

An Investigation into the Influence of Fractal Dimension on Visual
Search: Insights in the Context of Search and Rescue

by

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The field of search and rescue organizes the identification and return of missing and lost people. Visual search is a main part of conducting a successful search and rescue mission. Visual searches for search and rescue take place in natural environments of differing levels of complexity. In order to model the different complexities of natural environments, Fractal Dimension (D) is used. This research uses a visual search task to model performing a visual search for a sign of a missing individual in a natural environment. Shoeprints are the first sign search and rescue personnel are taught to find in natural environments. The visual search experiment uses shoeprints as the sign that is being searched for to simulate a search and rescue environment. The experiment found a significant effect of Fractal Dimension (D) on both reaction time and accuracy ($p < 0.001$).

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Table of Contents

Introduction	6
Background	8
Search and Rescue Operations	8
Vision Science Research	10
Fractal Dimension of an Environment	13
Gap in Knowledge	14
Navon Task	16
Systemizing Quotient (SQ-R)	16
Hypotheses	18
Methods	21
Participants	21
Stimuli and Experiment Creation	21
Procedure	22
Navon Task	22
Systemizing Quotient Revised	23
Statistical Methods	23
Results	25
Fractal Dimension (D) Effect on Reaction Time in Visual Search Task	25
Shoeprint Present or Absent Effect on Reaction Time Across D in Visual Search Task	25
Fractal Dimension (D) Effect on Accuracy in Visual Search Task	25
Fractal Dimension (D) and Error Types	26
Systemizing Quotient-Revised Score Effect on Reaction Time	26
Systemizing Quotient-Revised Score Effect on Accuracy	26
Discussion	33
Future Directions	35
Limitations	36
Conclusion	37
Appendix	38
Systemizing Quotient-Revised Statements	38
Bibliography	43

List of Figures

Figure 1. Example of the stimuli in the visual search task with shoeprints.....	19
Figure 2. The five types of shoeprints used in the visual search task.....	19
Figure 3. Shoeprint depicting heel mark, compression, and toe dig.....	20
Figure 4. Reaction Times (sec) Across Fractal Dimension (D).....	27
Figure 5. Mean Reaction Times (sec) by Fractal Dimension	28
Figure 6. Mean Reaction Time by Fractal Dimension and if Shoeprint is Present or Absent.....	29
Figure 7. Relationship between accuracy and D	30
Figure 8. Incorrect responses as percentage by D	31
Figure 9. Systemizing Quotient-Revised Score and Reaction Time (sec).....	32
Figure 10. The SQ-R score and percent of incorrect responses.....	32

Introduction

The field of search and rescue (SAR) is responsible for the detection and recovery of missing people. The role of search and rescue members in missing person cases, specifically in which the missing person is in the wilderness, is invaluable. Search and rescue teams are responsible for conducting environmental searches to find clues to deduce the direction of travel of a missing person. A common target that search and rescue teams look for are shoeprints.

The ability to conduct an effective visual search is a crucial part of a search and rescue mission. However, there is no established method for how to train people to conduct effective visual searches in natural environments. A visual search task, in the context of vision science, involves looking for a target among a scene of distractors (Wolfe, 2010). The use of a shoeprint as a target for a visual search task would accurately simulate a type of visual search conducted in SAR.

Visual searches in SAR can occur in a wide range of environments. From my own experience in search and rescue training, I learned from expert trackers that the sign that they are looking for is dependent on the type of environment in which the search is being conducted in. The type of vegetation, or lack thereof, the moisture within the ground, the angle of the sun, and nightfall are all factors that influence an expert SAR tracker's visual search process. Different types of rock, sediment, vegetation, and snow will all affect how complex the environment that a SAR visual search is being conducted in is. Beyond the complexity of the search environment, expert trackers have also noted that the identity of the missing person will influence what type of gait pattern is being searching for. For example, a missing individual who was lost while foraging for mushrooms or hiking will have a different gait pattern from a person who may not want to be found.

In order to simulate different levels of complexities of search environments, this experiment uses backgrounds of 5 different fractal dimensions. A fractal is a self-similar pattern that repeats at various scales and can be characterized mathematically (see Background). The fractal background will quantify how inherent properties of a search environment affect a visual search.

The following experiment will examine the effect of fractal dimension on accuracy and reaction time of the visual search. Half of the images used will have shoeprints and the other half will not. This will simulate conducting a real-world visual search in a SAR mission in which it is unknown to the searcher if the target is present or absent. The experiment will also use the Navon Task and Systemizing Quotient-Revised (see Background) to assess if participants have local processing biases.

Background

Search and Rescue Operations

There are over 600,000 people reported missing in the United States according to The National Missing and Unidentified Persons (NamUS) database (*Home | NamUs*, n.d.). A common method to search for missing individuals is through ground search and rescue operations. The emergency operation of locating and rescuing missing or injured individuals is known as search and rescue (SAR). Search and rescue (SAR) efforts involve ground search teams and/or unmanned aerial vehicles (UAVs) depending on the terrain and amount of space needed to search. The effective execution of search and rescue operations can mean the difference between life and death. Search and rescue efforts often occur in situations with limited resources, thus well-trained individuals and coordinated efforts are crucial.

The organization of SAR operations is dependent on the type of land the search is being conducted upon. Federal land is under the jurisdiction of following agencies: National Park Service, Bureau of Land Management, Fish and Wildlife Service, and the Forest Service(DeSantis, n.d.). The National Search and Rescue Committee creates voluntary standards and guidance for federal entities to follow. This committee creates the NSP: *National Search and Rescue Plan*. The NSP is a voluntary agreement outlining how operations with SAR are to be coordinated, and details federal agencies' duties. The four federal agencies listed above have the power to lead SAR operations on their lands. It is acknowledged by Congress that each agency will have operations taking different forms. On Forest Service and Bureau of Land Management Lands, SAR efforts are generally led by the local law enforcement of the county. On Fish and Wildlife Service Land, federal wildlife officers typically are the principal leader of SAR operations unless the incident surpasses their level of expertise. In National Parks, the National

Park Service is the principal responder to SAR events. The National Park Service policy allows for "qualified SAR organizations or authorized local authorities" to aid in SAR efforts following a formal agreement (DeSantis, n.d.). It should be noted that 84% of SAR incidents on federal land occurred on National Park Service Land. The National Park Service receives an average of 11.2 SAR incidents each day (Heggie & Amundson, 2009). The National Park Service lands that reported the highest SAR incidents in order of amount are as follows: Grand Canyon National Park, Lake Mead National Recreation Area, and Yosemite National Park.

In the United States, if a search and rescue operation is occurring on non-federal land the County Sherriff's Department leads the SAR efforts. A ground SAR team is contacted by the Sherriff's Department when it is determined that a ground search team is necessary. The ground SAR team consists of trackers who are volunteers possessing differing levels of experience in SAR. In SAR, a "tracker" is defined as a person who conducts a visual search to detect and follow signs of human passage (*Search and Rescue Glossary and Acronyms*, n.d.). The SAR team is trained by their local SAR non-profit organization. Ground SAR teams typically work in natural rather than man-made environments, thus the term "wilderness SAR" will be used to describe SAR efforts occurring in a natural environment. The ground SAR groups are entirely volunteer based; their training is not standardized and varies across organizations. Still, their knowledge and experience in ground search and rescue are critical to a successful search. The following research is meant to be applied to all personnel who could be involved in SAR efforts.

