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An abstract of
a thesis submitted to the Faculty of Emory College of Arts and Sciences of Emory University in partial fulfillment of the requirements of the degree of Bachelor of Science with Honors

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Abstract

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Epilepsy affects 50 million people worldwide and has profound implications in many facets of everyday life. For example, learning can be impaired in people with epilepsy, as children with the disease have a higher risk for learning disabilities. Eye tracking has been shown to be an effective measure in both assessing and improving memory in an academic setting. In this thesis, we focus on assessing memory, an important aspect of learning. Specifically, we explore differences in memory performance between neurotypical individuals and individuals with epilepsy within a task that involves the addition of objects from a scene.

We created a task where participants watched a series of similar short videos. Later, videos were replayed with the addition of certain objects that appeared in earlier videos. Data analysis in python was done to calculate the duration of time a participant spent looking at these added objects. An initial test-run of this toolkit with neurotypical individuals shows the possibility of using a toolkit such as this to assess memory. Our hope is that this toolkit can inform technologies that lead to better learning outcomes for individuals with epilepsy.

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Contents

Chapter 1

Introduction

Epilepsy is one of the most common neurological disorders in the world. Those with the disorder have a higher rate of learning disability and may have trouble retaining information [2]. As a result, there is a need for technology that accommodates the unique learning needs of people with epilepsy. This study proposes a toolkit that may be used to quantify memory deficits in people with epilepsy through eye tracking. The development of this toolkit, which is a computer-based eye-tracking framework, will be the primary contribution of this study. This framework could be used in the creation of further technologies to quantify certain visual deficits associated with epilepsy or other neurological disorders. The framework may also be utilized in developing technologies to aid those with epilepsy use technology more seamlessly.

Visual paired cognitive assessments quantify the amount of time a participant looks at a new stimulus compared to a stimulus they have already seen. Existing research has shown that the use of eye-tracking is as effective as standard paper tests when used for visual paired cognitive assessments [6]. Eye-tracking has also been found to be a dependable metric for testing explicit memory in people with epilepsy through various recall games [5]. However, there is not any literature on whether eye-tracking is a viable avenue for testing memory without direct recall. Up until now, eye-tracking devices have been primarily used to test explicit memory. Previous work has shown that eye-tracking may be a viable avenue to test a participant's recall abilities during game-like trials [4].

The lack of literature on implicit memory and eye-tracking means it remains unclear whether eye-tracking provides direct evidence of memory deficits when a participant is not specifically prompted to recall what they observed on-screen. Existing literature also notably only presents visual stimuli in the form of static images [4] [5]. A test that utilizes videos may reveal eye-tracking patterns closer to those seen in daily life, as day-to-day activities rarely consist of solely viewing static images.

The aims of this study are twofold. First, it proposes a toolkit that may be used to quantify memory deficits in people with epilepsy. It also aims to expand the scope of previous memory tests by examining the viability of eye-tracking technology in testing implicit memory with the use of videos. It is hypothesized that the use of eye-tracking technology in conjunction with other methods may highlight more specific areas of deficit that underlie constructs such as learning or memory (e.g., relative contribution of attention, executive function, and actual learning and memory subtypes). A further understanding of these constructs will allow for more sophisticated models of learning and memory, and ultimately lead to more effective and personalized interventions for people living with epilepsy.

Future data collected from the toolkit created in this study may be used to propose design guidelines that will facilitate the creation of technologies that are more easily utilized by those with epilepsy. A potential application for these guidelines is in the context of technology-based learning. A greater understanding of the memory needs of students with epilepsy could lead to the creation of more accommodating learning technologies. This would in turn lead to a greater probability of successful academic outcomes for those students. As the prevalence of distance learning has increased due to the COVID-19 pandemic and the increasing popularity of MOOCs, technology plays a larger role than ever in education. Consequently, the development of user-friendly technology has become more critical. This includes the development of technologies for those who may have difficulties in memory-related tasks due to epilepsy.

Results could also be used to develop tasks that better determine the root neurological cause behind memory and learning deficits in people with epilepsy. Eye-tracking could lead to a more complete picture of how recognition, retention, or other aspects of memory are different in people with epilepsy-related memory deficits. A better understanding of how visual processing relates to memory could lead to more effective treatment methods for epilepsy-related learning disabilities and memory issues in the future.

