	2174.4815	709.54371
	Valid N (listwise)	27				

Table 5. Reaction time descriptive statistics per fractal group.

Table 6

AQ Correlations

Group			AQ	ER-40	Visit Duration	Visit Count	Reaction Time
Low	AQ	Pearson Correlation	--				
		N	24				
	ER-40	Pearson Correlation	-.241	--			
		Sig. (2-tailed)	.257				
		N	24	27			
	Visit Duration	Pearson Correlation	-.482*	-.089	--		
		Sig. (2-tailed)	.017	.659			
		N	24	27	27		
	Visit Count	Pearson Correlation	-.228	-.060	.656**	--	
		Sig. (2-tailed)	.285	.768	<.001		
		N	24	27	27	27	
	Reaction Time	Pearson Correlation	.118	-.185	-.201	-.236	--
		Sig. (2-tailed)	.583	.357	.315	.236	

		N	24	27	27	27	27
Medium	AQ	Pearson Correlation	--				
		N	24				
	Tx Score	Pearson Correlation	-.024	--			
		Sig. (2-tailed)	.911				
		N	24	27			
	Visit Duration	Pearson Correlation	.084	-.026	--		
		Sig. (2-tailed)	.724	.907			
		N	20	23	23		
	Visit Count	Pearson Correlation	-.190	-.012	.184	--	
		Sig. (2-tailed)	.374	.951	.400		
		N	24	27	23	27	
	Reaction Time	Pearson Correlation	.370	.055	.165	-.243	--
		Sig. (2-tailed)	.076	.785	.452	.222	
		N	24	27	23	27	27
High	AQ	Pearson Correlation	--				

	N	25				
Tx Score	Pearson Correlation	-.319	--			
	Sig. (2-tailed)	.120				
	N	25	27			
Visit Duration	Pearson Correlation	-.076	-.092	--		
	Sig. (2-tailed)	.717	.647			
	N	25	27	27		
Visit Count	Pearson Correlation	.339	-.151	.454*	--	
	Sig. (2-tailed)	.097	.454	.017		
	N	25	27	27	27	
Reaction Time	Pearson Correlation	.039	.271	.123	.106	--
	Sig. (2-tailed)	.855	.172	.541	.598	
	N	25	27	27	27	27

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 6. Correlations between the AQ and the ER-40 Score, ER-40 Reaction Time, Visit Duration, and Visit Count.

Table 7

Outlier Adjusted AQ and Visit Duration Correlations

Group			AQ	Visit Duration
Low	AQ	Pearson Correlation	--	
		N	23	
	Visit Duration	Pearson Correlation	-.123	--
		Sig. (2-tailed)	.575	
		N	23	26
Mid	AQ	Pearson Correlation	--	
		N	25	
	Visit Duration	Pearson Correlation	-.332	--
		Sig. (2-tailed)	.105	
		N	25	27
High	AQ	Pearson Correlation	--	
		N	24	
	Visit Duration	Pearson Correlation	.246	--
		Sig. (2-tailed)	.246	
		N	24	27

Table 7. Correlation table between the AQ and Visit Duration, adjusted for outliers.

Table 8

CNS Correlations

Group			CNS	ER-40 Score	Visit Duration	Visit Count	Mean RT
Low	CNS	Pearson Correlation	--				
		N	24				
	ER-40 Score	Pearson Correlation	.042	--			
		Sig. (2-tailed)	.847				
		N	24	27			
	Visit Duration	Pearson Correlation	-.246	-.089	--		
		Sig. (2-tailed)	.247	.659			
		N	24	27	27		
	Visit Count	Pearson Correlation	-.386	-.060	.656**	--	
		Sig. (2-tailed)	.063	.768	<.001		
		N	24	27	27	27	
	Reaction Time	Pearson Correlation	-.116	-.247	-.043	-.135	--
		Sig. (2-tailed)	.590	.215	.833	.500	

		N	24	27	27	27	27
Mid	CNS	Pearson Correlation	--				
		N	23				
	ER-40 Score	Pearson Correlation	-.130	--			
		Sig. (2-tailed)	.555				
		N	23	27			
	Visit Duration	Pearson Correlation	.062	-.026	--		
		Sig. (2-tailed)	.800	.907			
		N	19	23	23		
	Visit Count	Pearson Correlation	-.289	-.012	.184	--	
		Sig. (2-tailed)	.182	.951	.400		
		N	23	27	23	27	
	Reaction Time	Pearson Correlation	.155	-.093	.084	-.175	--
		Sig. (2-tailed)	.481	.644	.704	.384	
		N	23	27	23	27	27
High	CNS	Pearson Correlation	--				

	N	25				
ER-40 Score	Pearson Correlation	-.170	--			
	Sig. (2-tailed)	.418				
	N	25	27			
Visit Duration	Pearson Correlation	.263	-.092	--		
	Sig. (2-tailed)	.204	.647			
	N	25	27	27		
Visit Count	Pearson Correlation	.187	-.151	.454*	--	
	Sig. (2-tailed)	.370	.454	.017		
	N	25	27	27	27	
Reaction Time	Pearson Correlation	-.088	.262	.129	.163	--
	Sig. (2-tailed)	.676	.186	.522	.417	
	N	25	27	27	27	27

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 8. Correlations between the CNS and the ER-40 Score, ER-40 Reaction Time, Visit Duration, and Visit Count.

Table 9

Multivariate Descriptive Statistics

	Group	Mean	Std. Deviation	N
Happy_Diff	1.00	.0741	.26688	27
	2.00	.3704	.49210	27
	3.00	.1111	.32026	27
	Total	.1852	.39087	81
Sad_Diff	1.00	.6667	.91987	27
	2.00	1.0000	.83205	27
	3.00	1.0000	1.17670	27
	Total	.8889	.98742	81
Anger_Diff	1.00	.9259	1.23805	27
	2.00	1.5556	.97402	27
	3.00	1.1481	1.13353	27
	Total	1.2099	1.13706	81

Fear_Diff	1.00	.8148	.73574	27
	2.00	.8519	.98854	27
	3.00	.6296	.83887	27
	Total	.7654	.85545	81
Neutral_Diff	1.00	.8148	.83376	27
	2.00	1.0741	1.03500	27
	3.00	.8519	1.13353	27
	Total	.9136	1.00247	81

