A Visual Cortex Examination: Familiarity and Selective-ROI BOLD Signal differences between Scenes and Objects, Behaviorally and Neurologically

By Alliyah Steele

1) Personal Section:

Did you know that we've been studying the expanses of outer space longer than our own brains?! The term neuroscience was coined barely a century ago, proving how little we know about the 3 pound supercomputer within each and every one of us. [41]

I've always been fascinated by science which would eventually lead me to the love of the brain. As a kindergartener I forced my grandma to read me a volcano book every night (likely to her frustration, but it helped her pass her teaching masters test at 72!). At 7-years-old I was fascinated by moss under microscopes and at 9, the earth's magnetic field. At 12-years-old I was inspired by astrophysicist Michio Kaku TV segments to invent a tessellated carbon-nanotube space junk shield (Cleverly prototyped with plumbing store pipes I dragged my little sister and grandma along to get!). This endeavor sparked my first passion: astrophysics.

As I delved deeper into space, I also found a second passion: neuroscience. My grandmother (and single parent), despite her poor upbringing with four other siblings, was able to go to college and complete original neuroscience research! Taking honors biology in 9th grade further sparked my interest in neuroscience, as there was so much more I wanted to know beyond our small unit. I found that the same unexplored ness I loved about space was also ever more present in neuroscience. Our brains store more than 5,000 desktop computers and form more than 100 trillion connections (!) leaving so much room for discovery.

As a student tutor especially, I've always been fascinated by the way people learn. My tutoring business applies hands-on and technological teaching methods. Sometimes this approach would yield shocking results like a friend increasing more than 30 points on a test! This left me wondering when exactly the point of learning had occurred and wanting to know more about how memories were bound. Therefore, my first science research project idea was using EEG (Electroencephalogram), a wearable brain imaging technology, to try to meter physiological activity while studying flashcards. I ended up being unable to pursue this research in the end. It was very difficult to find a mentor within the new, particularly vast world of neuroscience. I also lost my first mentor at IBM as well as access to an EEG.

Unbeknownst to me, however, these perceived failures were leading me down an even more interesting path! The next mentors (Dr. Elissa Aminoff and Dr. Shira Baror of Fordham University) I found focused on vision and the brain. At first I was sure I wouldn't be interested in this as I was so set on studying learning. Although, as I started reading background literature, I became hooked! I found it incredible the way the brain stores the people, places, and items we see everyday like shelved books in a library. Everything is so expertly categorized while also allowing the brain to make connections between related concepts (Ex: Cat and Dog). It's crazy to think that of the brain's immense processing power, close to half of it is dedicated singularly to processing vision!

My mentors gave me a lot of freedom in designing my 1st-year experiment but recommended I use their database, BOLD5000. This database consisted of images and the matching fMRI data of 4 participants who viewed over 5,254 images in one sitting.

As I read through past literature I noticed that very few studies looked at the effect of past experience, or familiarity on visual processing. This can be loosely defined as how often you see a visual stimulus in everyday life or how accustomed you are to it. This led me to pursue my first-year project on whether living environment (Rural, urban, or suburban) affected visual processing and familiarity to related images (From each of the 3 living environments).

I collected the responses of over 200 survey participants from each living environment. I asked them to rank each image on familiarity and then compared that survey data to BOLD5000's fMRI functional results. Surprisingly, there were physiological differences between each subject group! These results postulate that something as simple as where you live can affect familiarity and consequently brain activity. To complete this research I had to learn Matlab as well as basic statistical analysis (Paired and unpaired t-tests, linear regressions, correlations etc.). Luckily, as a self-taught coder I could apply my programming background to processing the towering amounts of data in the experiment. My mentors helped me learn SPSS (Statistical Package for Social Sciences) and get started with Matlab. The rest of the data analysis, collection, and writing I did exclusively myself. It was a great experience seeing what being a researcher was really like (And of course doing my happy dance whenever I found significance!).

The following year of research was daunting due to the pandemic which limited access to labs and ability to contact mentors. Despite this, I was able to thrive doing my 2nd year of research completely independently. I could rely on the experience from doing my previous year's study. I also was lucky enough to participate in Harvard's Pre-College program. Taking their Introduction to Neuroscience program helped to build foundation brain knowledge. It was this 2nd year research project that would earn me a spot in Regeneron's 2021 Science Talent Search.

I realized that my first year of research shared a significant shortcoming with previous research: it only examined scenes. In reality if you just look around you while reading this, You'll grasp how many scenes, objects, hues, patterns, colors and other features our brains are challenged to encode. It makes it all the more incredible that the brain can sort through all this in less than 13 milliseconds! In this second year of research I wanted to examine the processing differences between scenes and objects on the basis of fMRI activity as well as familiarity. Once again I took the approach of recruiting 200+ survey participants and having them rank scenes and objects 1-5 on familiarity. This time I used a new statistical platform, Graphpad Prism. This program aided not only to create more elegant graphs but also to run more advanced normalization tests such as the Anderson-Darling test. I used my background in Java and Javascript programming to select out the scenes and objects I used out of the list of 5,000 for each participant. I then wrote a Matlab program to sum the brain activity within each of the visual cortex areas of interest for familiar and unfamiliar images, as well as scenes and objects.

Overall, there were many fascinating things I learned from my research. First off, the brain prioritizes scenes over objects when it comes to visual recognition. The brain uses a heuristic approach to guess what objects may be present using the scene. For example, "If there's a beach maybe there will be a beach ball." Therefore, scenes were far more significant towards familiarity than objects. Another significant finding related to the visual cortex processing pipeline. Past studies assert that memory interfacing does not occur in the lower levels of the visual cortex. However, both this year's study and last year's studies show significant evidence that lower stages of the visual cortex actually participate in high-level processes. Some examples are short-term memory and mental imagery.