The process of finding a missing person in the context of wilderness search and rescue primarily is dependent on the ability to conduct successful and efficient visual searches. SAR's initial focus is on using the point last seen (PLS) to determine the direction of travel of the missing person to minimize the physical area that needs to be searched. A tracker's role is to

identify the direction of travel through the identification of a "sign" and to continue sign detection until the conclusion of the search. A "sign" in SAR is physical evidence of the passage of an individual. The processes that guide and affect the detection of a sign can be understood through vision science research. Research findings in vision science have broad applications for the field of wilderness search and rescue. Results from visual search studies can lead to the development of a methodological approach to teaching "trackers" in search and rescue. Proven training programs could be developed as more advanced findings from the intersection of visual search and wilderness SAR come to light.

Vision Science Research

The process of visual search in the context of SAR has not been extensively researched. Applications of vision science research to wilderness SAR are rare, as there is just a singular review that investigates this intersection (McClanahan, 2021). Research on this intersection is crucial for the improvement of SAR practices. Visual search in humans is known to involve exploratory eye movements (saccades) and visual attentional processes (Van Der Lans et al., 2008). Saccades are rapid eye movements that shift between points of fixation (Leigh & Kennard, 2004). Previous research has found that there are three to five saccadic movements each second when performing a visual search task on a single image (G. J. Zelinsky, 2008). Information is not processed during a saccadic movement; cognitive processing of images occurs only during periods of fixation (Matin, 1974). It can thus be deduced that the number of fixations necessary to identify a target increases concurrently with scene complexity (G. Zelinsky & Sheinberg, 1995). Shifts of attention can occur more covertly and independently of shifts in eye position as illustrated by the Posner Task (Posner et al., 1980).

In a novel environment or image, there are three principal information sources that will guide the visual cognitive system: low-level saliency (regions of contrast from color, luminance, and intensity), target template information, and scene context (Malcolm & Henderson, 2010). Target template information is a representation of the target that exists in visual working memory. In terms of distractors, it has been found that an object or area of a scene that possesses similar characteristics to a target is more likely to be a point of fixation (G. J. Zelinsky, 2008). The field of cognitive neuroscience has used computer models to prove the validity of visual guidance theories. The three informational factors previously listed above were modeled separately and together. The prediction of the fixation locations from the computer model was compared to the actual fixation locations of humans (Ehinger et al., 2009). It was found that models that combined the use of low-level saliency, target schema, and scene context found the most locations that were the points of fixation that occurred in human subjects.

Human visual perception is limited in its processing bandwidth as are all human senses. Visual attention can only process 20-50 items per second. We overcome our limited resources, in the context of visual perception, through guiding search with the use of selective attention. These can be referred to as "cognitive shortcuts". The theory explored next was presented by a review of attentional guidance. It is more complex and specific towards human attention than the three principles presented by Malcolm & Henderson (2010). Thus, the exploration of how these rules of guidance interact is crucial to improving accuracy in search tasks, as noted in Wolfe & Horowitz (2017). Attention in visual search was proposed to be guided by five factors: bottom-up saliency, top-down feature guidance, scene structure and meaning, previous experience in search, and relative value of targets and distractors (Wolfe & Horowitz, 2017). Bottom-up saliency is defined as being driven by the scene with certain visual characteristics of the scene

inducing more attention than others. Top-down salience is intentional, driven by the person conducting the visual search, as knowledge of the features of the targets is used to direct attention. Scene guidance refers to how the scene will guide a person's attention to the zones with the highest likelihood of possessing targets. Guidance from previous experience and relative/perceived values of visual information is self-explanatory. Cognitive processes of attention can be applied to better understand the mechanisms of visual search in wilderness SAR.

The qualities that make an effective searcher in wilderness SAR are not operationally defined. In order to develop this knowledge, research on individual differences in the perceptual propensities or biases of searchers must be compared to their performance on a visual search task. In tangential relation, while a "bottom-up" local processing bias in individuals has been associated with greater drawing accuracy (Drake & Winner, 2011), other research indicates that expertise in drawing is associated with perceptual flexibility in the use of context rather than reliance of pre-existing local perceptual biases associated with bottom-up processing (Robles et al., 2022). Either theory can predict why some individuals are less susceptible to global processing errors. Analogously, an inquiry into whether "bottom-up" processing tendencies are indicative of more accurate visual search performance is necessary. The Systemizing Quotient-Revised (SQ-R; Wheelwright et al., 2006) can be used to investigate local processing biases (Robles et al., 2022). A high SQ-R score is indicative of an individual who has a high tendency to systemize. Additionally, we will use a Navon task to determine if global processing is impaired, which is expected in individuals with a local processing bias (Navon, 1977). The SQ-R and Navon task will be used in this experiment to investigate their relationship to visual search performance.

Fractal Dimension of an Environment

In search and rescue, field searches are conducted in an extensive range of environments. As previously discussed, scene structure and meaning has a principal role in guiding visual search. Thus, this experiment seeks to address the question of how different environments affect search performance. To represent different levels of complexity of environments, fractals will be used. A fractal is a self-similar pattern that repeats at various scales and can be characterized mathematically. Natural environments are made up of patterns with repeating imagery through distinct scales (ex: a tree and its branches) (B. B. Mandelbrot, 1982). Fractal dimension (D) is used to quantify the fractal complexity of an image. The formula used is $D = \frac{\log(N)}{\log(S)}$ with N being the number of distinct pieces that are repeated, and S being the magnification/scaling factor. D can be understood with the example of a coastline (B. Mandelbrot, 1967). $D = 1.0$ represents a straight line and $D = 2.0$ represents a filled plane in Euclidean geometry. The D of natural objects ranges between 1.0 - 2.0 and a coastline with more intricacies and self-repetitions would possess a higher D . Human aesthetic preference for statistical fractals peaks within $D = 1.3 - 1.5$ (Spehar et al., 2003). Aesthetic preference is not expected to affect performance in a visual search task. Lower complexity fractal environments will likely result in a sign being more visible. The D in this experiment represents the range of complexity in the ground that is being searched (see *Figure 1*). For example, sand has inherent differences in fractality when compared to a grass field or the ground of a forest. The exact fractal dimension that quantifies a specific environment is not determined in this experiment, as this experiment is meant to be a broad outline of D 's effect on visual search.

Gap in Knowledge

The research question this experiment investigates is how the fractal dimension of an environment affects visual search performance for a Euclidian sign. The Euclidian sign is representative of the passage of a missing individual in the context of search and rescue. The Euclidian sign used is in the shape of a shoeprint (see *Figure 2*). The experiment will be a computer-based visual search task. While computer-based visual search tasks possess inherent differences from a visual search in a natural environment, it is reflective of an individual's performance in a naturalistic (3D) environment (Botch et al., 2023). A shoeprint is used as the sign in this experiment because in SAR training shoeprints are the first sign that a novice tracker is taught to identify. Trackers are taught a range of methods to determine the existence and validity of the sign of a shoeprint. Tracking sticks are commonly used to measure stride interval and shoeprint length. Three-person tracking teams are used to ensure that signs are not missed and to correct errors by the primary searcher. Three-person teams also help to alleviate visual search fatigue by the primary searcher through frequent rotation. Flagging tape is used to mark identified signs. Light in the environment is taught as an inherent property that affects the conspicuity of a sign. Dawn and dusk are noted as being the ideal times for search as shadows allow compressions in the ground to be more visible. An experienced tracker is able to use the knowledge of light's effect on the visibility of signs in their identification process. Shoe prints are taught as being made up of three distinct components. These are the heel mark, compression, and toe dig (see *Figure 3*). When distinct shoeprints are not visible, trackers are taught to look for signs of passage. For example, if a search is being conducted in a vegetated landscape searchers are told to look for vegetation damage, and the transfer of organic material. Anecdotal accounts of previous search and rescue operations from experienced trackers noted a distinctive

case of a missing individual with dementia. The person of interest was ultimately found, an effort made easier by the fact that they were wearing two right shoes each bearing different shoeprints. This is evidence of how shoeprints, especially when distinct, can serve as guiding features of detection. Advanced trackers have also noted that a common novice error is seeing a sign when there is none present. This error can be paralleled in vision science research to the topic of pareidolia. Pareidolia is the tendency to perceive a meaningful sign or image in the absence of one. A fractal dimension of 1.3 may increase the susceptibility of pareidolia occurring (Bies et al., 2016).

