The Effects of Childhood Exposure in Natural Environments on Attentional Fatigue through Visual Intervention of Fractal Images

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Abstract

The fractal dimension of the visual natural world has been seen as a way to quantify the specific visual characteristics of nature that bring about restorative benefits. However, how an individual responds to the natural environment may depend on past experience, and specifically the time spent in nature as a child. The aim of this study is to investigate if time spent in natural environments during childhood affects the magnitude of adult restoration of attentional fatigue in response to viewing images of varying fractal dimensions. The sample included 51 participants between the ages of 17 and 58 (M = 21.22, SD = 6.82; 35.3% male, 64.7% female) recruited through advertisements placed within the university. Participants completed two sessions of a modified psychomotor vigilance test (PVT) with exposure to one of three fractal images during an intermediary rest period. A survey was completed to assess connectedness to nature and time spent in different environments in childhood as well as in adulthood. Data for both subjective fatigue and objective task performance was collected. The findings did not support an effect of image viewing on attention restoration but did show a significant association in the mid-fractal image group between childhood exposure to natural environments and subjective fatigue change. Post hoc analyses show that contrary to expected findings, childhood time in nature was a predictor of increased subjective fatigue relative to baseline. These results raise further questions about the mechanisms that visual engagement with nature might benefit attention, as well as the impact of nature exposure in childhood on our cognitive processes.

Declaration

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METHODOLOGY	Development or design of methodology; creation of models.	X	X	
PROJECT ADMINISTRATION	Management and coordination responsibility for the research activity planning and execution.		X	
SUPERVISION	Oversight and leadership responsibility for the research activity planning and execution, including mentorship external to the core team.		X	
RESOURCES	Provision of study materials, laboratory samples, instrumentation, computing resources, or other analysis tools.		X	
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VISUALIZATION	Visualization/data presentation of the results.	X		
WRITING – ORIGINAL DRAFT	Specifically writing the initial draft.	X		
WRITING – REVIEW & EDITING	Critical review, commentary or revision of original draft	X	X	

The Effects of Childhood Exposure in Natural Environments on Attentional Fatigue through Visual Intervention of Fractal Images

The benefits of nature have been long hailed with multiple papers evidencing how critical exposure of being in a multisensory and immersive natural environment is to our well-being. One proposed benefit is the restorative effects of nature on attention (Kaplan, 1995). Today, with the constant stream of stimuli available at our fingertips through smartphones and other portable devices, less time is spent outdoors (Larson et al., 2019). Combined with the accelerated decline of natural spaces (Stokstad, 2019), it is more important than ever to get to know 'mother nature' and its intricacies, and how they affect us. This is especially so with the advancement of the technological world where people are increasingly being disconnected from the natural one. Much literature has documented how simply viewing nature has positive effects. A study by Ulrich (1984) found that by viewing nature through a window, postoperative recovery experience and time were improved. Another study observed how the passive viewing of nature effectively reduced acute stress levels (Olafsdottir et al., 2020). The positive benefits of viewing nature have been theorised to extend our attention capacity and recovery, yet what specific visual properties of nature that potentially induce these benefits remains relatively unexplored. Further, how our individual experiences and perceptions of nature influence any effect on attention has not been investigated.

Nature and Attention

An emerging theory of how viewing nature might be beneficial for attention is Kaplan's Attention Restoration Theory (ART) (Kaplan, 1995). According to this theory, attention itself can be distinguished into two categories, directed attention which is a top-down cognitive process, and undirected attention, a bottom-up process. Directed attention, also referred to by Kaplan as *hard fascination*, can be said to take place when attention is intentionally directed towards a stimulus, thus consuming cognitive resources. This can happen when faced with a physical threat but also takes place in the more common place activities such as watching television or scrolling through social media. Undirected attention, also known as *soft fascination*, takes place when engagement with the stimulus requires minimal cognitive effort, thus leaving cognitive capacity for other mental processes such as reflection. Being in nature is a prime example of undirected attention as the visual aspects of nature are intrinsically interesting and without stimulus or goal directed demands to direct attention to specific features - pleasing to look at while not being overly stimulating. The process of reflection (i.e., pondering and sorting out our internal thoughts) is important for reducing the internal noise that is taxing on the limited resources of directed attention.

It is crucial that the distinction between directed and undirected attention is made as too often they are considered part of the same restorative category (Basu et al., 2019). Directed attention is a finite resource that needs to be restored over time, while undirected attention is theorised to accelerate the restoration of the directed attention by providing a break away from directed attention as well as allowing space for reflection. Although the specific visual aspects of what is softly fascinating or otherwise has not been clearly defined, there is consensus that the intricate configuration of the visual make-up of nature incorporates such aspect (Taylor et al., 2011; Tennessen & Cimprich, 1995; Valtchanov & Ellard, 2015). In a study where blink rates were used as a measure of cognitive processing, it was found that viewing urban scenes led to increased blink rates compared to viewing natural scenes (Valtchanov & Ellard, 2015). The reduced cognitive load when viewing natural scenes is evidence for ART's assumption that the natural environment consists of softly fascinating stimuli.

Fractals in Nature

The unique and complex structure of the natural world which had once been difficult to quantify, has been discovered to possess fractals - repeating visual patterns that can be observed at different magnifications (Mandelbrot, 1982). These complex ratios of change in detail to the change in scale can be differentiated into exact and statistical fractals, with the difference being the inclusion of a degree of randomness into the latter while maintaining its statistical qualities across scales. While exact fractals depict a more precise albeit artificial visual, statistical fractals offer an organic aesthetic that better mimics fractals in the real world and are prevalent in nature - from panoramic coastlines to the foliage of a tree. Statistical fractal patterns have also been found outside of the natural world such as in the arts (Mureika et al., 2010). An example would be the highly valued collection of Jackson Pollock's aesthetically pleasing abstract paintings, which contain a measure of fractals similar to that typically seen in nature (Mureika, 2005; Taylor et al., 2011). Employing mathematical formulae, fractals can be quantified by their fractal dimension, *D* (Fairbanks & Taylor, 2011). Ranging from values from 1-2 where a smooth line is equal to a value of 1 and a filled out area is equal to a value of 2, the increasing amount of fine structure in a pattern would correspond with higher D values. Statistical fractals typically lie somewhere in the mid-range of this scale. In a study conducted by Taylor and Spehar (2016), it was found that many natural scenes tend to lie between the low to mid fractal range of D = 1.3-1.5. This includes a majority of mountain ranges, cloud formations, and trees.