One of the best things about neurobehavioral research is how diverse it's applications are! Looking at the brain's reactions to scene and object as well as familiarity could heed insight into Altzheimers disease therapy and diagnosis as well as the mechanics of visual hallucinations in Schizophrenia. It could be used to optimize K12 education for special needs students, improve advertisements, and even aid in preventing car accidents.

The best advice I could give a new researcher is to "go with the flow", "follow your passions, and ,"dare to be different". My research journey definitely went off the beaten path, but I ended up finding an area of neuroscience that I never thought I'd be interested in but was! Don't think that your research needs to happen in a lab or have intense mentor involvement to be impactful. My research had none of those things yet I was able to place in the science talent search as well as many other national and international competitions.

You'll be surprised by the things you can do when you're truly passionate about a topic. Research should be one of the greatest times of your life as it gives genuine insights into what you may do in the future. You get to spend your time studying what you want instead of being given some prescribed curriculum, utilize that time! You also learn so many skills many don't learn until college, such as statistical analysis, how to public speak, as well as write a scientific paper.

Lastly, don't be scared to make your research and presentation style unique. The whole goal of research is to do something or find something no one else has before! Don't be scared to try out a new approach or even present your research in a unique way (I enjoy using a lot of analogies and fun facts). After all, proper and engaging science communication is the only way to make your ideas latch on.

Overall doing this research has validated my decision to pursue computational neuroscience in college! I had so much fun putting it all together and learned so much about the brain and myself throughout the process. I've been lucky enough to be accepted into Harvard this past year and will be continuing my education there. I definitely want to continue my research into the brain, learning, and vision. I'd also like to delve deeper into computer science and gain my doctorate in neuroscience (Dr. Steele has a nice ring to it!). As a National Program Co-director of the non-profit ThinkSTEAM (Organization encouraging more girls into STEM) I'd like to continue my work to inspire girls and other minorities into science and technology fields as well at Harvard. I wish all the new researchers the best in their journeys! Remember to remain open, curious, and creative and to enjoy the ride.

2) Research Section:

1) Abstract

The brain dedicates half of its cortex to one sense, vision. Despite interactions between the visual cortex (VC) and temporal lobe, few publications explore familiarity's role in visual processing. Last year's study established that living environment significantly affected familiarity ($p = 0.004$**). Familiarity also impacted BOLD signals of the VC's stimuli-selective Regions of Interest (ROIs): RSC ($p = 0.01$*), OPA, LOC and PPA. The current study furthers this analysis by including both scenes and objects to explore if there are neurobehavioral differences between these categories on the basis of familiarity. Behaviorally, N=204 participants completed a 60 question scene and object survey rating images on familiarity. Neurologically, behavioral results were compared to fMRI data of N=3 participants from the BOLD5000 database. Contradictory to functional results, objects were rated significantly higher on familiarity than scenes ($p = 0.000384$***). Neurologically, results indicated that familiarity continues to significantly affect neural processing but that it's impact is limited to scenes ($p =0.04$*). This study significantly supports that the EVC may have a role in both low-level and high-level processing. Future studies should examine the possibility of using our methodology as a baseline to diagnose memory disorders. The interaction between learning and familiarity could also be examined for use in K12 Education and beyond.

2) Introduction

2.1 Hierarchical Structure of the VC

The *Homo Sapien* brain dedicates more than half its cortex to a single sense: vision [1] allowing visual information to be processed and acted upon in less than 13 milliseconds [23]. This is made possible by the brain's Visual Cortex (VC). The VC is primarily localized in the Occipital Lobe, the main vision lobe, but also has procedures in Temporal (Center of long-term memory) and Parietal Regions (Lobe involved in sensory coordination procedures). This cortex is organized hierarchically into 6 processing centers,V1-V6, computation becomes more complex with each additional layer.

The study's control area is the Early VC (EVC) which handles low-level characteristics (Ex: brightness) image processing [38]. The EVC contains V1-V3. As information approaches layer 6, higher level processes such as recognition and categorization occur.

Once information has been processed through all 6 centers, it is relayed to the Ventral Stream. The Ventral Stream leads to the Temporal Lobe: The brain's long-term memory center. It's here that nerve impulses can be interfaced with past memories to facilitate categorization and recognition [5-6].

2.2. Concept Cells Construct Stimuli-Selective ROIs and Facilitate Familiarity

Within the neurons of the ventral stream there are areas selective to only specific kinds of visual stimuli. Inside the Temporal Lobe there's a more specialized memory center known as the Hippocampus. It's here that several selective sites are stored, but others are also located in the Occipital Lobe [2-15][40]. The neurons in these areas are grouped into networks known as concept cells. Concept cells are neural networks that respond to onlys certain objects or concepts. A hypothetical example of this would be a neuronal network that represents a cat. Everytime one sees one the network will fire in recognition.

Our study will focus on 4 (Same as in [9]) concept cell dependent regions of interest (ROIs): The Parahippocampal Place Area (PPA), Retrosplenial Cortex (RSC), Occipital Place Area (OPA) and Lateral Occipital Cortex (LOC). The concept cell networks in the PPA, RSC, and OPA are scene selective, meaning they exhibit higher activity for scenes than objects [4]. The networks in the LOC, however, are object-selective [3]. Whenever a certain structure is perceived (Ex: Networks located in PPA represent specific places like a beach or mall) the associated group of concept cells will fire [5]. As the item represented by the network is viewed more often, neuronal connections become stronger, as does the memory and subsequently it's familiarity.

