Title
The Visual Saliency of Cave Formations and its Implication for Cave Archaeology

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Publication Date
2017

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA, MERCED

The Visual Saliency of Cave Formations and its Implication for Cave Archaeology

A Thesis submitted in partial fulfillment of the requirements for the degree of Master of Arts

in

World Cultures

by

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2017

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Acknowledgments

This thesis could not have been possible without the efforts of several people. I would like to thank my advisor Holley Moyes for her support and patience. Her work has served as the inspiration for this thesis, and I am forever appreciative of the opportunities she has given me to contribute to the expanding field of Maya cave archaeology.

I would also like to thank my committee members and the University of California, Merced Department of World Cultures and History. I am grateful for the support and kindness of Rick Dale. His generosity proved to be the lynchpin of this thesis. Without it, the essential data needed for this project would have been unobtainable. I would also like to show my gratitude for Mark Aldenderfer, whose guidance helped me navigate through the murky waters of this data set.

I am indebted to Antonio Mai, Javier Mai, Erin Ray, Pedro Carvijal, Gonzalo Pleitez, and all the members of the Belize Cave Reconnaissance Project for helping me transport and operate cumbersome camera and lighting equipment through jungles, over mountains, and into the bowels of the earth.

Abstract

Visual saliency has been investigated by the cognitive sciences to explore how people perceive and understand their landscapes. Archaeological research involving visual saliency has been limited to either human manipulated environments or the interior of human-made constructions. My research explores visual saliency in relation to complex cave environments in Mesoamerica, to better understand how ancient peoples interacted with these spaces. I am testing the hypothesis that the location of ritual within the caves was influenced by the visual characteristics of naturally occurring cave formations. I conducted laboratory experiments that tested the visual saliency of natural cave formations. With the aid of eye tracking cameras, the direction of the visual focus of participants was measured and recorded while the participants briefly viewed images of cave formations. The data collected from the experiment indicates that the participants' gazes were fixated on areas of extreme morphological contrast. These results confirm that the previously understood aspects of visual saliency are also applicable to complex cave environments and offers a new interpretative framework for future archaeological investigations into ritual human activity within caves.

Introduction

Caves are one of the least hospitable environments on earth and the species that call them home can only do so because of highly specialized evolutionary adaptations designed to cope with the absence of sunlight. Yet, thousands of years ago, caves served as a special theater where humanity exercised one of the most defining characteristics that sets us apart from the rest of the animal kingdom. Images of animals and geometric designs were painted onto the barren rock walls of caves as far back as 38,000 B.P. (Clottes 2012). In fact, caves have served as some of the earliest repositories for both the tangible and intangible manifestations of abstract thought and culture. Remains of human activity such as, durable ceramic vessels, stone tools, other artifacts and even burials have been uncovered within the dark zones of countless caves across the world.

Archaeologists are slowly beginning to realize that much of the cultural material recovered from the dark zones of caves are the result of ritual behavior (Moyes 2012). This makes sense because deep caves are an unlikely venue for human habitation. Their morphology is extremely complex and runs counter to the logical layout of human constructed landscapes. They frequently contain stalagmites, stalactites, boulders, extreme ascents or descents, and other morphological characteristics that inhibit movement. The absence of sunlight makes navigation impossible without the aid of an exterior light source. What is it about these specialized environments that attracts these particular human behaviors? It has been suggested by Holley Moyes that it is the very morphological qualities that make caves dangerous and treacherous that also make them so appealing. Along with their colleagues (Moyes et. al. in press), they posit that caves offer “transcendental affordances,” in which the qualities of darkness and poor visibility stimulate imagination. This, in turn, encourages imaginative abstract thought that often accompanies ritual activities, which may include making offerings to deities among other things.

Caves often figure into cosmologies, and nowhere have they played a larger role than in Mesoamerican thought. Archaeological and ethnographic evidence demonstrates that the earth is considered sacred in Mesoamerican cultures. Caves are frequently represented in the iconography and ethnohistory of the ancient Maya and continue to be important elements of modern Maya religion (Brady 1991, 1997; Freidel et al. 2001; Brady and Ashmore 1999). Mountains and caves feature strongly in ritual practices and to this day pilgrimages are made to shrines devoted to earth deities (Vogt 1969; Vogt and Stuart 2005). In traditional Maya religions caves are revered as the homes of deities and portals to other realms of existence (Brady and Prufer 2005; Moyes and Brady 2005). Ethnographically we see the importance of caves, but most modern rituals are conducted outside of caves and not in cave interiors (Scott 2009). However, for the ancient Maya the deep dark interiors of caves were important venues of ritual activity as evidenced by a plethora of artifacts both domestic and exotic found in archaeological sites (Brady and Peterson 2008).

In her spatial analyses of the Main Chamber of the ancient Maya cave site Actun Tunichil Muknal, Moyes used GIS to explore artifact placement within the cave (Moyes 2001, Moyes 2005). These artifacts consisted of fragmented ceramic vessels and sherds, lithics, jewelry, pyrite mirror fragments, and broken groundstone objects totaling 1408 discrete entities. She divided geomorphic features in the cave into seven overlapping categories and computed the number of artifacts that fell within .50 cm of each. Here results indicated that most artifacts were placed in pools (51%) or along walls and walkways (28%), but many were also located at the base of free standing boulders (27%) or on the floor surrounding or placed within stalamitic or stalacto-stalagmitic columns (20%). Some objects were tucked into niches (13%), some found among jumbled boulders in ceiling collapse (8%) and others placed in small private spaces or alcoves that could contain one or two people (5%). The interpretation of these findings was confined within a methodological framework that was based on Maya ethnohistoric and ethnographic research. However, this interpretation did not take into consideration the locations of cave formation types relative to the morphology of the immediate environment of the chamber or the visual qualities of the individual cave formations. This would include large imposing stalacto/stalagmitic columns, reflective cave formations, or free standing boulders.

I hypothesize that the visual saliency of cave formations may have influenced the placement of ritual artifacts within caves by the ancient Maya. In this study, I investigate visual saliency of cave morphology using an eye tracking camera to record where participants direct their focal gaze at 2-dimensional photographs of interior cave spaces. The results of this study can inform alternative interpretations of artifact placement described in the ATM investigation by addressing whether some cave formations or their morphological characteristics are more visually salient then the others. This research is of interest not only in this particular cave study but will help to establish some general principles concerning the interpretation of cave space that may prove useful not only for archaeologists but for other researchers as well.

A recent turn in archaeological theory prompted by Christopher Tilley engages philosophies of phenomenology (Tilley 1994). This began and is often associated with landscape approaches. Although the use of phenomenology in archaeology has influenced many researchers, it has undergone considerable criticism. His critics note, among other things, that within landscape studies there is too much emphasis on the visual and that the approach does not account for the diversity of human experience (Brück 2005; Hamilakis 2013). Additionally, Julian Thomas (2004) argues that perception is always an act of interpretation, which would imply that modern humans can never understand how people of the past perceived or conceptualized their worlds. Is this necessarily true? This is one of the more serious debates that archaeologists contend with. If we consider evolutionary approaches to understanding space, then phenomenology and shared experience may obtain more purchase in archaeological interpretation.

I will begin with a discussion of the relationship between archaeology and phenomenology (Chapter 1). I then discuss visual saliency as a method for thinking about human sensory experience (Chapter 2). This is followed by a discussion of eye tracking and how it will be using it to explore the saliency of cave morphological features in experiments with human subjects (Chapter 3). Chapter 4 is a description of the results of my study and Chapter 5 is an analysis of my findings. Chapter 6 is a discussion and Chapter 7 summarizes the work.

Chapter 1

Archaeology and Phenomenology

The idea of understanding shared experience is rooted in the philosophical discipline of phenomenology. Phenomenology, while existing as a concept since the time of Aristotle, was fully developed into its own discipline by German philosopher Edmund Husserl. Husserl emphasizes that the only way to fully understand the truth of a phenomena is to fully describe and comprehend the way the phenomena presents itself to the consciousness of the individual (Moran 2000). This idea was then later expanded upon by the philosophers Maurice Merleau-Ponty and Martin Heidegger, who argued that the truth of a phenomena could only be fully appreciated through the understanding of the individual's perception of the experience, not just the experience itself (Embree 2013). As described by Merleau-Ponty in his book *The Phenomenology of Perception,* "the most primordial form of experiences is that of embodied perception" (Merleau-Ponty 1942). The key element in this philosophical search for better understanding the how people engage with their world is not found only within a person's interactions with their environment, but how they perceive their environment through their sensory organs.

Through a phenomenological scope, it is not farfetched to think that two different people could share similar experiences when they perceive the same environment. This is particularly key when considering the experiences of people in the past when we consider that human body has not evolved significantly over the last several thousand years. If compared, people living 2000 years ago would be biologically very similar to those living today. Not enough time would have passed for the human brain and the sensory organs to evolve in a way that would alter how sensory data is perceived. Phenomenology is an appropriate framework for studying the perception of modern people to help gain insight as to how people in the past perceived their environment.

However, this path of analyzing the past is not without its problems. Archaeologists have been looking at how past people have engaged with their environment through a phenomenological lens since the 1980's. Even though the sensory organs have not changed over the last 2000 years, the same cannot be said about the environment in which past people lived. Christopher Tilley first applied this approach while conducting research at England's Stonehenge (1994). Using his own body as a phenomenological lens, Tilley tried to better understand where the processional pathways of the ancient locals would have been with relation to the megaliths and the lines of sight they created (Tilley 1994). His work, as well as the work of many other archaeologists using this approach, have been heavily criticized for applying this methodology to areas that have since changed. The earth is a dynamic place. Most landscapes are in a constant state of flux. Sediments are always eroding from one place and being deposited at another. Ocean front cliff sides crumble into the sea and are transported to the shores of distant lands by the tide. Humanity has been manipulating vast expanses of land for cultivation and urbanization to meet the demands of our multiplying populations. This is especially true for archaeological sites located near or in developed areas. With human development tends to come an array of visual, olfactory, audible, and tactile sensations that would otherwise be completely absent from natural landscape as well as landscapes that were inhabited by ancient people.

However, caves are one of the few environments on earth whose morphology tends to remain relatively static, sometimes only gradually changing over the course of hundreds or even thousands of years. Resulting in a landscape that has remained essentially the same since the time of the ancient Maya. This means that the interior spaces of modern caves contain the same visual stimuli that the ancient Maya would have seen. The restrictive morphology of caves also provides a unique opportunity that cannot be applied to most above ground landscapes. Within a cave, one is generally limited in the directions they can navigate. These navigable paths often contain obstacles, such as boulders and uneven terrain, which along with the walls and ceilings, confine a person to a limited trajectory. Compared to those on the surface, forces of change are infrequent within caves, though of course erosion, ceiling collapse or earthquakes can create radical and abrupt changes. Still, caves are somewhat insulated them from most natural disasters and at many sites the preservation is remarkable (Woodward and Goldberg 2001). It is for this reason a phenomenological interpretive framework is well-suited for cave archaeological sites.

Chapter 2

Theoretical framework: Visual Saliency

Perception is the physical processing of sensory data. It is the process that converts the sights, smells, feels, and sounds of the environment into understanding. It is through this process that the unorganized world is identified categorized and understood. However, the process of understanding the world around us does not stop with perception. Once the sensory data is perceived it is then interpreted by the individual. The culture of an individual creates the framework for interpretation and dictates what kind of meaning is applied to the already perceived sensory information. It is through this process of perception and interpretation that we make sense and understand the environment.

The visual saliency of an object is how noticeable an object is. The more salient an object is, the more visually noticeable the object is to the observer. Visual saliency is defined by the visual qualities belonging to an object in relation to the visual qualities of the surrounding environment. In other words, visual saliency is not an intrinsic feature of the individual object. Visual saliency exists only in the contrasting relationship of the object's visual qualities and the visual qualities of the environment. These visual qualities include luminosity, color, orientation, texture, and motion (Itti and Koch 2001; Parkhurst et al. 2002).

Luminosity describes the light intensity of an object, or how reflective an object appears to be. This is the same relationship between a shiny reflective painted surface and a dull flat painted surface. The shiny paint reflects more light back at the observer, while the dull flat paint appears to absorb more light, making it appear less intense. Color is the visual perception of light that is reflected off an object. Orientation refers to position of an object relative to the positions of the objects surrounding it. Texture is the visual complexity of an object's surface. For example, a carpeted floor provides more visual texture than a smooth concrete floor because the observer can see the individual threads of the carpeting, creating a complex visual texture. The smooth concrete floor provides little in the way of smaller individual things for the observer to see, resulting in a less complex visual texture. The motion of an object can also be a defining feature of visual saliency if the object of focus has a direction or speed of motion that differs to the direction or speed of the surrounding objects.

Independently these visual qualities do little in attracting visual attention. It is only when the luminosity, color, and orientation of the object differs with the other objects in the surrounding environment does the object become visually salient. It is for this reason that red ball would be easy to spot if it was in a field of green grass. Or why reflective safety vests are easily noticeable when they appear in your car's headlights at night.

Humans, by nature, are visual creatures. The majority of the world we live in is perceived and understood through our eyes (Gibson 2013). As vital as vision is to our survival, there are still many aspects of vision that are not fully understood and are hotly debated. One issue is how and where we decide to focus our visual attention. Researchers in the cognitive sciences have been debating for decades over the where and why our eyes decide to focus. The arguments have centered around two prominent theories, the first of which, is described as the "top down" approach, which argues that visual attention is endogenous and is controlled by cognitive processes (Findlay 2009; Chun 2000). The other, described as the "bottom up" approach, argues that visual attention is exogenous and is determined by the visual properties of the objects being perceived (Findlay 2009).

Over the years, researchers have been able to provide strong evidence for both approaches, resulting in a unified theory where endogenous and exogenous approaches work parallel with each other (Findlay 2009; Parkhurst et al. 2002; Chun 2000). However, the debate continues over which of the two processes holds greater influence over the direction of our gaze. The endogenous approach emphasizes that the visual attention of a person is heavily influenced by their own cognitive processes (Chun 2000; Parkhurst et al. 2002). This has been seen in experiments where the attention of the participant focuses on areas in the visual field that are relevant to an assigned task (Chun 2000). These areas of focus would vary depending on the type of task that was given. For example, an individual who was asked to navigate through an unfamiliar area would pay closer attention to spatial landmarks as well as the path that is being traversed more so than an individual who is already familiar with the area. The idea of cognitive processes guiding visual focus was also investigated by Chun (2000), who sought to better understand the role "contextual cuing" plays in directing visual attention. Through what Chun describes as contextual cuing, the nature of the observed environment has the potential to significantly affect what objects appear to be more visually salient to the observer (Chun 2000). Chun argues that visual objects tend to be very structured and regular in their placement within particular contexts. This regularity tends to be dependent on the objects recognized purpose as well as the observer's familiarity with the context (Chun 2000). For example, if an individual were to walk into the living room of a current American home they would expect to see sofas, chairs, decorations, and a television set. Assuming this individual also grew up in a typical modern American household, their visual focus would gravitate towards and identify the furnishings that are expected to exist within the context of the living room. The understanding of the context limits what 0types objects the observer expects to see, thus the endogenous approach is inherently biased towards culture. However, the endogenous approach can be interrupted by objects within the observer's field of vision (Bruce and Tsotsos 2009), such as, when a sudden movement is seen out of the corner of your eye, and attention is forced away from the current task at hand and relocated to where the movement occurred.

The exogenous approach emphasizes that visual attention is influenced by the visual properties of an object, as the viewer perceives it. The visual saliency of the object is not inherent in the object itself. The object only becomes highly salient when its visual properties are notably different from the rest of the surrounding environment. The attention grabbing qualities of an object are created by contrast of color, texture, orientation, visual complexity, and movement (Itti and Koch 2001; Findlay and Gilchrist 1998; Treisman and Gelade 1980; Chun 2000; Henderson 2003). Returning to Chun's room experiment, the exogenous approach would dictate that the more visually salient objects would be defined the relationship between the visual qualities of the objects and the visual properties of the room itself. For example, imagine a room that has bright white walls and an extremely fuzzy shag carpet. Inside this room, resting on the white shag carpet is a very dark coffee table. Both exogenous and endogenous approaches would predict that a person entering the room would immediately notice the dark coffee table. The endogenous approach predicts the coffee tablet to visually salient because the observer would expect to see some form of a table, assuming the observer came from a culture where coffee tables are common place. The exogenous approach, on the other hand, would predict that the coffee table is visually salient because the dark color of the table contrasts with the white carpeting and walls and the smooth, hard texture of the table would contrast with soft cords of the shag carpet.

The validity of the bottom up approach has been determined through laboratory experiments that utilize technologies such as eye tracking cameras and computer algorithms (Harel et al. 2007; Itti and Koch 2001). In these experiments researchers have created algorithms that depict the independent salient features of an image, which are represented visually in the form of maps. One of the more commonly used algorithms produced by Itti and Koch, determines the visual saliency of an image by creating individual maps that depict areas of color, orientation, and reflective intensity (luminosity) (Findlay and Gilchrist 1998; Harel et al. 2007). These three individual maps are then combined to create a single saliency map. The data generated from these algorithms have been compared to the results from experiments where participants viewed the same image while having their eye movements recorded by an eye-tracking camera. There results showed a strong correlation between what the algorithms determined visually salient and what the participants determined salient.

Chapter 3

Methodology

The experimental method used in this research utilizes an eye tracking camera manufactured by SensoMotoric Instruments, to measure the location of a participant's focal fixation as they viewed an image depicting the interior space of a cave. Focal fixation is the location where the viewer directs the focus of their visual attention. Twelve volunteer participants were recruited through the University of California, Merced SONA research participant system and were compensated .5 class credits for their participation. For the experiment, each participant was seated at a desk in an isolated corner of a laboratory. The participant then filled out a questionnaire pertaining to their previous experience with caves. The participant was then told the purpose of the experiment and how it would be administered. The distance between the laptop computer and the participant was then adjusted to ensure the participant's eyes were within range of the eye-tracking camera. The eye-tracking camera was then calibrated to the participant. Once calibrated, the laptop computer's screen displayed photographs of the interior spaces of caves. Each photograph was displayed for 10 seconds before automatically displaying the next photograph. It was during these 10 seconds that the eye-tracking camera recorded the location and duration of the participant's visual focus. Ten different photographs were shown throughout the experiment to each participant. The post processing software Begaze was used to create a video that depicts the saccads, rapid movements of the eye that deliver the eye's focus to the next visual fixation, and visual fixation of the participant (Richardson et al. 2007). Analysis was only done on the saccads that occurred during the first 3 seconds of viewing. This is because after the first 3 seconds, the participant's eyes would have gathered enough visual information to start consciously selecting what to visually focus on. It is after this three-second mark that the higher cognitive functions start to take over the saccad directions.