The purpose of the experiment is to determine if a relationship exists between visual search performance and the fractal dimension of the environment (background) that the search is being conducted in. The systemizing quotient and Navon task will provide insight into whether a local processing bias can predict accuracy and efficiency in a visual search task. A follow-up study might investigate how priming can affect search performance. A training condition might also be useful to determine the efficacy of what this research hopes to lead to. Existing literature demonstrates that targeted training in visual search has a significant effect on correct identifications (Krzepota et al., 2015). Training programs often involve the practice of eye movements in six directions of fixation (Erickson, 2020).

However, the exact training program methodology that yields the most efficient visual search is not adequately examined in the literature. Thus, future directions can explore different methods of training, specifically in the context of SAR. The application of existing visual search training programs to SAR practices has not been researched. The goal of this research is to provide sufficient information to explore the efficacy of different visual search training programs that may involve a method that is tailored to the specific environment in which the search is

being conducted. This first requires quantifying what environmental complexity is associated with the successful identification of a sign. Followed by research on how training can affect visual search success across different search environments.

Navon Task

In the Navon Task participants are presented with compound stimuli; in this experiment the stimuli are small letters that make up the shape of a large letter. The small letters are identified as being a local structure and the large letter is a global structure (Navon, 1981). These stimuli can be congruent (meaning the large letter is the same letter as the smaller letters) or incongruent (the large letter is a different letter than the smaller letters). Participants are asked to identify the stimuli on either a local or global level.

Using the Navon task, three effects have been discovered. The first being the *global precedence effect* as there is on average a faster identification of stimuli at the global level over the local level (Kimchi, 1992). The second being the slower response times for incongruent trials known as the *interference effect* (Navon, 1977). The third is that interference from incongruence slows down the identification of local stimuli more than it does for global stimuli recognition, this is known as *inter-level interference effect* (Gerlach & Poirel, 2018).

Systemizing Quotient (SQ-R)

The Systemizing Quotient Revised is a questionnaire that measures an individual's interest in different types of systems (Wheelwright et al., 2006). These include natural, abstract, social, mechanical, and collectible systems. A higher score on the SQ-R is thought to be correlated with a perceptual bias towards processing local details over global ones. SQ-R score is not predictive of an individual's intelligence quotient score (Ling et al., 2009). Sex differences in the SQ-R have been identified as male subjects are known to report higher on the systemizing

quotient than female subjects (Billington et al., 2007). The mean SQ-R score for men is 61.2 (SD = 19.2) and for women it is 51.7 (SD = 19.2) (Wheelwright et al., 2006). Systemizing quotient revised score and autism quotient scores have a significant correlation (Wheelwright et al., 2006). The explanation for this correlation is not fully understood, but one theory is that people with autism have an elevated local processing bias than the general population (Plaisted et al., 1998).

An experiment that compared Navon Task and SQ-R scores found people with higher SQ-R scores were more likely to perform faster on detecting local stimuli and were more susceptible to distractors on the local level (during incongruent styles with the global stimuli being the target) (Billington et al., 2008). Billington et al. (2008) used an fMRI while participants completed the Navon Task and found that people with a higher SQ-R score have increased activation in the right lateral prefrontal cortex (LPFC) during incongruent compared to congruent stimulus presentation. Participants with higher SQ-R scores were also found to have more brain regions activated, including the motor cortex, inferior parietal lobe, and extrastriate visual cortex during incongruent stimuli presentation. Activation of the LPFC is correlated with maintaining an attentional set, specifically in the presence of distractors (Banich et al., 2000). An attentional set is what directs the selection of task-relevant information away from what is deemed less relevant information (Briggs et al., 2018). Attentional set is a cognitive bias that is meant to make the completion of a task more efficient. It is thought that having a high systemizing quotient is correlated with an enhanced ability to use an attentional set (Weissman et al., 2002).

Hypotheses

It is hypothesized that 1) as fractal dimension increases the reaction time will be longer, 2) as fractal dimension increased increases the responses will be less accurate, and 3) a higher SQ-R score will be positively correlated with accuracy.

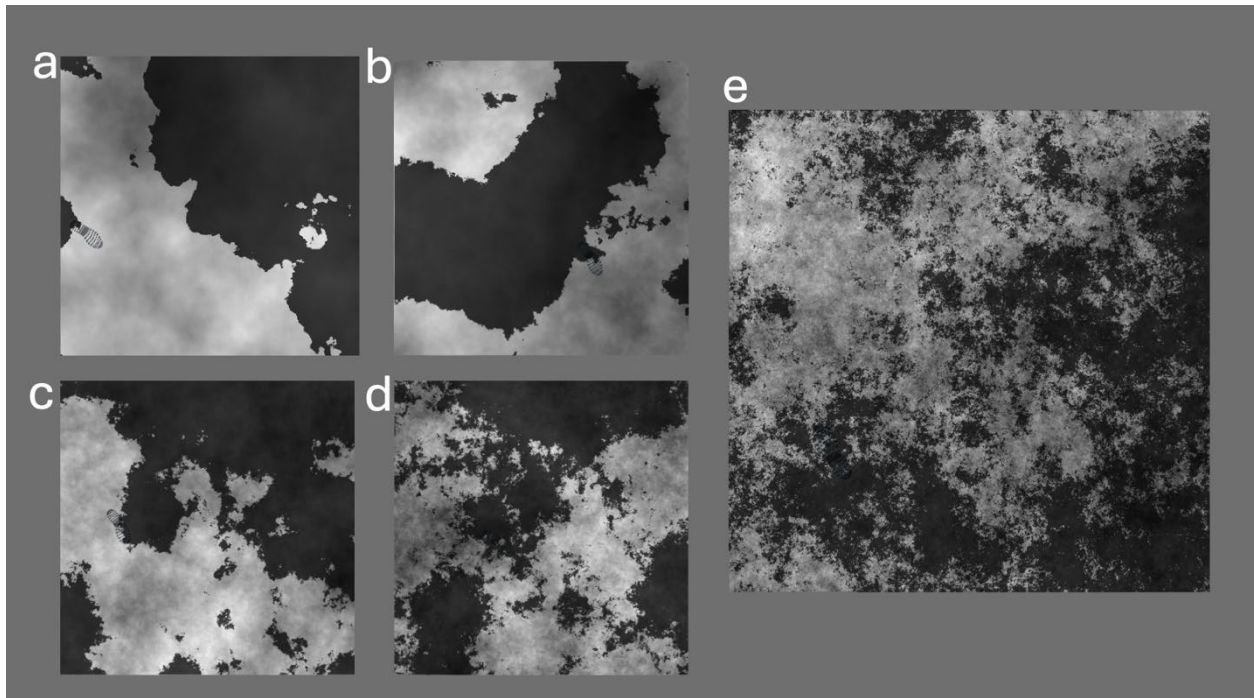


Figure 1. Example of the stimuli in the visual search task with shoeprints.

In a) $D = 1.1$, b) $D = 1.3$, c) $D = 1.5$, d) $D = 1.7$, e) $D = 1.9$. The same footprint is present in all 5 stimuli.