Visual Familiarity, this study's focus, is defined as how accustomed one is with a visual stimulus. It is a high-level feature since it also gauges memory strength of a particular concept. High-level image features and areas (PPA, LOC, RSC, OPA) are concerned with more abstracted, memory related functions than their low-level counterparts (EVC) [40]. Several past studies have indicated the importance of familiarity within VC processing **(**[4][7-8][10-15]).

2.3. Lack of Clarity on Roles of Image Identity and Familiarity in Visual Processing

Importantly, the role of familiarity and memory within VC processing isn't completely understood. [16] shed light on the growing debate in neuroscience over which factors hold greatest precedence over image processing. It's also been asked how the content or categorization of an image (Ex: object or scene) dictates its processing. There's only a small body of research analyzing the difference between scene and objects neurologically with significant sample size [9][12][13][26]. Examining only scenes does not provide as holistic an analysis as may be necessary to completely comprehend visual processing. Importantly, no previous study has examined familiarity dependent differences between scenes and objects

2.4 fMRI BOLD Signal and ROI Analysis

Notably, the majority of VC research studies use Functional Magnetic Resonance Imaging (FMRI). fMRI is a brain scan that creates a 3D mapping of the human brain. It does so using a measure known as Blood-Oxygen Level-Dependent signal (BOLD signal). This small decimal unit works on the basis that areas of the brain with a greater flow of oxygenated blood are more active than others. fMRI models are divided into grids with subsections known as voxels. Each voxel represents thousands of neurons, scientists using ROI analysis map out areas of interest using voxel coordinates. They also average BOLD signals across voxels groups to conceptualize activity levels in various brain regions [5].

2.5 BOLD5000 Database

[9] created a database called BOLD5000 featuring over 5,000 unique images from SUN (Scene Understandings) [18], Imagenet, [17] and COCO (Common Objects in Context) [31] along with corresponding fMRI data. This study improved image quality of each dataset and verified selectivities of several VC ROIs (PPA, RSC, OPA, LOC, etc.). Their study however, had a very small sample size (n=4). This is one of the few studies to include both scenes and objects, making its analysis more representative of human visual processing than its contemporaries ([7-8][16][20][23][25][27][37] - Only scenes, [10-12][14-15][21]- Only objects).

2.6 Indication of the Familiarity's Role within Visual Processing and Recognition

[3] found scene and object pathways are separate but cross over at high-level processing stages. The scene pathway speeds recognition by generating object predictions that can be utilized by the object-selective pathway. [3] also found intact objects (high quality image) that were clearly visible were able to be recognized faster than degraded counterparts (low quality image), highlighting that stimuli inline with past memories can be recognized more easily. Although this study fails to examine memory-dependent differences between scenes and objects.

[4] began to suggest the precedence of high-level features by developing the idea of Associative Processing: the concept that visual processing relies more on high-level interconnections between distributed neuronal networks and memory than low-level characteristics.

[20] similarly to [3] compared conventional images to those that violated the brain's intrinsic predictions (Ex: Fire hydrant on a mailbox). It showed scenes with fewer context violations were recognized faster, highlighting the importance of memory and cranial predictions in visual processing. Like previous studies, they don't examine familiarity's effect in visual processing and only focus on scenes.

[11][12]13][14] and [15] also depicted the importance of memory in visual categorization. These studies showed that individuals' past experiences with the object dictated whether VC selective ROIs were modulated. This observation also leads to the suggestion of familiarity as a major processing modulator. [13] focuses on both scenes and objects while [11][12-15] are limited to only objects and therefore may not be the best comparison to natural visual processing.

[13] evaluated familiarity in the Medial Temporal Lobe (MTL), a ventral stream site, directly, finding certain areas of the MTL were more significantly modulated by familiar stimuli. This study is beneficial in it's analysis of both scenes and objects. Although, this study examines a large generalized region, the MTL, instead of pursuing a more specific analysis into Stimuli Selective ROIs inside (Ex: PPA) and outside (Ex: OPA and LOC) that facilitate recognition.

[7] and [8] found images of more familiar locations elicited higher BOLD signals in the PPA, RSC, and Transverse Occipital Sulcus. These studies didn't contain a significant sample size and also didn't examine objects.

Last year's study examined environmental familiarity showing that living environment significantly affected image preference, and that the RSC significantly favored familiar stimuli (RHRSC-$p<.01$**, LHRSC- $p<.01$**). The relationship between familiarity and BOLD was marginally ($p = 0.05$) linear in the RHRSC. Similarly to [7] and [8], our previous study only examined scenes.

Despite the strides made by these studies, none have evaluated if there are hemodynamic differences between scenes and objects. Nor have they examined neurobehavioral differences between familiar and unfamiliar members of each of these subsequent categories (Ex: Familiar scenes, unfamiliar scenes). This has also never been examined specifically within the VC's stimuli-selective ROIs (PPA, RSC, OPA, LOC). The current study will also feature a larger sample compared to past studies [17][18][3] and will use multivariate analysis to gauge the family-dependent differences between scenes and objects.

3) Goals and Hypothesis

The Goals for this study are:

1) Extract the top 3 most and least familiar members of each stimuli category (scenes and objects) and examine if there is a commonality within each category.
2) Examine if there's a significant difference in familiarity rankings and BOLD signals between scenes and objects (Similar analysis to [3]). Previous literature [2-15] indicates that scenes and objects have different pathways and areas within the brain but this study will specifically indicate if there are hemodynamic differences.
3) Determine if familiar and unfamiliar members within each category exhibit significantly different familiarity rankings or BOLD signals (Same analysis as last year's study [7][8] [13]). This will

show if the brain favors more familiar stimuli even within respective categories. This is also being done with a significant sample size (n=201) unlike several other familiarity studies in this field [3][7][8].