The prevalence of the low to mid-range fractal patterns in the natural world has been observed to go hand in hand with a subjective preference for statistical fractal patterns in a similar density range (D = 1.1 – 1.5) (Sprott, 1993). There is also a tendency to prefer higher *D* values when it comes to exact fractals due to the greater simplicity of precise repetition (Bies et al., 2016). This preference for low to mid D values can be observed in nature, as well as computer and human generated fractals and is known as fractal fluency (Taylor & Spehar, 2016). This has been found to be driven by the balance between the human desire for engagement and complexity as well as the desire for refreshment and relaxation (Robles et al., 2021). Thus, the visual elements of nature that are recuperative seem to be the very same that we as humans are tuned to seek out. The universality of fractal fluency is also shown to be established at a young age (Robles et al., 2020).

Childhood & Nature

Much time in nature is spent in the name of relaxation or recuperation, with many individuals regarding time in nature as a getaway from the busy hustle and bustle of life. This is due in part to adulthood perceptions of nature's many benefits, though it has been shown that those beliefs are significantly influenced by childhood exposure and engagement with nature (Wells & Kristi S. Lekies, 2006). Despite having a natural affinity and curiosity for the outdoors, children are not typically cognizant of these benefits. They instead view the natural environment through a different lens, that is, as an open space that allows for discovery and exploration with minimal adult interference. Such an environment supports autonomy where children are able to test and develop their skills while evoking complex play behaviour such as risk-taking, spontaneity and discovery (Martens & Molitor, 2020). In addition to honing their physical, social and emotional control, this leads to a self-affirming connection to nature that builds their confidence in both the natural and built environment (Livingstone, 2005). This is further evidenced by research showing how children and adults gain cognitive benefits from similar exposure to nature, such as the increased capacity to concentrate and performance in memory tasks (Stevenson et al., 2019; Tennessen & Cimprich, 1995). Just as exposure to natural views provide attentional benefits to adults , the same is seen in studies with children (Schutte et al., 2017; Taylor et al., 2002). However, the literature behind this is much less developed for children compared to adults.

The benefits of making those cognitive and psychological connections with nature during such a critical developmental period are far-reaching, affecting individuals down the line throughout the rest of life. There is evidence on how childhood exposure influences how we think and behave as adults, with a considerable bulk of evidence showing how early exposure can be linked to the adoption of pro-environmental behaviours (Collado & Evans, 2019; Evans et al., 2018; Rosa et al., 2018). In a 1-year longitudinal study involving children, it was found that greater exposure to natural environments led to an increase in attention (Dadvand et al., 2017). These long-term effects, signals the growing importance of nature exposure early in life amidst a world where time in nature is seen more as a novelty than a necessity. However, not much is known about how exposure to natural environments in childhood may impact those same attentional resources later in adulthood. We posit that the relationship to nature which is established at a young age is a key factor in determining the magnitude of benefits that can be gained in adulthood.

Intervention Through Fractal Exposure

This current study aims to investigate whether varying levels of fractal density influence attention recovery following a demanding cognitive task, as well as consider whether such effects are influenced by childhood exposure to nature. Attention restoration will be measured through metrics of both objective and subjective fatigue. The hypotheses for this study are: 1. the intervention of viewing fractal images will be restorative on objective and subjective fatigue, with the mid-fractal range having the greatest effect; and 2. time spent in natural environments during childhood will lead to greater fatigue restoration in response to image viewing.

Method

Participants

The current study is part of a larger study that is investigating the effects of mid-range fractal images as being restorative to attention following depletion of attentional resources. For the purpose of this paper, we will only include the relevant materials and procedures used in this study. Participants were recruited from two sources, the first being undergraduate psychology students with the incentive of obtaining class credits. The second source of participants was recruited through a poster that linked to a google form which was open to the public and posted on university notice boards. An incentive of being entered into a draw for vouchers was provided to encourage participation. The research was presented as a cognitive experiment using images, and recruitment information carefully worded to not disclose any details that might potentially influence participant behaviour during the study. The research was presented as a cognitive experiment using images. Entry criteria included being 18 years of age or older, having normal or corrected to normal vision, and having a basic proficiency in English. Exclusionary criteria for the present study included self-report psychiatric conditions, medical or mobility conditions that would impact their ability to complete the task, and an absence of having consumed alcohol or elicited substances in the 24 hours prior to the study. A total of 51 participants were recruited (Mean age= 21.22, SD = 6.82; 35.3% male, 64.7% female). Data from 3 participants were excluded due to technological issues that led to unreliable data collection. The study was approved by the School of Psychology Human Research Ethics Sub-committee, The University of Adelaide (approval number 22/65), and informed consent was provided by all participants.

Design

The study took on a pseudorandomised controlled experimental design that included both within and between group comparisons. The experimental element of the study consisted of images at varying fractal densities that also served as the independent variables. Participants were placed into one of three fractal groups: high, mid and low. The dependant variables included the objective fatigue rate of participants, which was operationalised as their response time (RT) on a computerised test, and subjective fatigue, in which participants self-evaluated on a Likert scale. Both RTs and subjective fatigue scores (SF) were compared between groups as well as within groups across the two time points of the experiment.