Table 9: Multivariate Descriptive Statistics

Table 10

Multivariate Tests

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Intercept	Pillai's Trace	.763	47.650[b]	5.000	74.000	<.001	.763
	Wilks' Lambda	.237	47.650[b]	5.000	74.000	<.001	.763
	Hotelling's Trace	3.220	47.650[b]	5.000	74.000	<.001	.763
	Roy's Largest Root	3.220	47.650[b]	5.000	74.000	<.001	.763
Group	Pillai's Trace	.200	1.668	10.000	150.000	.093	.100
	Wilks' Lambda	.805	1.697[b]	10.000	148.000	.086	.103
	Hotelling's Trace	.236	1.725	10.000	146.000	.080	.106
	Roy's Largest Root	.206	3.097[c]	5.000	75.000	.014	.171

a. Design: Intercept + Group

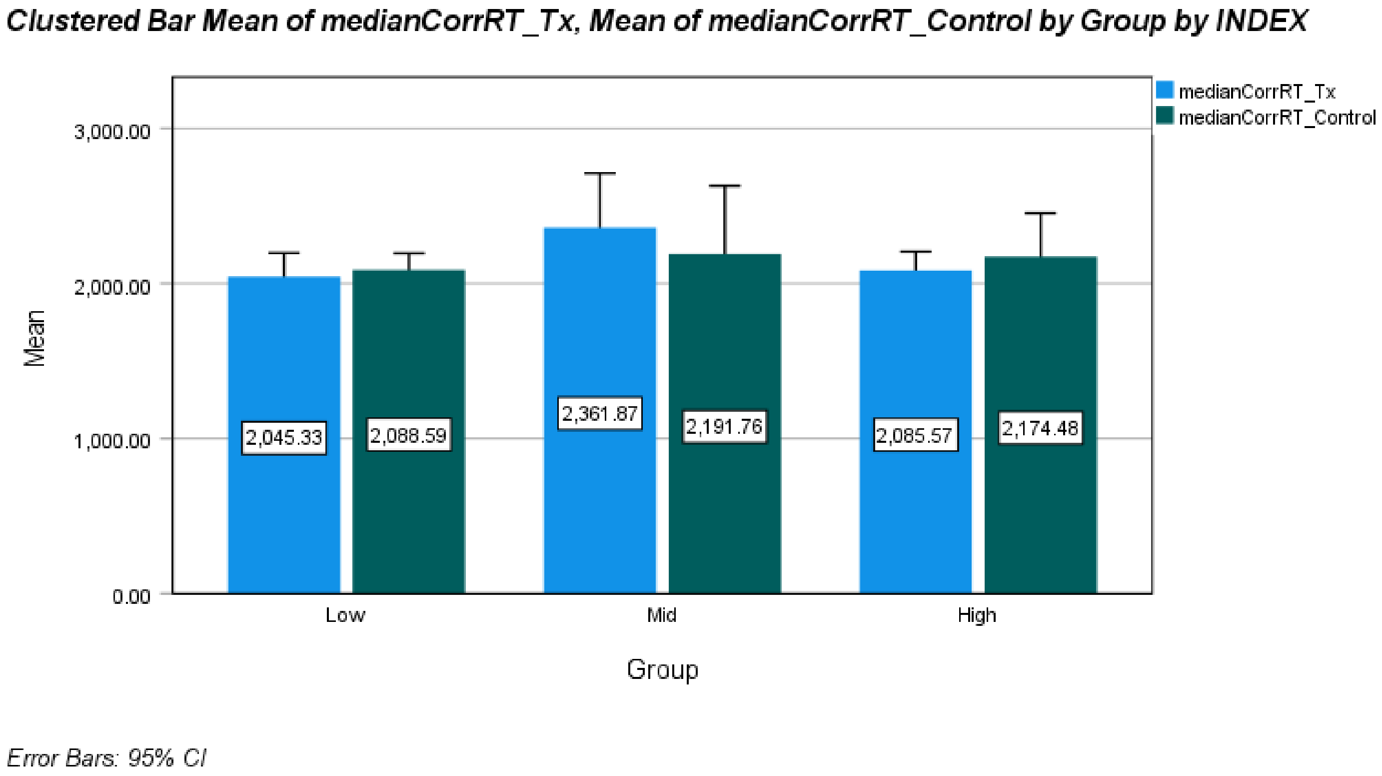
b. Exact statistic

c. The statistic is an upper bound on F that yields a lower bound on the significance level.

Table 10: Multivariate Test for the differences between the number of each emotion that was correctly identified during the control condition and the corresponding fractal condition.