4) Check if the EVC has significantly lower BOLD signal (Same analysis as last year) than experimental areas (PPA,RSC, LOC, OPA). This is being undergone to examine if the abnormal results found in last year's experiment (That high-level familiarity affected the low-level EVC) aren't coincidental.

It is hypothesized that:

1) More familiar stimuli will generally be ranked higher behaviorally and will yield higher BOLD signals [7][8][13].This will occur since concept cell networks will be more interconnected and exhibit higher activity when a stimulus has been consistently reinforced [5].
2) The PPA, RSC, and OPA will exhibit higher BOLD signal for scenes than objects since they're scene-selective areas. The RSC will be the only area showing significance (Same result seen in our previous exploration and corroborated by [2][3][4][5][6].
3) The LOC, as an object-selective region, will yield higher BOLD signal for objects. [3] [5]. [2][6][4][9].
4) The EVC will have significantly lower BOLD signal than experimental ROIs since it's a low-level area, independent of high-level familiarity [4-5][9][38].

4) Methodology

This procedure will attempt to complete a thorough neurobehavioral analysis of familiarity differences between scenes and objects. This research was completed independently with no mentor assistance. The student designed the experiment, created and administered the survey, developed 6 codes to parse over 15,000 neural records, completed all statistical analysis, and drew all conclusions.

4.1 Survey Construction

The stimuli used for the survey consisted of 30 scenes and 30 objects. Within each of these categories there were 15 unfamiliar and 15 familiar stimuli members. Scenes were awarded labels of familiar and unfamiliar based on the results of our previous study. Objects were categorized into familiar and unfamiliar categories based on behavioral results of previous studies [7][8][13][14].Objects were derived from Imagnet [17] database images within BOLD5000 [9], and scenes, SUN [18]. The images had resolutions and sizes normalized by [9]. Any emotionally triggering images were also removed by that study. The inclusion of both stimuli types meets the 2nd goal of analyzing neurobehavioral differences between scenes and objects. The survey's focus on familiarity meets the third goal of metering the effect of familiarity perceptually and cognitively. Google Sheets didn't allow image order to be scrambled for each participant, therefore, it's unclear if behavioral effects were biased by uniform stimuli order. However the number of participants tested (N = 204) makes results likely to be more accurate and representative of the general population. The survey commenced with a definition of familiarity based on previous literature [13][7][8]. The task was to classify each image on familiarity using a Likert Scale of 1 (Not familiar at all) to 5 (highly familiar). This continuous rating scale was similar to the one used in [13].

4.2 Behavioral Participants

The survey was taken by N= 204 participants obtained from Amazon MTURK. Participants resided in the United States and were mandated to be over 18 years of age (Same age range as [9]). Each participant was compensated 5 cents for their complete responses. Subjects agreed to an informed consent form administered at the beginning of the survey. Participants had up to 1 hour to rank each image (About 1 minute per image, time limit justified by [21-23]). All data was anonymous with no identifying data being collected. Participants were only referenced by a number.

4.3 Survey Analysis

Data was collected and organized in Google Sheets. A series of binary and numerical labels were used to tag data for statistical analysis. Familiar images were awarded a 1, and unfamiliar a 0. Scenes were identified by the number 3 and objects a 2. For each image in the study, all participant's 1-5 rankings were averaged to generate a familiarity score. To meet the first experimental goal, all the images in the study had their familiarity scores compared to derive the top 3 familiar and top 3 unfamiliar. Statistical analysis was computed in Graphpad's Prism 8 Statistical Program. First several normalization tests (Anderson-Darling test, D'Agostino & Pearson test, Shapiro-Wilk test, and Kolmogorov-Smirnov test) were run to robustly check that data wasn't abnormal and fit a standard bell curve. Several unpaired t-tests were also computed. The t-tests were unpaired since they were between two distinct subject groups (scene/object and unfamiliar/familiar) These t-tests fit the behavioral portion goal 2 to examine if there are familiarity differences between scenes and objects. They also helped to carry out goal 3 of examining if familiar and unfamiliar classified images were actually ranked (from 1-5) differently within the context of this experiment (Overall, and within the scene and object categories respectively). Significance was recognized as a p value $<.05$.

4.4. Neurological Participants

fMRI data was obtained from the BOLD5000 database [9] and had already been preprocessed and normalized (N = 4). Logistically, all 204 behavioral participants could not be affixed to fMRI headsets and therefore were only compared to 3 functional subjects (Participant 4 was rejected since they didn't finish their image viewing [9]). The restrictions of the COVID-19 pandemic also prevented the collection of new functional data. This analysis is still somewhat robust since each individual viewed over 5,000 images while under fMRI. This study is unprecedented in its number of stimuli. Nonetheless, [9] makes clear the need for future studies to emulate their experiment with a higher number of subjects.

4.5 Java, Javascript and Matlab Programming

The functional data was organized in a large table in which each row of BOLD signals corresponds to a different image within BOLD5000. However, each participant had their images scrambled so each set of 5,254 row numbers was unique for each subject [9]. It would be manually infeasible to find the matrix numbers of the 60 images used in this study. Therefore, 3 Javascript programs were developed within an online compiler. Collecting these row numbers sufficed the neurological portions of goals 2 and 3 to examine BOLD signal differences on the basis of familiarity and image identity (Scene or object).