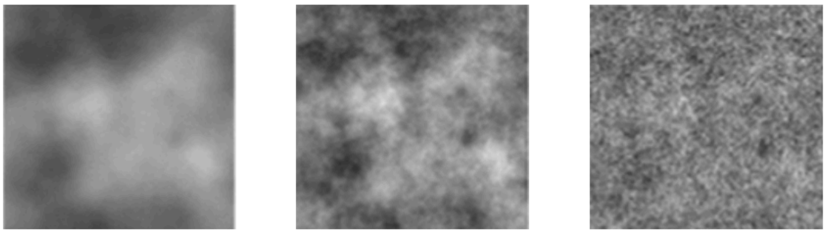
Procedures and Measures

Fractal Images

Three fractally curated images at different alpha slope values were prepared to depict low-density (α= 2.25), mid-density (α = 1.5) and high-density (α = .75) fractals (Spehar et al., 2016), as illustrated in Figure 1. To accurately represent the dimensionality of visualisation, the fractal images were then generated into 2-minute videos. The moving patterns in the videos were set to maintain their determined fractal densities with a constant temporal speed of 1.25Hz, found to be the ideal temporal speed for human viewing (Van Veen et al., 2015). Prior to the start of the experiment, all participants were told to concentrate on immersing themselves in the visual presented. Distribution of visuals was randomised through programming (low = 14, mid = 18, high = 19).

Figure 1.

Fractal images.



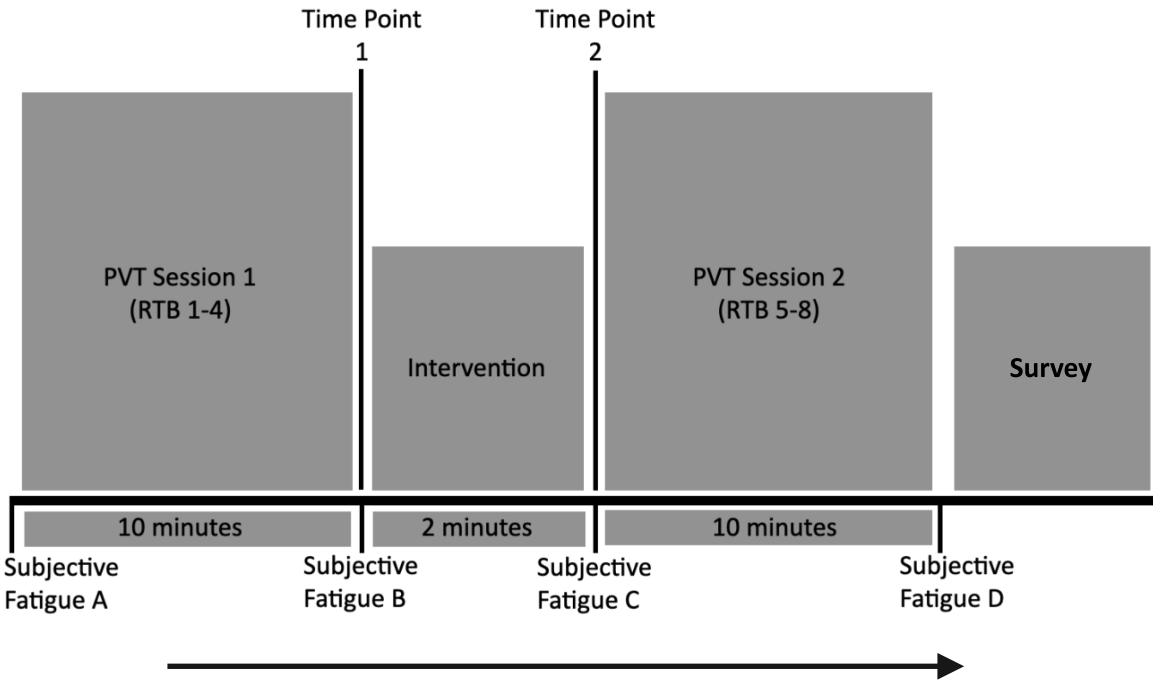
α= 2.25 α= 1.5 α= .75

Psychomotor Vigilance Task and Subjective Fatigue

As depicted in Figure 2 below, Participants' RT were measured using a modified Psychomotor Vigilance Test (PVT), a computerised test that is typically used to measure alertness by recording RTs upon perceiving a stimulus on a computer that occur at random inter-stimulus intervals (Basner & Dinges, 2011) In this experiment, the PVT ran for two sessions of 10 minutes per session (80 trials), and RTs were grouped into response time blocks (RTB) of 20 trials each. The stimulus was a stopwatch that appeared on the screen and the press of the spacebar button on the keyboard registered the RTs. Following the first session, one of three fractal videos would play on the computer screen, as illustrated in Figure 1. This intervention stage lasted for 2 minutes. Participants were asked to rate their subjective fatigue on a five-point Likert scale prior to and post each session as illustrated in Figure 2.

Figure 2.

Experimental procedure.



The purpose of the first PVT session was to establish a reference point for participants' objective and subjective fatigue. Following intervention, the same measurements were taken to determine if any changes could be observed. Hence, two time points were established within the experiment, as shown in Figure 2.

Connectedness to Nature Scale (CNS) and exposure to nature

Participants were then asked to complete a survey after the experiment through the Qualtrics platform which included the Connectedness to Nature Scale (CNS) (Mayer & Frantz, 2004). The CNS is a self-report questionnaire that aims to measure an individual's experiential connection to nature from an affective point of view. Connectedness to nature has been operationalised as 'the extent to which an individual includes nature within his/her cognitive representation of self (Schultz, 2002). The scale consists of 14 items that are rated on a five-point scale ranging from 'Strongly disagree' (1) to 'Strongly agree' (5). The CNS considers the extent to which individuals feel a part of nature (e.g., "I often feel a kinship with animals and plants"; "I often feel part of the web of life") and is scored by averaging across all 14 items after reverse scoring 3 of the items. The CNS was found to have a good internal reliability (α = .84) (Mayer & Frantz, 2004). In the present study, participant CNS scores ranged from 2.07 to 4.57 (M = 3.38; SD = .55).