Figure 2. The five types of shoeprints used in the visual search task.

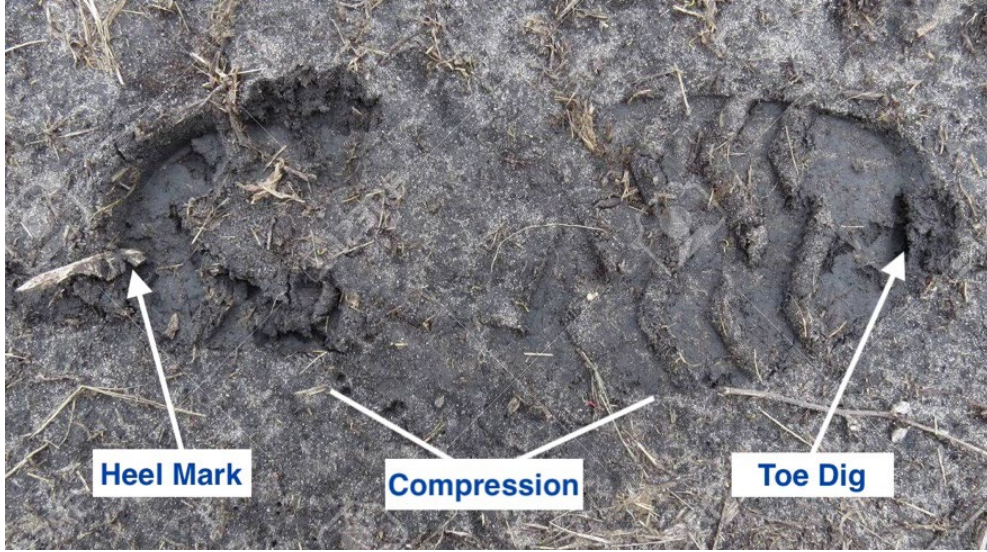


Figure 3. Shoeprint depicting heel mark, compression, and toe dig.

Methods

Participants

Participants (n=18, 14 female) were recruited from the University of Oregon Human Subjects Pool. The age range was 18-21 with the mean age being 19.26. Informed consent was acquired before the beginning of the study. All participants were recruited from the Psychology and Linguistic Departments' Human Subject pool at the University of Oregon. Informed consent was acquired following a protocol approved by the Institutional Review Board at the University of Oregon, and all measures were performed in accordance with relevant guidelines and regulations for research involving human subjects as approved by this review board.

Stimuli and Experiment Creation

Three hundred statistical fractals were created in MATLAB with D of 1.1, 1.3, 1.5, 1.7, and 1.9. Half being grey-scale statistical fractals and the other half being black and white (coastline) statistical fractals. The complexity of the fractal is set by the rate that the pattern decreases in size with each iteration (Robles et al., 2020). This rate is determined by the fractal dimension (D).

Adobe Photoshop was used to overlay the fractal grey-scale and black and white fractals to create a total of 150 images. In Adobe Photoshop the white background of the black and white fractal was removed, and the opacity was set to 75%. The grey-scale image was set to 100% opacity. The black and white fractal was overlaid on top of the grey-scale image. Seventy-five of the images had a footprint added. The footprint was placed on top of the two images and set to a 50% opacity. The location of the footprint was randomized using a grid pattern and a random number generator. The angle of the footprint was randomized using a random number generator.

There are 5 shoeprint types (see *Figure 2*) that were used 3 times with each being a certain size (small, medium, and large) at each fractal dimension, resulting in 15 unique footprint-fractal background combinations per *D*.

PsychoPy (OmicX) was used to create the visual search experiment with the presentation of stimuli being randomized for each session. The image would be shown until a response was recorded. Following a response a new image would be shown. Under each image "press y if the shoeprint is present, press n if the shoeprint is absent" was printed. Psychopy recorded the participant ID, reaction time, and response for each of the 150 images.

Procedure

A researcher conducted this experiment in one session that lasted approximately 35 minutes. Participants sat approximately 25 inches from the computer screen. The session began with the visual search task. Research assistants read the instructions to the participants and stated, "please respond as quickly and accurately as possible". Participants were to click the f-key that was relabeled as "y" if the shoeprint was present and the j-key relabeled as "n" if there was no shoeprint present. This was to control for an effect of the y and n-keys not being in the same row of the keyboard. First, there was a practice block with 10 images. There were 2 images from each fractal dimension with one having a shoeprint and the other not. After the practice block there was a break and participants then began the main block.

Navon Task

After the visual search task, research assistants started the Navon Task. The Navon Task used compound stimuli made up of S and/or H. The stimuli were either congruent (the same letter made up the global stimulus and local stimuli) or incongruent (different letters made up the

global stimulus and local stimuli). There were four blocks, starting first with a practice block for identifying the small letters (local stimuli), following this with the main block with trials for identifying the small letters. The third block was a practice trial block for identifying the large letter (global stimulus) and then a main block with trials for identifying the large letter. Each stimulus was presented for 200 milliseconds. Following this participants were prompted to respond by either pressing the s-key or the h-key.

Systemizing Quotient Revised

The final task was to complete the SQ-R, which is a questionnaire made up of 75 statements that participants respond to with "strongly agree", "slightly agree", "slightly disagree", or "strongly disagree". The questions are meant to explore the degree to which a person systemizes the world. Example statements include "When I learn a language, I become intrigued by the grammatical rules" and "I do not particularly enjoy learning about facts and figures in history". The response can be scored either a 2, 1, or 0. Half the questions are scored in reverse order to avoid response bias. The maximum score is 150 and the minimum score is 0. See appendix for list of statements. The SQ-R was published in 2006 and as a result is outdated in a few of its questions. Participants were instructed of this prior to completing the SQ-R and were told to "answer the best they can".

Statistical Methods

Data processing and statistical analyses were conducted in RStudio (Version 2024.12.1) using ggplot for figure creation. A mixed-effects ANOVA was used to test the effect of fractal dimension on reaction time. A three-way ANOVA was used to test the interaction of stimulus presence or absence and fractal dimension on reaction time. Both ANOVAs used Satterthwaite's method because of the small sample size and to account for unequal variances. A linear mixed

effects model (LMM), a type of linear regression, was used to allow for both fixed and random effects. LMM was used to analyze the effect of shoeprint (present or absent) on reaction time.

A general linear mixed model (GLMM) was used to analyze fractal dimension's effect on accuracy and fractal dimension and error types. The GLMM was used with binomial distribution and logistic regression rather than linear regression, as accuracy and error type are not continuous. A linear regression was used to analyze SQ-R scores and reaction time. A logistic regression was use to analyze SQ-R and accuracy. Statistical significance was set to $p < .05$.

Results

Fractal Dimension (*D*) Effect on Reaction Time in Visual Search Task

A mixed-effects ANOVA was used. This accounted for fractal dimension being a fixed effect and the participant number as being a random effect. There was a significant effect of fractal dimension (*D*) on reaction time, $F(1, 2681) = 223.19, p < .001$ (*Figures 4 & 5*).

Shoeprint Present or Absent Effect on Reaction Time Across *D* in Visual Search Task

A linear-mixed effects model (LMM) was used. There was a significant effect of the shoeprint being absent on the reaction time ($p < .001$). There was not a significant effect of the shoeprint being present on reaction time ($p = .29$).

A three-way ANOVA was used to test the significance of fixed and random effects. There was a significant main effect of fractal dimension (*D*), $F(1, 33.68) = 19.19, p < .001$. There was no significant main effect of stimulus presence on reaction time, $F(2, 317.59) = 1.98, p = .140$. There was a significant interaction between fractal dimension (*D*) and stimulus presence, $F(2, 388.79) = 8.10, p < .001$. *Figure 6* uses mean reaction times to visualize this relationship.