The first program formatted the numbers and image names in the database in such a way that they would be in a valid format (Spliced them with quotation marks and commas) for the second and third programs. The second program used a linear search algorithm to find and return the matrix numbers of all the scenes in the study. The third did the same but for objects.

Now that the matrix numbers were known, programming in Matlab could ensue. Two programs were developed: One to sum the BOLD signals in each cortical area (RSC, OPA, LOC, EVC, PPA) bilaterally for scenes and the other for objects. Importantly, since each participant had unique matrix numbers, instead of manually inputting these (For each of the 3 participants) a simple Java program in Dr. Java IDE was developed to improve efficiency. This code used a concatenation method with parameters to substitute in the unique row numbers for each participant. It then outputs the uniquely formatted codes for each participant which could then be pasted and run in Matlab.

4.6 ROI Statistical Analysis

Now that all 3 participants' BOLD signals were collected, neurological analysis could ensue. Google Sheets was again utilized to organize and perform simple statistical functions on data. The BOLD signals of all 3 participants were averaged with the others to create a mean set of evoked brain activity. The same numerical labels (1-familiar, 0-unfamiliar and 3-scenes, 2-objects) from the behavioral portion were utilized for neurological comparisons. The control area was the EVC. This area was chosen as a control since it computed mainly low-level functioning and shouldn't be biased by high-level familiarity [5-6][38]. The experimental, high-level ROIs were the RSC, OPA, PPA, and LOC. A series of unpaired t-tests were run in Prism to statistically suffice the neurological portions of goal 2 and 3, and goal 4- to examine if the control area has significantly lower BOLD signal than experimentals. These tests would effectively test the validity of all our hypotheses (1-4) neurologically. Overall these measures assessed if behavioral trends were in corroboration with neurological markers. Importantly, some image labels were lost or rejected by [9], so in this analysis only 11 objects (7 familiar, 4 unfamiliar) and 17 (9 familiar, 8 unfamiliar) scenes were analyzed. Future analysis should aim to have equal numbers of scenes and objects, and familiar and unfamiliar members to improve consistency.

All aspects of this study, including research question development, experimental design, and analysis were completed without any mentor assistance.

5) Results and Discussion

The main objective of this study was to examine if there are neurobehavioral familiarity dependent differences between scenes and objects. It is expected that more familiar stimuli will be ranked higher both behaviorally and neurologically across stimuli groups [7-8][13]. The RSC, OPA, and PPA should demonstrate a BOLD signal bias towards scenes while the LOC, towards objects [3] [2-6][9]. The EVC, as a low-level area [5-6][38] shouldn't be modulated by familiarity, therefore exhibiting a significantly lower BOLD signal than experimental ROIs.

5.1 Behavioral

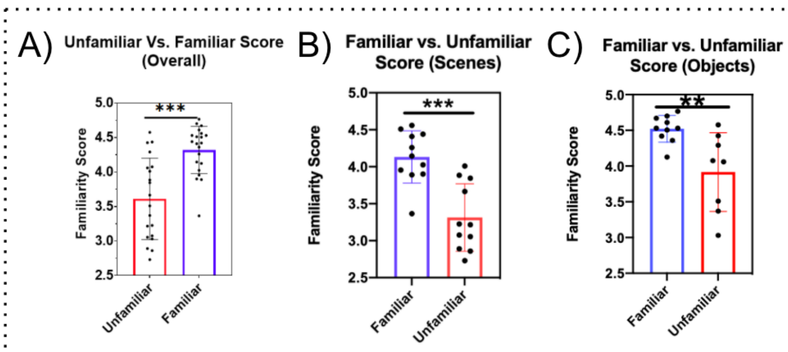

Figure 1. A) Unpaired T-Test shows a significant difference between familiarity scores (1-5) between unfamiliar (0) and familiar (1) ranked images overall **B)**Unpaired t-test showing within the sene category, familiar ranked images are scored significantly higher. **C)**Unpaired t-test showing a significant contrast between familiar and unfamiliar image rankings within the object category.

The behavioral portion of our first hypothesis that familiar ranked stimuli (1) would be ranked significantly from unfamiliar stimuli (0) was corroborated (Figure 1). This result validates the 0 or 1 familiarity ratings awarded to each image in this study (labels obtained from last year's study). It justifies using them in other behavioral tests and the neurological portion of the analysis to rate the effect of familiarity on BOLD signal.

Interestingly the correlation between familiarity ranking and familiarity score was stronger in scenes than in objects (Figure 1 B & C). This may relate to the fact that according to [3], object-selective areas do not evoke as much high-level functioning as scenes-selective areas do. The VC uses memory predictions from the scene-selective areas like the RSC and OPA to predict what objects will be in a given scene. Therefore, it's plausible that scenes would be more correlated to the measure of familiarity than objects. Also, according to [7][8] and [25], the RSC, PPA, and OPA (Scene-Selective ROIs) are part of a visual navigation circuit within the brain. Navigation is a neural process that relies on familiarity to operate. Scenes provide the most information regarding navigation (As they reflect surroundings), and therefore are favored within those regions. [7] and [8] also showed that the PPA and RSC significantly favor more familiar scenes. This information also justifies the fact that scenes would induce higher familiarity effects within the brain than objects.