The photographs used as the visual stimuli were taken in Ofrenda Cave, located in the Maya mountains of western Belize (Moyes et al. 2016). Ofrenda Cave contains many concentrations of artifacts that commonly associated with ancient Maya cave ritual. The cave contains relatively large and open chambers, which allow a larger portion of the cave to be captured in a single photograph. This provides the viewer of the photograph with opportunity to see as much of the cave as possible while viewing one image.

Illuminating the interior of the cave in the photographs used in the study proved difficult. Successful navigation through the dark zone of a cave requires an exterior source of light. The ancient Maya navigated through these spaces with wooden torches made from pine (Moyes et al. 2016). Light produced by flames as two unique qualities: 1) the color of the flame is often seen reflecting off objects and 2) the flickering of the flame does not produce a consistent light source which creates moving shadows. In keeping with this thesis' phenomenological framework, every attempt was made to photograph the cave environment in the same way the ancient Maya would have encountered it. This meant photographing the interior of the caves with torch light illumination. Lit pine torches produce large amounts of charcoal as the flame consumes the pine wood, which would result in a large deposition of modern carbon on the cave floor while photographing. This method of illumination was not used because the introduction of modern carbon to the cave floor would have added an unnecessary complication to the chronological archaeological record. Test photographs were taken with the light of propane torches, but the flickering light produced moving shadows which blurred the images on the photographs. Ultimately battery powered construction lamps were used for the final photographs because of their steady light source and their zero effect on the archaeological chronological record. The construction lambs also provided a light source that was consistent in luminosity output. Propane and wood fueled torches would have been a more realistic means of illuminating the caves interior, however they are not consistent with the intensity of the light they produce. The brightness of the flame can vary depending on the richness of the fuel and the amount of oxygen available in the atmosphere of the cave. The consistency of battery powered constructions lights makes it possible for the same lighting to be reproduced for future experiments.

To understand the relationship between two objects, the objects first must be well defined. This is easy to do with a traffic cone and a paved road, but this kind of identification is difficult to do with a photograph of a cave's interior. Generally, boulders, floors, and ceilings are easy to identify from one another. Speleothems, on the other hand, can be more difficult to distinguish. Speleothems are the result of mineral enriched water percolating through the bedrock and being deposited inside of a cave (Cacchio et al. 2004). The minerals eventually accumulate and have the potential to grow into any number of shapes and sizes. Each potential form the accumulated minerals can turn into have their own unique classification, but all are considered a type of speleothem. This complicated classification system was not pertinent to this study, so all formations will be referred to as speleothems. Speleothems can grow on to any surface and can make it difficult to distinguish where the speleothem growing on the cave floor end and where the floor begins. Five experienced cave archaeologists were asked to assist in deciding how the distinguish the cave formations types. Each cave archaeologist was given a set of the photographs used in the experiment and asked to quickly draw boundaries around objects that shared similar visual qualities. Every part of the photograph had to be incorporated into a polygon boundary, resulting in a mosaic like partitioning of objects across the entire photograph. Using their images as a guide, the partitioned photographs were then used to demarcate polygon boundaries to isolate the individual cave features and formations. The polygons were identified by the cave formation type they encompassed. The polygons were designated into ceiling, speleothem, void, floor, and rock types. These polygons made it possible to quantify the visual qualities of the cave features bound within the polygon. The partitioned photographs were used as a template and the defined borders of the polygons were recreated as layers in adobe Photoshop C6.

Visual saliency is an abstract concept that is usually associated with qualitative research. For the purposes of this research, however, visual saliency had to be quantifiable. How can one say that an object is more visually salient than another? Some sort of standard needed to be utilized. For this thesis, the histogram panel in Adobe Photoshop C6, which is used to display the tonal range of an image, was used to help quantify aspects of visual saliency of formations found in caves. As stated in the previous chapter, visual saliency is defined by the visual qualities of orientation, color, movement, and luminosity, and how these qualities contrast with those of the surrounding environment. Photoshop's histogram panel has the capability to select different channels that filter out specific types of tonal data so that only a particular type of data will be displayed. Of the several channels available, the pixel count channel and the luminosity channel were used in this research. The luminosity channel measures the light intensity of each individual pixel providing the user with an averaged pixel luminosity for either the entire image or for an individual layer. Table 1 shows the what qualifies as low luminosity, medium luminosity, and high luminosity for this thesis. The pixel count channel generates a count for all the pixels found with the entire image or within a given layer. Both the luminosity and pixel count channels were used to determine the average pixel luminosity and the pixel count data sets for each polygon.

The same polygons were then created in BeGaze, the eye tracking camera's post processing software. BeGaze allows the user to create overlays of any size and shape over the photograph being post processed. These overlays are call "areas of interests", or AOI's. The AOI functions in the same way as the polygon layers used in Photoshop. Once an AOI is created and overlaid on top of an image, BeGaze calculates how many focal fixations were directed within the boundary.

The average pixel luminosity, focal fixation, and pixel size data sets were then plotted on a scatter plot with the statistics program Past Project. Pearson's R coefficient was then used to determine what kind of correlation exists between the data sets.

Central Bias

The concept of a center bias has long been known and tested (Tatler 2007). Studies have shown that people subconsciously direct their gaze at the center of anything framed, such as the boarder around a screen or the frame around a painting. The potential for a central bias needed to be taken into consideration because the cave images were shown to the participants on a laptop computer screen. The frame created by the laptop computer could potentially have had an influence on the direction of the participant's gaze. Therefore, a center bias test analysis was conducted on the results of the experiment to see if the direct of the participant's focus would show a bias towards the center of the photograph. Using BeGaze, an AOI polygon was created to define the center of the photograph and was replicated in the exact spot for every photograph. A second AOI polygon was created and placed across the entire photograph to calculate how many fixations fell outside of the designated center.

Table 1: Qualitative description of polygon average pixel luminosity ranges.

Range of Average Pixel Luminosity	
Low	0 - 40 APL
Medium	41 - 80 APL
High	80 APL and Over

Chapter 4

Results

The results from each individual photograph will be presented in this chapter. Each photograph will be discussed along with the individual polygons that gathered enough focal fixations to warrant analysis. First, I will discuss the potential of central bias and its effects on this study.

Central Bias

The initial focal fixations that occurred within the first 100 milliseconds of recording and are shown in (Table 12). This table gives the percentages of how many focal fixations occurred outside of the center AOI and how many occurred outside of the center AOI. The central bias for these photographs appears to be minimal. Of the ten photographs used in the experiment, three of the photographs showed a tendency for a central bias. This tendency occurred in photographs 0520 with 56%, 9615 with 50%, and 0652 with 46% of the participant's focal fixations falling within the central AOI. In the remaining seven photographs, the percentages of focal fixations within the center AOI were below 36%.

The reason for most of the initial fixations for photographs 0520, 9615, and 0652 being in the center of the photograph was not likely not caused by central bias. The reason for these initial fixations being in the center of the photographs was not because the participants were conditioned to look at the center of the photograph, but because the center of the photographs happen to contain polygons that attracted visual attention. Photograph 0520 had most of the speleothem 3 polygon within the boundaries of the center AOI. The speleothem 3 polygon received a total of 26 focal fixations and was viewed by 9 different individual participants.

Photograph 9615 had portions of speleothem 2, void 3, and speleothem 3 within the boundaries of the center AOI. Speleothem 2 received 20 focal fixations and was viewed by 11 different individual participants. Void 3 received 19 focal fixations and was viewed by 10 different individual participants. Speleothem 3 received 9 focal fixations and was viewed by 6 individual participants.

Photograph 0652 had portions of the polygons ceiling 2 and speleothem 2 within the boundaries of the center AOI. The ceiling 2 polygon received 36 focal fixations and was viewed by 12 different individual participants. Speleothem 2 received 20 focal fixations and was viewed by 8 different participants. The likelihood of these polygons attracting similar focal fixations counts if they were not located in the center of the photograph would be high.

Photograph 0442

Photograph 0442 was taken in the large central Chamber 5 of Ofrenda Cave. This photograph contains six prominent speleothem columns, one large weathered fallen speleothem, a large exposed portion of weathered bed rock, several dark voids, eroded dead stalactites across the ceiling, and a mud floor. The image was broken up into 17 partitions. The eye movements and visual fixations of 12 participants were successfully recorded. The interior of this chamber is open and easy to navigate and provides easy access to the surrounding chambers. The layout of this portion of the cave is much like a large open dome with a hill in the center, with the chamber at the top of the hill in the center of the dome. All the surrounding chambers are separated from this chamber by large formations, unlike other parts of the cave where chambers are separated by constricted passage ways.

Speleothem 3 and Void 1 both had the most fixations with 13 focal fixations within the first 3 seconds of the experiment. Speleothem 5 and void 3 both had the second most with 11 focal fixations each. The polygon with the third highest fixation count was the floor polygon with 10 fixations and the fourth most was speleothem 6 with 9 fixations. Speleothem 3 had the highest luminosity rating with a value of 129.62 lumens as well as the highest fixation count with 13 focal fixations.

Speleothem 3 is a speleothem column that is located on the center right side of the photograph. Most its mass exists closest to the ceiling and gradually tapers down to a thin column that connects with the floor of the cave. It is boarded by void 1 to the right and void 2 two the left.

Like speleothem 3, void 1 has the highest focal fixation count with 13 visual fixations and has an average pixel luminosity of 11.89 lumens. Some faint formations can be seen in the distance of void 1. Void 1 is the space between speleothem 3 and speleothem 1, located at the far right of the photograph. Being real objects that reflect light, as opposed to the absence of objects like the voids, speleothem 1 and speleothem 3 have relatively high luminosity values with speleothem 1 at 129.62 lumens and speleothem 3 at 79.86 lumens. Void 1 is also bordered above by the ceiling polygon and to the bottom by the floor polygon. The ceiling polygon has an average pixel luminosity of 97.25 lumens and the floor polygon has an average pixel luminosity of 40.71 lumens.

Speleothem 3 and Speleothem 5 were the most viewed polygons and were fixated on by 9 out of the 12 (75%) participants. Speleothem 3 received a total of 13 fixations and speleothem 5 received a total of 11 fixations. The second most viewed objects were void 1 and the floor, with both objects fixated on by 7 (58%) of the participants. Void 1 received a total of 13 fixations and the floor received a total of 10 fixations. This shows that these objects were not only fixated on once and then disregarded, but instead were able to draw the attention of some of the participants a second time.

Table 2: Photograph 0442 Data

Polygon	Number of Fixations	Average Pixel Luminosity	Pixel count	Views by number of Individuals
Speleothem 1	2	79.86	24426	2
Speleothem 2	6	105.84	11694	4
Speleothem 3	13	129.62	8912	9
Speleothem 4	4	91.3	4759	3
Speleothem 5	11	110.25	4417	9
Speleothem 6	9	71	4311	6
Speleothem 7	2	95.39	1115	2
Speleothem 8	5	42.52	3961	2
Speleothem 9	7	70.14	3477	4
Void 1	13	11.89	7805	7
Void 2	4	17.31	52989	3
Void 3	11	18.85	6730	5
Void 4	2	10.51	8874	1
Void 5	2	26.1	2455	2
Void 6	4	13.56	710	4
Ceiling	7	97.25	34843	3
Floor	10	40.71	59076	7

Figure 1. Photograph 0442.

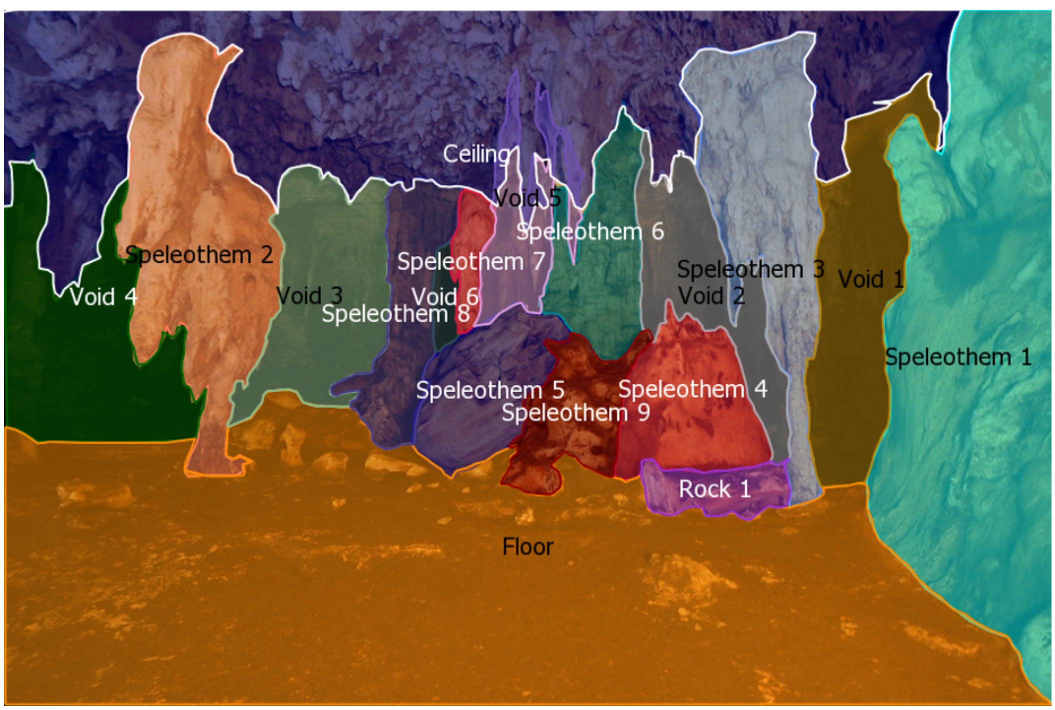

Figure 2. Photograph 0442 AOI Polygons.

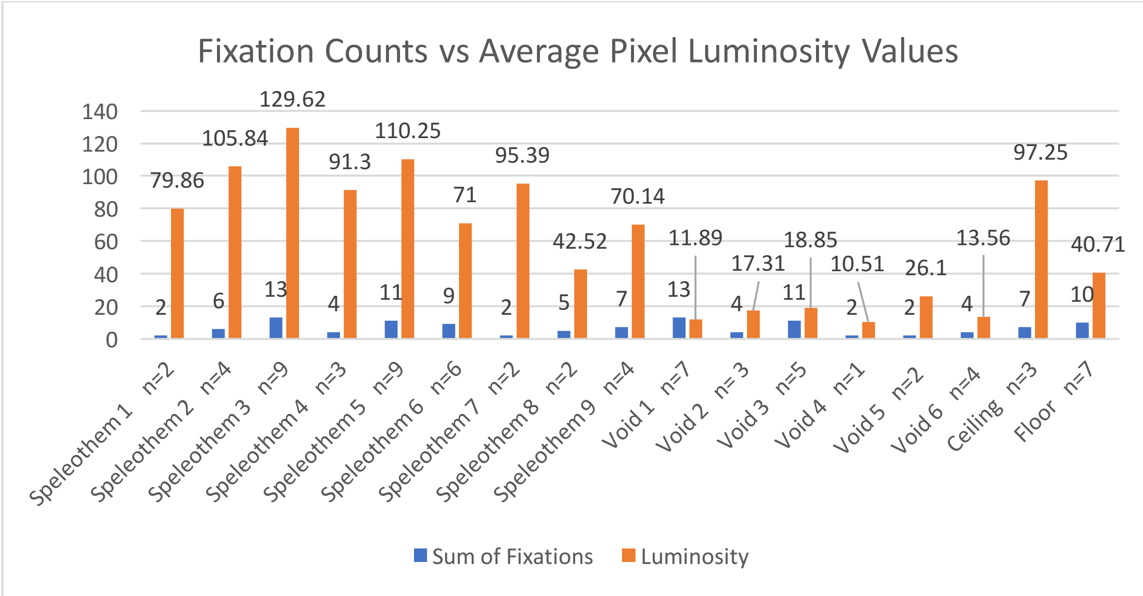

Figure 3. Sum of focal fixation vs average pixel luminosity for photograph 0442. N indicates number of individuals that viewed each feature.

Photograph 0504

Photograph 504 was taken in Chamber 6 of Ofrenda cave. Photograph 504 was partitioned into nine different polygons. The speleothem formations of the picture were grouped into three different polygons; speleothem 1, speleothem 2, and speleothem 3. Three voids were also defined and were designated void 1, void 2, and void 3. The remaining three polygons defined the cave's ceiling, floor, and a concentration of 3 prominent boulders on the cave floor. The three boulders are close in proximity with each other and were designated as rocks. The average pixel luminosity values of all three formations, rocks, and ceiling are like each other and fall within the high APL range. The void polygons fall within the low APL range of 19 APL to 23 APL. The floor polygon is a little more luminous with 33.46 APL.

Speleothem 1 has the greatest number of visual fixations with 31 and an average pixel luminosity value of 96.16 lumens. Speleothem 1 is a column that connects the floor to the ceiling and takes up approximately 1/3 of the entire picture. The speleothem is located on the right side of the photograph and is boarded to the left by void 3, the ceiling to the top, and the floor to the bottom. The pixel count for speleothem 1 is 59057, making it one of the largest polygons in the experiment.

Speleothem 2 is a speleothem conglomeration with three prominent stalagmites growing the center of the top of the conglomeration's base. The base of the conglomeration is made of numerous objects that could have once been speleothems, boulders, or exposed bedrock. This array of formations does not contribute much to the verticality of the speleothem 2 but provide intricate texture, especially when contrasted to speleothem 1 and the floor polygon. Speleothem 2 had the second highest focal counts with 27 visual fixations and the highest average pixel luminosity value of 100.72 lumens.

Speleothem 3 is a large column located on the left side of the photograph. It is a large and continuous formation that connects the ceiling to the ground and takes up approximately 1/5 of the photograph and has a pixel count of 39040. Although this visually prominent object registered an average pixel luminosity of 85.82 lumens it only received one focal fixation. Speleothem 3 is bounded by the ceiling polygon to the top, the floor polygon to the bottom, and void 1 to the right. Besides being smaller, speleothem 3 has very similar visual characteristics to speleothem 1 yet only received 1 focal fixation during the first three seconds of testing. The lack of focal attention for speleothem 3 could be explained by the fact that there is minimal localized contrast between it and the surrounding voids and formations. Even though there is a localized contrast between speleothem 3 and void 1, the degree of this contrast is not as extreme as the contrast created by speleothem 2 and its surrounding voids or the with the chipped section of speleothem 1.

Speleothem 2 was viewed by 11 out of the 12 (91%) participants and attracted 27 independent focal fixations. The second most viewed polygon was speleothem 1, which was viewed by 9 out of the 12 (75%) participants and received 31 individual focal fixations. This shows that the participants not only glanced at these polygons once, but that they kept returning to these polygons for additional viewing.

Table 3: Photograph 0504 Data.