Fractal Dimension (*D*) Effect on Accuracy in Visual Search Task

A generalized linear mixed model (GLMM) with a binomial distribution with logistic regression was used. The model showed fractal dimension (*D*) having a significant effect on accuracy ($p\text{-value} < .001$). The relationship was negative with a higher fractal dimension (*D*) having lower accuracy in responses ($B = -3.37$). *B* represents the slope of the regression line (*Figure 7*).

Fractal Dimension (*D*) and Error Types

A generalized linear mixed model (GLMM) with a binomial distribution was used for the logistic regression to see if fractal dimension (*D*) affected error types (false positives and false negatives). There was a significant effect for fractal dimension on false negatives ($p < .001$). There was not a significant effect for fractal dimension on false positives ($p = .76$). *Figure 8* illustrates this relationship.

Systemizing Quotient-Revised Score Effect on Reaction Time

A linear regression was used to analyze if a participant's SQ-R score affects reaction time in the visual search task. There was no significant effect of SQ-R score on reaction time ($p = .799$) (*Figure 9*).

Systemizing Quotient-Revised Score Effect on Accuracy

A logistic regression was used to analyze if a participant's SQ-R score affects accuracy in the visual search task. There was no significant effect of SQ-R score on accuracy ($p = .508$) (*Figure 10*).

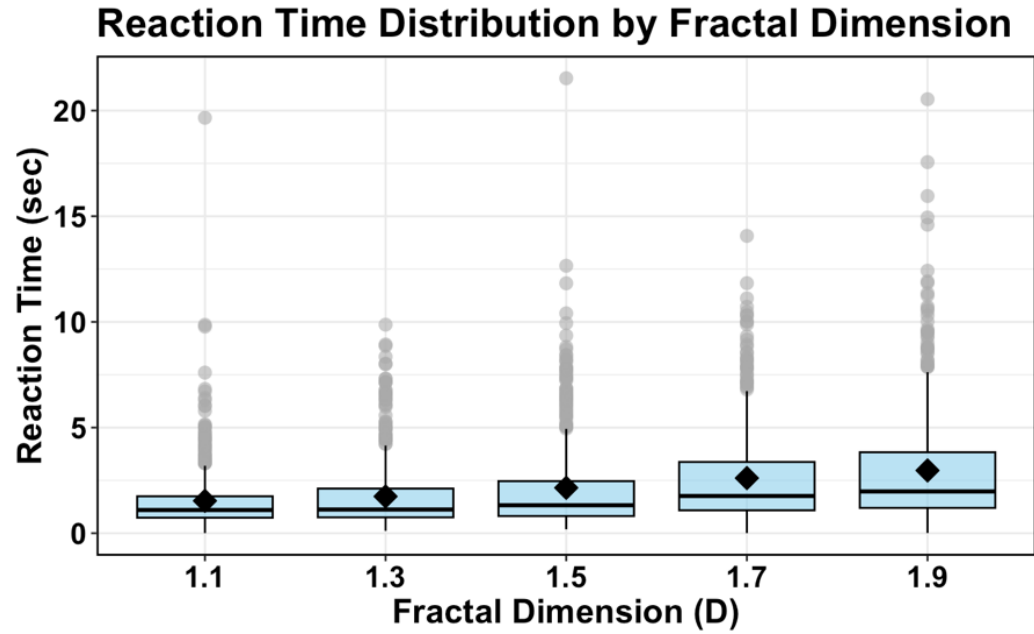


Figure 4. Reaction Times (sec) Across Fractal Dimension (D)

The diamonds represent the mean, while the line in the middle of the box represents the median value. The box shows the middle 50% of the data. Outliers are represented by the grey dots. The fractal dimension significantly affects reaction time ($p < 0.001$).

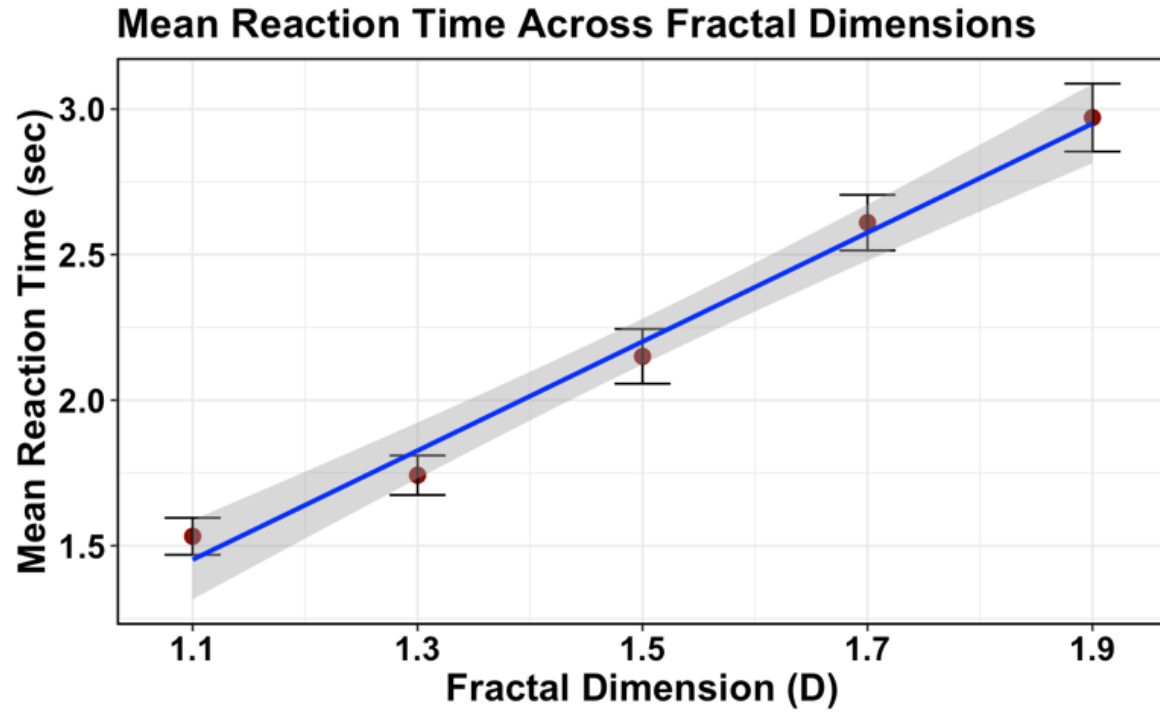


Figure 5. Mean Reaction Times (sec) by Fractal Dimension

This graph illustrates the relationship between D and mean reaction times (sec). The red dots represent the mean reaction time for each D. Error bars represent +/- SEM. The blue line represents the regression line. The shaded gray area represents the 95% confidence interval for the regression line.