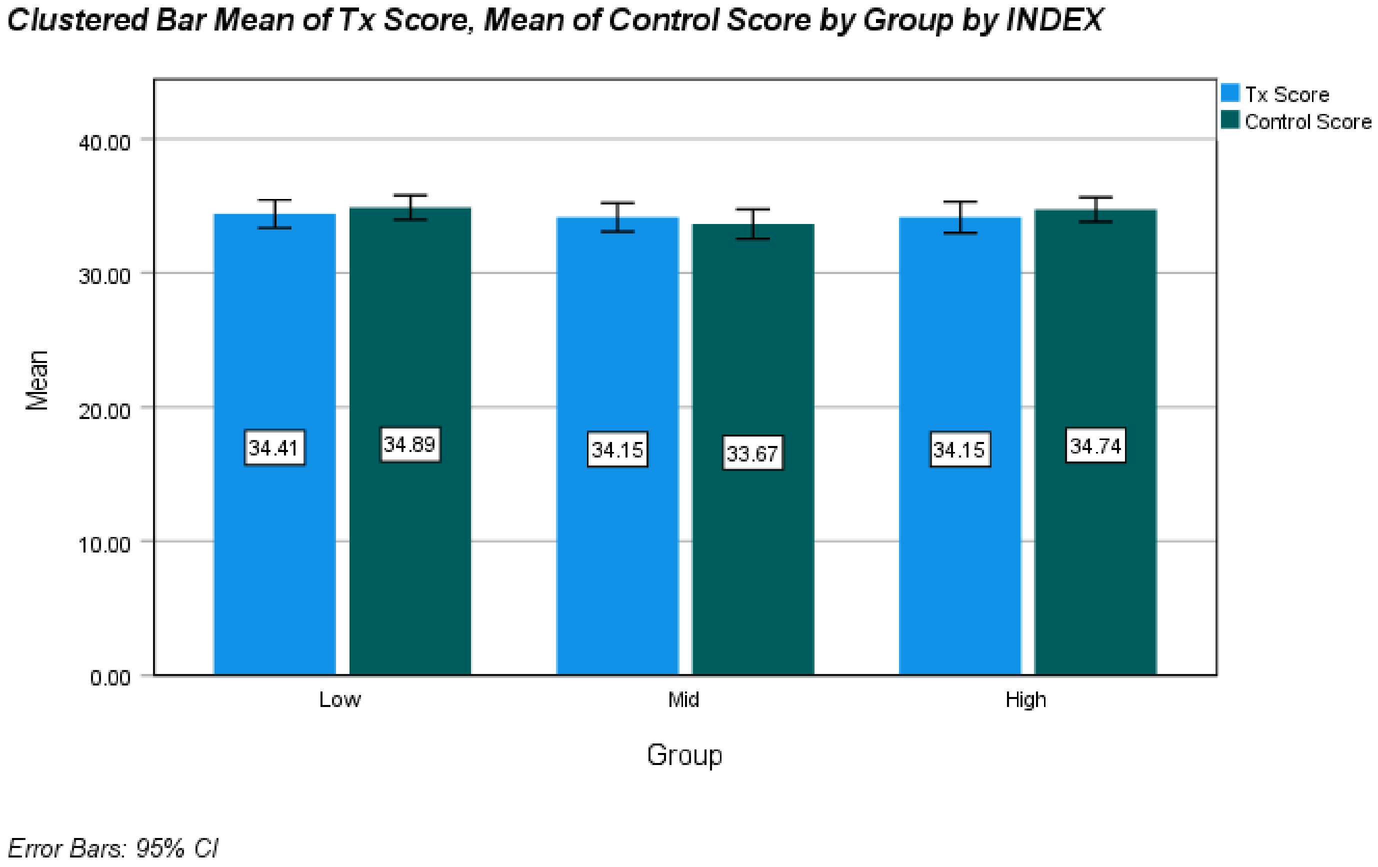
Appendix B – Graphs

Graph 1
Reaction Time: Fractal group vs Control



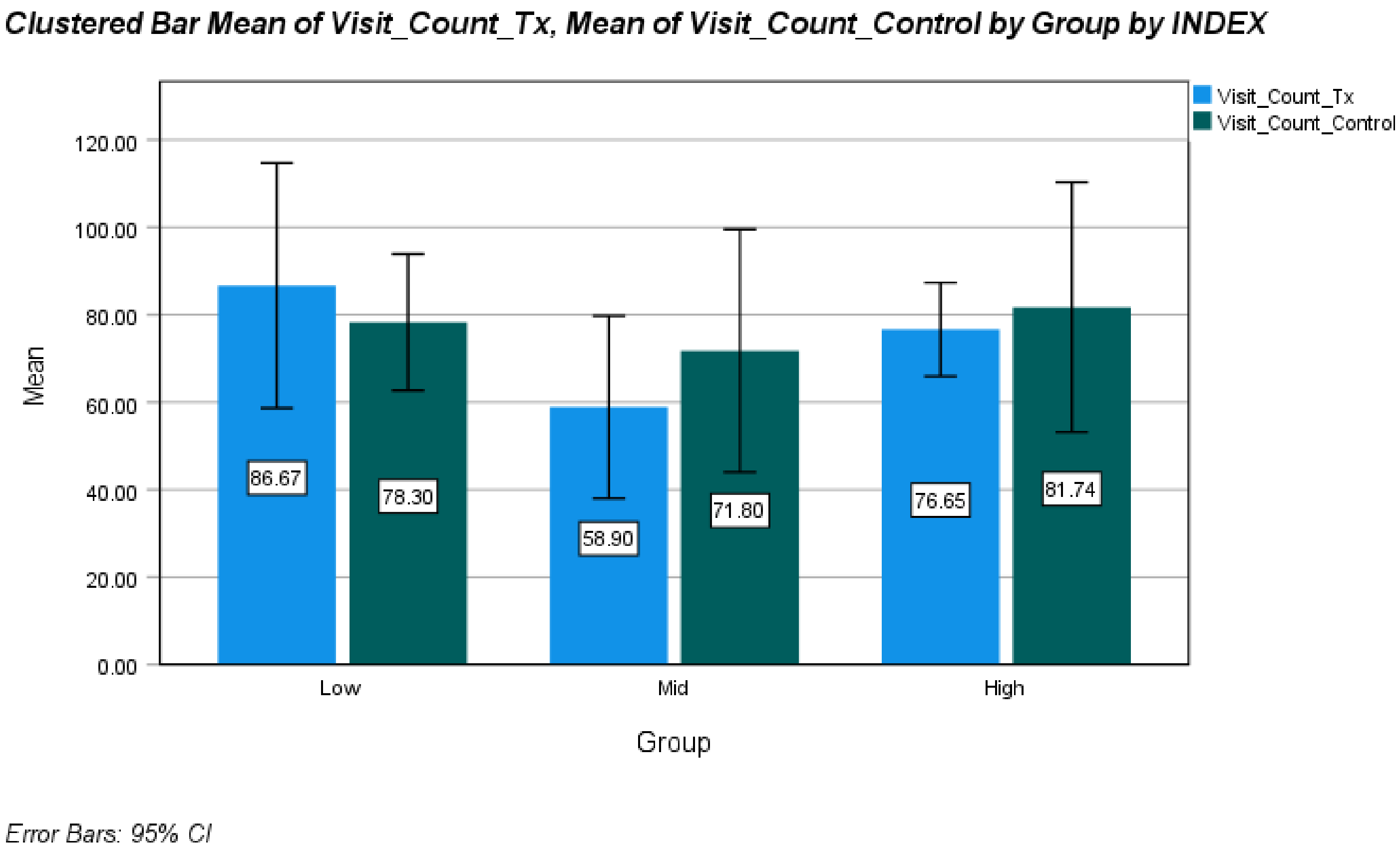
Graph 1. Mean Reaction Time of each group to identify the correct ER-40 faces after fractal exposure as compared control.