Chapter 2

Related Works

In the past, related works have shown the efficacy of eye-tracking in the diagnosis of certain psychiatric disorders. For example, researchers were able to use eye-tracking devices to correctly identify participants with ADHD over 80 percent of the time [8]. In the study, fixation duration was used as the primary identifier for identifying participants with ADHD, although saccades (quick jerky eye movements) were also used to identify participants with ADHD. The trials dealt strictly with verbal memory, tracking participants' eye movements as they read a sentence. Jayawardena's study is also notable in its use of areas of interest (AOIs) to highlight certain parts of sentences as notable. This thesis will use a similar scheme of AOIs to highlight certain parts of visual stimuli.

Eye tracking has also been demonstrated to possibly be a viable complement to paper-based tests. A study examined the effectiveness of using eye tracking to evaluate participants' performance in a visual paired comparison (VPC) test [6]. A VPC test involves a familiarization and testing phase. In the study, the time a subject spends viewing a novel stimulus compared to a familiar stimulus was compared using eye tracking. A modest correlation between the results from the eye-tracking device and existing paper tests was observed.

Eye tracking has not only proved to be useful in diagnosing mental disorders, it has also displayed positive effects in improving memory and learning. An article examined the effects of eye-tracking training in children who had difficulty learning [3]. The researchers found that children who underwent 20 weekly 50-minute eye-tracking training sessions performed better on delayed recall memory tests, had improved reading ability, and were able to learn at a faster rate after the training sessions compared to students who did not undergo the eye-tracking training sessions.

In a meta-analysis of studies that use eye-tracking to analyze neurological conditions, eye-tracking devices have been used to study epilepsy “for two main purposes: clinical evaluation and the elucidation of neural mechanisms” [12]. In the same meta-analysis, it is suggested that eye movement could serve as a marker for cognitive impairment for patients with epilepsy. This is reflected in the topics common in epilepsy eye-tracking studies such as memory, face recognition, and brain activation. Results gathered in Tao’s meta-analysis suggest that ocular movement during eye-tracking tasks “may serve as a marker of brain activation” [12].

As for the viability of the Pupil Labs Core eye-tracking device, which is the device used for the trials in this thesis, a study by Wang, Lu, and Harter validates its effectiveness in assessing learning in an academic setting. The study looks at different kinds of eye-tracking systems, and examines their strengths and weaknesses. Regarding head-mounted eye-tracking systems, (which is what the Pupil Labs Core device used in this thesis is categorized as) the paper states that they are “quite useful when subjects can easily wear them and move freely in natural indoor and outdoor environments” [13]. The authors concede that these kinds of eye-tracking devices may be less appropriate for studies over two to four hours in duration. However, the study designs of the trials in this thesis require less than 30 minutes to complete. Therefore, this drawback of a head-mounted eye-tracking device should not prove to be a detriment.

This thesis will use a subset of the Dynamic AOI Toolkit developed by Faraji et. al in their article, “A toolkit for wide-screen dynamic area of interest measurements using the Pupil Labs Core Eye Tracker.” The researchers used the toolkit to detect gaze patterns when participants viewed a traffic scene. The study involved participants viewing a series of 13 videos of traffic. The toolkit was used by the researchers to place bounding boxes known as “areas of interest” over each video [7]. The bounding boxes track the objects contained within them using the OpenCV package along with other packages within the toolkit. According to the package’s documentation, OpenCV is “a library of Python bindings designed to solve computer vision problems” [10]. The amount of time that a participant’s gaze was within the bounding box was calculated through the use of the toolkit. Dwell times were calculated based on moments of “entry” and “exit.” This means that the frames between when a participant’s gaze entered and exited an area of interest were defined as the dwell time. Multiple participants’ dwell times were also able to be calculated by overlaying all of their gaze positions over a single video.

Faraji et. al’s study was performed on a set of three computer monitors in a controlled lab setting. Participants were allowed to freely move their heads during the trials. In addition, Apriltags were placed on the bezels of three monitors in order to define a surface which eye movements could be mapped onto. Apriltags are markers similar to QR codes that can be placed onto flat surfaces. They interface with Pupil Labs’ API to provide for an easier mapping of gaze positions [7].

For the trials done in this thesis, a similar protocol to Faraji et. al’s study was used, albeit with some key differences. Similarities from Faraji’s study include the use of computer monitors to display the trial scenes, the freedom for participants to move their heads during the trials, and a similar controlled lab setting. However, instead of three separate monitors like Faraji’s study used, a single monitor was employed for all trials that were performed.

Perhaps the most significant difference between Faraji's study and this study is the method of data analysis. This study employed use of the Dynamic AOI Toolkit, but only for placement of areas of interest on the video. Although the Toolkit provides scripts to overlay participant gaze position on to videos, this study used additional python scripts to achieve a similar overlay. This was done due to software compatibility issues between the toolkit and lab equipment.