A number of questions which aimed to gauge how much time was spent in natural or built environments in childhood (6-12 years) as well as in adulthood (past 2 months). Time spent outdoors overall was included as a question. Participants rated the questions on a five-point Likert scale ranging from “Not at all” (1) to “Everyday” (5). Time spent in a typical week in specific natural environments (i.e., grassed field, woodland, waterways etc.) in childhood as well as adulthood was also included as a question to increase recall accuracy via prompting. In those questions, participants would respond on a scale of 0 to 25 hours. The number of hours spent in each environment was totalled to be used in the analyses as a variable called Childhood Total (CT) and Adulthood Total (AT).

Data Analysis

All statistical analyses were carried out in the program IBM SPSS Statistics (version 27 for Windows) and observed statistical significance thresholds of $\alpha = 0.05$. Visual inspection of histograms and Q-Q plots of the variables used showed that each displayed a normal distribution within groups. CT was found to be skewed and so was log transformed (CTL) to ensure assumptions of normality were met. Initial group differences were assessed using one-way ANOVAs for continuous data and chi-square for categorical data. Pearson’s correlation was also conducted to explore the association between variables.

For the purposes of this study, two time points were established within the experiment for statistical analysis, as indicated in Figure 2. Time point 1 (TP1) outcomes consisted of the difference in RT from RTB 1 to RTB 4, as well as the difference of subjective fatigue A and subjective fatigue B (i.e., the change in fatigue from baseline across the first PVT session). Time point 2 (TP2) outcomes consisted of the difference in RT from RTB1 to RTB5, as well as the difference of subjective fatigue A and subjective fatigue C (i.e., the change in fatigue following the intervention relative to baseline). In this way, individual differences in baseline fatigue are accounted for, and relative changes in scores are in reference to the same baseline.

The initial RT trials at the beginning of each PVT session were initially examined to screen for apparent learning effects of the task. It was found that the initial RTs during each session were much higher due to either a learning or a surprise effect, wherein participants were not prepared to respond to stimuli that appeared very quickly after task commencement. To account for this, the first two RTs in each session was omitted from the study. Mean values in RTB1 and subjective fatigue scores (SF) were also found to vary within the different fractal groups as shown in the Table 1. This further supported the use of relative values in analyses as described above.

Table 1.

Group differences in mean score in RTB1.

α	**Mean (ms)**	**Standard Deviation**
75	316.04	30.60
150	306.88	57.0
225	297.36	74.10

Childhood time in nature on subjective fatigue and RT

The hypotheses were analysed using linear mixed effects modelling (LMM). Group (high, mid, low), time (TP1, TP2) and CTL were included as fixed effects. Participants were included as a random factor, with PVT, RT and FS included as dependent variables in separate models. This method of analysis was used as it does not assume equal time points within the study. Moreover, this study involves a combination of categorical (e.g., fractal groups) and continuous data (e.g., childhood time spent in natural environments) which can be accommodated using this approach (Brauer & Curtin, 2018). Additional models were initially constructed removing the participants as random factors; however, this did not significantly improve the Akaike Information Criterion (AIC) model fit parameters and so the decision was made to retain participant in models. Post hoc analyses were run using t-tests where appropriate to assess differences between and within groups at the two time points.

Participant characteristics

To test for group differences in gender and handedness, chi-square analyses were conducted. Further one-way ANOVA analyses were also conducted to test for group differences in age and CNS scores. A correlation analysis was also run to look at the relationship between the variables.

Results

Pearson's correlations were conducted on the variables and found that while time spent in built environments as a child was strongly correlated to time spent in built environments in adulthood (r = .52, p < .005), there was an insignificant correlation between time spent in natural environments as a child and in adulthood (r = 25, p = .07). Further, while time spent in natural environments as a child had an insignificant correlation with AT (r = -.26, p = .07), CTL was found to have a significant correlation with AT (r = .40, p = .004). From this analysis, it was concluded that the breakdown of specific environments in ACL and AT provided for more accurate data. Hence, ACL and AT were used in the main models of analyses.

Participant characteristics

No significant differences were observed for gender (X^2(2, N = 51) = 0.83, p = .66) and handedness (X^2(4, N = 51) = 4.05, p = .40). All groups were found to be balanced as the results of the ANOVA were insignificant as shown in Table 3.

Table 3

ANOVA for group differences.

		F-Value	P-value	Eta-Squared Value
Age		.88	.42	.035
CNS		1.48	.24	.058
Natural	**Childhood**	.46	.63	.019
	Adulthood	.36	.70	.015
Built	**Childhood**	.04	.96	.002
	Adulthood	.04	.96	.002
Outdoors	**Childhood**	.39	.68	.016
	Adulthood	.18	.83	.008

In a correlation analysis, it was found that CNS scores were not significantly correlated to CLT (r = -.07, p = .64), AT (r = .04, p = .8), time spent in a built environment in childhood (r = .14, p = .33) and in adulthood (r = .16, p =.26), time spent outdoors in childhood (r = -.04, p = .79) and in adulthood (r = .08, p = .58). However, a significant correlation was found between CNS scores and time spent in natural environments as an adult (r = .35, p = .01).

Group and Time on SF and RT

Table 6.

Estimated marginal means (SD) and F-values for LMMs.