Polygon	**Sum of Fixations**	**Average Pixel Luminosity**	**Pixel Count**	**Views by Number of Individuals**
Floor	3	33.46	22226	3
Ceiling	10	92.24	24653	5
Speleothem 1	31	96.19	59057	9
Speleothem 2	27	100.72	21924	11
Speleothem 3	1	85.82	39040	1
Void 1	10	23.85	13971	6
Void 2	4	22.67	2180	2
Void 3	9	19.63	8186	7
Rocks	1	86.37	2709	1

Figure 4. Photograph 0504.

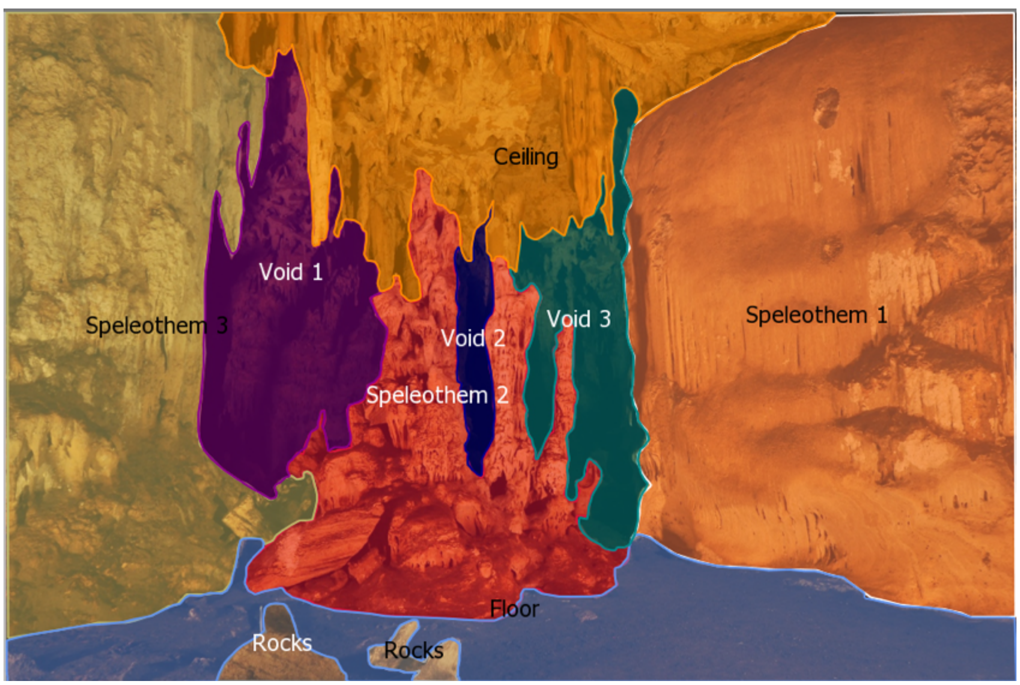

Figure 5. Photograph 0504 AOI Polygons.

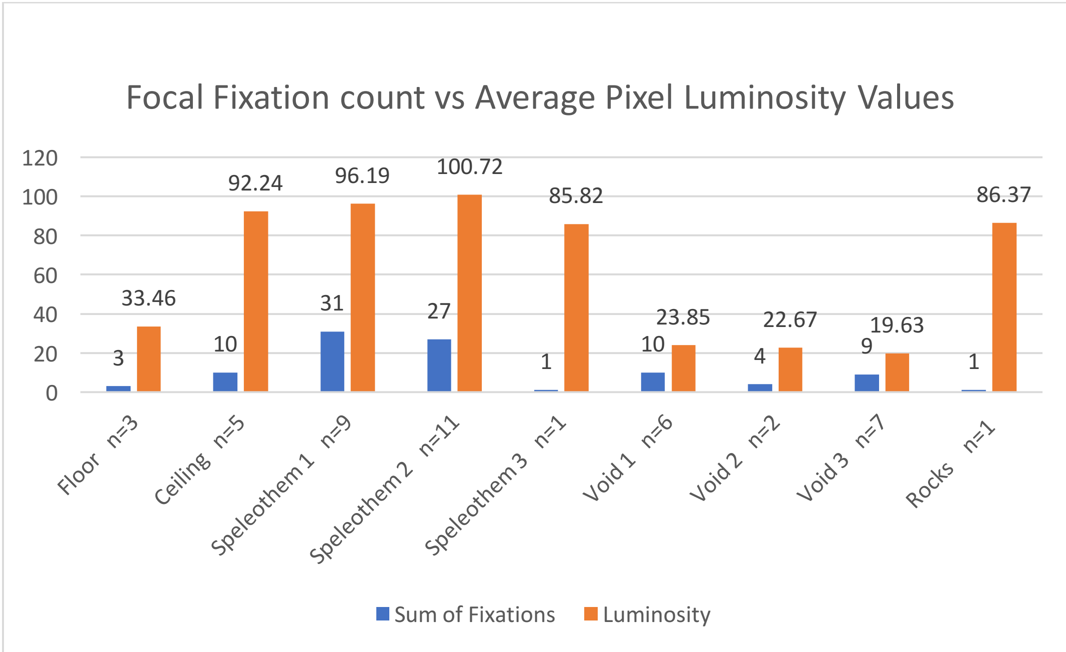

Figure 6. Sum of focal fixation vs average pixel luminosity for photograph 0504. N indicates the number of individuals that viewed each feature.

Photograph 0476

Photograph 0476 was taken in Chamber 7 of Ofrenda cave. The photograph was taken at the top of a slope and is upslope of a very prominent votive deposit of ceramic vessels and human remains (Moyes: in publication) The descent of the slope is visible in this photograph.

The ceiling 2 polygon is located at the left side of the screen and is made up of 35669 pixels. It attracted 26 focal fixations and registered an average pixel luminosity value of 43.26 lumens. This polygon is a part of the cave ceiling is undecorated and bare rock. It is also in the background of the photograph, so it is has a lower average pixel luminosity value than the ceiling 1 polygon, which is at a more foreground position in the photograph. The bare rock has a mottled pale yellow and white color pattern. There is a minimal contrasting between ceiling 2 and its neighboring polygons, with the exception of the floor 2 polygon which has a darker color due to the accumulated bat guano and sediment. Most the focal hits for ceiling 2 occurred in the furthest most right part of the polygon that is framed by speleothem 2 and speleothem 7. Even though this part of the polygon is like the rest of the polygon, this specific are is contrasted by the vertical stalactites of speleothem 7 and the large stalagmite of speleothem 2, creating a localized contrast.

Speleothem 7 is a series of stalactites and columns that are growing from the ceiling and running along the ceiling in a horizontal pattern. Speleothem 7 has an average pixel luminosity value of 92.03 lumens and attracted 18 focal fixations during the first 3 seconds of participant viewing. It is in the center left of the picture has a pixel size of 15492.

Floor 1 is an outcrop of the cave's bedrock that protrudes out at a location where the surrounding ground begins to descend downwards towards the ledge of offerings. Floor 1 is approximately in the middle of the photograph and is bordered above by speleothem 7 and below by floor 2. It has an average pixel luminosity value of 57.62 and attracted a total of 11 focal fixations. Floor 1 has a similar color to the surrounding floor 2 polygon, where the top of floor 1 is just as exposed to the accumulation of bat guano as the surface of floor 2. The exposed face of the outcrop is whiter in color due to the limestone composition of the bedrock.

The ceiling 1 polygon is center top of the photograph and is boarded by speleothem 7 to the bottom as well as speleothem 4 to the right and ceiling 4 to the left. Ceiling 1 attracted 11 focal fixations during the allotted time and has an average pixel luminosity value of 100.42 lumens. Ceiling 1 is mostly absent of speleothem decorations, except for a few stalactites along the upper most frame of the photograph. Most ceiling 1's unique physical character is defined by a large portion of bare bedrock. Like ceiling 2, ceiling 1 has a mottled yellow and white color composition, though not the degree of ceiling 2. It is also depicted as being more luminous than ceiling 2, yet less than half of the focal fixations.

The floor 2 polygon consists of all of the cave floor depicted in the picture with the exception of the bedrock outcrop of floor 1. Floor 2 is the largest polygon in the photograph. It composes most of the lower half of the photograph and contains 190816 pixels. It has an average pixel luminosity value of 56.62 lumens and was fixated upon 10 times. Floor 2 is only bordered by the other polygons above. It contains no objects and only a few batches of exposed bedrock, leaving most the polygon a homogenous brown color. The downward descent of the cave floor is best represented in the floor 2 polygon.

The ceiling 2 polygon was viewed by 11 out of the 12 (91%) participants and received a total of 26 independent focal fixations. The second most viewed polygon was speleothem 7, which was viewed by 8 out of the 12 (66%) participants and received 18 independent focal fixations.

Table 4: Photograph 0476 Data.

Polygon	Sum of Fixation	Average Pixel Luminosity	Pixel Count	Views by Number of Individuals
Ceiling 1	11	100.42	34393	5
Ceiling 2	26	43.26	35669	11
Ceiling 4	1	113.15	10845	1
Speleothem 1	4	89.03	548	4
Speleothem 2	2	76.87	2868	2
Speleothem 3	2	41.54	892	2
Speleothem 4	3	73.81	6665	3
Speleothem 5	1	92.02	928	1
Speleothem 6	1	91.68	666	1
Speleothem 7	18	92.03	15492	8
Void 1	8	29.13	8746	4
Void 2	0	10.94	800	0
Floor 1	11	57.62	8264	7
Floor 2	10	56.62	190816	5

Figure 7. Photograph 0476.

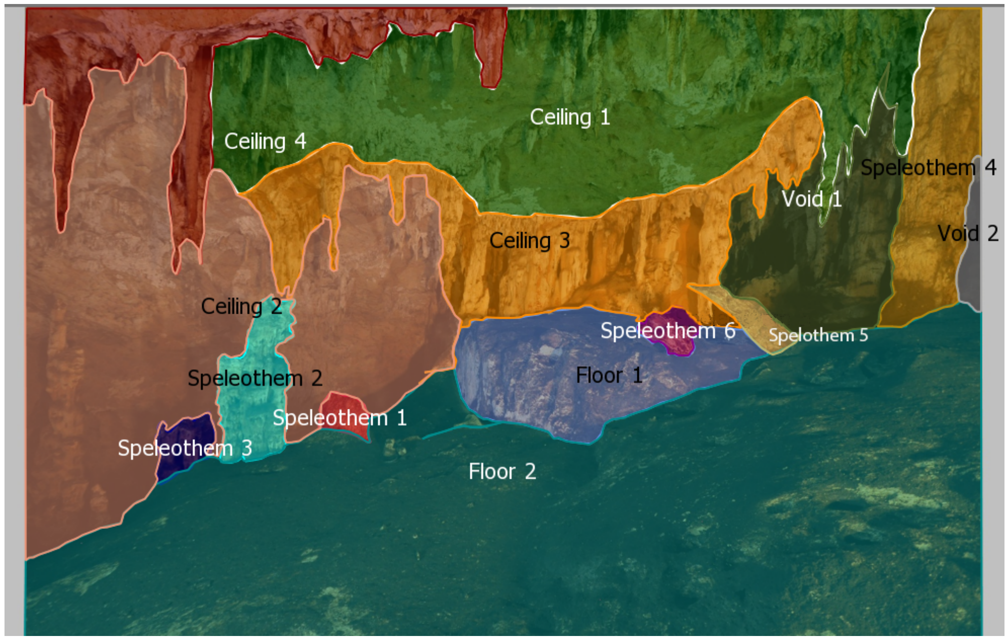

Figure 8. Photograph 0476 AOI Polygons.

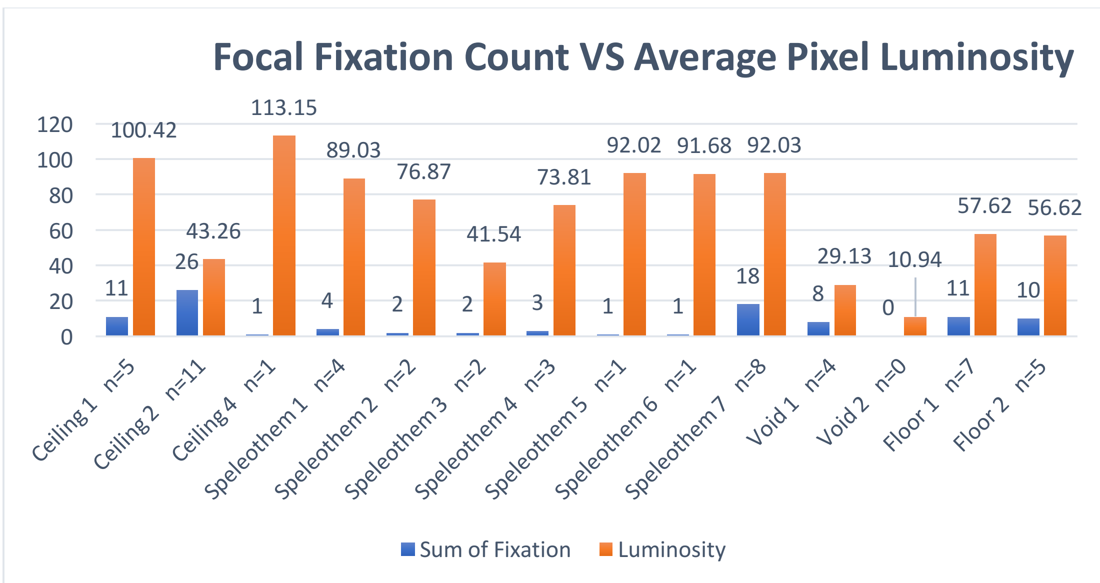

Figure 9. Sum of fixations vs average pixel luminosity for photograph 0476. N indicates the number of individuals that viewed the feature.

Photograph 0513

Photograph 513 was taken in chamber 6 of Ofrenda cave and provides a different viewing of the same chamber that was used in photograph 504, but from a different position and includes several different formations. It is one of the more complex photograph with dozens of formations, textures, and colors. In total 15 polygons were carved out of the photograph. Much of the upper half of the picture is made up of series of vertical formations. This image of verticality runs counter to the directionally ambiguous floor.

Speleothem 2 is a large speleothem column that is centrally located in the picture. It an average pixel luminosity value of 118.85 lumens and received 27 focal fixations within the first 3 seconds of recording. It is a large speleothem that is comprised of 27519 pixels. It is bounded at the top by the ceiling polygon, to the right by void 4, to the left by void 5, and below by the floor. The base of speleothem 2 has a darker coloration than the middle and upper portions of the speleothem, creating a gradient of luminosity from lighter to dark. The base of the speleothem is still a lighter brown color than the floor polygon on which it rests.

The ceiling polygon in this photograph is very heavily decorated with small stalactites across the entire polygon. Formation 2 and 3 are both complete speleothem columns and connect to the ceiling. The ceiling has an average pixel luminosity value of 56.74 lumens and received 15 focal fixations. The ceiling polygon is bordered below with void 6, formations 5, void 5, formation 2, void 4, formation 1, void 2, and void 3. Besides the voids, the ceiling does not contrast much with the formations, with all of them sharing a similar average pixel luminosity value.

Speleothem 1 is the three-pronged speleothem that was also depicted in photograph 504. It consists of 3 prominent stalagmites growing out of a conglomeration base. The base is made of possible boulders and fallen speleothems that have since been actively dripped on and formed into the current formation. The shapes of these former boulders and fallen speleothems can still be seen in the formation. Speleothem 1 is boarded to the left by void 4, and to the right by void 3 and the smaller rock polygon. Void 2 also exists in the space between two of the three speleothem columns. The floor polygon and the ceiling polygon exist below and above formation 1, respectively.

Speleothem 3 is a large stalagmite column that exists on the left side of the photograph. It has an average pixel luminosity value 96.84 lumens and received 9 focal fixations. Is bordered to the left by void 6 and to the right by void 5. Much like speleothem 2, speleothem 3 has a gradient of color that transitions from lighter to darker the closer it gets to the floor.

Void 5 is a shadow created by formation 2. Even though this polygon does not represent an actual absence of space, it is depicted as a void by the camera. Void 5 had an average pixel luminosity value of 21.12 lumens and received 9 focal fixations.

Void 4 is a space between formation 2 and formation 1. It has an average pixel luminosity of 17.77 lumens and received 9 focal fixations. Void 4 is surrounded to the left by formation 2, to the right by formation 1, and to the top by the ceiling polygon.

Floor polygon has an average pixel luminosity of 40.23 lumens and received 4 focal fixations. It spans across the lower third of the photograph. Several limestone rocks ranging from small to medium in size are visible across the surface along with a few subtle dips and rises of the cave floor.

Void 2 is the space between the two largest stalagmites growing from formation 1. It has an average pixel luminosity value of 16.78 lumens and was fixated on 4 times during the first 3 seconds of recording. Void 2 is surrounded by the formation 1 polygon on all sides, except for the ceiling polygon above.

Void 3 is located on the far-right side of the photograph and shares a border with formation 1, the ceiling, and the rock polygon. Void 3 was gazed upon only 2 times and has an average pixel luminosity value of 14.37 lumens.

Speleothem 2 and the ceiling polygon were viewed by the most participants. Both polygons were attracted the attention of 9 out of the 12 (75%) participants. In terms of individual fixations, speleothem 2 received 27 focal fixations and the ceiling received 15 focal fixations. The second most viewed polygons were speleothem 1 and speleothem 3. Both were viewed by 8 out of the 12 (66%) participants. Speleothem 1 attracted 15 independent focal fixations while speleothem 3 attracted 9 independent fixations.

Table 5: Photograph 0513 Data.

Polygon	Sum of Fixations	Average Pixel Luminosity	Pixel Count	Views by number of Individuals
Floor	4	40.23	52087	3
Ceiling	15	56.74	3057	9
Speleothem 1	13	101.05	16892	8
Speleothem 2	27	118.85	27519	8
Speleothem 3	9	96.84	14224	8
Speleothem 5	0	33.87	2473	0
Void 2	3	16.78	1282	2
Void 3	2	14.37	5322	2
Void 4	9	14.77	6457	5
Void 5	9	21.12	5440	7
Void 6	0	17.33	42.59	0
Rock	0	40.27	887	0
Rock 1	0	56.37	742	0
Rock 3	0	80.21	1518	0
Rock 2	4	57.8	3348	4

Figure 10. Photograph 0513.