Graph 2
ER-40 Score: Fractal group vs Control



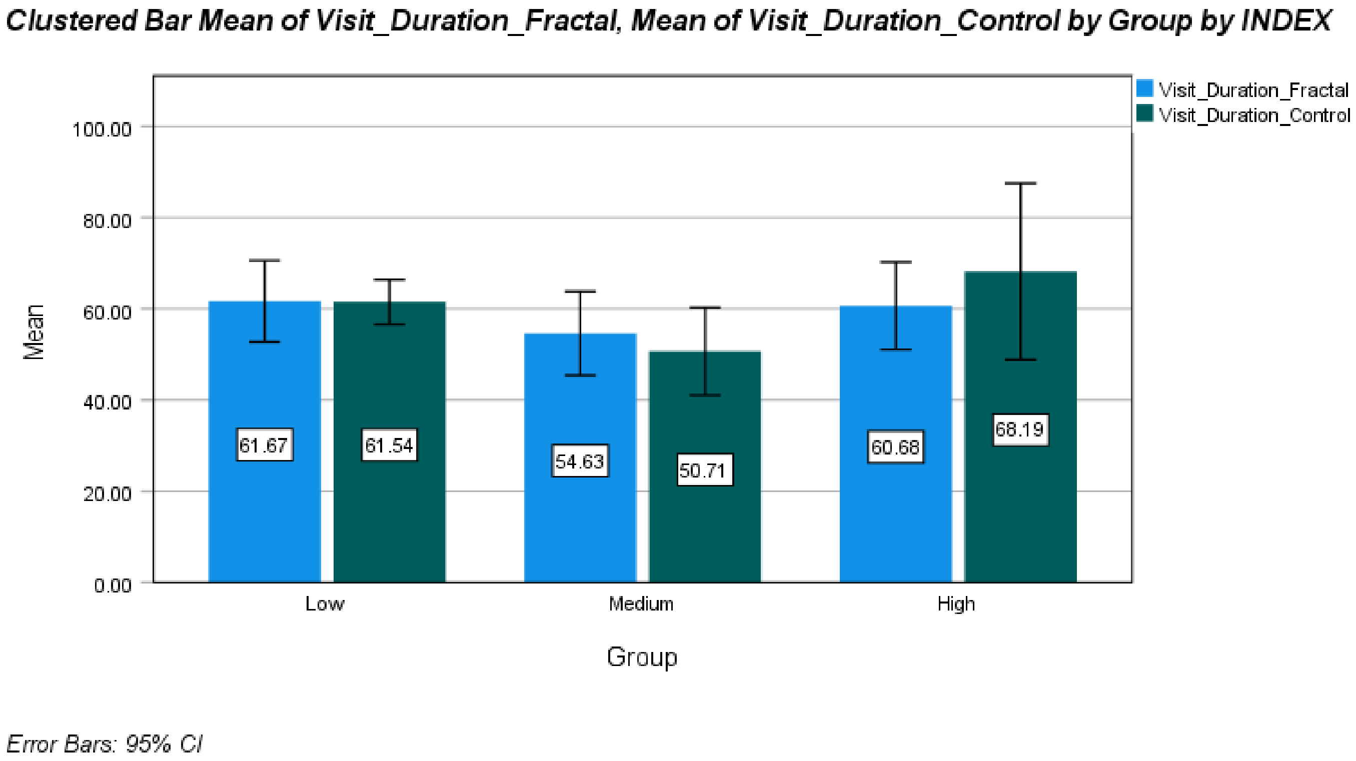
Graph 2. Mean ER-40 score of each group within the ER-40 faces after fractal exposure as compared control.

Graph 3
Visit Count: Fractal group vs Control



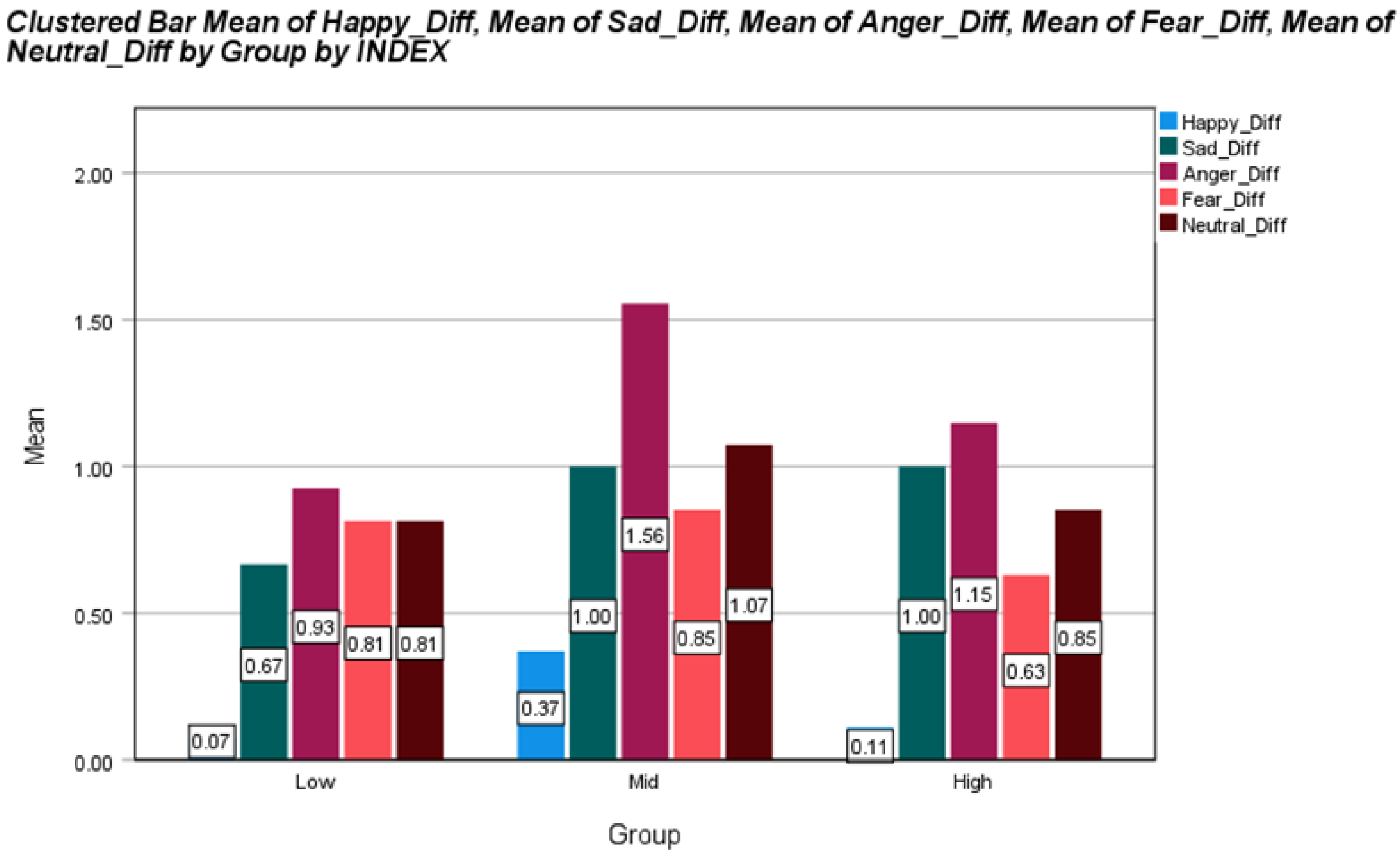
Graph 3. Mean Visit Count of each group within the ER-40 faces after fractal exposure as compared control.