High	Mid	Low	F-values

	T1	T2	T1	T2	T1	T2	Group	Time	Group x Time	CTL
SF	1.43 (.20)	1.64 (.20)	.52 (.21)	1.12 (.21)	.44 (.24)	.37 (.24)	7.30***	4.84**	3.01*	1.99**
RT	18.40 (5.58)	4.0 (5.58)	17.98 (5.76)	3.4 (5.76)	5.06 (6.59)	11.54 (6.59)	.09*	2.92**	2.24*	6.72***

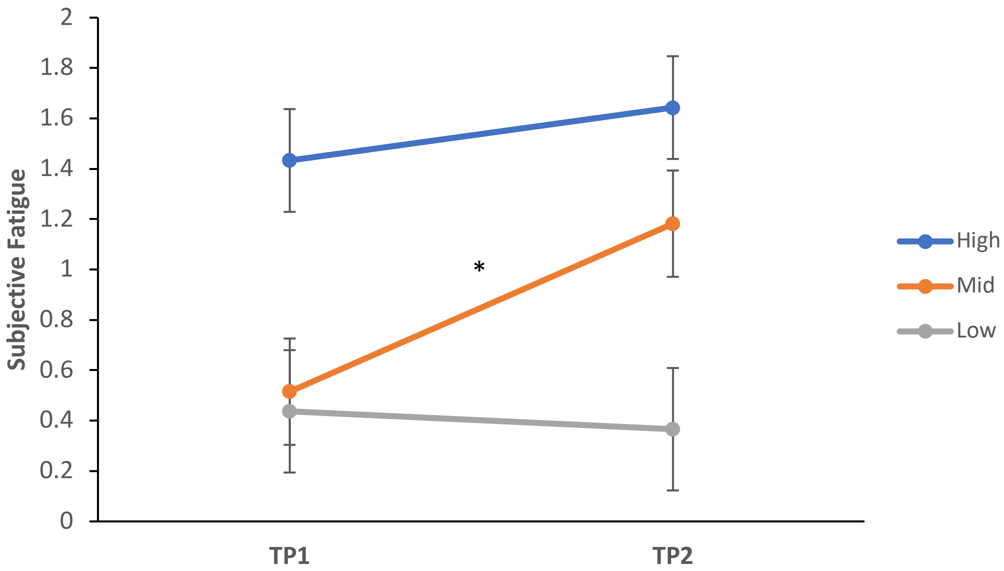
Note: Standard deviations are presented in parentheses.

* p > .05; ** p < .05; *** p < .005

For SF, the results of the LMM indicated main effects of group (*p* = .002), time (*p* = .03), and a borderline effect of group by time interaction (*p* = .058). The model also found a significant main effect of CTL (*p* = .02). Given the main effects of group, time and the borderline interaction of group by time, additional t-tests were run to explore the difference between groups at each time point as well as the change within groups over time. As illustrated in Figure 3, a significant difference was found within the mid-fractal group between SF at TP1 (*M* = .66, *SD* = .91) and TP2 (*M* = .1.33, *SD* = .108); *t*(17) = -4.123, *p* = .001. However, no significant differences were found in the high-fractal group (*t*(18) = -.776, *p* = .45) and low-fractal group (*t*(13) = .434, *p* = .67).

Figure 3.

Mean group and time differences on subjective fatigue.



*p < .05; **p < .005

Further comparisons were made at each time point between each combination of group pairs and no significant differences were found within any group combination (p > 0.5 for all groups).

Post hoc correlation analyses show that CTL was significantly correlated with the fatigue scores in TP1 (r = .30, p = .03) but not with fatigue scores at TP2 (r = -.10, p = .50). To account for effects of fatigue at baseline, a regression analysis was run with baseline fatigue and the change in fatigue at TP1 as predictors. Although baseline fatigue was not a predictor (p = .44), the change in fatigue remained significantly associated with CTL at p = .03.

For RT, the results of the LMM indicated no significant main effects of group (p = .91), time (p = .10), and no significant group by time interaction (p = .12). However, the model found for a significant main effect of CTL (p <.001). Despite this effect, post hoc correlation analyses showed that CTL had no significant correlations with RT at TP1 (r = .26, p = .06) or TP2 (r = .01, p = .94).

Discussion

To the best of our knowledge, this is the first study investigating the effects of childhood exposure in natural environments and fractal images on attentional restoration through metrics of response time and objective fatigue. Regarding the first hypothesis, that viewing fractal images will be restorative to fatigue, only the mid-fractal image was found to have a significant effect on SF. However, the direction of the effect was not as expected, whereby the intervention of the mid-fractal image had a negative relationship with SF. This is an interesting finding, given that previous research indicates that viewing mid-fractal imagery is most recuperative on cognitive resources. Exposure to the fractal images showed no significant effects on RT. With regards to the second hypothesis, that time spent in natural environment during childhood would lead to greater fatigue restoration in the experiment, results showed that CLT did in fact have an association with SF. However, post hoc analyses show that the association was on the rate of fatigue overall rather than on attentional restoration as part of the experimental manipulation.

Intervention of Fractal Images

Contrary to existing literature on the preference for mid-fractals and the effect of viewing such images on attention restoration (Robles et al., 2020, 2021; R. P. Taylor & Spehar, 2016; Tennessen & Cimprich, 1995; Van Oordt et al., 2022), this study found that fractal images of any range did not have a restorative effect on either RT or SF over time. Although further analyses showed that there is a significant difference of SF in the mid-fractal group over time, this does not seem to be attributed to the intervention. Interestingly, intervention of the mid-fractal image led to an increase of SF over time which is the opposite of our predicted findings. Given this study focuses on just the visual aspect of nature, and its specific fractal content, there are elements of the visual perception of nature that are unexplored. Lighting intensity and colour has been found to be an influence on attention and reaction time (Amini Vishteh et al., 2019; Dehghan et al., 2017). Recognition of imagery in interventions using natural scenery has also been found to improve cognitive ability (Varkovetski, 2016). The images constructed for this study were statistical representations of fractals and thus is unlikely to garner any recognition or familiarity. While the purpose of this study was to explore the effect of fractals specifically, controlling for these variables may have removed the key contributors in understanding the role and impact of our visual system on our attentional resources. Intervention of the low and high-fractal images found for no significant effects on fatigue. However, given that there was a borderline interaction of group and time, it is likely that this study was underpowered, and a larger sample size would more accurately identify whether an interaction between group ad time is in fact evident.