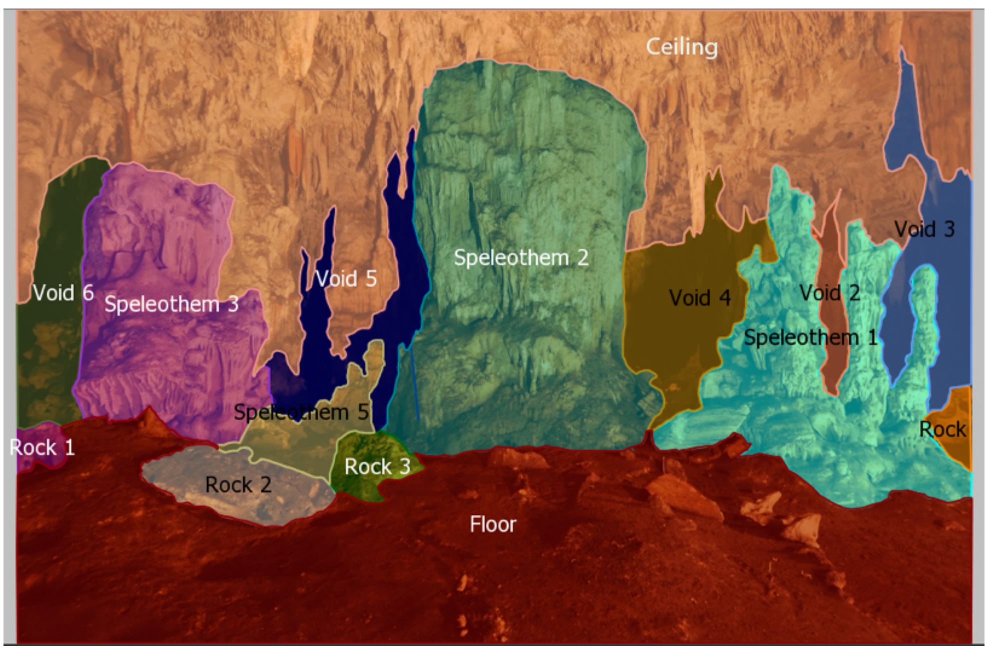

Figure 11. Photograph 0513 AOI Polygons.

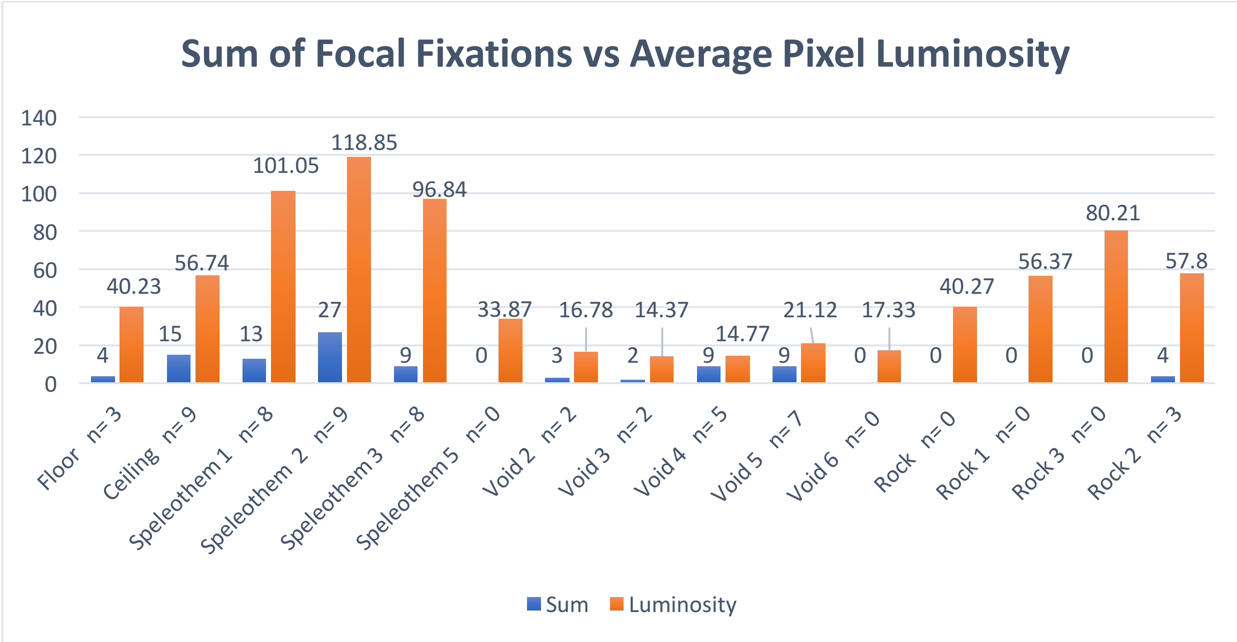

Figure 12. Sum of fixations vs average pixel luminosity for photograph 0513. N indicates the number of individuals that viewed the feature.

Photograph 0631

Photograph 0631 was partitioned into 14 different polygons. Of the polygons 7 of which are speleothems; 3 voids; 2 ceilings, and 2 floors. In the middle of the photograph is a large speleothem conglomeration. This speleothem conglomeration represents six of the seven speleothem polygons. The conglomeration is made up of several dozens of different drip formations, all growing out of what is more than likely a large bedrock outcrop on the cave floor. These formations range in color and shape as well as have formed consistently along some form of drip pattern, resulting in the conglomeration being broken up into six polygons.

Speleothem 4 is the middle left portion of the speleothem conglomeration. It is distinct from the other formations in this conglomerations by an average pixel luminosity value of 149.27 lumens. It also has distinct morphology in that this portion of the conglomeration has a steeper face that intersects with areas of the conglomeration that have much less steep slope. This dramatic change in slope angle creates a visible “cliff like” effect. Several small stalagmites that are no taller than a foot and a half are also growing out of formation 4. This average pixel luminosity value of 149.27 lumens for formation 4 as well as the steep slope of the formations face create a strong contrast to the surrounding parts of the conglomeration as well as the rest of the objects in the photograph.

Ceiling 1 is on the right side of the photograph and is characterized by a portion of the cave wall in the background of the photograph. The polygon is one of the more darker parts of the photograph with an average pixel luminosity value of 38.16 lumens. This portion of the cave is lacking in visual complexity and is devoid of formations or anything growing on the bare rock wall. Most of the focal fixations are along the border shared with the very luminous speleothems 4 and 6.

Void 3 had 12 focal hits and an average pixel luminosity value of 31.4 lumens. Void 3 is a darkened area to the right side of the screen. Ceiling 2 and formation 3 are immediately to the left and creates a graduated luminosity contrast with them. A decorated portion of the caves back wall can barely be made out though the darkness of the void, but are still visible. This decorated portion of the wall, even though the speleothems are not as visually prominent as they are in other parts of the photograph, is probably what drew the focal attention of the participants.

Speleothem 1 is a large collection of small stalactites that are growing from the ceiling of the cave and directly above the large speleothem conglomeration that is made up by formations 2, 3, 4, 5, 6, and 7. Speleothem 1 and the speleothem conglomeration more than likely formed from the same drip flow and will one day meet to form a large speleothem column. Speleothem 1 has an average pixel luminosity value of 80.83 lumens and received 18 focal fixations from the participants. It is boarded to the left by ceiling 1, to the right by void 3, and to the bottom by the speleothem conglomeration. The bulk of the speleothem is center right of the picture. The visual patter created by the high concentration of stalactites is unique in the photograph and creates a visual texture contrast to the bare rock cave walls in the ceiling 1 polygon.

Speleothem 4 was the most viewed polygon in photograph 0631 and attracted the attention of 10 out of the 12 (83%) participants, while receiving 24 independent focal fixations. Speleothem 1 and speleothem 3 were viewed by 8 out of the 12 (66%) participants, making them the second most viewed polygons. Speleothem 3 and speleothem 8 received 18 and 17 independent focal fixations, respectively. The third most viewed polygon was ceiling 1 with 7 out of the 12 (58%) participants viewing it. This is particularly notable since ceiling 1 also attracted a total of 21 independent focal fixations.

Table 6: Photograph 0631 Data.

Polygon	Sum of Fixations	Average Pixel Luminosity	Pixel Count	Views by Number of Individuals
Speleothem 1	18	80.83	27107	8
Speleothem 2	4	66.69	13094	4
Speleothem 3	17	83.29	14055	8
Speleothem 4	24	149.27	10508	10
Speleothem 5	5	108.95	1006	2
Speleothem 6	2	130.11	10656	2
Speleothem 7	0	65.42	1979	0
Speleothem 8	0	68.65	828	0
Ceiling 1	21	38.16	40733	7
Void 1	3	22.23	654	3
Void 2	0	25.9	414	0
Void 3	12	31.4	26612	6
Floor 1	3	64.35	21270	2
Floor 2	3	37.31	23622	3

Figure 13. Photograph 0631.

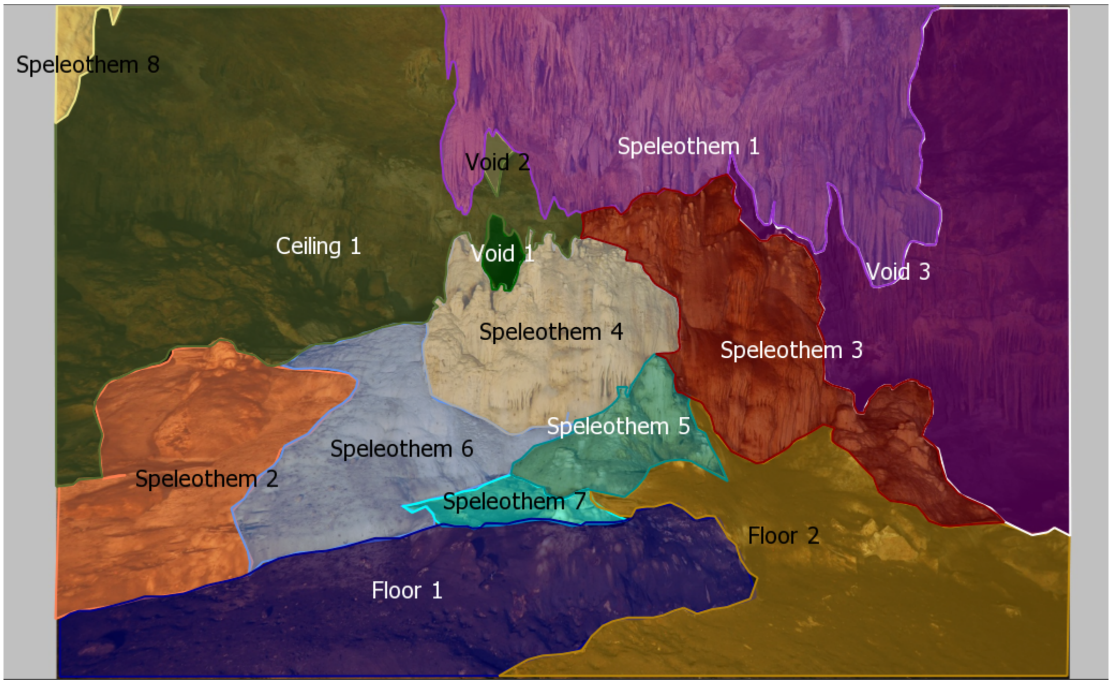

Figure 14. Photograph 0631 AOI Polygons.

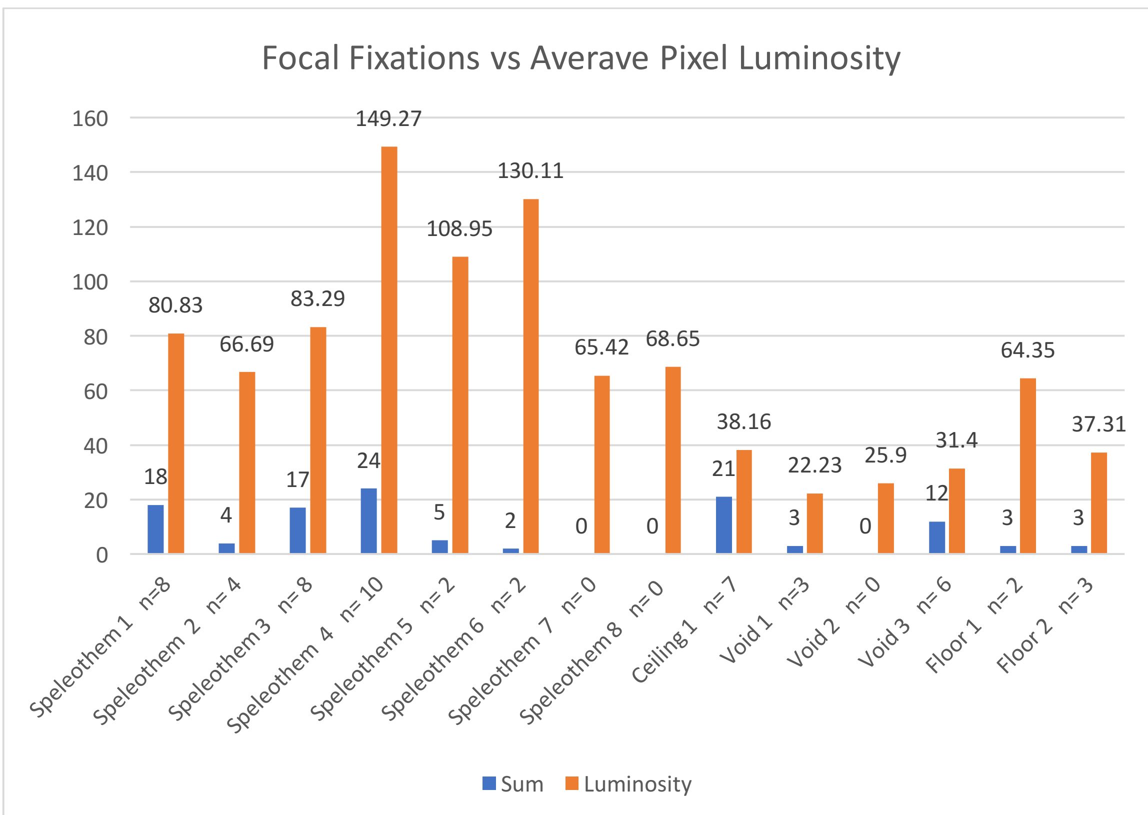

Figure 15. Sum of fixations vs average pixel luminosity for photograph 0631. N indicates the number of individuals that viewed the feature.

Photograph 0652

Picture 0652 is of the largest entrance chamber of Ofrenda cave. Photograph 0652 was partitioned into 11 different polygons, all based on likeness of physical and visual characteristics. Two ceilings, seven speleothem formations, one void, and the floor of the cave. Ceiling 2 received the most fixations with 36 focal fixations and has an average pixel luminosity value of 68.9 lumens. Ceiling 2 is also the largest polygon of the photograph, containing 48269 pixels. Ceiling 2 polygon is bordered by speleothem 5, speleothem 2, speleothem 1, speleothem 6, and ceiling 1.

Speleothem 2 is a large speleothem flowstone located in the far-left side of the photograph. It was focused on 20 times and has an average pixel luminosity value of 123.58 lumens. The polygon is bordered by speleothem 5, ceiling 2, speleothem 1, and the floor polygons.

Ceiling 1 is large portion of the cave wall and can arguably be identified as the start of the twilight zone of the cave. It received 19 focal fixations from the participants and has an average pixel luminosity value of 35.7 lumens. This part of the cave wall is mostly composed of bare cave wall and has a few small formations. The ceiling 1 polygon is bordered by speleothem 6, ceiling 2, speleothem 7, speleothem 4 and speleothem 3.

Speleothem 6 is a tall speleothem column located in the middle right of the photograph. It was focused on 14 times by the participants during the first 3 seconds of the experiment and has an average pixel luminosity value of 143.22. The speleothem tapers towards the center and connects the large entrance's tall ceiling to the cave floor. It is bound by ceiling 2, ceiling 1, speleothem 3, and speleothem 1.

Speleothem 7 is a large speleothem column on the far-right side of the photograph. It acquired 14 focal fixations and has an average pixel luminosity of 113.25. It is bound by ceiling 1, speleothem 4, speleothem 3, floor, and completely encompasses void 1 polygon.

Table 7: Photograph 0652 Data

Polygon	Sum of Fixations	Average Pixel Luminosity	Pixel Count	Views by Number of Individuals
Ceiling 1	19	35.7	22420	8
Ceiling 2	36	68.9	48269	12
Speleothem 1	1	99.37	16038	1
Speleothem 2	20	123.58	21772	8
Speleothem 3	4	141.82	3696	4
Speleothem 4	2	73.73	4976	2
Speleothem 5	0	78.9	4336	0
Speleothem 6	14	143.22	6670	10
Speleothem 7	14	113.25	24289	7
Void 1	0	20.3	1406	0
Floor	1	116.72	22648	1

Figure 16. Photograph 0652.

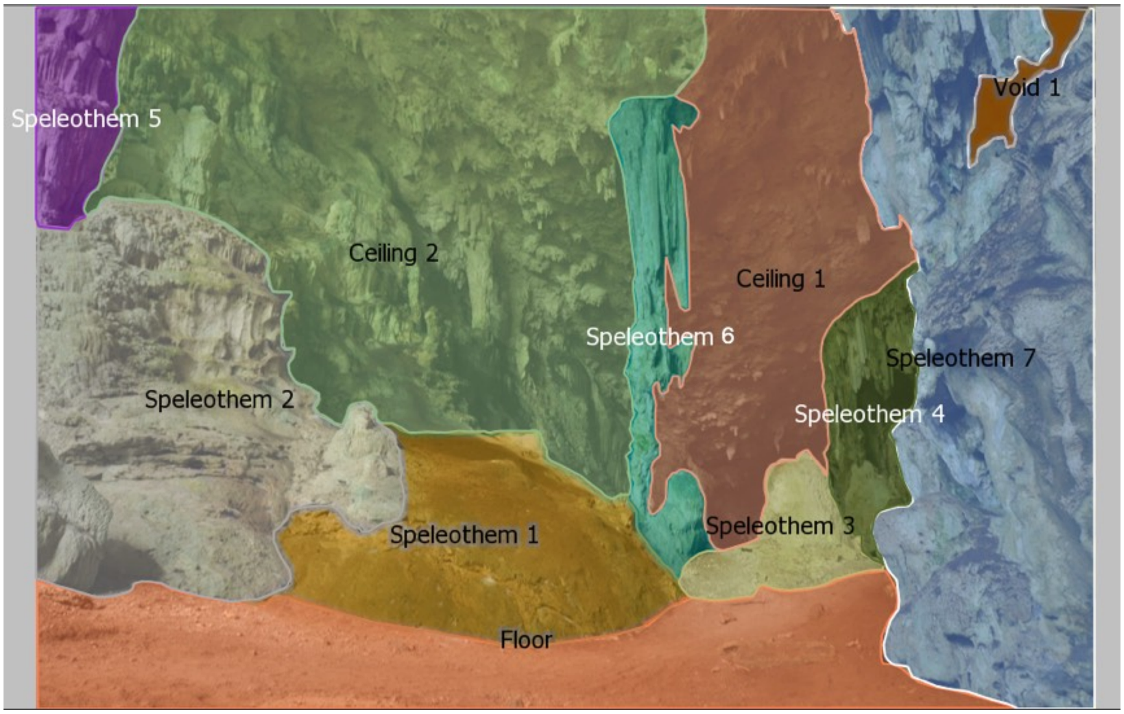

Figure 17. Photograph 0652 AOI Polygons.