Graph 4
Visit Duration: Fractal group vs Control



Graph 4. Mean duration of each group within the ER-40 faces after fractal exposure as compared control.

Graph 5
ER-40: Fractal group vs Control



Graph 5. Mean difference between the number of each emotion that was correctly identified during the control condition and the corresponding fractal condition.

Appendix C

The Autism Quotient

Definitely agree Slightly agree Slightly disagree Definitely disagree

1. I prefer to do things with others rather than on my own.
2. I prefer to do things the same way over and over again.
3. If I try to imagine something, I find it very easy to create a picture in my mind.
4. I frequently get so strongly absorbed in one thing that I lose sight of other things.
5. I often notice small sounds when others do not.
6. I usually notice car number plates or similar strings of information.
7. Other people frequently tell me that what I've said is impolite, even though I think it is polite.
8. When I'm reading a story, I can easily imagine what the characters might look like.
9. I am fascinated by dates.
10. In a social group, I can easily keep track of several different people's conversations.
11. I find social situations easy.
12. I tend to notice details that others do not.
13. I would rather go to a library than to a party.
14. I find making up stories easy.
15. I find myself drawn more strongly to people than to things.
16. I tend to have very strong interests, which I get upset about if I can't pursue.
17. I enjoy social chitchat.
18. When I talk, it isn't always easy for others to get a word in edgewise.
19. I am fascinated by numbers.

20. When I'm reading a story, I find it difficult to work out the characters' intentions.

21. I don't particularly enjoy reading fiction.

22. I find it hard to make new friends.

23. I notice patterns in things all the time.

24. I would rather go to the theater than to a museum.

25. It does not upset me if my daily routine is disturbed.

26. I frequently find that I don't know how to keep a conversation going.

27. I find it easy to 'read between the lines' when someone is talking to me.

28. I usually concentrate more on the whole picture, rather than on the small details.

29. I am not very good at remembering phone numbers.

30. I don't usually notice small changes in a situation or a person's appearance.

31. I know how to tell if someone listening to me is getting bored.

32. I find it easy to do more than one thing at once.

33. When I talk on the phone, I'm not sure when it's my turn to speak.

34. I enjoy doing things spontaneously.

35. I enjoy doing things alone.

36. I find it easy to work out what someone is thinking or feeling just by looking at their face.

37. If there is an interruption, I can switch back to what I was doing very quickly.

38. I am good at social chitchat.

39. People often tell me that I keep going on and on about the same thing.

40. When I was young, I used to enjoy playing games involving pretending with other children

41. I like to collect information about categories of things (e.g., types of cars, birds, trains, plants).

42. I find it difficult to imagine what it would be like to be someone else.
43. I like to carefully plan any activities I participate in.
44. I enjoy social occasions.
45. I find it difficult to work out people's intentions.
46. New situations make me anxious.
47. I enjoy meeting new people.
48. I am a good diplomat.
49. I am not very good at remembering people's date of birth.
50. I find it very easy to play games with children that involve pretending.

Psychologist Simon Baron-Cohen and his colleagues at Cambridge's Autism Research Centre have created the Autism-Spectrum Quotient, or AQ, as a measure of the extent of autistic traits in adults. In the first major trial using the test, the average score in the control group was 16.4. Eighty percent of those diagnosed with autism or a related disorder scored 32 or higher. The test is not a means for making a diagnosis, however, and many who score above 32 and even meet the diagnostic criteria for mild autism or Asperger's report no difficulty functioning in their everyday lives.

How to score: "Definitely agree" or "Slightly agree" responses to questions 2, 4, 5, 6, 7, 9, 12, 13, 16, 18, 19, 20, 21, 22, 23, 26, 33, 35, 39, 41, 42, 43, 45, 46 score 1 point. "Definitely disagree" or "Slightly disagree" responses to questions 1, 3, 8, 10, 11, 14, 15, 17, 24, 25, 27, 28, 29, 30, 31, 32, 34, 36, 37, 38, 40, 44, 47, 48, 49, 50 score 1 point.