Mean Reaction Time by D and Stimulus Condition

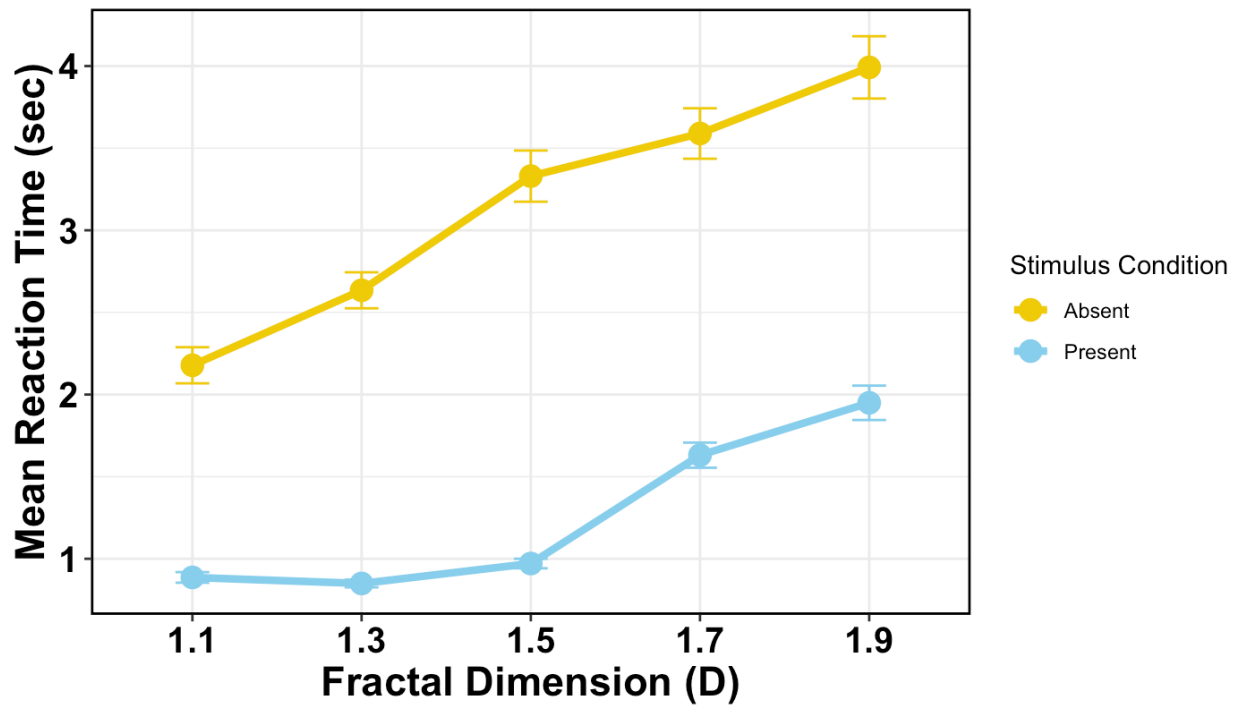


Figure 6. Mean Reaction Time by Fractal Dimension and if Shoeprint is Present or Absent.

The blue line represents the trend of the mean reaction time for when the shoeprint is present. The yellow line represents the trend of the mean reaction time for when the shoeprint is absent. There was a significant effect of the shoeprint being absent on the reaction time across D ($p < 0.001$).

There was no significant effect of the shoeprint being present on reaction time across D ($p = 0.29$).

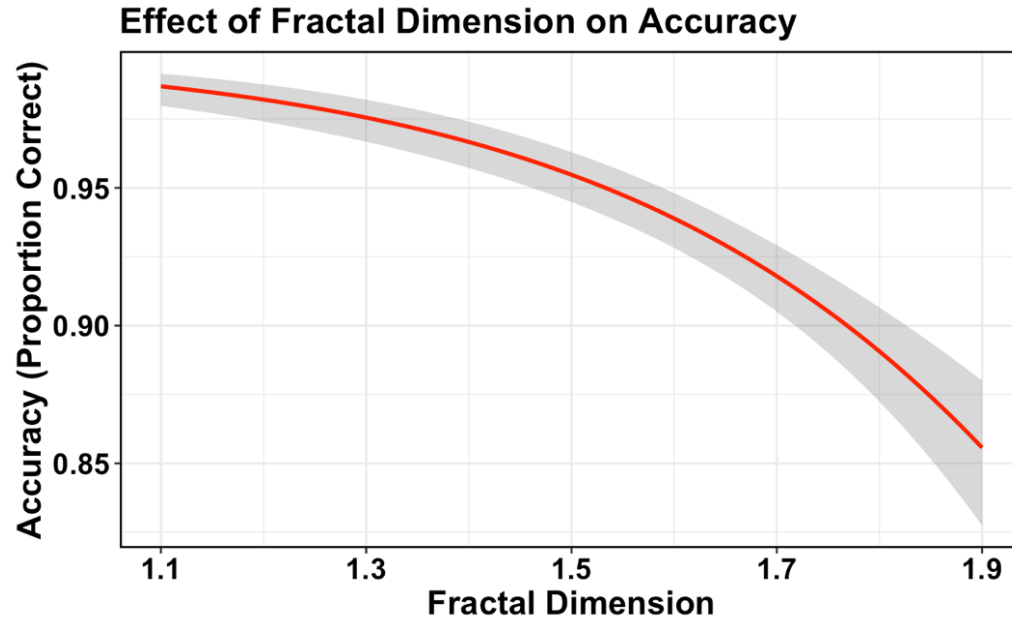


Figure 7. Relationship between accuracy and D .

The red curve is the logistic regression line based on a GLMM. This shows the predicted relationship between fractal dimension (D) and accuracy. The slope of the line is represented by a $B = -3.37$. The gray area represents the confidence interval.

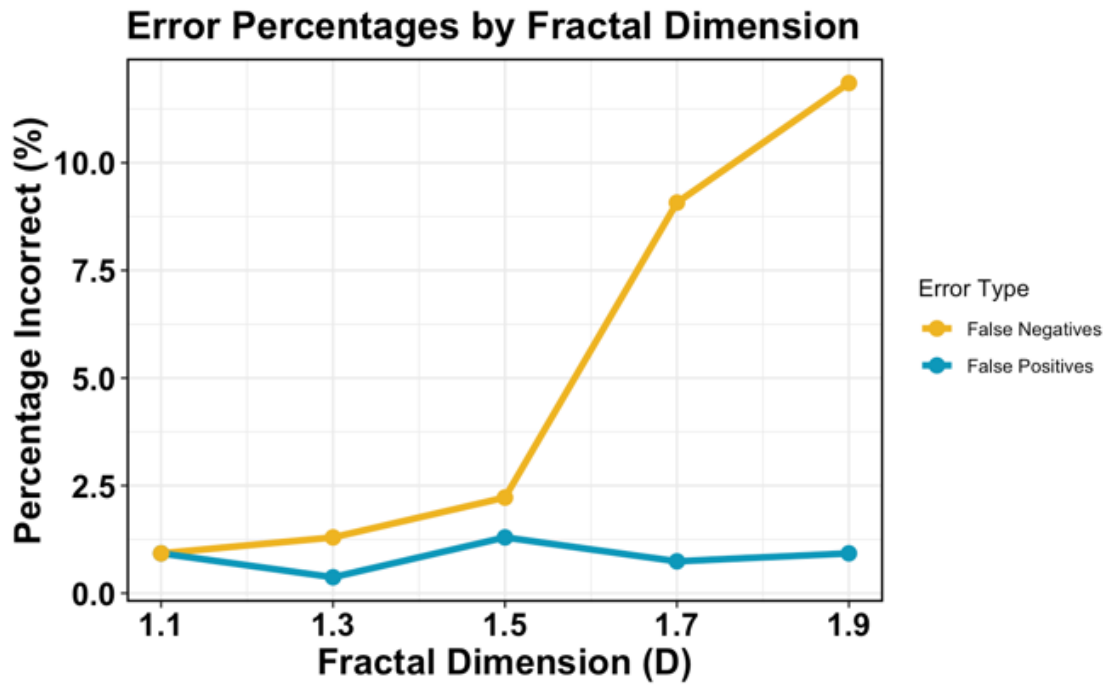


Figure 8. Incorrect responses as percentage by D .