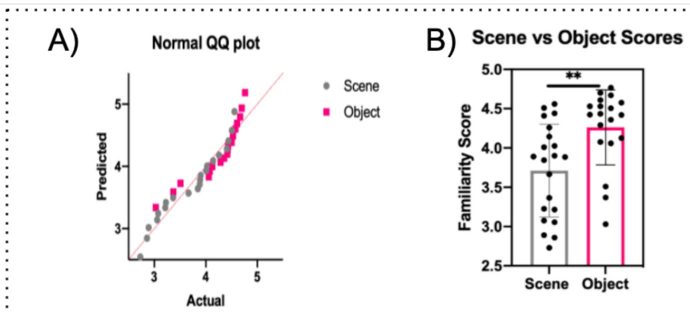

Figure 2. A) Familiarity Scores (1-5) within the scene and object categories significantly fit a normal distribution best fit line (Anderson-Darling Test p< .01**, D'Agostino & Pearson p<.05*, Shapiro-Wilk p<.01**, Kolmogorov-Smirnov test p<.05*). **B)** Unpaired T-tests shows objects are scored significantly higher than scenes.

Interestingly, however, and conversely to the idea that scene's induce more familiarity effects than scenes, throughout the experiment objects were ranked significantly greater than scenes. Scenes were rated significantly different than objects (Figure 2. B) with objects being ranked significantly higher. In addition the three most familiar stimuli: clock, rubik-original, and laptop (In order of familiarity) were all objects. The three least familiar (cave, brewery, glaciers-outdoors) were all scenes. Behaviorally, the word object becomes synonymous with familiar, and scene with unfamiliar (Similar to in last experiment urban becoming synonymous with familiar).

It's clear this did not result from any inequities in the subject groups. There were exactly 30 scenes and 30 objects, and 15 unfamiliar and 15 familiar within each group. The large sample size (N=201) also rules out any subjectivity of individual participants skewing results especially since the data fit a normal distribution (Figure 2. A).

[26] suggests an explanation regarding the debate surrounding the role of the hippocampus; Whether it be primarily involved in scene construction or multifaceted associative processes. Their study specifically shows different parts of the hippocampus are recruited for a variety of simultaneous tasks from object recognition, to scene construction. [16] supports this viewpoint in describing just one part of the hippocampal cortex, the PPA has so many distinct roles (contextual associations, semantic categorization, distance judgement, 3D layout, etc.).

Future studies should attempt to further classify the behavior of the hippocampus and it's intrinsic ROIs, especially as emerging studies find many of the ROIs functioning are not as "black and white" as simple being scene or object selective. However, the overwhelming evidence supporting the scene-selective and object selective areas remains prominent over alternate theories [2-15]. Importantly, the results of the current experiment are likely more comparable to real life than the previous study since both scenes and objects are included. It is unrealistic to test only scenes or only objects since naturally the VC has to simultaneously process both image calibers.

5.2 Neurological

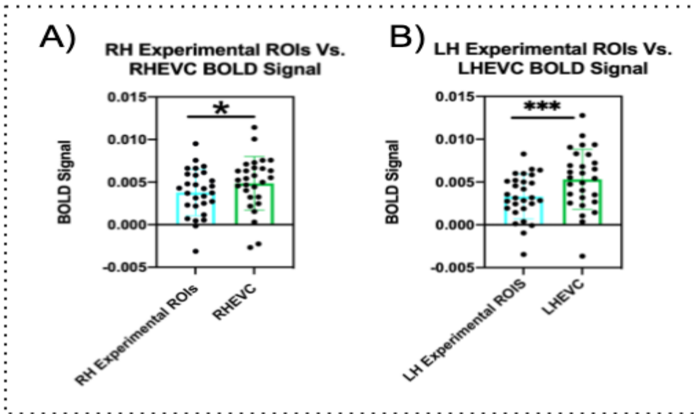

Figure 3. A) Unpaired t-test shows the RHEVC had significantly higher BOLD signal than it's right hemisphere counterparts. **B)** Unpaired t-test demonstrated that LHEVC has significantly higher BOLD signal than other LH ROIs.

The final hypothesis that the EVC would exhibit lower BOLD signal than the other ROIs was completely refuted. The EVC, in fact, was significantly higher in BOLD signal than the other ROIs (Figure 3). The greater significance on the left hemisphere follows the pattern established before. This unexpected result was also seen visually (Within a histogram the EVC favored familiar images). Therefore, it is clear that although the EVC is not significantly biased towards objects or scenes, it seems to be functioning higher than the high-level areas. This is unexpected as those areas should be modulated by the familiarity variable in this experiment. Notably the EVC did not show any significant interactions within tests examining familiarity and stimuli identity (scene or object).

It's queer that our supposed low-level expermental area would fair better than so many of the experimental areas in tests of high-level familiarity. Despite this, burgeoning studies such as that of [28] are finding the EVC does have a role in memory. Specifically, the EVC is a center for visual working memory and mental imagery. Working memory when recruited enough can be transformed into permanent memory in the hippocampus (location of scene-selective ROIs like the RSC) by the brain's Limbic System (Hypothalamus, Amygdala, Thalamus, Cerebellum, Hippocampus [5]). It is also known (as per the discussion of concept cells before) that as interconnections between cellular networks representing concepts strengthens, so does inherent familiarity. Therefore, there's a case to be made that the EVC's roles cause it to be modulated by familiarity. In this case, the EVC is different from the other selective areas, as it responds to building familiarity in both scenes and objects (All kinds of stimuli filter through this area regardless of identity). Further study would be required to isolate the role of the EVC in familiarity.