Appendix D

The Connectedness to Nature Scale

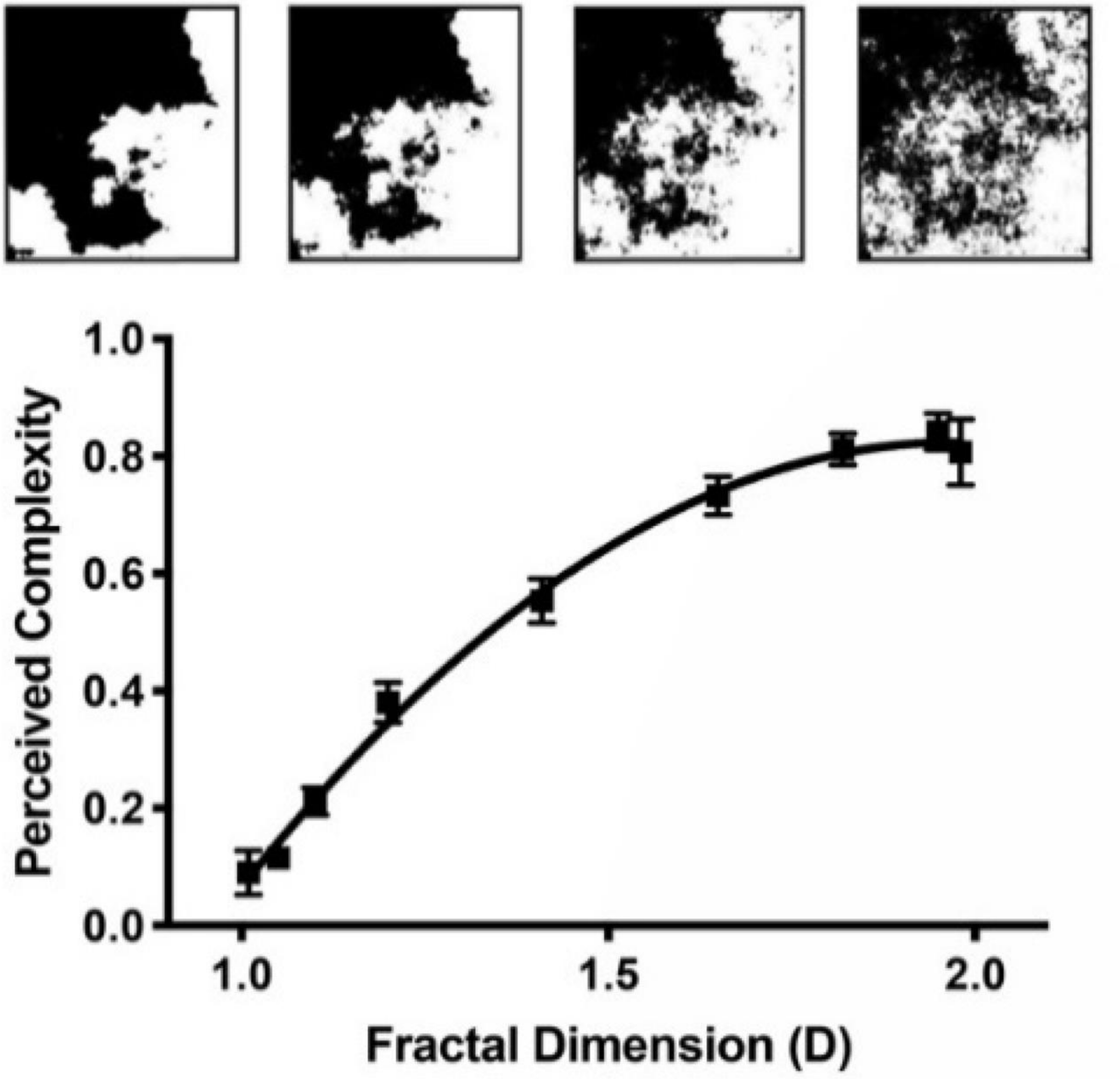
Please answer each of these questions in terms of the way you generally feel. There are no right or wrong answers. Simply state as honestly and candidly as you can what you are presently experiencing.

Strongly Disagree Somewhat disagree Neutral Somewhat agree Strongly Agree

1. I often feel a sense of oneness with the natural world around me.
2. I think of the natural world as a community to which I belong.
3. I recognize and appreciate the intelligence of other living organisms.
4. {reverse} I often feel disconnected from nature.
5. When I think of my life, I imagine myself to be part of a larger cyclical process of living.
6. I often feel a kinship with animals and plants.
7. I feel as though I belong to the Earth as equally as it belongs to me.
8. I have a deep understanding of how my actions affect the natural world.
9. I often feel part of the web of life.
10. I feel that all inhabitants of Earth, human, and nonhuman, share a common ‘life force’.
11. Like a tree can be part of a forest, I feel embedded within the broader natural world.
12. {reverse} When I think of my place on Earth, I consider myself to be a top member of a hierarchy that exists in nature.
13. I often feel like I am only a small part of the natural world around me, and that I am no more important than the grass on the ground or the birds in the trees.
14. {reverse} My personal welfare is independent of the welfare of the natural world.

Appendix E

Fractal Dimension

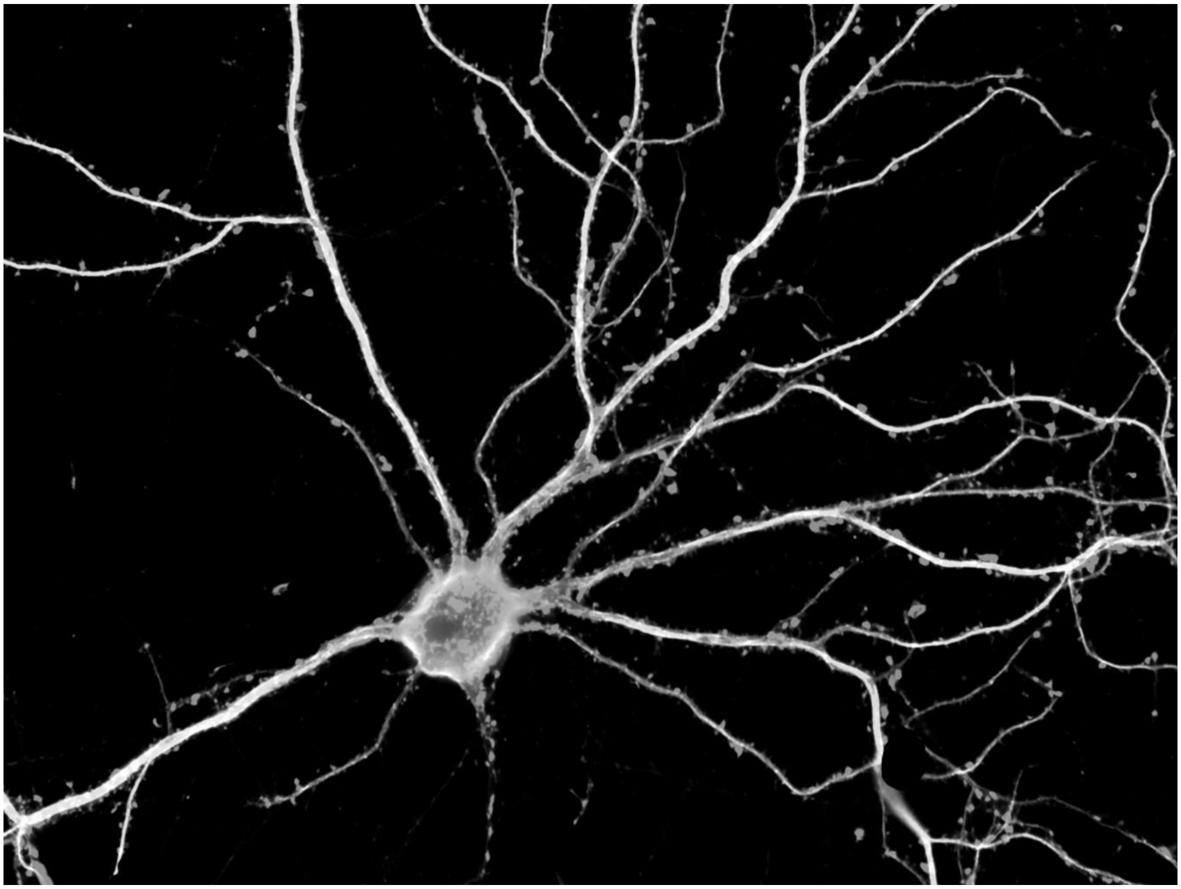


(Figure 1 from Taylor, 2021)