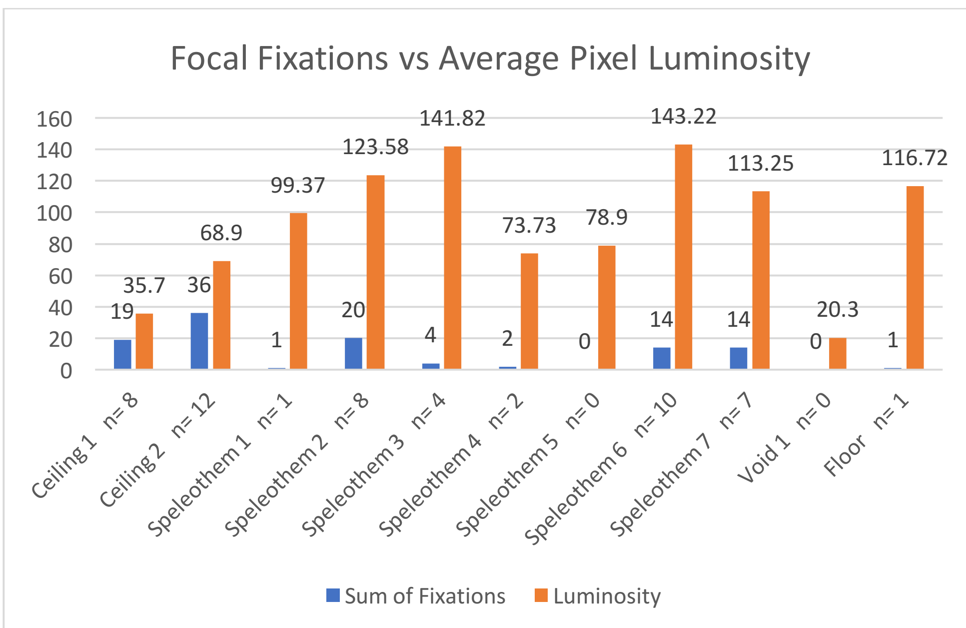

Figure 18. Sum of fixations vs average pixel luminosity for photograph 0652. N indicates the number of individuals that viewed the feature.

Photograph 0639

Photograph 0639 was taken in the large entrance chamber of Ofrenda cave. The photograph was broken up into twelve polygons with each polygon containing like visual elements. Six speleothem polygons, four ceiling polygons, one rock polygon, and one void polygon were created. Photograph 0639 is a visually complex image. Every space in this photograph is decorated in one way or another, resulting in a high degree of visual textures and complexity.

The ceiling 1 polygon received the most focal fixations of the photograph with 46 fixations and registered an average pixel luminosity value of 88.34 lumens. Ceiling 1 is defined by a series of medium sized stalactites growing out of the cave's ceiling. It is framed by ceiling 4 above, ceiling 1 to the left, speleothem 5 to the left, speleothem 8 below, ceiling 5 to the right, and speleothem 9 to the right.

Ceiling 6 was focused on the second most, with 29 fixations and has an average pixel luminosity value of 69.29 lumens. This formation lies in the center of the photograph and is immediately below the ceiling 1 polygon. It is above speleothems 3, 2, and 1. Ceiling 6 is defined by a noticeable lack of speleothems and brown and white mottling of coloration of the bare limestone.

Speleothem 3 received 14 focal fixations and had an average pixel luminosity value of 90.68 lumens. It is also made up of 34670 pixels. Speleothem 4 is a large flowstone with several stalagmites growing from it. The outer layer of calcite covering the flowstone is has a rippled texture and is clean of mud and guano in several places, giving it a high luminosity value.

Speleothem 1 is a large stalagmite located in the bottom right corner of the photograph. It received only 6 fixations yet had an average pixel luminosity value of 120.53 lumens, which was the highest value of the photograph. It is boarded by void 1 to the left and void 2 from above. It also shares a small boarder with the furthest right side of ceiling 2.

Speleothem 2 is a limestone boulder that has some speleothem growth. It received only 5 focal fixations and has an average pixel luminosity value of 106.57 lumens. It is located at the bottom center right of the photograph and is very close in proximity to speleothem 1. Speleothem 2 is mostly surrounded by void 1 from the sides and the top. A sliver of an extension of speleothem 3 separates most of speleothem 2 from the bottom edge of the photograph.

Ceiling 2 was the most looked at polygon. It was viewed by all the participants and received 29 independent focal fixations. Ceiling 1 was looked at the second most and was viewed by 10 out of the 12 (83%) participants. It had also received 46 independent focal fixations.

Table 8: Photograph 0639 Data.

Polygon	Sum of Fixations	Average Pixel Luminosity	Pixel	Number of Individual Views
Ceiling 1	46	88.34	47191	10
Ceiling 2	29	69.29	20999	12
Ceiling 3	0	48.82	9007	0
Ceiling 4	2	77.67	8096	2
Ceiling 5	3	80.96	15953	2
Speleothem 1	6	120.53	12972	5
Speleothem 2	5	106.57	6051	4
Speleothem 3	14	90.68	34670	8
Speleothem 4	3	65.68	20262	3
Speleothem 7	0	50.53	6970	0
Void 1	3	35	11365	3
Rock	0	58.74	2733	0

Figure 19. Photograph 0639.

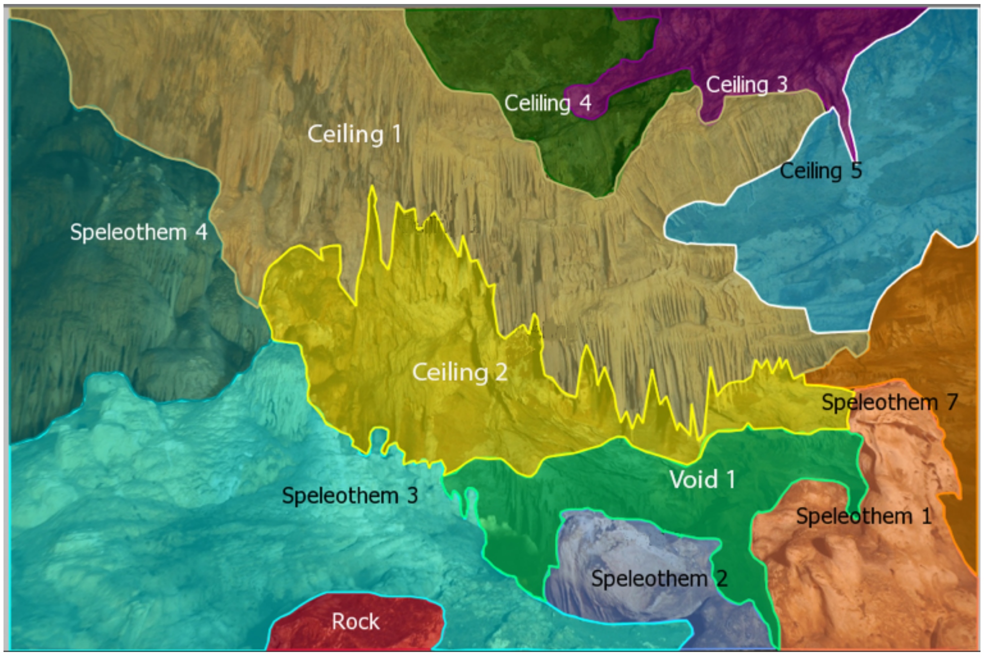

Figure 20. Photograph 0639 AOI Polygons.

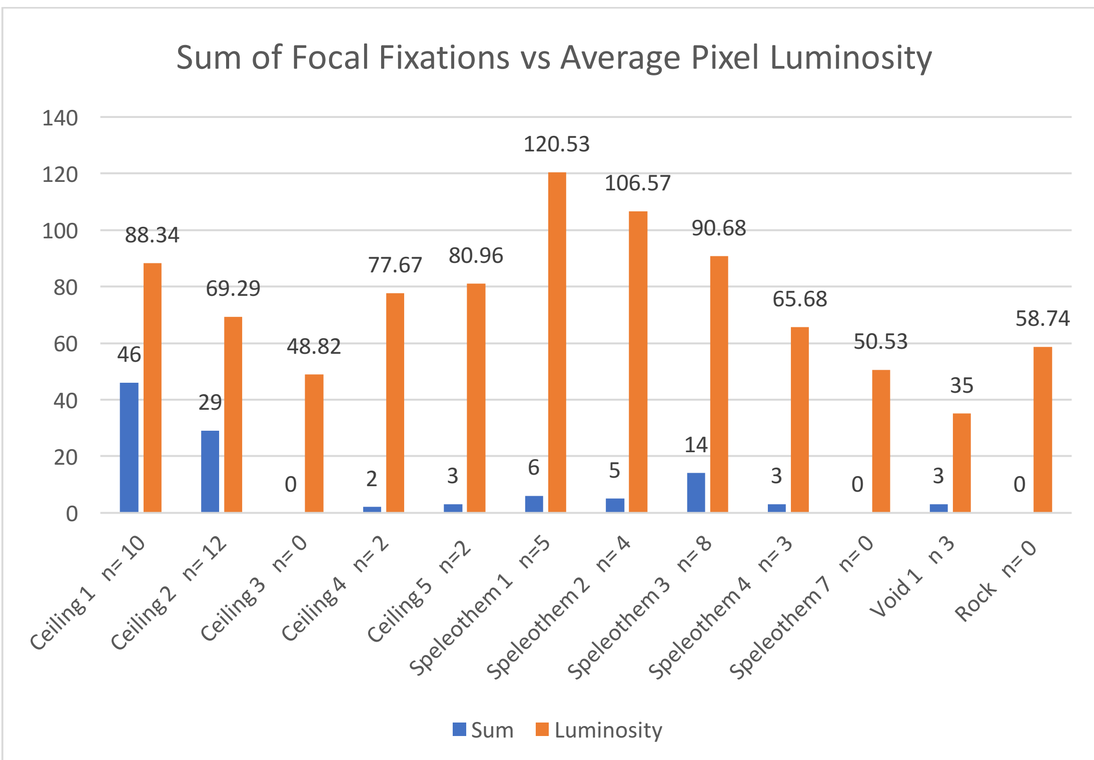

Figure 21. Sum of fixations vs average pixel luminosity for photograph 0639. N indicates the number of individuals that viewed the feature.

Photograph 1015

The photograph was broken up into 17 different polygons. The ceiling 1 polygon received 31 fixations and had an average luminosity value of 96.67 lumens. It is surrounded by the ceiling 2 polygon from above and ceiling 4, speleothem 3, ceiling 5, speleothem 6, speleothem 4, void 5, and ceiling 3. The ceiling 1 polygon is defined by a series of medium sized stalagmites across the upper portion of the photograph.

Speleothem 4 attracted 14 focal fixations and had an average pixel luminosity of 74.7 lumens. The polygon is the upper most section of a larger speleothem column that also comprises the speleothem 6 and speleothem 5 polygons. The speleothem 4 polygon is light in color and has a smooth texture, making it visibly distinct from the other polygons that make up the rest of the speleothem column. It is bordered by ceiling 3, void 3, speleothem 5, and speleothem 6.

Ceiling 2 is a section of the cave ceiling that is absent of speleothems and has a yellow and orange mottled color. It is surrounded by the ceiling 1 polygon and is located at the far top of the photograph. Ceiling 2 has an average pixel luminosity value of 115.27 lumens and received a total of 9 focal fixations.

Speleothem 3 has an average pixel luminosity of 87.39 lumens and received 8 focal fixations during the first 3 seconds of recording: The polygon is defined as by a large speleothem column that is conjoined to a large flowstone base. Several stalagmites are growing out from the larger flowstone base. Speleothem 4 is bordered by ceiling 1, ceiling 5, void 2, speleothem, ceiling 4, void 1, and the floor polygon.

Ceiling 1 polygon received the most views with 9 out of 12 (75%) participants looking at it within the first three seconds of recording. Ceiling 1 also attracted 31 independent focal fixations. The second most viewed polygon was speleothem 4, with 8 out of 12 (66%) participants. Speleothem 4 also received a total of 14 independent focal fixations.

Table 9: Photograph 1015 Data.

Polygon	Sum of Fixations	Average Pixel Luminosity	Pixel	Number of Views by Individuals
Ceiling 1	31	96.67	28921	9
Ceiling 2	9	115.27	17762	5
Ceiling 3	4	35.64	24380	3
Ceiling 4	7	70.23	16557	4
Ceiling 5	5	52.34	3360	3
Speleothem 1	1	67.77	12856	1
Speleothem 2	0	70.73	5778	0
Speleothem 3	8	87.39	33224	5
Speleothem 4	14	74.7	13561	8
Speleothem 5	4	40.75	14614	4
Speleothem 6	5	41.42	8048	4
Void 1	4	8.22	6722	3
Void 2	0	8.57	2101	0
Void 3	2	7.66	3644	1
Void 4	0	11.17	803	0
Void 5	1	21.43	932	1
Floor	0	42.76	3083	0

Figure 22. Photograph 1015.

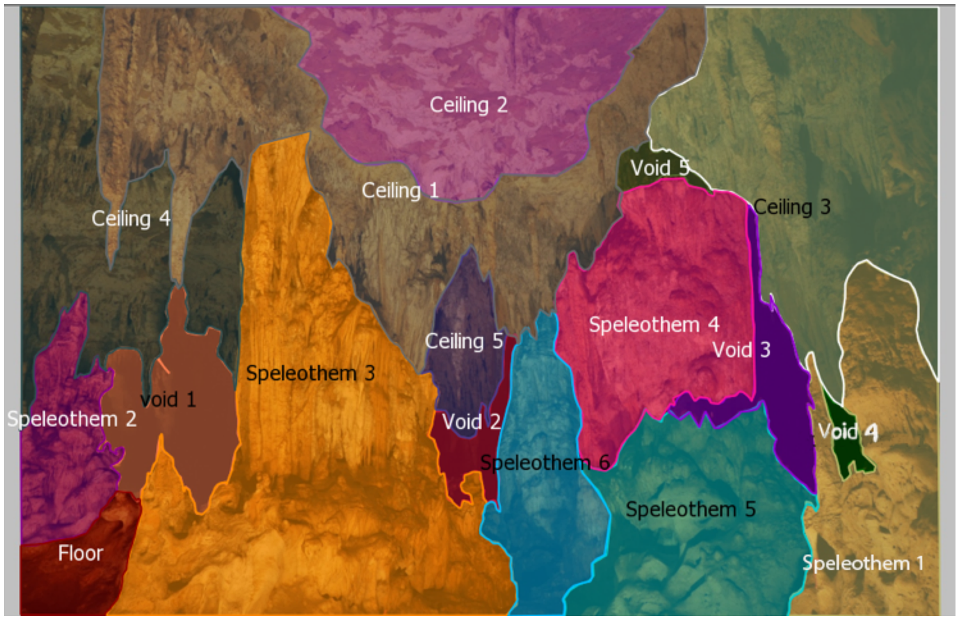

Figure 23. Photograph 1015 AOI Polygons.

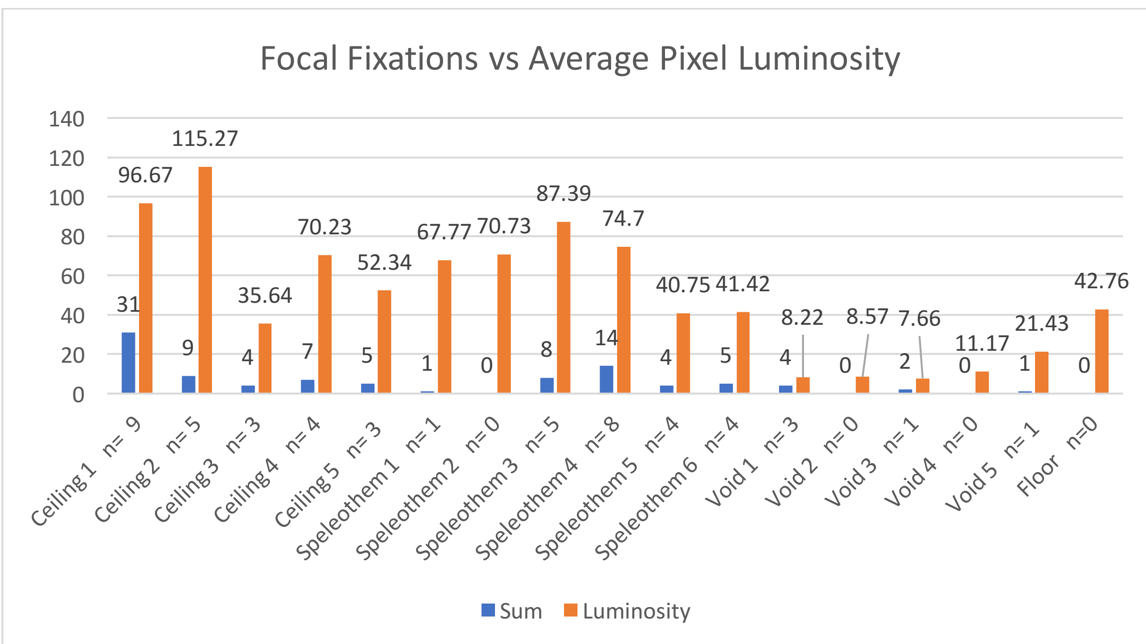

Figure 24. Sum of Fixations vs Average Pixel Luminosity for photograph 1015. N indicates the number of individuals that viewed the feature.

Photograph 9615

The objects within the photograph were broken up into 15 different polygons. Most of the visual fixations are concentrated in the polygons that make up two speleothem columns located at the center right of the photograph and the voids between these two columns.

Speleothem 2 received 22 focal fixations, which is the highest count of the photograph, and has a registered average pixel luminosity value of 68.95 lumens. This luminosity value is low compared to the other polygons in the photograph. Speleothem 2, however, is in the middle of the photograph.

Ceiling 2 has a focal fixation count of 10 and an average pixel luminosity value of 79.14 lumens. Speleothem 1 has a focal fixation count of 14 and an average pixel luminosity value of 135.88 lumens. Speleothem 1 and Ceiling 2 are two parts of one large speleothem column that is located on the right center side of the photograph. The area of the column designated as speleothem 1 is the only part of the column that is below an active drip and is still growing. This active deposition of calcium rich water has given speleothem 1 a white color, which produces a significantly higher luminosity value. Ceiling 2, which is the upper part of the column that connects to the cave's ceiling is no longer growing and has a dulled brownish yellow color, which produces its lower average pixel luminosity value of 79.14 lumens. Ceiling 2 also has several dozens of dead small stalactites that were once part of the same drip flow that form the ceiling 2/speleothem column. The speleothem 1/ceiling column is also framed by void 3 to the left and void 2 to the right. Void 3, which has an APL value of 29.65 and void 2, which has an average pixel luminosity of 22.84 lumens are both substantially lower than the average pixel luminosity value of speleothem 1/ceiling 2 formation.