Chapter 3

Methods

3.1 Recommended Method of Participant Recruitment

The following criteria for participants are recommended to run the trials in this thesis effectively. To be eligible for this study, control participants should be at least 18 years of age, have native English language proficiency, have no neurological or psychiatric disorders (physical medical conditions are acceptable), and no history of substance abuse problems. For the experimental group, at least 12 participants with epilepsy are suggested to be recruited. The participants in the experimental group should not have undergone surgery for epilepsy at the time of the study.

3.2 Proposed Setting and Materials

Participants should be instructed to wear a Pupil Labs Core headset, which is an eye-tracking device with three cameras. The front-facing camera records at 720p and 60 Hz, and has a 0.60 degree accuracy and 0.02 degree precision. The device also contains two eye cameras, which record the pupils of the participant at 192 x

192 resolution and 200 Hz [9]. The Pupil Labs Core device can be linked via a wired connection to a desktop computer in the testing area.

The trials should all be performed in the same room, with the same overhead lighting so that the brightness level of the room would not be a factor in biasing the data. Although monitor size should not pose a significant difference in study results, the trials in this thesis were designed to employ a 27 inch monitor with a 3840 x 2160 resolution. The area immediately behind and around the desktop monitor should be made free from visual distractions and as close to visually homogeneous as possible.

The desktop computer employed in the preliminary trials was a desktop running Windows 10. Its specifications included an Intel i7-7700k processor, 16 gigabytes of 3200MHz DDR4 RAM, and an EVGA GeForce GTX 1080 Ti graphics card. Storage of participant data and Unity scenes was handled through an external Samsung SSD.

The scenes to be shown in both tasks were developed in Unity version 2020.3.17f1 and were modified from Noah Okada's cognitive tasks with permission [11]. Additional Unity environments to show the scenes were developed in Unity version 2021.3.16f1. Scenes were first saved as mp4 videos before being shown. This was done to resolve the difference in Unity versions, and caused no discernible difference in task design. Saving scenes as videos also improves study flexibility, as the only change needed to test additional scenes is to replace the existing video file paths with new paths within the "play_vids" script.

The Unity scenes show common everyday environments such as a gym, an amusement park, and a supermarket. The scenes involve the participant slowly traversing these scenes in a first-person perspective.

The participant should be seated so that the entire monitor comfortably fits within the frame of the Pupil Labs Core device's front-facing world camera. In the lab setting where preliminary data was gathered, seating the participant approximately 0.5 meters from the monitor with their forehead roughly level with the top of the monitor proved to be effective in ensuring the entire monitor was consistently recorded by the Pupil Labs Core device.

Apriltags are small fiducial markers developed by researchers at the University of Michigan [1]. Apriltags are used as reference points for the Pupil Labs Core device and the Dynamic AOI toolkit. Placing six Apriltags on the monitor helped in identifying surfaces (the monitor) within the Pupil Capture Software, in addition to adding a coordinate system to said surfaces. Six Apriltags should be placed along the bezel of the monitor to define the monitor as a surface within the Surface Tracker plugin of the Pupil Capture software [9].

It is recommended to use the Pupil Capture software to track eye movements from participants during the trials. Furthermore, the Pupil Labs Player software should be used to export gaze location, pupil location, and fixation time from the tracked eye movements of the participants. If data is not exported using the Pupil Labs Player software, the AOI overlay and data analysis toolkits will not be able to be used, as they require specific data formats.

3.3 Toolkit: Defining AOIs and Data Analysis

In the proposed methodology (described below), certain objects are added to the first, seventh, and twelfth Unity scenes of the second trial. For these scenes with added objects, areas of interest are defined as boxes around the objects that are added. Areas of interest are limited to a maximum of one per scene (due to only one object being added to each of the first, seventh, and twelfth scenes). Areas of interest are not defined for scenes besides the first, seventh, and twelfth scenes in the second trial.

Faraji's Dynamic AOI toolkit allows the selection of areas of interest on the screen for use with the Pupil Labs Core eye-tracking device [7]. Before areas of interest are defined, and prior to performing any modification to the eye-tracking recording, the Dynamic AOI Toolkit was used to place Apriltags on the borders of the video.

After Apriltags are placed on each participant's video, Areas of Interest are defined and tracked semi-automatically using the Dynamic AOI Toolkit. For each of the 3D environments in the second trial with an object added, a bounding box is drawn around that object with the Dynamic AOI Toolkit's semi-automatic selection algorithm (explained below).