The yellow line represents the trend of false negatives across fractal dimension. The blue line represents the trend of false positives across fractal dimension. There was a significant effect for fractal dimension on false negatives ($p < 0.001$). There was no significant effect for fractal dimension on false positive ($p = 0.76$).

Relationship Between SQ-R and Reaction Time

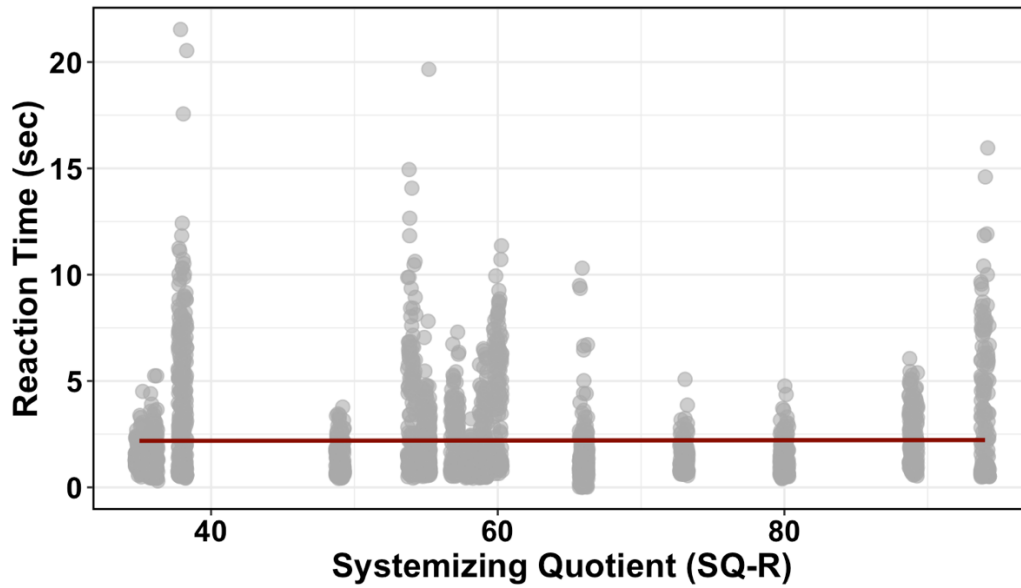


Figure 9. Systemizing Quotient-Revised Score and Reaction Time (sec).

Each vertical line of gray dots represents the spread of a participants reaction times. The red line representing the regression line. There was no significant effect of SQ-R score on reaction time ($p=0.799$).

SQ-R and % of Incorrect Responses

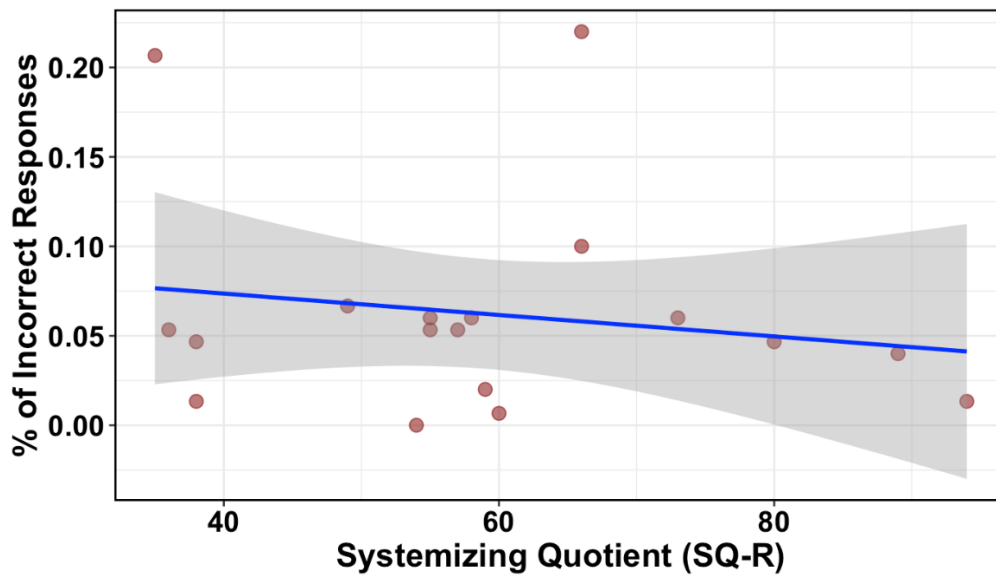


Figure 10. The SQ-R score and percent of incorrect responses.

Each red dot represents a single participant ($n=18$). The blue line represents the regression line. The shaded gray area represents the 95% confidence interval for the regression line. There was no significant effect of SQ-R score on accuracy ($p = 0.508$).

Discussion

The main purpose of the experiment was to examine how the complexity of the environment in which a visual search is being conducted affects reaction time and accuracy. This experiment was designed to model different types of environments that search and rescue missions can occur in. The goal of this research is to provide a foundation for future research to examine types of training and if their effect is environmental complexity dependent. This research aimed to establish a difference in visual search performance depending on the type of environment the visual search is being conducted in.

There was a significant effect of fractal dimension on reaction time ($p < 0.001$) (*Figure 4*). This result confirms the hypothesis. These results suggest that an environment of a higher complexity is a significant factor in the efficiency of a visual search. An environment with an increased complexity requires more time to search for a target. These findings were expected and are paralleled in vision science literature that shows increased "global clutter" results in increased reaction time (Beck et al., 2010). Existing vision science literature has not used fractal dimension (D) to quantify complexity or distractors within a visual search.

The linear-mixed model showed a significant effect of shoeprint being absent on reaction time ($p < 0.001$). There was not a significant effect of the shoeprint being present on reaction time ($p = 0.29$). The absence of a shoeprint causing a significant increase in reaction time is a result of a prolonged visual search. A visual search is concluded when a target is found. In the cases where there is no target, a participant will continue to search until they are confident that there is no target. Through the same logic it makes sense why there was no significant effect of the presence of a shoeprint on reaction time. *Figure 6* visualizes this relationship and shows that there is a less of an increase in reaction time from D of 1.1 to 1.5 when there is a shoeprint present. The

relationship of how reaction time is affected by increased fractal dimension when the image has no shoeprint is more linear and constant than when there is a shoeprint. This could be because a search in which a target is present is easier and is less affected by the complexity of the background until a fractal dimension of 1.7 (*Figure 6*).

A three-way ANOVA showed a significant interaction between stimulus presence or absence and fractal dimension ($p < .001$). This indicates that the effect of fractal dimension (D) on reaction time was different depending on if the footprint was present or absent. Fractal dimension (D) appears to have a stronger effect when the footprint is absent (*Figure 6*). The ANOVA model did not find a main effect of shoeprint presence or absence on reaction time. This could be due to the significant interaction between footprint presence or absence and fractal dimension. This result can be interpreted as meaning that the effect of footprint presence or absence on reaction time depends on the fractal dimension. When considered independently from fractal dimension, no effect of stimulus presence or absence on reaction time was found.

Fractal dimension was found to have a significant effect on accuracy ($p < 0.001$). The relationship was negative with a higher fractal dimension having lower accuracy in responses ($B = -3.37$). This result confirms the hypothesis that a higher fractal dimension would result in less accurate responses. This result is expected as more complex backgrounds lead to more errors in visual search tasks (Wolfe et al., 2002). This finding means that SAR training should focus on conducting visual searches in complex environments where errors are more likely to occur.