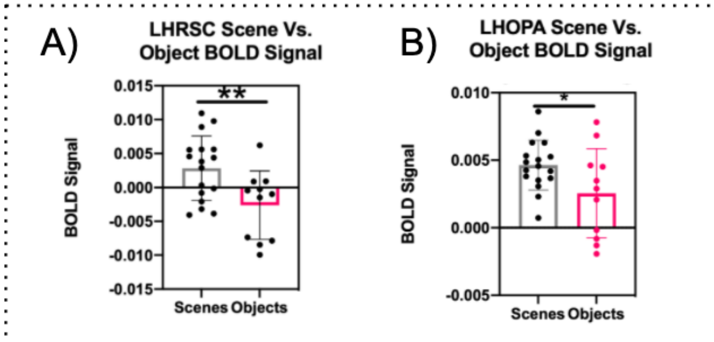

Figure 4. A) Unpaired t-test shows the LHRSC has significantly higher BOLD signal for scenes than objects. **B)**Unpaired t-test illustrates that LHOPa has significantly higher BOLD signal for scenes than objects.

The second conjecture that the PPA, OPA, and RSC would significantly favor scenes, with only the RSC being significant, was only partially corroborated. Strangely, all the significance was localized to the left side of the brain. This is opposite to the results of last year's study in which the most significance was located in the right hemisphere. The LHRSC (Figure 4. A) and the LHOPA (Figure 4. B) both significantly favored scenes over objects.

The significance of the OPA and RSC is expected, the fact that the RSC had higher significance is also in line with this study's predictions. These two areas are known to be scene-selective. The RSC likely had greater significance due to [4] and [5]'s notion that the RSC is the center of navigational memory and takes the lead in the brain's scene-selective navigation circuit (Also supported by [27] and [37]- Specifically cites RSC as part of an anterior navigation circuit). Therefore, it's clear the RSC would have the greatest association with familiarity than any of the other scene-selective ROIs involved in the navigational circuit (OPA-[25] and PPA- [7][8][27]).

The OPA also did not demonstrate significance in our last experiment. Perhaps the addition of objects to the stimuli mix increased significance since there was a greater contrast (Not just familiar and unfamiliar members of one category, but two separate, distinct categories: scenes and objects). The OPA also, according to [25], has a role in navigation memory. The fact that it is less significant towards familiarity than the RSC hints it may also be secondary memory structure like the PPA, in the navigation circuit. Despite this, more studies are necessary to determine the ROI hierarchy within the brain's navigation circuit and its relations to memory.

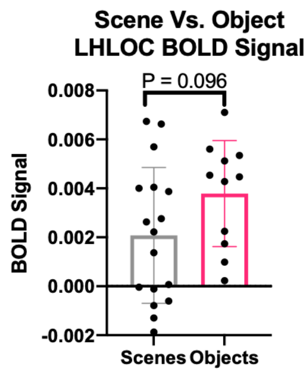

Figure 5. Unpaired t-test shows insignificant difference between LHLOC BOLD signal evoked by scenes and objects.

All the other ROIs were far from significant except for the LHLOC which showed a non-significant preference for objects (Figure 5). The LOC may not have reached significance since object stimuli, one again were outnumbered by scenes. It's p value, although insignificant, shows an attraction to objects as expected.

The fact that significance was localized to the left goes against the notion that the left VC takes the lead in linguistic visual processing , and therefore may have a decreased role in high-level familiarity processing. It's important to note that language related visual processing (Such as work of the Visual Word Form Area -VWFA, decoding number and letter shapes while reading) is also a high-level associative process like that discussed in [4]. More research is necessary to distinguish roles of the left and right VC, and assess if there are familiarity-dependent links between linguistic and visual processing.

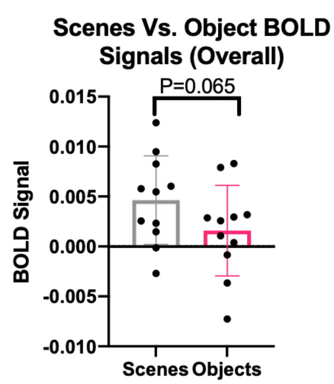

Figure 6. Unpaired t-test shows insignificant difference between over BOLD signal across ROIs evoked by scenes and objects.

A test examining if scenes and objects exhibited significantly different BOLD signals was nearly significant (Figure 6) . Once again, the discrepancy between numbers of scenes and objects in this experiment may have skewed results. This p-value, however is very close to significance and demonstrates the differences in processing of scenes and objects are consistent with our behavioral findings.

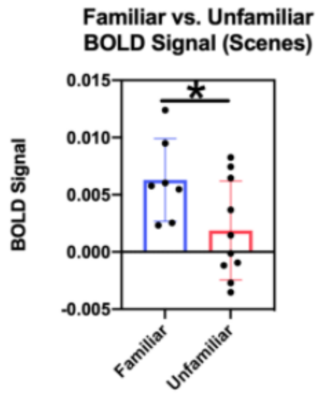

Figure 7. Unpaired t-test shows that ROIs overall exhibit higher BOLD signal when exposed to familiar ranked scenes than unfamiliar.

The hypothesis that stimuli with higher familiarity would yield higher BOLD signal was only partially corroborated. Interestingly, this relationship was only seen within scene stimuli, with familiar scenes being rated significantly higher than unfamiliar (Figure 7). However, no significant familiarity effects were viewed within the object category. These results are in line with figure 1 results showing that scenes had a higher correlation between familiarity rating (0 or 1) and ranking (1-5) than objects (Figure 1 B & C). However, they disagree with figure 3B which shows objects being ranked higher in familiarity behaviorally.