Defining the areas of interest is done by using a slightly modified version of Dynamic AOI Toolkit licensed under the GNU General Public License [7]. Modifications were made to the Toolkit to conform with Windows file path conventions (the original toolkit only supported Mac and Linux file paths). Modifications were also made to support the dimensions of the screen used during the trial, as well as the unique testing environment inside the laboratory (these modifications were made in the “__constants.py” file). Experiments that employ MacOS or Linux devices should download Faraji's original Dynamic AOI Toolkit to ensure correct functionality. Additionally, experiments that use different monitor sizes or testing environments should make modifications to the “__constants.py” file within the toolkit to reflect this.

Fixation time is calculated as the amount of time that a participant positions their gaze on an area of interest during the second trial. The Pupil Labs software contains a “confidence” value for each gaze measurement. This value defines the certainty with which the software can determine if a person is looking at a certain area on screen. Data entries with confidence values of below 70 percent were discarded for this experiment.

After trials are performed, the Dynamic AOI Toolkit is used to define the areas of interest for the first, seventh, and twelfth scenes of the second trial. This is done through the use of the “selection.py” file within the toolkit. This file uses OpenCV's computer vision algorithm to automatically track objects within a bounding box defined by the user. The added objects in the second trial have bounding boxes drawn around them, and are tracked automatically using the toolkit. The Dynamic AOI Toolkit produces an output file with data on the coordinates of the AOI bounding boxes for the second trial.

Further processing of the data produced by the Dynamic AOI Toolkit is performed with Python version 3.12.0 and Numpy version 1.26.2. This processing is done to align the frame numbers for the Pupil Labs gaze data with the AOI coordinate data that was gathered from the Dynamic AOI Toolkit. The processing also calculates the proportion of time that a participant views an AOI during the time that the AOI was on-screen. Although the Dynamic AOI Toolkit provides files for calculating the time that a participant viewed an AOI, software compatibility issues prevented the use of the Dynamic AOI Toolkit for this purpose.

The output of the Python file is a text file containing the number of "hits" (the number of frames that a participant's gaze overlapped with the AOI on screen), the "total rows," which is the total number of frames that an AOI was on screen, and the "hit ratio," which is simply the number of hits divided by the total rows.

3.4 Proposed Procedure

Before starting the task, participants should be asked to perform calibration of the headset while keeping their head as still as possible. Calibration involves participants looking at five black and white targets on a white background on screen while only moving their eyes. If calibration is unsuccessful, the process should be repeated until the confidence of calibration becomes sufficient (greater than 70 percent) for the upcoming tasks. Confidence for the calibration tasks is defined using the Pupil Capture software.

Following calibration, participants should be instructed to complete a "practice trial" which involves viewing a 4-second fixation of a white cross on a black background immediately followed by a 5-second video clip of 3D Unity environments which are recreations of common day-to-day environments. Immediately following the 3D Unity environment, another 4-second fixation is shown, followed by another 5-second video clip of a Unity environment. Participants are instructed to look at the fixation when it appeared on the screen, and look wherever they liked when the Unity environments appeared. Gaze and pupil data is not recorded for each practice trial, as this trial is only designed to give participants familiarity with the experiment procedure.

After the practice trial is completed, participants move on to the first trial. The procedure for this trial is an extended version of the practice trial. Alternating 4-second fixations and 5-second Unity 3D Environments appear on the screen. A total of 15 fixations and 15 Unity Environments are to be shown during this trial. Once again, participants should be instructed to look at the fixation when it appeared and relax their eyes for the remainder of the trial. During the trial, participants are instructed to keep their head as still as possible and only track objects on the screen with their eyes. However, a head restraint device is not required during this trial. The Dynamic AOI Toolkit is assumed to compensate for any incidental head movement [7].

Next, participants commence the second trial, which involves watching a second series of 15 videos. This second series of videos involves similar scenes to the first trial, but with certain objects added to some scenes. The first, seventh, and twelfth scenes are chosen to each have an object added to the environment. Repeat scenes from the first trial, as well as novel scenes are also presented to participants for the remainder of the scenes. Fixations appear between scenes exactly as they did for the two previous trials. The duration for the fixations remain 4 seconds in duration, and the videos of 3D environments remain 5 seconds in duration as well.

Chapter 4

Results

4.1 Results From Clinically Normal Volunteers

Due to pending IRB approval, data from experimental subjects with epilepsy was not able to be gathered. Therefore, preliminary data gathering was done through the participation of clinically normal volunteers.