The interventions did not have a significant effect on RT over time, in contrast to the results found for SF. Although both are measures of fatigue, SF is an individual's perceived measure of attentional fatigue, while RT is the objective measure of performance in an attentional task. In a study by Cronan and colleagues (2012), it was found that the participants' subjective assessment of their cognitive ability reflected in the objective measures. The results of this study do not seem to support this and could mean that a discrepancy exists between perceived cognitive ability and cognitive performance (Mäntynen et al., 2014). A study by Marino and colleagues (2009) found that subjective perception of cognition is associated with mood rather than actual performance. It is possible that this finding carries on to perception of cognitive ability as well given the link between cognitive ability in youth on cognition in later-life (Kremen et al., 2019). If this is found to be true, the results of the fractal intervention may reveal associations between visual stimuli and mood, and may uncover an unexplored component in attention restoration.

Impact of Childhood Time in Nature on Attention Restoration

The amount of time spent in nature during childhood was found to have a significant effect on SF and RT. However, upon further analysis, the association remains significant only up to the point of intervention for measures of SF. Rather than having an impact on attention restoration as hypothesized, the results suggest that the rate of attentional fatigue was a predictor of childhood time spent in natural environments where greater attentional fatigue was associated with more time spent in nature during childhood. It also suggests that perhaps childhood exposure to nature has less of an effect on the magnitude of benefits gained by being in nature. This is further supported by the correlation between CNS scores and time spent in natural environments during adulthood, and the lack thereof between CNS scores and time spent in natural environments during childhood. Although this seems to contradict the findings in Dadvand and colleagues' (2017) study, the difference lies in the continuous long-term exposure to natural environments that persisted into adulthood in their study, whereas the participants in this current study may have had sporadic bouts of exposure during childhood that was not maintained in adulthood.

Theoretical Implications

The unexpected results of this exploratory study of childhood experiences and fractal images on cognitive ability bring about some theoretical implications. Firstly, fractal density alone does not seem to have an effect on attention restoration. Although previous studies have shown that it is associated with the restoration of attentional resources (R. P. Taylor et al., 2011; Tennessen & Cimprich, 1995; Valtchanov & Ellard, 2015; Van Oordt et al., 2022) exploratory studies involving other visual elements of the natural world would be required to identify the key components that bring about the recuperative quality of being in nature. Secondly, the results of the study suggest that spending time in nature during childhood may have less of a long-term effect on adulthood cognitive abilities. Although childhood exposure to nature has been shown to benefit cognitive development in childhood and influence behaviour later on in adulthood (Collado & Evans, 2019; Martens & Molitor, 2020; Rosa et al., 2018), this study suggests that the relationship built between an individual and nature need not be established in childhood but rather is more directly linked current exposure to nature in.

Limitations and Future Directions

A limitation of this study is the small sample size. Given the borderline result of the analysis, it is likely that a significant effect may be found with a larger sample size. Further, the data on childhood time spent in nature is retrospective which may not be reliable (Berney & Blane, 1997; Blome & Augustin, 2015; Horvath, 1982). Accordingly, steps were taken to increase the accuracy of recall by specifying the various natural environments time might have been spent in. Yet another limitation lies in the difficulty of knowing if directed or undirected attention was taking place during intervention of the fractal images. Given the importance of the specific processes such as reflection that undirected attention encompasses, understanding the way in which participants are perceiving the intervention is fundamental towards furthering this theory. Effort was put in by requesting that participants empty their minds as much as possible and focus on the image whilst allowing their thoughts to flow throughout the intervention period.

Future studies to further understand the role of childhood experiences in nature on cognitive benefits in adulthood might include a longitudinal study to track childhood exposure and the possible changes in magnitude of benefits as the relationship with nature progresses with time. Additionally, a repeated study including measures to ascertain if such exposure to nature was sustained from childhood to adulthood might provide insight as to the importance of early childhood experiences. Further, studies could also look at quantifying the fractal range of the environments of exposure. By doing so, more in-depth information may be gathered on the specific benefits or effects of time spent in such fractal environments. A more targeted strategy which includes a directed and undirected attention task within the context of differing fractal conditions may also help better control for such variability in participant responses.

Conclusion

This study investigated whether time spent in natural environments during childhood affects the magnitude of adult restoration of attentional fatigue in response to viewing images of varying fractal dimensions. The results of the study suggest that fractal images as an intervention does not have a significant effect on attention restoration. Also, childhood time spent in nature does not seem to be associated with a greater magnitude of cognitive benefits owing to a greater relationship with nature. However, the small sample size and nature of retrospective data used in this study may have minimised the possible effects in the analyses. Future studies should look at including other visual elements of nature to capture the immersive experience of being in the natural environment. A longitudinal study on childhood exposure would also allow for increased accuracy of data. The results of this exploratory study should be used to guide further investigations into the intricacies and benefits of viewing nature as well as the effects of childhood time in nature on cognitive development.

References

Amini Vishteh, R., Mirzajani, A., Jafarzadehpour, E., & Darvishpour, S. (2019). Evaluation of Simple Visual Reaction Time of Different Colored Light Stimuli in Visually Normal Students. *Clinical Optometry*, *Volume 11*, 167–171. https://doi.org/10.2147/OPTO.S236328

Basner, M., & Dinges, D. F. (2011). Maximizing Sensitivity of the Psychomotor Vigilance Test (PVT) to Sleep Loss. *Sleep*, *34*(5), 581–591. https://doi.org/10.1093/sleep/34.5.581

Basu, A., Duvall, J., & Kaplan, R. (2019). Attention Restoration Theory: Exploring the Role of Soft Fascination and Mental Bandwidth. *Environment and Behavior*, *51*(9–10), 1055–1081. https://doi.org/10.1177/0013916518774400

Berney, L. R., & Blane, D. B. (1997). Collecting retrospective data: Accuracy of recall after 50 years judged against historical records. *Social Science & Medicine*, *45*(10), 1519–1525. https://doi.org/10.1016/S0277-9536(97)00088-9