Void 3 registered 19 focal fixations and an average luminosity value of 29.65 lumens. It is bound by ceiling 2, speleothem 3, and speleothem 2.

Speleothem 3 has 9 focal fixations and an average luminosity value of 62.86 lumens. Speleothem 3 is also physically associated with the speleothem 1/ceiling 2 formation. From the perspective of the viewer, speleothem 3 is growing out the same base as speleothem 1/ceiling 2 column but appears to split off and form it's on large stalagmite. However, this is an illusion created by a shadow casted by a bulbous portion of speleothem 1/ceiling 2.

Floor 4 was viewed 2 times during the first three seconds of the experiment. It is located at the far bottom left side of the photograph. It has a high average pixel luminosity value of 128.5 lumens and is framed by the much darker floor 5 polygon, which has an APL of 46.9 lumens.

Speleothem 2 was the most viewed polygon, with attracting the attention of 11 out of the 12 (91%) participants. It also had attracted 20 independent focal fixations. The second most viewed polygon was void 3, with views from 10 out of the 12 (83%) participants. Void 3 had also acquired 19 independent focal fixations.

Table 10: Photograph 9615 Data.

Polygon	Sum of Fixations	Average Pixel Luminosity	Pixel Count	Number of Individual Views
Void 1	2	27.72	13142	1
Void 2	2	22.84	18221	2
Void 3	19	29.65	17839	10
Void 4	1	14.52	2248	1
Speleothem 1	14	135.88	22355	9
Speleothem 2	20	68.95	14234	11
Speleothem 3	9	62.86	13103	6
Speleothem 4	2	64.24	8320	2
Floor 1	4	45.411	27933	3
Floor 2	2	40.26	1300	1
Floor 4	2	128.5	8382	1
Floor 5	0	46.9	18954	0
Ceiling 1	8	100.78	62071	5
Ceiling 2	10	79.14	27345	5
Rock	3	69.96	1778	3

Figure 25. Photograph 9615.

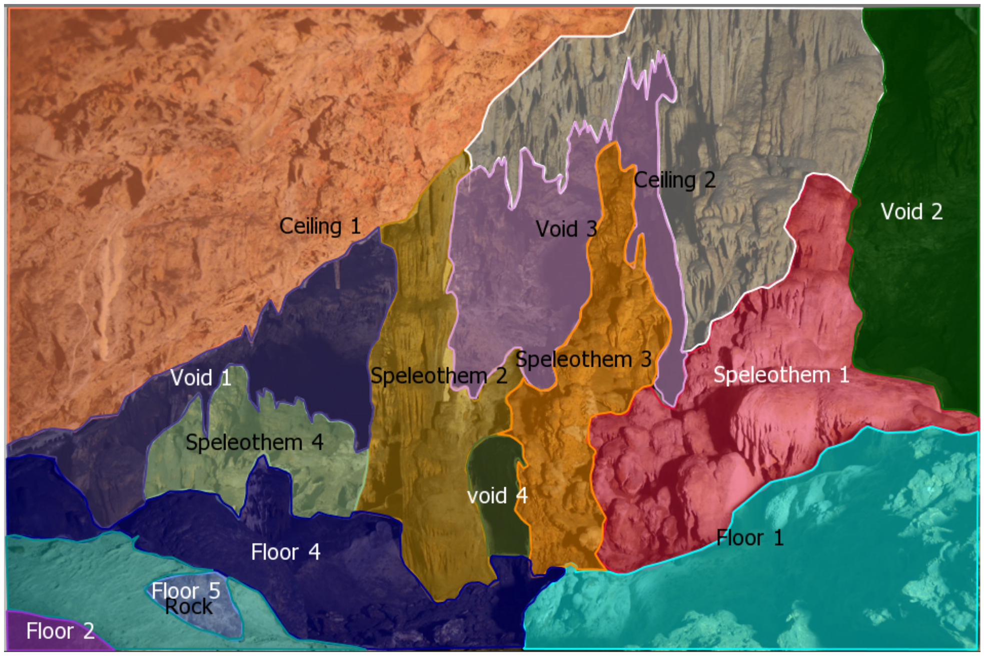

Figure 26. Photograph 9615 AOI Polygons.

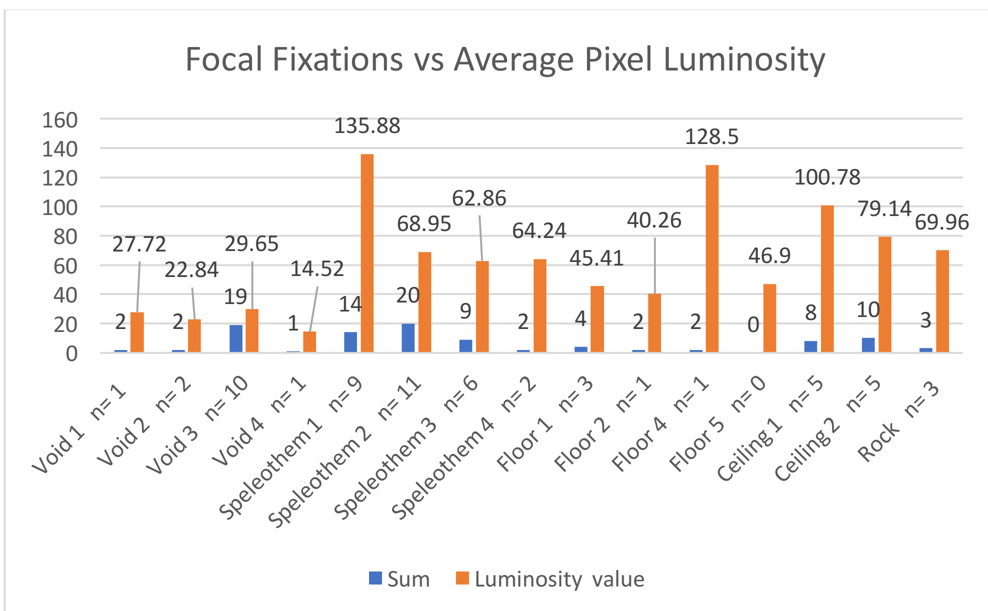

Figure 27. Sum of focal fixations vs average pixel luminosity of photograph 9615. N indicates the number of individuals that viewed the feature.

Photograph 0520

Photograph 0520 was taken in chamber 6 of Ofrenda cave and is facing the south-east wall. For the purpose of analysis, the photograph was broken up into 18 polygons, grouping objects in the photograph based on likeness of visual characteristics. Of the 18 polygons, 7 were identified as voids, 6 were speleothems, 2 were ceilings, one rock, and one floor.

Speleothem 3 is a speleothem column that connects the ceiling to the floor. The base of the column is wide and includes several weathered medium sized stalagmites. It is bordered by speleothem 2, void 4, ceiling 2, void 5, and the floor polygons. Speleothem 3 received 26 focal fixations during the first three seconds of the experiment and has an average pixel luminosity value of 83.33 lumens. A significant portion of speleothem 3 is in the center of the photograph.

Speleothem 2 received 12 focal fixations and has an average pixel luminosity value of 93.47 lumens. Speleothem 2 is a heavily weathered stalagmite located near the center of the photograph. It is surrounded by the ceiling 1, void 4, speleothem 3, and floor polygons. The void 1 and void 2 polygons are located within the speleothem 2 polygons.

Ceiling 2 polygon represents the ceiling portion of the cave's wall in chamber 6. It received 11 focal fixations during the first three seconds of the experiment and has an average pixel luminosity value of 92.11 lumens. It is made of 41169 pixels and is the second largest polygon in the photograph. Several dozens of small stalactites can be seen growing from this section of the cave ceiling.

Ceiling 1 polygon needs to be changed to speleothem 8. It received 8 focal fixations during the first three seconds of recording and has an average pixel luminosity value of 69.74 lumens. Speleothem 8 is a large speleothem column that contains 38633 pixels. It located on the far-left side of the photograph and is bordered by ceiling 2, void 4, speleothem 2, and the floor polygons.

Speleothem 3 received the most views with attracting the attention of 9 out of the 12 (75%) participants. It also acquired a total of 26 focal fixations. The second most viewed polygons were ceiling 2 and speleothem 2. Both were viewed by 7 out of the 12 (58%) participants, and had received 11 and 12 independent focal fixations, respectively.

Table 11: Photograph 0520 Data

Polygon	Sum of Fixations	Average Pixel Luminosity	Pixel count	Number of Individual Views
Void 1	2	22.8	287	2
Void 2	0	33.14	3053	0
Void 3	2	11.98	5712	1
Void 4	6	33.14	3053	4
Void 5	1	22.99	4619	1
Void 6	0	34.08	23.79	0
Void 7	0	34.53	5954	0
Void 8	4	20.01	17.13	4
Ceiling 2	11	92.11	41169	7
Speleothem 1	2	86.13	6853	1
Speleothem 2	12	93.47	8255	7
Speleothem 3	26	83.33	14524	9
Speleothem 4	0	203.85	447	0
Speleothem 5	8	45.14	1854	6
Speleothem 6	0	104.31	2988	0
Speleothem 7	8	69.74	38633	6
Floor	2	27.94	46630	2
Rocks	3	43.26	10338	3

Figure 27. Photograph 0520.

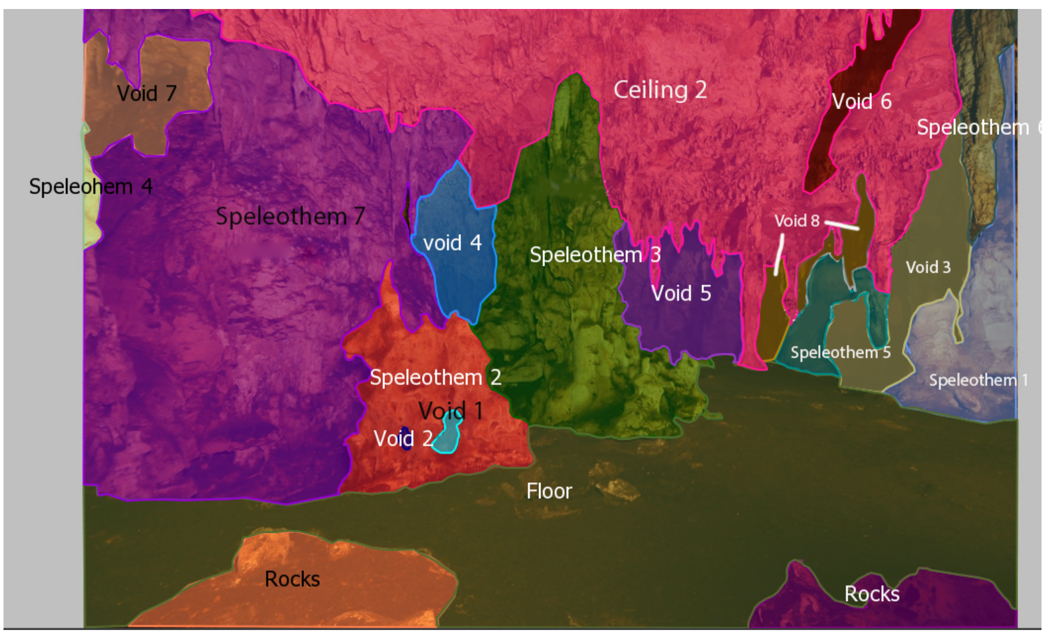

Figure 28. Photograph 0520 AOI Polygons.

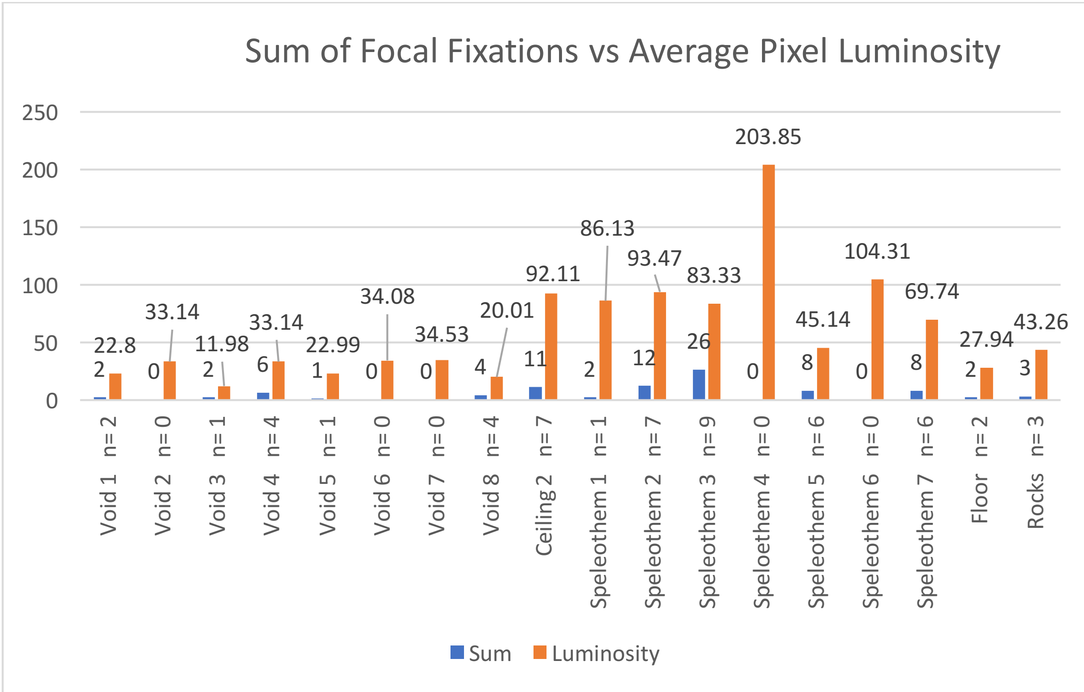

Figure 29. Sum of fixations vs average pixel luminosity for photograph 0631. N indicates the number of individuals that viewed the feature.

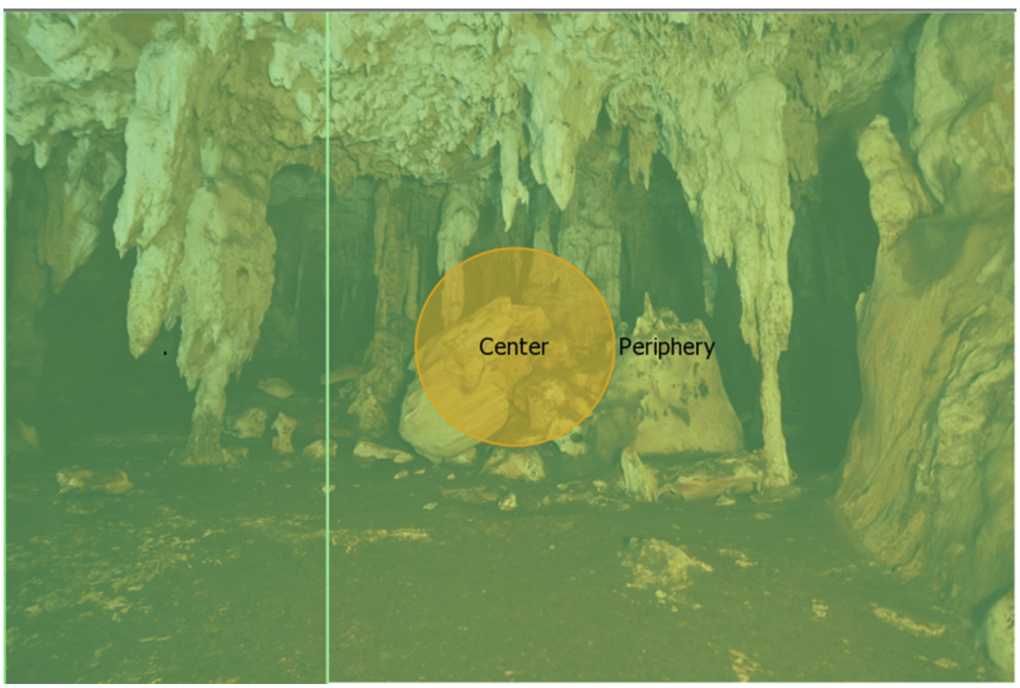

Figure 31. Photograph of center and periphery AOIs.

Table 12: Center bias results for each photograph.

Center Bias Results			
Photograph	Center AOI Focal Fixation Counts	Peripheral AOI Focal Fixation Counts	Percentage of Focal Fixation Counts within Center AOI
0504	2	9	11%
0520	5	4	56%
0639	4	7	36%
0652	6	7	46%
9615	5	5	50%
0476	1	11	8%
0513	1	9	10%
0631	2	9	18%
1015	0	9	0%
0442	1	10	9%

Chapter 5

Analysis

In this chapter, the individual photographs will be analyzed. The relationships of contrasting orientation, luminosity, and pixel size of individual polygons to the other polygons represented in the photograph will be explored. Next, the aggregated data from all the photographs will be analyzed and discussed. For the aggregated analysis, the average pixel luminosity, focal fixation counts, and pixel counts of all the polygon types from the individual photographs were combined to create a comprehensive data set. The data for the average pixel luminosity, focal fixation counts, and pixel counts were grouped by their respective polygon types and averaged. The averaged data was then analyzed through linear regression analysis to determine the predictability of the relationships between focal fixation counts and luminosity of the polygon types.

Analysis of Individual Photographs

Photograph 0442

The r correlation coefficient of all participant fixation data calculated with the average pixel luminosity of the partitioned objects for photograph 0442 was .173, resulting in a weak positive correlation. Speleothem 5 received 11 focal fixations, was viewed by 9 individuals, and had an APL of 110.25 lumens. Speleothem 5 is a fallen section of a large speleothem. It rests on top of an amorphous speleothem conglomeration. The other objects in this amorphous speleothem conglomeration share similar luminosity values, but are not as high as that of speleothem 5. Speleothem 5 has a notably different orientation to the other objects in the photograph. Most the other objects featured in photograph 0442 are orientated either parallel or perpendicular to the ground. After falling from either its base or anchor in the ceiling, speleothem 5 rested partially on the amorphous speleothem conglomeration, resulting in the speleothem resting at about 30 degrees parallel to the cave floor. This 30-degree orientation is visibly noticeable not only because one end rests higher than the other, but because the prominent drip striations that were created while the formation was growing are now at an approximate 30-degree angle to the horizon. Orientation contrast between an object and the other objects in the environment is one of the components of visual saliency theory, and provides an explanation as to why speleothem 5 drew the attention of the participants (Itti and Koch 2001).