Three volunteers were recruited for the purpose of examining the effectiveness of the toolkit developed in this thesis. After consenting to the study, the participants were guided through each of the trials according to the proposed methodology described in the "Materials and Methods: Proposed Procedure" section above. The total time taken for the participants was roughly 10 to 15 minutes including the time needed for calibration and explanation of the trials.

After extracting data from the Pupil Labs Player software, defining AOIs in the Dynamic AOI Toolkit, and performing further data processing in python, the following results were obtained:

One participant generated 44 frames of "hits" among 387 frames where an AOI was on screen, giving an 11.37 percent hit ratio. The other two participants generated 0 hits among 338 and 305 possible frames where an AOI was on screen. Although it is possible that these are legitimate results, a result of 0 hits is likely due to a programming error in the data processing script. More investigation into the data is needed to determine the cause of no hits being produced for two of the volunteer participants.

4.2 Hypothesis for Future Experiments

It is hypothesized that experimental participants will generate fewer "hits" than the clinically normal control participants tested during this preliminary trial. This is due to memory deficits observed in many epilepsy patients [2]. If the toolkit developed in this thesis correctly targets a subset of memory in which people with epilepsy present deficits, it would logically follow that participants with epilepsy will not remember previous scenes as well as clinically normal participants. Therefore, participants with epilepsy will likely not fixate their gaze on an added object in a scene as heavily as participants without epilepsy, as they would be more likely to split their attention between more areas of the scene.

Chapter 5

Conclusion

The results generated from the creation of this toolkit show that although the toolkit may be effective in calculating fixation time for AOI gaze times when working properly, further optimization of the toolkit is needed to eliminate possibly erroneous results from appearing in the results.

Further work could also be done to optimize the testing workflow. During the testing of participants, it was noted that Unity often took a considerable amount of time to open each trial project. There was also considerable latency between pressing "play" on each scene and the scene fully running. Porting each trial to a stand-alone video that could be shown to participants outside of Unity may help to alleviate these issues.

Due to the low time commitment required from each of the trials, the toolkit developed in this thesis could be used to develop quick memory assessments for people with epilepsy in the future. Although the trials in this toolkit are not designed to replace traditional paper-based tests, they may provide helpful additional metrics for assessing memory in people with epilepsy.

As demonstrated by Jayawardena's study, analysis of AOIs through eye-tracking has been used previously to identify ADHD without the use of traditional paper-based tests [8]. Additionally, Bott's eye-tracking Visual Paired Comparison task showed a mild correlation with preclinical Alzheimer's Disease Composite tests [6]. Due to the use of eye-tracking and AOIs in the toolkit developed in this study, there is potential to expand this toolkit to evaluate cognitive deficits associated with ADHD. The toolkit in this thesis also shares similarities with Bott's Visual Paired Comparison Task. Therefore, the toolkit's function may be also expanded to study cognitive deficits related to Alzheimer's Disease as well.

A potential technological implication of this toolkit is the development of more accessible computer systems for those living with epilepsy-related cognitive deficits. With the prevalence of online learning in the modern world, guidelines for effective distance-learning methods are needed. These guidelines should include methods for improving information retention for students with memory deficits, such as those prevalent in people with epilepsy. Improvement of information retention may be implemented through the development of new guideline-cognizant technologies or new pedagogical methods related to guidelines. To develop these guidelines, a greater understanding of the memory deficits associated with epilepsy is needed. This understanding may be gleaned through further studies that make use of this toolkit.

A potential limitation of the toolkit developed in this thesis is the method of manually defining AOIs within the Dynamic AOI Toolkit. Due to the user having to manually draw bounding boxes around each AOI, variation will become present in the coordinates of the bounding boxes that are drawn. This may lead to identical gaze positions being classified as "hits" for certain users, and not classified as "hits" for others. Another potential limitation is the inherent technological limitations presented by using Unity scenes as representations of realistic environments. Although Unity provides fairly high-resolution textures for use in scenes, these scenes still do not fully represent real-life environments. Using video from real-life environments may help to improve this potential limitation.

Following the conclusion of this thesis, the next steps for this research include optimizing the data-analysis workflow, gathering data on an epileptic experimental group (pending IRB approval), and comparing the data of said experimental group to a larger group of control participants.

Chapter 6

Code

Code used in this project may be accessed on this repository: https://github.com/skodjet/Epilepsy-Eye-Tracking-Toolkit

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