Bies, A. J., Blanc-Goldhammer, D. R., Boydston, C. R., Taylor, R. P., & Sereno, M. E. (2016). Aesthetic Responses to Exact Fractals Driven by Physical Complexity. *Frontiers in Human Neuroscience*, *10*. https://doi.org/10.3389/fnhum.2016.00210

Blome, C., & Augustin, M. (2015). Measuring Change in Quality of Life: Bias in Prospective and Retrospective Evaluation. *Value in Health*, *18*(1), 110–115. https://doi.org/10.1016/j.jval.2014.10.007

Brauer, M., & Curtin, J. J. (2018). Linear mixed-effects models and the analysis of nonindependent data: A unified framework to analyze categorical and continuous independent variables that vary within-subjects and/or within-items. *Psychological Methods*, *23*(3), 389–411. https://doi.org/10.1037/met0000159

Collado, S., & Evans, G. W. (2019). Outcome expectancy: A key factor to understanding childhood exposure to nature and children’s pro-environmental behavior. *Journal of Environmental Psychology*, *61*, 30–36. https://doi.org/10.1016/j.jenvp.2018.12.001

Cronan, T. P., Léger, P.-M., Robert, J., Babin, G., & Charland, P. (2012). Comparing Objective Measures and Perceptions of Cognitive Learning in an ERP Simulation Game: A Research Note. *Simulation & Gaming*, *43*(4), 461–480. https://doi.org/10.1177/1046878111433783

Dadvand, P., Tischer, C., Estarlich, M., Llop, S., Dalmau-Bueno, A., López-Vicente, M., Valentín, A., De Keijzer, C., Fernández-Somoano, A., Lertxundi, N., Rodriguez-Dehli, C., Gascon, M., Guxens, M., Zugna, D., Basagaña, X., Nieuwenhuijsen, M. J., Ibarluzea, J., Ballester, F., & Sunyer, J. (2017). Lifelong Residential Exposure to Green Space and Attention: A Population-based Prospective Study. *Environmental Health Perspectives*, *125*(9), 097016. https://doi.org/10.1289/EHP694

Dehghan, H., Mohebian, Z., & Yadegarfar, G. (2017). Evaluation of Effects of Different Levels of Brightness on Attention and Reaction Time under Laboratory Conditions. *Journal of Ergonomics*, *4*(4), 48–56. https://doi.org/10.21859/joe-04047

Evans, G. W., Otto, S., & Kaiser, F. G. (2018). Childhood Origins of Young Adult Environmental Behavior. *Psychological Science*, *29*(5), 679–687. https://doi.org/10.1177/0956797617741894

Fairbanks, M. S., & Taylor, R. (2011). Measuring the scaling properties of temporal and spatial patterns: From the human eye to the foraging albatross. *Nonlinear Dynamical Systems Analysis for the Behavioral Sciences Using Real Data*, 341–366.

Horvath, F. W. (1982). Forgotten unemployment: Recall bias in retrospective data. *Monthly Labor Review*, *105*(3), 40–43.

Kaplan, S. (1995). The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology*, *15*(3), 169–182. https://doi.org/10.1016/0272-4944(95)90001-2

Kremen, W. S., Beck, A., Elman, J. A., Gustavson, D. E., Reynolds, C. A., Tu, X. M., Sanderson-Cimino, M. E., Panizzon, M. S., Vuoksimaa, E., Toomey, R., Fennema-Notestine, C., Hagler, D. J., Fang, B., Dale, A. M., Lyons, M. J., & Franz, C. E. (2019). Influence of young adult cognitive ability and additional education on later-life cognition. *Proceedings of the National Academy of Sciences*, *116*(6), 2021–2026. https://doi.org/10.1073/pnas.1811537116

Larson, L. R., Szczytko, R., Bowers, E. P., Stephens, L. E., Stevenson, K. T., & Floyd, M. F. (2019). Outdoor Time, Screen Time, and Connection to Nature: Troubling Trends Among Rural Youth? *Environment and Behavior*, *51*(8), 966–991. https://doi.org/10.1177/0013916518806686

Livingstone, T. (2005). *Child of Our Time*. Random House.

Mandelbrot, B. B. (1982). *The fractal geometry of nature* (Vol. 1). WH freeman New York.

Mäntynen, A., Rosti-Otajärvi, E., Koivisto, K., Lilja, A., Huhtala, H., & Hämäläinen, P. (2014). Neuropsychological rehabilitation does not improve cognitive performance but reduces perceived cognitive deficits in patients with multiple sclerosis: A randomised, controlled, multi-centre trial. *Multiple Sclerosis Journal*, *20*(1), 99–107. https://doi.org/10.1177/1352458513494487

Marino, S. E., Meador, K. J., Loring, D. W., Okun, M. S., Fernandez, H. H., Fessler, A. J., Kustra, R. P., Miller, J. M., Ray, P. G., Roy, A., Schoenberg, M. R., Vahle, V. J., & Werz, M. A. (2009). Subjective perception of cognition is related to mood and not performance. *Epilepsy & Behavior*, *14*(3), 459–464. https://doi.org/10.1016/j.yebeh.2008.12.007

Martens, D., & Molitor, H. (2020). Play in appropriate natural environments to support child development (*Fomento del desarrollo infantil mediante el juego en entornos naturales apropiados*). *PsyEcology*, *11*(3), 363–396. https://doi.org/10.1080/21711976.2020.1782040

Mayer, F. S., & Frantz, C. M. (2004). The connectedness to nature scale: A measure of individuals' feeling in community with nature. *Journal of Environmental Psychology*, *24*(4), 503–515. https://doi.org/10.1016/j.jenvp.2004.10.001

Mureika, J. R. (2005). Fractal dimensions in perceptual color space: A comparison study using Jackson Pollock's art. *Chaos: An Interdisciplinary Journal of Nonlinear Science*, *15*(4), 043702. https://doi.org/10.1063/1.2121947