There was a significant effect for fractal dimension on false negatives ($p < .001$) (*Figure 8*). There was not a significant effect for fractal dimension on false positives ($p = .76$). False negatives occurred more than false positives and at higher rates in fractal dimensions of 1.7 and

1.9. False negatives may be more likely to occur than false positives for a few reasons. This could be visual fatigue from prolonged searching, impatience, or poor eyesight.

There was no significant effect of SQ-R score on reaction time ($p=0.799$) (*Figure 9*). The SQ-R was not a predictor of reaction time which is contrary to what was predicted. There was not a significant effect of SQ-R score on accuracy ($p=0.508$) (*Figure 10*). A greater number of subjects might reveal a small effect, but the current data did not reveal a significant relationship.

Future Directions

Analysis will occur again with more participants to provide more power for statistical analyses. Future research should measure expert SAR trackers in a visual search task to explore if they differ in reaction time, accuracy, and SQ-R scores from novice trackers. Future research can use multiple shoeprints to simulate gait patterns in a SAR visual search paradigm. A SAR visual search paradigm should be created that closely simulates a visual search conducted for wilderness SAR. Follow-up research should also implement a training condition. A training condition and a control condition can explore the validity of a training on improving visual searches in simulated natural environments. Future research can explore what fractal dimension (D) represents a specific environment.

Limitations

The data set includes 18 participants, which leads the analysis to be more strongly affected by outliers and has insufficient power to detect small relationships. The current analysis did not include the Navon Task data, as cleaning the data proved to be incredibly complex; however, once data collection is finished the Navon Task will be used in the final analysis. Another limitation is that not all participants received the same exact treatment. There was a total of 5 different research assistants that ran participants (myself included). I observed on multiple occasions that not all participants were told to complete the visual search task as "quickly and accurately" as possible. This may have resulted in reaction time data to not be accurate. The Systemizing Quotient-Revised was published in 2006 and as a result has statements that are outdated. These outdated statements may have resulted in inaccurate SQ-R scores as the average age of participants was 19.26 and thus, they may have been too young to properly infer what certain statements meant.

Conclusion

The research aimed to accurately model a search and rescue visual search. The results of the experiment determined the presence of a strong effect of fractal dimension (D) on accuracy and reaction time. The SQ-R was not shown to have a relationship with visual search performance. This is a promising finding, as there may be less of a barrier to become an effective searcher if cognitive styles do not predict better visual search performance.

Efficiency is crucial for a successful search and rescue mission. The effect of fractal dimension (D) on reaction time and accuracy provides confirmation for the need of a proven visual search training method. An empirical visual search training program that focuses on modeling searches conducted in complex environments could improve searcher's reaction time and accuracy.

Appendix

Systemizing Quotient-Revised Statements

1. I find it very easy to use train timetables, even if this involves several connections.
2. I like music or book shops because they are clearly organised.
3. I would not enjoy organising events e.g. fundraising evenings, fetes, conferences.
4. When I read something, I always notice whether it is grammatically correct.
5. I find myself categorising people into types (in my own mind).
6. I find it difficult to read and understand maps.
7. When I look at a mountain, I think about how precisely it was formed.
8. I am not interested in the details of exchange rates, interest rates, stocks and shares.
9. If I were buying a car, I would want to obtain specific information about its engine capacity.
10. I find it difficult to learn how to programme video recorders.
11. When I like something I like to collect a lot of different examples of that type of object, so I can see how they differ from each other.
12. When I learn a language, I become intrigued by its grammatical rules.
13. I like to know how committees are structured in terms of who the different committee members represent or what their functions are.
14. If I had a collection (e.g. CDs, coins, stamps), it would be highly organised.
15. I find it difficult to understand instruction manuals for putting appliances together.
16. When I look at a building, I am curious about the precise way it was constructed.
17. I am not interested in understanding how wireless communication works (e.g. mobile phones).
18. When travelling by train, I often wonder exactly how the rail networks are coordinated.

19. I enjoy looking through catalogues of products to see the details of each product and how it compares to others.
20. Whenever I run out of something at home, I always add it to a shopping list.
21. I know, with reasonable accuracy, how much money has come in and gone out of my bank account this month.
22. When I was young I did not enjoy collecting sets of things e.g. stickers, football cards etc.
23. I am interested in my family tree and in understanding how everyone is related to each other in the family.
24. When I learn about historical events, I do not focus on exact dates.
25. I find it easy to grasp exactly how odds work in betting.
26. I do not enjoy games that involve a high degree of strategy (e.g. chess, Risk, Games Workshop).
27. When I learn about a new category I like to go into detail to understand the small differences between different members of that category.
28. I do not find it distressing if people who live with me upset my routines.
29. When I look at an animal, I like to know the precise species it belongs to.
30. I can remember large amounts of information about a topic that interests me e.g. flags of the world, airline logos.
31. At home, I do not carefully file all important documents e.g. guarantees, insurance policies
32. I am fascinated by how machines work.
33. When I look at a piece of furniture, I do not notice the details of how it was constructed.
34. I know very little about the different stages of the legislation process in my country.

35. I do not tend to watch science documentaries on television or read articles about science and nature.
36. If someone stops to ask me the way, I'd be able to give directions to any part of my home town.
37. When I look at a painting, I do not usually think about the technique involved in making it.
38. I prefer social interactions that are structured around a clear activity, e.g. a hobby.
39. I do not always check off receipts etc. against my bank statement.
40. I am not interested in how the government is organised into different ministries and departments.
41. I am interested in knowing the path a river takes from its source to the sea.
42. I have a large collection e.g. of books, CDs, videos etc.
43. If there was a problem with the electrical wiring in my home, I'd be able to fix it myself.
44. My clothes are not carefully organised into different types in my wardrobe.
45. I rarely read articles or webpages about new technology.
46. I can easily visualise how the motorways in my region link up.
47. When an election is being held, I am not interested in the results for each constituency.
48. I do not particularly enjoy learning about facts and figures in history.
49. I do not tend to remember people's birthdays (in terms of which day and month this falls).
50. When I am walking in the country, I am curious about how the various kinds of trees differ.
51. I find it difficult to understand information the bank sends me on different investment and saving systems.
52. If I were buying a camera, I would not look carefully into the quality of the lens.

53. If I were buying a computer, I would want to know exact details about its hard drive capacity and processor speed.
54. I do not read legal documents very carefully.
55. When I get to the checkout at a supermarket I pack different categories of goods into separate bags.
56. I do not follow any particular system when I'm cleaning at home.
57. I do not enjoy in-depth political discussions.
58. I am not very meticulous when I carry out D.I.Y or home improvements.
59. I would not enjoy planning a business from scratch to completion.
60. If I were buying a stereo, I would want to know about its precise technical features.
61. I tend to keep things that other people might throw away, in case they might be useful for something in the future.
62. I avoid situations which I can not control.
63. I do not care to know the names of the plants I see.
64. When I hear the weather forecast, I am not very interested in the meteorological patterns.
65. It does not bother me if things in the house are not in their proper place.
66. In maths, I am intrigued by the rules and patterns governing numbers.
67. I find it difficult to learn my way around a new city.
68. I could list my favourite 10 books, recalling titles and authors' names from memory.
69. When I read the newspaper, I am drawn to tables of information, such as football league scores or stock market indices.
70. When I'm in a plane, I do not think about the aerodynamics.
71. I do not keep careful records of my household bills.

72. When I have a lot of shopping to do, I like to plan which shops I am going to visit and in what order.

73. When I cook, I do not think about exactly how different methods and ingredients contribute to the final product.

74. When I listen to a piece of music, I always notice the way it's structured.

75. I could generate a list of my favourite 10 songs from memory, including the title and the artist's name who performed each song.

(Systemizing Quotient, SQ-R - Form, n.d.)

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