Speleothem 5 is a part of a greater speleothem conglomeration that is in the center of the photograph. Speleothem 4, 5, 6, 8, and 9 are the other designated polygons that make up the speleothem conglomeration. Speleothem 5 received a higher number of fixations than the other polygons that make up the speleothem conglomeration; with speleothem 4 receiving 4 fixations; speleothem 6 receiving 9 fixations; speleothem 8 receiving 5; and speleothem 9 receiving 7 fixations. In total, the speleothem conglomeration was focused on by the participants 26 times. The average pixel luminosity range of these polygons fell between 71 lumens to 110 lumens.

The rest of the conglomeration attracted more visual fixations than the other polygon objects in the photograph. The conglomeration is also surrounded by voids the left and right as well as the large and relatively visually simple floor immediately below. These bordering polygons have a significantly lower luminosity rating and create a surrounding contrast to the conglomeration's luminosity. To the left of the conglomeration, void 3 received 11 focal fixations and an average pixel luminosity of 18.85 lumens; void 2 with 4 focal fixations and a APL of 17.31 lumens; void 5 with 2 focal fixations and APL of 26.1 lumens; Void 6 with 4 focal fixations and a APL of 13.56 lumens; and the floor with 10 focal fixations with a APL of 40.71 lumens.

Twenty total visual fixations for the speleothem conglomeration. The surrounding voids and floor have a total number of 30 fixations, a third of which belong to the floor polygon. The collective pixel average luminosity of the speleothem conglomeration is 362.06 lumens and the total luminosity of the bordering polygons is 116.53 lumens. Together, the speleothem conglomeration and the surrounding polygons create a highly luminous object that is surrounded by polygons that exhibit significantly less luminosity. This relationship between the conglomeration and the surrounding void creates a significant contrast in luminosity, which in turn makes the speleothem conglomeration and the surrounding voids/floor significantly visually salient.

The relationships between the speleothem conglomeration and the surrounding voids creates an area of localized contrast in the photograph. The voids create a darker area of low average pixel luminosity values around the much more luminous speleothem conglomeration. This gradient of low luminosity to high luminosity generates a visual contrast that is limited to this area of the photograph, which is a likely contributing factor to this part of the photograph attracting most the participant's focal gaze. The same localized contrast also occurs with the neighboring speleothem 3 and voids 1 and 2.

Photograph 0504

The Pearson's r coefficient between visual fixations and average pixel luminosity has a positive linear correlation of .447. All the speleothem polygons this photograph fall within a tight APL range, with speleothem 1 having an APL of 96.19 lumens, speleothem 2 having 100.72 lumens, and speleothem 3 having 85.82 lumens. Speleothem 1 attracted the most fixations not because it had a high luminosity value, the highest being speleothem 2, but because it is a large, visually imposing formation made up of 59057 pixels. A significant portion of the formation is also visually simplistic. 4/5ths of the formation has the appearance of being extremely weathered and smooth. This smooth texture quality is in stark contrast to the rest of the formations that have a very sharp and visually complex appearance. Most of the participant's fixations that fell within the boundaries of speleothem 1 were focused on an area the size of a basketball where the most recent layer of speleothem growth had been broken off, revealing a darker part of the formation. This part of the formation is not only darker than the rest of the formation but also breaks the otherwise consistent texture of the formation and creates a localized contrast.

Speleothem 2 has three stalactites growing out of the base are all bound and defined by void 1, 2, and 3. The average pixel luminosity value of these voids are 23.85 lumens (void 1), 22.67 lumens (void 2), and 19.63 lumens (void 3). The low average pixel luminosity value of these also creates a dramatic contrast to the highly luminous columns and base of speleothem 2. Speleothem 2 is also centrally located in the picture, which could have influenced its high fixation number.

Photograph 0476

The Pearson's r coefficient between the average pixel luminosity value of the polygons and the number of focal fixations within the boundaries of the polygons was -0.179. Despite the extremely weak negative r coefficient, a rational explanation for understanding why people looked where they look can be gathered. Ceiling 2, even though it has an average pixel luminosity value of 43.26 lumens, acquired 26 focal fixations, making it the most fixated polygon of the photograph. Closer inspection of the data shows that most of those 26 focal fixations occurred within the most right portion of the polygon, which is bounded by speleothem 7 to the right and speleothem 2 to the left. Speleothem 7 and speleothem 2 have greater average pixel luminosity values than ceiling 2, with speleothem 7 having a value of 92.03 lumens and speleothem 2 having a value of 78.87 lumens. This difference creates a localized contrast of luminosity values, which in turn attracts focal fixations.

Speleothem 7's received the second highest fixation count with 18 focal fixations and had the third highest average pixel luminosity value. Some contrast exists between the series of parallel stalactites that make up the polygon and the floor and ceiling 1 polygons which are mostly absent of objects that would set an orientation pattern. The polygon's high average pixel luminosity value were probably the main contributors to this polygon's high focal fixation count, which is the second highest in the picture.

Photograph 0513

The Pearson's r coefficient between focal fixation count and the average pixel luminosity value was .59, which was the strongest positive correlations of the experiment. This can be explained by the visual qualities of the speleothems and the dark voids. The speleothems that attracted most the fixations were relatively clean and absent of dirt and mud. Each of the speleothems were also bound by dark voids. The arrangement between the voids and the speleothems are along the center horizon of the photograph and are bound by equally large polygons at the top, ceiling, and the bottom, floor, of the photograph. When looked at holistically, the collective image is a series of alternating speleothems and voids that are "sandwiched" between the visually homogenous floor and ceiling polygons. This layout results in a contrasting pattern of void 6; speleothem 3; void 5; speleothem 2; void 4; speleothem 1; void 2; speleothem 1 again; and void 3. A contrasting affect is responsible in part for these high numbers when the surrounding polygons are taken into considerations. Void 4 and void 5 registered very low average pixel luminosity values with 14.77 lumens and 21.12 lumens, respectively. These low APL values are contrasted with the high 118.85 lumens of speleothem 2.

Photograph 0631

Pearson's r for the correlation between number of focal fixations and average pixel luminosity was .015, depicting a weak positive correlation. In the center of the photograph is a speleothem conglomeration that was partitioned into the polygon formations 3, 4, 5, and 6. 52 of the 112 participant focal fixations were within the boundaries of the polygons and the average pixel luminosity value of these polygons ranged from 83 lumens to 149 lumens. The ceiling 1, void 3, void 1, floor 1, floor 2, and floor 1 are the surrounding polygons and completely encompass the speleothem conglomeration. As previously stated, the average pixel luminosity value of the polygons surrounding the speleothem conglomeration are significantly less, ranging from 22.23 lumens to 64 lumens. This creates a strong luminosity contrast between the speleothem conglomeration and its surrounding environment. This contributed to almost half of the total fixations being acquired by the conglomeration.

Speleothem 1 received 18 focal fixations counts and was viewed by 8 individuals. This might have to do with the localized contrast of object orientation. The defining character of speleothem 1 is a compact concentration of medium sized stalactites. These stalactites are well defined and point downward. The surrounding polygons of ceiling 1, speleothem 4, and speleothem 3 lack the visual complexity of speleothem 1, creating a localized contrast of orientation.

Photograph 0652

Pearson's r for the correlation between number of focal fixations and average pixel luminosity was .113, showing a weak positive correlation. The ceiling 2 polygon received the most focal fixations, 36, yet has no apparent visual qualities that would make it more salient than the rest of the polygons in the photograph. A closer inspection as to where the fixations occurred within the ceiling 2 polygon revealed a concentration of fixations toward the right side of the image. The majority of all the focal fixations that occurred while gazing photograph 0652 occurred in the right side of the photograph, which contains polygons speleothem 6, ceiling 2, and speleothem 7. These polygons account for 83 of the total 111 focal fixation counts. The ceiling 1 polygon has an APL of 35.7 lumens, which differs dramatically from the APLs of the surrounding polygons of speleothem 6 (143.22 lumens) and speleothem 7 (113.25 lumens). With only the most far right side of the ceiling 2 being taken into consideration, a pattern of alternating dark and light polygons can be observed, resulting in an area of contrasting luminosity. It is this pattern of contrasting luminosity that drew the focal attention of the participants to this area of the image.

Photograph 0639

Pearson's r coefficient between the number of focal fixations and average pixel luminosity value is .275 for photograph 0639, depicting a weak positive relationship. The ceiling 1 polygon received the most fixations with a total of 46 focal fixations, yet the polygon only had the 4th highest luminosity value of the photograph. However, a localized contrast exists between this polygon and the surrounding polygons. This relationship is not defined by luminosity values but instead by texture and object orientation. Ceiling 1 is surrounded by ceiling 6, 5, 4, and 3. These polygons were defined by lack of prominent speleothems and mostly consisted of mottled bare limestone cave walls, creating a notable contrast to the abundant stalactites that defined ceiling 1. The size and concentration of the stalactites in the ceiling 1 polygon creates a noticeable parallel pattern that distinguishes it from the surrounding bare rock walls.

The ceiling 2 polygon was fixated on 29 times and has the second highest focal count of the photograph. The ceiling 2 polygon, even though it had a low luminosity value, creates a localized contrast with the surrounding polygons with regard to visual complexity. Ceiling 2, as previously described, is lacking in visual complexity when compared to the ceiling 1 and speleothem 3 polygons.

Speleothem 1 and 2 received only 6 and 5 focal fixations, respectively, yet had the two highest luminosity values of the photograph. This could be because of a center bias. Even though these speleothems had the highest luminosity level, and had a localized contrast with voids 1 and 2, their location in the photograph prevented them from drawling the initial attention of the participants.

Photograph 1015

The Pearson's r coefficient between the average pixel luminosity and the focal fixation count was a moderate positive correlation of .599, which was the highest correlation of the study. The ceiling 1 polygon attracted the most fixations with 31 focal fixations, yet had an average pixel luminosity value of 87.39 lumens and surrounded by ceiling 2, ceiling 4, speleothem 3, ceiling 5, speleothem 4, void 5, and ceiling 3. The ceiling 1 polygon is made up of a series of downward facing stalactites that run along most of the length of the photograph. Immediately above ceiling 1 is the polygon ceiling 2, which is comprised of mottled yellow and brown barren rock and contains no stalactites. This dramatic contrast of visual textures most likely helped influence the high concentration of fixations in this area.

Photograph 9615

The average pixel luminosity value and focal fixation count of photograph's polygons had a weak positive Pearson's r coefficient of .25. Speleothem 2 and void 3 received the highest number of fixations with 20 belonging to speleothem 2 and 19 belonging to void 3. Speleothem 1 had the second highest focal fixation count of 14 fixations and had an APL of 135.88 lumens.

The floor 4 polygon received only 2 focal fixations, yet has an APL of 128.5 lumens, which is the second highest in the photograph. The high luminosity value of this polygon can be attributed to the living flowstone that coves this part of the cave floor in the photograph. Living flowstone is made of up deposited calcite, which, when left undisturbed, has a natural brilliant white color. The theory of focal attention being directed to areas of high contrast should have lured the participants focus to this polygon, yet it only received 2 participant fixations during the experiment. I believe this is because of the polygons location in the picture being at the far bottom corner, one the furthest places from the center of the photograph. With all the other complex areas in this photograph, the localized contrast of floor 4 with floor 5 and the high average pixel luminosity of the polygon were not enough to attract the participant's focal attention among the wash of visual complexity with the rest of the photograph.

Photograph 0520

Photograph 0520 had a weak positive r coefficient of .157 for the relationship between the average pixel luminosity and the number of focal fixations. Speleothem 3 acquired 26 focal fixations with an average pixel luminosity of 83.33 lumens and was viewed by 9 different participants. Speleothem 4 had the highest average pixel luminosity of 203.85 lumens, yet was unable to attract the focal attention of any participants. Speleothem 3's high focal fixation count is due to the fact that it is framed by the polygons void 4, void 5, and the floor. Void 4 polygon has an average pixel luminosity of 33.14 lumens, void 5 has an average pixel luminosity of 22.99 lumens, and the floor polygon has an average pixel luminosity of 27.94 lumens. These polygons are also visually simple compared to speleothem 3. Void 5 and void 4 contain faint depictions of formations in the background of the photograph, but are otherwise difficult to notice because of the lack of illumination. The floor polygon contains several rocks at the bottom of the polygon, but the polygon is relatively visually simplistic in the areas that boarder the speleothem 3 polygon. This the lower average pixel luminosity and visual simplicity of the floor, void 4 and void 5 polygons create a stark contrast to the more luminous and visually complex texture of speleothem 3, which in turn attracted the focal fixations of the participants.

Analysis of the individual photographs revealed that the polygons that attracted the most focal fixations within the first three seconds of recording did so because they were part of an area of localized contrast. The polygons that attracted the most focal fixations are the areas that showed contrast of luminosity, orientation, and visual texture.

Analysis of the individual photographs showed that there was a weak Pearson's r coefficient between the APL of the polygons and how many focal fixations the polygons received. However, a pattern did emerge when the locations of the highest focal count polygons within each picture was taken into consideration. The polygons that had acquired the most focal fixations tended to be located immediately adjacent to the polygons that contained contrasting visual qualities. The participant's visual attention was not directed to the speleothem polygon because of the speleothem's high APL value. The participant's focus was directed to the polygon because of how the speleothem contrasted with the less luminous void, resulting in the less luminous void receiving just a s many focal fixation counts as the nearby speleothem. The focal fixations of the participants being directed towards polygons in areas of contrasting APL values was observed in nine of the ten photographs. This same pattern of high focal fixation counts located in areas of contrasting orientation was observed in four out of the ten photographs, and in areas of contrasting texture in three of the ten photographs.

Aggregated analysis

All the data from the individual photographs was aggregated to see what the pixel count, APL, and focal counts relationships were across the speleothem, void, ceiling, floor, and rock polygons. The total sums and averages of the unique APL, fixation counts, and pixel counts of each polygon were calculated and sorted by polygon type and data type. Linear regression models were used to determine the linear relationships between the aggregated averages of the APL, focal fixations, and pixel counts data sets. The numerical range for the pixel size data set was significantly larger than the APL or focal fixation sets, which skewed the results of the linear regression models. Log 10 was used to transform the pixel size data into a more normalized data set which had a similar range to the APL and focal fixation data sets.

Figure 32 shows the linear regression results of the transformed averaged pixel count and the averaged focal fixation count. The speleothem point, void point, and rock point fell close to the line while the floor and ceiling points fell furthest away from the line of best fit. This indicates that the predictability of focal fixations for each polygon type based off the size of the polygon is higher for the rock, void, and speleothem polygons than it is for the floor and ceiling polygons. These results are particularly interesting considering the average pixel size for the floor and ceiling polygons are 25858.6 pixels and 25,193.4 pixels respectively, while the average size of the speleothem, void, and rock polygons are 11549.2, 5686.8, and 1959.3 respectively. Even though the average rock, void, and speleothem polygons are much smaller than the floor and ceiling polygons, the predictability of how many focal fixations they acquired is much stronger than the predictability of the larger floor and ceiling polygons. In other words, the size of the polygon is not a good indicator for predicting how many focal fixations they will acquire.

Similar results were discovered through the analysis of the non-transformed aggregated pixel count data and the aggregated fixation count. Indices were created by dividing the sum of focal fixations by the sum of pixel counts (Table 13), and dividing the sum of individual views by the sum pixel counts. As shown in table 13, the index value of the voids (.000689) and the speleothems (.000676) were similar even though the average size of all the voids was 5686.8 pixels while the average size of the speleothems was 11549.2 pixels. This shows that the participants looked at the voids just as frequently as the speleothems even though the average speleothem took up much more pixel space than the average void. Similar results were also shown when the sum the individual views considered, with the index value of the speleothems being .000415 and the index value of the voids being .000488 (Table 14).

Interestingly, these data show that the predictability of how many focal fixations for both the floor and ceiling polygons are equally weak when the polygon size is taken into consideration. Yet, the total independent view count for the aggregated ceiling polygons was 128 and the aggregated independent view count for the floor polygons was only 38. This discrepancy between the predictability and the actual counts might be because the ceiling polygons generally have a more visually complex texture than the floor polygons. The floors in Ofrenda cave are mostly made of mud. Large speleothems, bedrock outcrops and rocks are resting on the surface or protruding out of the mud, however these objects take up little of the total surface are of the floor polygons. Most of the floor polygons are visually simplistic flat mud surfaces. Ceilings tend to be more visually complex. Even when the ceiling of the cave does not contain any stalactites, the rock is often mottled in different colors or has some sort of visual texture quality, offering a visual stimulus that is more complex than the simple spaces of a mud floor.

Figure 33 shows the linear regression results of the average pixel luminosity and the average focal fixation count. The Pearson's r value of the graph is .54, indicating a moderate positive coefficient. The void, floor, and speleothem points all fell closest to the line of best linear fit, indicating that there is some predictability between how often these polygon types were fixated upon based off how luminous they are. The ceiling and rock polygons fell furthest away from the line of best fit, indicating a lower predictability of focal fixation based off the polygon type's APL. It is interesting because according to this graph, the number of focal fixations for the speleothem and void polygons are equally predictable based off their luminosity values, even though the averaged APL of all the void polygons is 20.44 lumens and the average APL of all the speleothem polygons is 87.34 lumens. This indicates that even though there is a substantial discrepancy between how luminous the average speleothems and voids are, the participants are just as likely to focus on a speleothem as they are to focus on a void.

Figure 34 shows the linear regression results of the transformed averaged pixel count and the average pixel luminosity. The Pearson's r value of this graph is a weak positive .138. This indicates that there is no strong linear relationship between the APL of all polygon types and the pixel size of all the polygons. Once plotted, all the polygon points fell far from the line of best fit. Of the five types the rock, ceiling, and floor polygons fell closest to the line with the void and speleothem polygons falling furthest from the line of best fit. This lack of a predictable relationship between the size and luminosity of the polygons is not surprising considering size and luminosity would logically not have any correlation with each other.

The linear regression analysis of the averaged aggregated data reveals two important points. First, the size of a polygon is not a reliable indicator for predicting focal fixation counts. This seems to be counter intuitive since logic states that the larger an object is, the more visually attractive the object should be. Second, the luminosity of a polygon is a moderately reliable indicator for predicting how often a polygon is fixated upon. Analysis showed that the predictability for the focal counts for the speleothem polygons and void polygons were equal even though they had different luminosity levels. This is especially interesting considering the luminosity is one of the visual qualities used to determine visual saliency in laboratory testing (Findlay and Gilchrist 1998; Harel et al. 2007). This implies that some other factor could be influencing where people are directing their focal attention.