Mureika, J. R., Fairbanks, M. S., & Taylor, R. P. (2010). *Multifractal comparison of the painting techniques of adults and children* (D. G. Stork, J. Coddington, & A. Bentkowska-Kafel, Eds.; p. 75310O). https://doi.org/10.1117/12.840411

Olafsdottir, G., Cloke, P., Schulz, A., Van Dyck, Z., Eysteinsson, T., Thorleifsdottir, B., & Vögele, C. (2020). Health Benefits of Walking in Nature: A Randomized Controlled Study Under Conditions of Real-Life Stress. *Environment and Behavior*, *52*(3), 248–274. https://doi.org/10.1177/0013916518800798

Robles, K. E., Liaw, N. A., Taylor, R. P., Baldwin, D. A., & Sereno, M. E. (2020). A shared fractal aesthetic across development. *Humanities and Social Sciences Communications*, *7*(1), 158. https://doi.org/10.1057/s41599-020-00648-y

Robles, K. E., Roberts, M., Viengkham, C., Smith, J. H., Rowland, C., Moslehi, S., Stadlober, S., Lesjak, A., Lesjak, M., Taylor, R. P., Spehar, B., & Sereno, M. E. (2021). Aesthetics and Psychological Effects of Fractal Based Design. *Frontiers in Psychology*, *12*, 699962. https://doi.org/10.3389/fpsyg.2021.699962

Rosa, C. D., Profice, C. C., & Collado, S. (2018). Nature Experiences and Adults' Self-Reported Pro-environmental Behaviors: The Role of Connectedness to Nature and Childhood Nature Experiences. *Frontiers in Psychology*, *9*, 1055. https://doi.org/10.3389/fpsyg.2018.01055

Schultz, P. W. (2002). Inclusion with Nature: The Psychology Of Human-Nature Relations. In P. Schmuck & W. P. Schultz (Eds.), *Psychology of Sustainable Development* (pp. 61–78). Springer US. https://doi.org/10.1007/978-1-4615-0995-0_4

Schutte, A. R., Torquati, J. C., & Beattie, H. L. (2017). Impact of Urban Nature on Executive Functioning in Early and Middle Childhood. *Environment and Behavior*, *49*(1), 3–30. https://doi.org/10.1177/0013916515603095

Spehar, B., Walker, N., & Taylor, R. P. (2016). Taxonomy of Individual Variations in Aesthetic Responses to Fractal Patterns. *Frontiers in Human Neuroscience*, *10*. https://doi.org/10.3389/fnhum.2016.00350

Sprott, J. C. (1993). Automatic generation of strange attractors. *Computers & Graphics*, *17*(3), 325–332. https://doi.org/10.1016/0097-8493(93)90082-K

Stevenson, M. P., Dewhurst, R., Schilhab, T., & Bentsen, P. (2019). Cognitive Restoration in Children Following Exposure to Nature: Evidence From the Attention Network Task and Mobile Eye Tracking. *Frontiers in Psychology*, *10*, 42. https://doi.org/10.3389/fpsyg.2019.00042

Stokstad, E. (2019). Landmark analysis documents the alarming global decline of nature. *Science (American Association for the Advancement of Science)*. https://doi.org/10.1126/science.aax9287

Taylor, A. F., Kuo, F. E., & Sullivan, W. C. (2002). Views of nature and self-discipline: Evidence from inner city children. *Journal of Environmental Psychology*, *22*(1–2), 49–63. https://doi.org/10.1006/jevp.2001.0241

Taylor, R. P., & Spehar, B. (2016). Fractal Fluency: An Intimate Relationship Between the Brain and Processing of Fractal Stimuli. In A. Di Ieva (Ed.), *The Fractal Geometry of the Brain* (pp. 485–496). Springer New York. https://doi.org/10.1007/978-1-4939-3995-4_30

Taylor, R. P., Spehar, B., Van Donkelaar, P., & Hagerhall, C. M. (2011). Perceptual and Physiological Responses to Jackson Pollock's Fractals. *Frontiers in Human Neuroscience*, *5*. https://doi.org/10.3389/fnhum.2011.00060

Tennessen, C. M., & Cimprich, B. (1995). Views to nature: Effects on attention. *Journal of Environmental Psychology*, *15*(1), 77–85.

Ulrich, R. S. (1984). View Through a Window May Influence Recovery from Surgery. *Science*, *224*(4647), 420–421. https://doi.org/10.1126/science.6143402

Valtchanov, D., & Ellard, C. G. (2015). Cognitive and affective responses to natural scenes: Effects of low level visual properties on preference, cognitive load and eye-movements. *Journal of Environmental Psychology*, *43*, 184–195. https://doi.org/10.1016/j.jenvp.2015.07.001

Van Oordt, M., Ouwehand, K., & Paas, F. (2022). Restorative Effects of Observing Natural and Urban Scenery after Working Memory Depletion. *International Journal of Environmental Research and Public Health*, *20*(1), 188. https://doi.org/10.3390/ijerph20010188

Van Veen, S. C., Van Schie, K., Wijngaards-de Meij, L. D. N. V., Littel, M., Engelhard, I. M., & Van Den Hout, M. A. (2015). Speed Matters: Relationship between Speed of Eye Movements and Modification of Aversive Autobiographical Memories. *Frontiers in Psychiatry*, *6*. https://doi.org/10.3389/fpsyt.2015.00045

Varkovetski, M. (2016). The reduction of directed attention fatigue through exposure to visual nature stimuli: Exploring a natural therapy for fatigue. *SURG Journal*, *8*(2), 5–13. https://doi.org/10.21083/surg.v8i2.3057

Wells, N. M. & Kristi S. Lekies. (2006). Nature and the Life Course: Pathways from Childhood Nature Experiences to Adult Environmentalism. *Children, Youth and Environments*, *16*(1), 1–24. JSTOR.