This could be explained by the fact that there was only one object-selective area (LOC) utilized in this experiment, therefore the object category may have been at a disadvantage (In a future study we could include the Perirhinal Cortex, another object selective ROI, [26]) Also, when searching for the matrix numbers it was discovered several of the scenes and objects used in the behavioral portion either had data their data missing within [9]'s files or were rejected. Therefore only 11 objects (7 familiar, 4 unfamiliar) and 17 scenes (9 familiar and 8 unfamiliar) were utilized. The deficit in the number of object stimuli may have impacted this outcome.

However, this neurological behavior is in line with past studies like [3] 's fMRI, EEG, and Neural Network analysis showing the most memory referencing occurring from the Scene-Selective, not object-selective cortex. Since familiarity is a high-level memory function it is intuitive that it would be directly correlated to scenes [40]. Additionally [25], [4], and [5] show that scene-selective areas (OPA, PPA, RSC) prefer familiar scenes over objects as they are most related to their navigational processes. Also, the top 3 familiar and top 3 unfamiliar of each category did not exhibit significantly different BOLD signals. Perhaps this was due to the small sample size, if the top 10 familiar and top 10 unfamiliar perhaps more significant effects would have been perceived. Importantly, the top 3 familiar images were all objects and therefore fall under the neurological and statistical explanations in the previous sentences (Regarding why figure 7's direct relation between scenes and familiarity does not apply to objects).

6) Conclusion

Overall, this research aimed to examine the familiarity-dependent differences between scenes and objects within the VC's Selective ROIs. Most past studies had analysis limited to scenes [4][7-8][11-12][15-16][20][23][25][27][37] and didn't examine familiarity within the VC with significant sample size [7][8][13]. Our behavioral study with 30 scenes and 30 objects was used to meter familiarity rankings for each image. Then our neurological analysis was undertaken to examine the effect of familiarity and image identity (scene or object) on VC ROI BOLD signal. This study suggests a new role for the EVC in high-level processing, corroborates the scene-selective ROI behavior seen in past studies [2-15], and mandates more research into processing differences between scenes and objects (Some behavioral and neurological data contradicted).

This research has immediate applications in the world of VC research. It's been long disputed whether high or low-level features have the greatest impact on processing [16]. This study contains evidence towards the prevalence of high-level features. It's clear that the brain exerts a high value on vision (50% of the Cerebral Cortex is dedicated to it [1]), by establishing the role of familiarity in VC processing neuroscience may be one step closer to understanding the dynamics of this sense. For this benefit to be realized, future research examining other types of familiarity is necessitated (Ex: Occupational familiarity, Does our occupation change which images one finds most familiar) in order to validate the widespread effects of this variable. By including both scenes and objects this study comes closer to a holistic view of visual processing. To increase realism, future studies should attempt to use Graphics Interchange Format images or short videos as stimuli. This would recruit the dorsal stream, an additional VC processing pathway that leads to the Parietal Lobe. These cortices calculate spatiotemporal and movement features within images and are stimulated within everyday VC processing [5-6].

Outside of the VC field, this research is pertinent to a variety of neurological disorders. Ties between familiarity and memory are clearly established. Familiarity expresses the strength of memory and logically could be affected during the onset of a memory disorder. The procedures used in this experiment to record familiarity measures and record fMRI of VC ROIs could possibly be used as a kind of baseline measure and diagnosis tool. If a patient was suspected to have a disorder such as Altzheimers or Dementia, they could have their pre-test compared to a post-test to meter if there is a significant difference. In order to verify the connections between familiarity and memory diseases a future VC familiarity study with a control group of healthy individuals and experimental group of diseased individuals (Have Altzheimers or Dementia) would be mandated. Concurrently, there have been studies that have shown that exposure to familiar stimuli is an effective therapy for memory diseases [34][35].

Evidence from this study could be used to support and promote the use of familiar images in this facet. Diseases such as Schizophrenia and Schizoaffective disorder are characterized through a set of positive and negative symptoms. One such positive symptom, visual hallucinations, is often a result of flawed circuitry within the VC [31][32][36]. Understanding the mechanisms of a healthy VC could be a vital stepping stone in understanding and working towards treating these illnesses.

This experimentation also has applications outside of neuroscience. Familiarity is likely to have a role in the process of learning. When someone learns they are effectively creating a new functional pathway by which action potentials can be transmitted. Familiarity could then, in effect, control the strength of the memory and therefore recall. A future study design could be to have a group of subjects rate the familiarity of a set of picture flashcards. They would then attempt to commit the names of the images into memory while under fMRI recording. This experimental design would allow researchers to determine if familiarity has facilitating ties to learning. If proven, this could apply in the classroom. Especially for special needs students, it could be beneficial for teachers to use familiar images in instruction (Ex [29] examined pictorial step-tied teaching, a process in which a specific image is associated with a term or step of a process and is then repeated). In the military, it could be examined if training soldiers in environments similar to future combat zones (Ex: Virtual Reality Training used in [30]) would improve performance. Furthermore, in the field of advertising it could be tested if using more familiar stimuli increases consumerism [39] . Within this study there is evidence that unfamiliar images evoke lower BOLD signal than their familiar counterparts. This could be a reason to test if driving in an unfamiliar environment increases the chance of an accident. This information could be pertinent to insurance companies and customers alike. Overall, this study achieved its purpose of conducting an unprecedented comprehensive neurobehavioral analysis of scenes and objects with a significant sample size. The findings most importantly indicate the impact of familiarity on visual processing and provide more insight on the behavior of the VC's selective and low-level cortices.

Future studies should extrapolate the role of familiarity in memory disorders and learning in order to facilitate widespread applications in cognitive disorders, K12 education, driving, the military, and advertising.

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