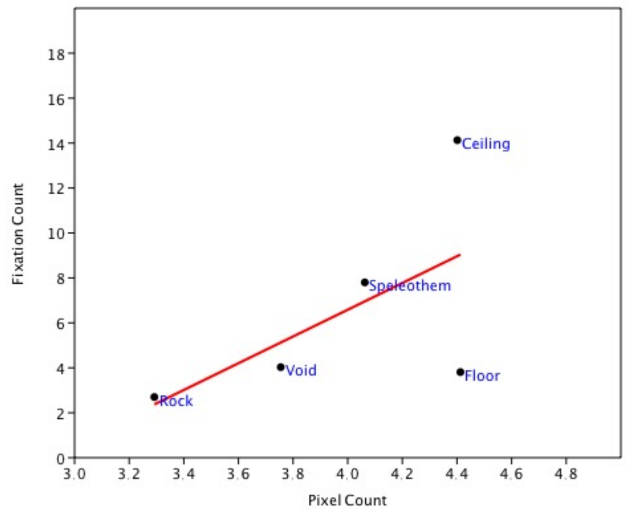

Figure 30. Linear Regression Analysis of aggregated fixation count vs aggregated pixel count. Pearson's r coefficient of .6.

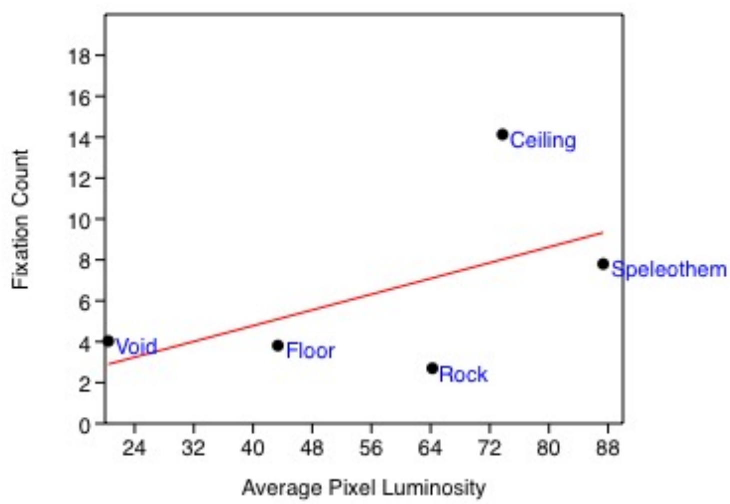

Figure 31. Linear regression analysis of aggregated fixation count vs aggregate average pixel luminosity. Pearson's r coefficient of .54.

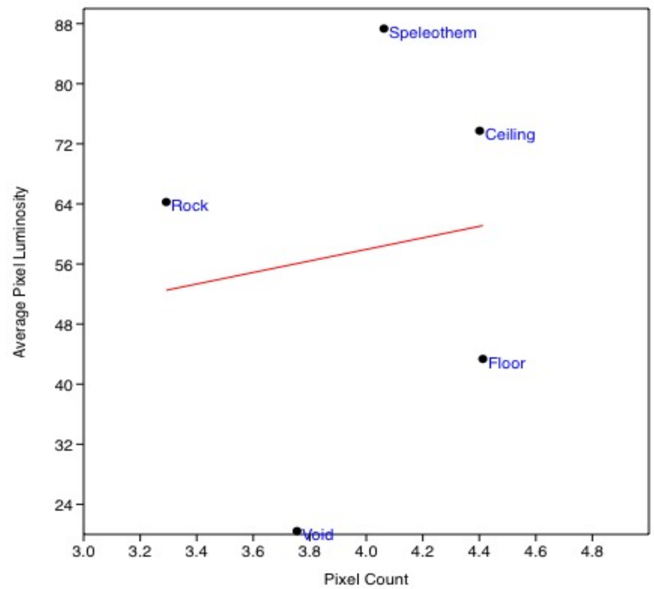

Figure 32. Linear regression analysis of aggregated average pixel luminosity vs aggregated pixel count. Pearson's r coefficient of .138.

Table 13. Shows the relationship size of the polygon types and sum of individual views.

Sum of Individual Views/ Sum of Pixels			
Type	**Sum of Individual Views**	**Sum of Pixel Counts**	**Index Values**
Speleothem	273	658306	0.000415
Voids	100	204725	0.000488
Floors	38	13715	0.002771
Ceilings	128	284445	0.000450
Rocks	6	554255	0.000011

Table 14. Shows the relationship size of the polygon types and the sum of independent focal fixations

Sum of Fixation/ Sum of Pixel Counts			
Type	**Sum of Fixations**	**Sum of Pixel Counts**	**Index Values**
Speleothems	445	658306	0.000676
Voids	141	204725	0.000689
Floors	42	13715	0.003062
Ceilings	311	284445	0.001093
Rocks	8	554255	0.000014

Limitations of Research:

There are limitations inherent in laboratory testing. One of which is the extreme difficulty that exists when trying to recreate a cave environment. The two-dimensional images used in my experiments do little to justify the complex nature of a 3D environment. The chaotic morphology of caves, coupled with the sensory deprivation that come from being in an environment that is completely absent of light has a unique influence on perception that cannot be reconstructed in a laboratory. The eye tracking camera used in this experiment requires a stationary computer to display the visual stimuli as well as to properly track and record the participant's eye movements. A portable eye tracking system would be able to record eye movement in low light, which would be beneficial. Having the ability to record the eye movements and focal fixations of a participant as they navigate around a real cave, with all the unique sensory qualities of cave acting on the participant in real time, would no doubt yield better real-world results.

This experiment was conducted with a sample size of twelve participants. Larger participant populations will always produce more representative results. However, each participant produced copious amounts of data that were appropriate for an exploratory investigation of this scale. Finally, this thesis tested the luminosity component of visual saliency theory as well as contrast and central tendency. Object orientation and movement were not directly tested through this methodology.

Chapter 6

Discussion

Analysis of the individual photographs shows that polygons which attracted focal fixations did so from almost all the participants. This depicts two important points. The first of which is that the polygons which received high independent focal fixation counts did not do so because of the efforts of one individual constantly returning to view the same polygon repeatedly. Secondly, it shows that polygons that received high focal fixation counts were visually interesting enough to attract the attention of multiple participants for repeated viewings.

The aggregated data shows that there is predicable relationship between the average pixel luminosity of speleothems and how many focal fixations the speleothems acquired during the first three seconds of testing. The same predictable relationship was also shown to be true for voids. This is interesting since there is a discrepancy of 67 lumens between the averaged APL of the aggregated speleothem category and the aggregated void category. It was hypothesized that the speleothems would attract more attention because of their higher luminosity values. Under this hypothesis, it would be reasonable to say that the voids, which had the lowest luminosity values because they are generally dark spaces, would attract fewer, if any focal fixations. The focal fixations of the participants should have been directed more frequently towards the more luminous speleothems and not towards the less luminous voids. However, the aggregated data does not fit this thesis' proposed hypothesis nor does it conform to the accepted visual saliency theory. The analysis of the aggregated data predicts that the less luminous voids are just as likely to be viewed as the more luminous speleothems.

The individual photograph analysis also showed that it was not just the visual quality of luminosity that attracted the focal attention of the participants, but instead it was the localized contrast. Analysis showed that the polygons that attracted the most visual attention were the ones that were in areas that also contained polygons of differing luminosity values, visual textures, and orientation. This localized contrast explains why the dark voids were just as visually attractive as the bright speleothems.

Once the data was aggregated into polygon categories, the consideration for where these polygons exist within the broader context of the photograph was lost. How the polygon relates to the other objects within the photograph, or how the object relates to the other objects surrounding it in its immediate vicinity, is imperative to being able to understand the visual saliency of an object. Visual saliency is in the relationship between the object and its environment, not within the object itself, which was something that became impossible to consider once the data was removed from their individual photographs and aggregated together.

Analysis of the data showed the luminosity value of the cave formations was as influential over where observers focused their visual attention, but only when the luminosity was spatially close to an object depicting a contrasting level of luminosity. This was particularly apparent with regards to speleothems and voids. Why though would the participants spend so much time looking into the voids after the contrast directed their visual attention there? The voids generally lacked any substantial visual texture, so there was little in the way of visual data for the eye to process. A possible explanation for this might have to do with how humans perceive dark spaces. Psychologist James J, Gibson theorized that objects have innate advantageous qualities that can be utilized by creatures that possess the intellect and physical ability to recognize and implement them (Gibson: 1979). Gibson termed his theory, the Theory of Affordances. For example, a stone that strong enough to not crumble under impact stress and is small enough to be manipulated by a human hand can also be used like a hammer to drive nails into a piece of wood. The hardness and small size of the stone afford it to be used like a hammer. Researchers Holley Moyes and Dan Montello applied Gibson's theory of affordances to their investigation of humanity's long time relationship with the dark zones of caves. In their article, Moyes and Montello hypothesize that caves afforded our ancient ancestors not only a ready-made emergency shelter from the environment, but also a place where one could go to find privacy and security. They suggest that the darkness of caves is alluring to us because they afford a strong sense of mystery, which could only feed humanity's ubiquitous sense of curiosity (Montello and Moyes: 2012). If the dark quality of caves among the backdrop of a landscape illuminated by daylight is enough tempt our intrinsic curiosity, then, from the perspective of the test participant viewing these photographs, a void amongst a backdrop of well-lit speleothems and limestone walls would off the same temptation.

Chapter 7

Conclusion

Caves are potentially somewhat static environments. Their subterranean placement offers protection from most of nature's destructive forces and the speleothems that decorate their interiors can take thousands of years to grow. The morphology of their tunnel systems and conditions of their formations can remain unchanged for millennia. This in situ preservation is particularly valuable when the location of the artifacts in relation to either other artifacts or cave formations is the focus of the research. Such immaculate artifact preservation has been recorded in Actun Tunichil Muknal, in the Roaring Creek drainage of Belize (Moyes 2001). Thousands of ceramic, lithic, bone artifacts, and human remains remain embedded in calcite can be seen on the floor of the cave's main chamber.

Archaeologist Holley Moyes (2001) conducted an archaeological investigation at this site to better understand the patterns of ancient Maya ritual behavior through spatial analysis of the locations of these artifacts and their spatial relationships to different cave formation types. Ethnographic and ethnohistoric research from modern and historic Maya groups was used to determine what types of cave formations would have had significant cultural meaning to the ancient Maya

Visual saliency theory and eye tracking technology would have worked well with the cognitive processual approach used in the ATM study. Understanding which of the cave formations were more visually salient could have helped to identify formation types that were not accounted for in the ethnohistoric or ethnographic research. Having an identification process that identifies potentially meaningful cave formations based on exogenous visual saliency, something that is ubiquitous across the human species and not dependent on culture, would only have strengthened the framework.

Although phenomenology is inherently subjective, its subjectivity has often been a point of contention when used as a framework for archaeological interpretation. Eye tracking technology, and others like it that can measure sensory information, provide an objective tool for quantifying human behavior. The combination of a phenomenological framework with technologies like eye tracking cameras strengthens the position of phenomenology in archaeology contrary to critiques that argue for the subjective historically and temporally situated views of phenomenology. Technology that records how humans perceive their environment is responsible for great advances in several fields of science. These advancements have helped the scientific community better understand ourselves. Incorporating the same technology into archaeological investigations can provide a better understanding of the behavior of people of the past.

Bibliography

Brady, James E.
1991 Caves and Cosmovision at Utatlan. *California Anthropologist* XVIII (1):1-10.

1997 Settlement Configuration and Cosmology: The Role of Caves at Dos Pilas. *American Anthropologist* 99 (3):602-618.

Brady, James E., and Wendy Ashmore
1999 Mountains, Caves, Water: Ideational Landscapes of the Ancient Maya. In *Archaeologies of Landscapes: Contemporary Perspectives*, edited by Wendy Ashmore and A. Bernard Knapp, pp. 124–145, Blackwell Publishers, Oxford.

Brady, James E. and Polly A. Peterson
2008 Re-envisioning Ancient Maya Ritual Assemblages. *In Religion, Archaeology, and the Material World*, edited by Lars Fogelin, pp. 78-117. Center for Archaeological Investigations Occasional Paper No. 36, Carbondale, IL.

Brady, James E., and Keith M. Prufer
2005 *In the Maw of the Earth Monster: Mesoamerican Ritual Cave Use*, edited by James E. Brady and Keith M. Prufer, pp. 1–17. University of Texas Press, Austin.

Brück, Joanna
2005 Experiencing the Past? The Development of a Phenomenological Archaeology in British Prehistory. *Archaeological Dialogues*, 12(01): 45 – 72.

Bruce, Neil D. B., and John K. Tsotsos
2009 Saliency, Attention, and Visual Search: An Information Theoretic Approach. *Journal of Vision,* 9(3): 5, 1-24.

Cacchio, Paola, Rosita Contento, Claudia Ercole, Giorigo Cappuccio, Maria Preite Marinez, and Aldo Lepidi.
2004 "Involvement of microorganisms in the formation of carbonate speleothems in the Cervo Cave (L'Aquila-Italy)." *Geomicrobiology Journal,* 21(8): 497-509.

Chun, Marvin M.
2000 Contextual Cueing of Visual Attention.*Trends in Cognitive Sciences* 4(5): 170–178.

Clottes, Jean
2012 Ritual Cave Use in European Paleolithic Caves. *In Sacred darkness: a global perspective on the ritual use of caves*. Moyes, Holley, ed. University Press of Colorado, Boulder.

Embree, Lester, Elisabeth A. Behnke, David Carr, J. Claude Evens, José Huertas-Jourda, Jose J. Kockelmans, W. Mckenna, Algis Mickunas, J.N. Mohanty, Thomas Nenon, Thomas M. Seebohm, and Rickhard M. Zaner.
2013 *Encyclopedia of phenomenology*. Vol. 18. Springer Science & Business Media.

Freidel, David A., Linda Schele, and Joy Parker
2001 *Maya Cosmos : Three Thousand Years on the Shaman's Path*. Perennial, New York.

Findlay, John M.
2009 Saccadic Eye Movement Programming: Sensory and Attentional Factors. *Psychological Research* 73(2): 127–135.

Findlay, John M., and Iain D. Gilchrist
1998 Eye Guidance and Visual Search. *Eye Guidance in Reading and Scene Perception*: 295–312.

Gibson, James J.
2013 *Ecological Approach to Visual Perception*. Taylor & Francis.

Hamilakis, Yannis
2013 Archaeology and the senses: Human experience, memory, and affect. Cambridge University Press, New York.

Harel, Jonathan, Christof Koch, and Pietro Perona
2007 Graph-Based Visual Saliency. *Advances in Neural Information Processing Systems* 19: 545.

Henderson, John
2003 Human Gaze Control during Real-World Scene Perception. *Trends in Cognitive Sciences* 7(11): 498–504.

Itti, Laurent, and Christof Koch
2001 Computational Modelling of Visual Attention. *Nature Reviews Neuroscience* 2(3): 194–203.

Merleau-Ponty, M, & Landes, D. A.
2012 *Phenomenology of Perception*. Abingdon, Oxon: Routledge.

Moyes, Holley

2012 The Cave as a Cosogram: The use of GIS in an Intrasite Spatial Analysis of the Main Chamber of Actun Tunichil Muknal, A Maya Ceremonial Cave in Western Belize, Department of Anthropology, Florida Atlantic University, Boca Raton, Florida.

2005 Cluster concentrations, boundary markers, and ritual pathways: A GIS analysis of artifact cluster patterns at Actun Tunichil Muknal, Belize. In *In the Maw of the Earth Monster: Mesoamerican Ritual Cave Use,* edited by James Brady and Keith Prufer, pp. 269-300. University of Texas Press, Austin.

2012 *Sacred Darkness: A Global Perspective on the Ritual Use of Caves,* edited by Holley Moyes, pp. 22-38. University press of Colorado, Boulder.

Moyes, Holley, Josue Ramos, and Gonzalo Pleitez,
2016 Looting Activity in Ofrenda Cave: A Special Report to the Belize Institute of Archaeology, Manuscript on file at the Belize Institute of Archaeology, Belmopan, Belize.

Moyes, Holley and James Brady
2005 The Heart of Creation, the Heart of Darkness – Sacred Caves in Mesoamerica. *Expedition Philadelphia, 47(3): 30-36.*

Moyes, Holley, Lilly Rigoli, Stephanie Huette, Daniel Montello, Teenie Matlock and Michael Spivey.
(in press). Darkness and the Imagination: The Role of Environment in the Development of Spiritual Belief. In *The Oxford Handbook of Light in Archaeology*, edited by Constantinos Pappadopoulos and Holley Moyes, Oxford University Press, Oxford.

Moran, Dermot
2000 *Introduction to Phenomenology*. Routledge, London.

Parkhurst, Derrick, Klinton Law, and Ernst Niebur
2002 Modeling the Role of Salience in the Allocation of Overt Visual Attention. *Vision Research* 42(1): 107 – 123.

Richardson, Daniel C., Rick Dale, and Michael J. Spivey
2007 Eye Movements in Language and Cognition. *Empirical Methods in Cognitive Linguistics*: 323–344.

Scott, Anne Marie
2009 Communicating with the Sacred Earthscape: An Ethnoarchaeological Investigation of Kaqchikel Maya Ceremonies in Highland Guatemala. Unpublished Ph.D. dissertation, Department of Anthropology, University of Texas at Austin.

Tatler, Benjamin W.
2007 The central fixation bias in scene viewing: Selecting an optimal viewing position independently of motor biases and image feature distributions. *Journal of vision* 7.14 (2007): 4-4.

Thomas, Julian.
2004 *Archaeology and Modernity*. London: Routledge.

Tilley, Christopher
1994 *A phenomenology of landscape: places, paths, and monuments.* Berg, Oxford.

Treisman, Anne M, and Garry Gelade
1980 A Feature-Integration Theory of Attention. *Cognitive Psychology* 12(1): 97–136.

Vogt, Evon Z.
1969 Zinacantan: A Maya Community in the Highlands of Chiapas. Harvard University Press, Cambridge.1981 Some Aspects of the Sacred Geography of Highland Chiapas. *In Mesoamerican Sites and World-Views*, edited by Elizabeth P. Benson, pp. 119-142. Dumbarton Oaks Research Library and Collection, Washington, D.C.

Vogt, Evon Z. and David Stuart
2005 Some Notes on Ritual Caves among the Ancient and Modern Maya. In the Maw of the Earth Monster: Mesoamerican Ritual Cave Use, edited by James E. Brady and Keith Prufer, pp. 155-185. University of Texas Press, Austin.

Woodward, Jamie C. and Paul Goldberg
2001 The Sedimentary Records in Mediterranean Rockshelters and Caves: Archives of Environmental Change. *Geoarchaeology* 16(4):327-354.