Appendix F

Fractal of mid-range complexity: Single Neuron and Dendrites

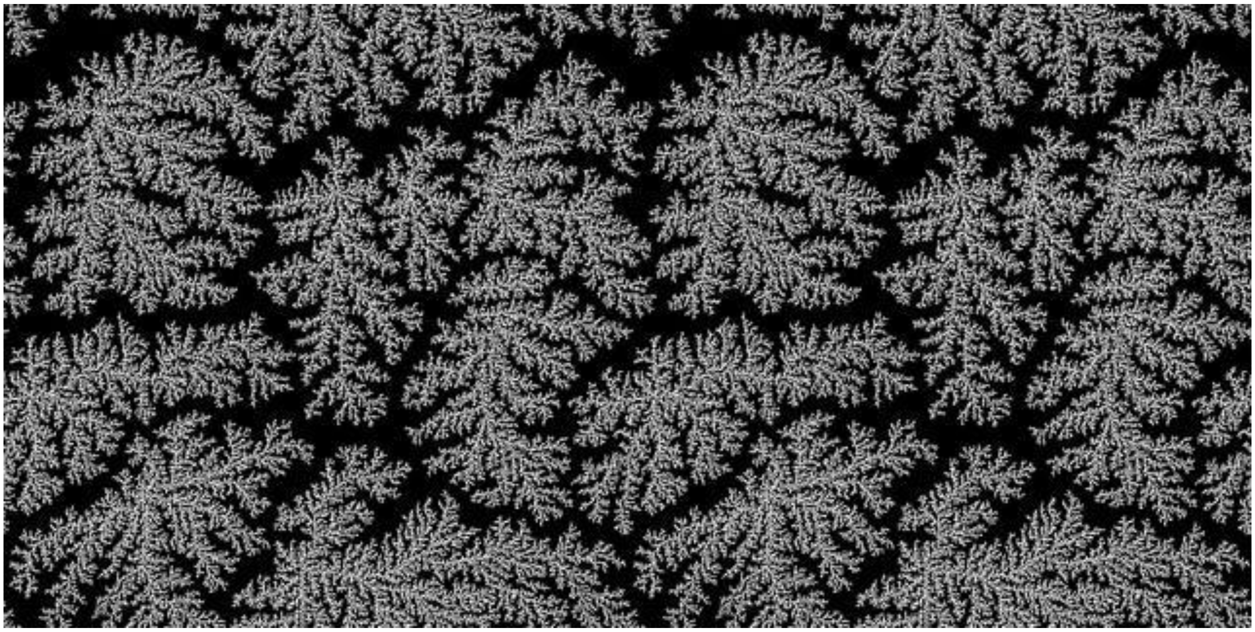
D = ~1.50



Appendix G

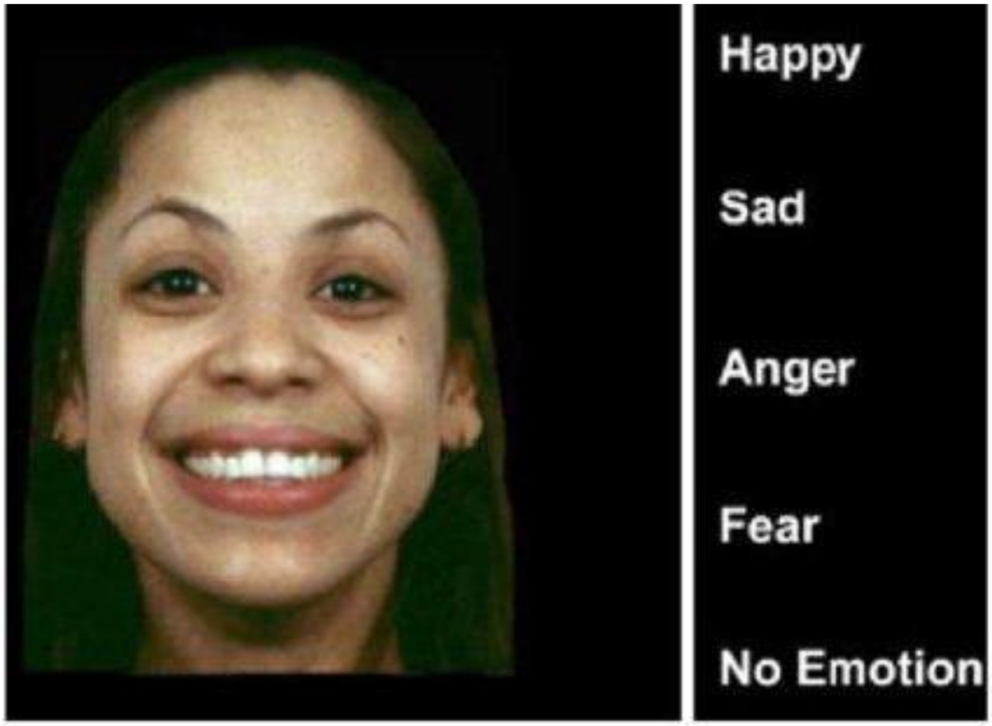
Fractal of high-range complexity: Crystal Cluster formed by Diffusion-Limited Aggregation

D = ~1.70.



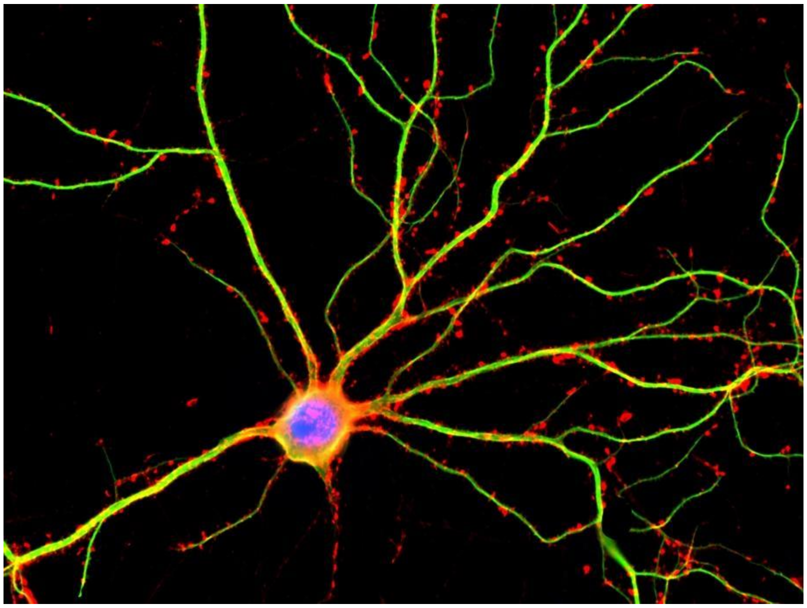
Appendix H

Sample Stimulus from Penn Emotion Recognition Test (ER-40)

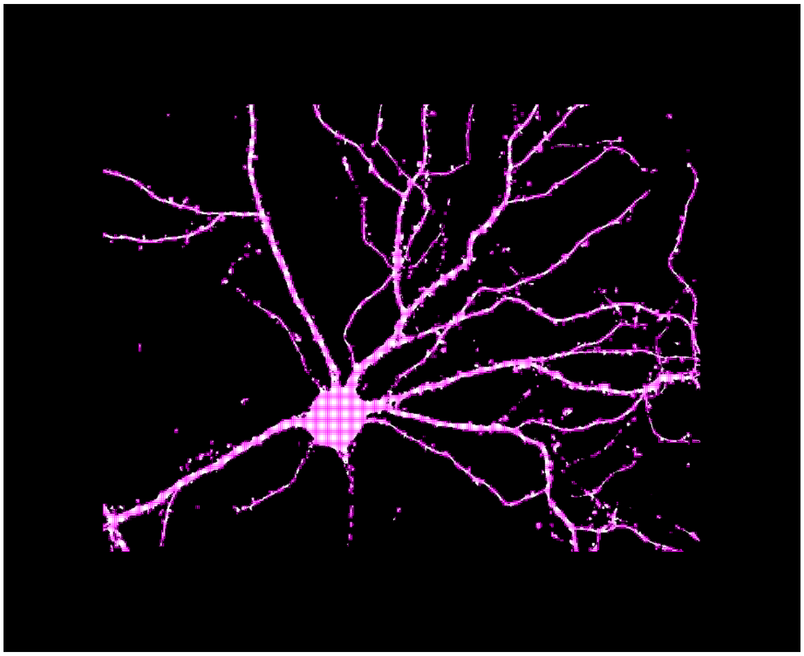


Appendix I

Pictures of box counting method for fractal dimension analysis



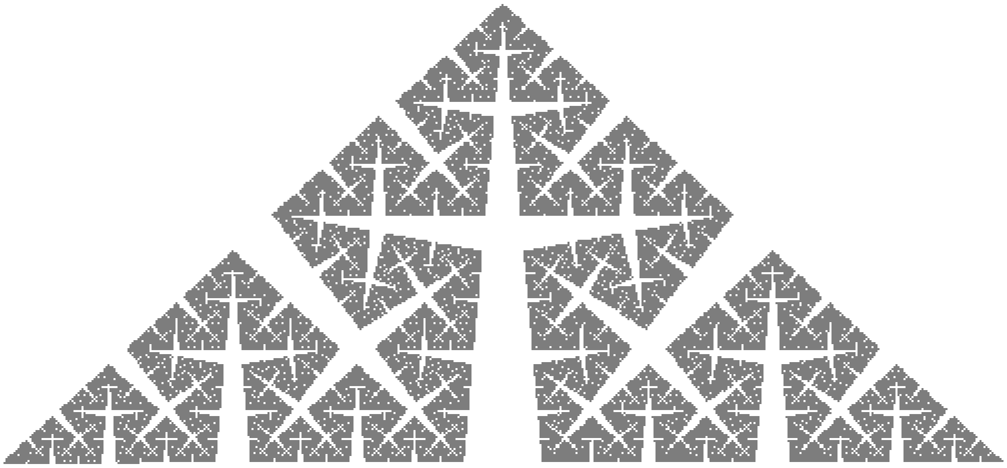
"Credit: Shelly Halpain at UC San Diego, with permission."



Binary image. One of 14 samples taken to assess dimensionality across different scales

Appendix J

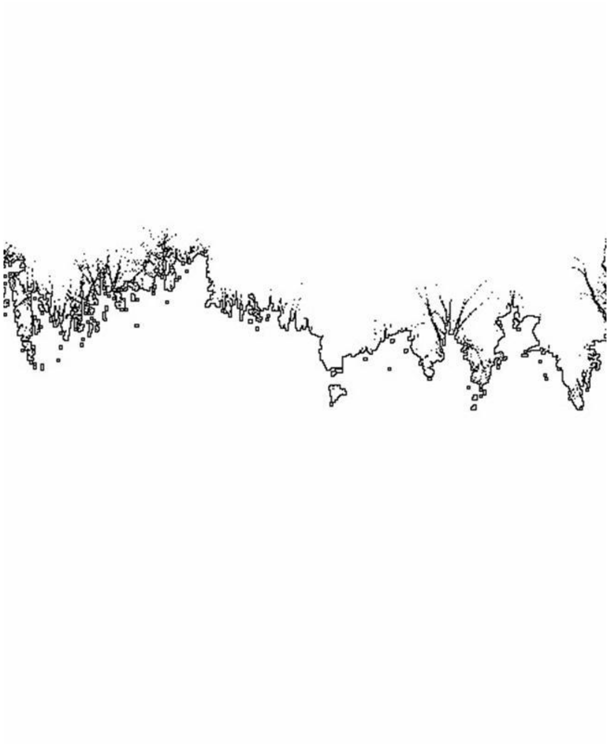
Koch Curve – Example of an Exact Fractal D = ~1.667



b

Appendix K

Mid-Range Particle Diffusion and Branching Fractal Stimuli. D = 1.4021



Name: Nathaniel Pagel

Degree: Master of Science

This document, submitted in partial fulfillment of the requirements for the degree from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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This document is being submitted by the appointed advisory committee as having met all the requirements of the School of Graduate Studies at the University of North Dakota and is hereby approved.

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Dean of the School of Graduate Studies

2/6/2023
Date