2024

A Novel Approach for Assessing Visual Perception

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May 2024

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ABSTRACT

BACKGROUND: As eye tracking devices improve and are used in research, they elucidate the impacts of visual variables and neurological disease on the visual perception. Visual symptoms have been linked to both structural and functional neurological diseases, including traumatic brain injury (TBI), Parkinson's disease, dementia, and Alzheimer's disease. These visual perceptual impacts indicate possible diagnostic criteria to identify and treat neurological disease. PURPOSE: This preliminary methodological study focused on data collection to investigate the uses of eye tracking and create a potential experimental design for future patient-based studies. The goal was to investigate the impact of target shape, animation, location, and background color on visual perception, as measured by fixation duration and number of fixations. METHODS: Four healthy sample participants were recruited and performed two eye tracking trials with randomized stimulus sets. Each stimulus set included four shades of background colors, from white to dark grey, two dynamic and two static targets, four target locations, in each quadrant of the screen, and four simple target shapes. RESULTS: The fixation counts and durations showed expected trends for background color, with more fixations the darker the background color due to longer processing time. Similarly, the animations showed more fixations for static as compared to dynamic stimuli due to ease of visual perception. The shape and location, however, showed unexpected effects with a decrease in fixations for the plus and star as compared to the circle and diamond, and decreased fixations in the top two quadrants as compared to the bottom two quadrants.

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ACKNOWLEDGEMENTS

First, I would like to thank my mentor, Sambit, for all of his support throughout the process of working on and writing my thesis the past two years. I appreciate his dedication to completing the process with me, even remotely, and giving me the freedom to learn and explore new research with his support. I would also like to thank Denise and Sue for their support when Sambit relocated, ensuring I had everything I needed to succeed in completing my honors thesis. Finally, thank you to my family, friends, and boyfriend for listening to me work through questions and ideas, staying up late with me to work on my thesis after all of my other homework, and providing endless encouragement.

CHAPTER ONE

Introduction

Eye tracking is an emerging area of research which can provide data to study visual processing and cognition by tracking eye movements.[1] This is a valuable source of insight into underlying neurological disease that impacts visual perception and may cause oculomotor dysfunction.[2] However, eye tracking devices are still under development and could be extended to a much larger research basis with updates and data collection. With improved devices such as wearables, data collected will have better ecological validity and results will be broadly generalizable to patient populations.[1] These devices also require more practice to fully utilize the research capabilities encompassed by eye tracking.

One of the research goals of our lab was to determine the role of visual perception in patients with chronic dizziness, or the recently established diagnosis of persistent postural-perceptual dizziness (PPPD). The Tobii Pro Spectrum eye tracker was newly acquired by the lab to investigate parameters of visual perception.[3] This study aimed to utilize the eye tracking device and design experimental protocols to investigate the role of visual perception in future studies with patient populations. The study was exploratory in nature, primarily aimed at testing feasibility, refining methodologies, and generating hypotheses.

The variables included in the visual stimuli in this study were background color, shape, location, and animation. The different background colors used were in various shades of grey, with all black shapes placed in each quadrant of the screen, some dynamic, or flashing, and some static. Our central hypothesis is that the stimuli will be most difficult to perceive when the foreground and background colors were most similar. Three specific hypotheses were evaluated based on the variables tested:

Hypothesis 1: We hypothesize that the lightest background color will show the shortest and least fixations on the target and darkest background color will have the longest and most fixations on the target.

Hypothesis 2: We hypothesize that the dynamic stimuli will have shorter and less fixations than the static stimuli.

Hypothesis 3: We hypothesize that the shape and location of the stimuli will have no effect on the duration or number of fixations on the target.

These hypotheses assumed that more familiar stimuli are processed faster, and require less fixations, while more complex stimuli require more and longer duration of fixations to be perceived. The shape and location were included as null hypotheses to evaluate the effect of the randomization included in the experiment.

CHAPTER TWO

Literature Review

The focus of this literature review is to provide extensive background of previous research in oculomotor control and visual perception. This is relevant to our research in terms of how visual processing is measured, what disorders may impact visual perception, and how eye tracking has been used in past research. There are two main categories of neurological disease which impact visual perception, structural and functional. Structural disease refers to physical changes in brain which affect oculomotor functions and can be visualized through imaging techniques. However, functional neurological disease refers to changes in brain function such as signaling which can affect visual perception and are usually difficult to see on readily available clinical tools and imaging. Both forms of disease can affect visual processing and perception of stimuli and their symptoms often have significant impacts on quality of life. Understanding how oculomotor function and visual perception are impacted by these diseases and what research has been published so far on the topic is important in developing future eye tracking studies to fill the gaps in research.

Oculomotor Control

Oculomotor control involves how an individual's eyes are moving in space and what those specific movements consist of. The three main types of eye movements which are typically studied are: saccades, pursuits, and fixations. Since the photoreceptors in the human eye are concentrated in one spot, the fovea, humans require frequent eye movements to take in different stimuli and piece together a whole picture of the world around them. These quick eye movements across the visual field are called saccades, and are typically 150 to 200 milliseconds

in length.[4] During saccades there is a loss of visual sensitivity, as it is difficult to distinguish contrast as the eye moves from place to place, until it settles on one point.[5] The settling between saccades is known as fixation on a point, but this does not mean the eye remains steady for long. In a fixation, the eye pauses just long enough to take in the details of the surroundings. Average fixations last 200-300ms, although they can be shorter or faster based on complexity of stimuli.[6] However, the fixation is not completely stationary, but contains microsaccades, or tiny movements to prevent neural adaptation to a fixed image, which would cause vision to fade.[7, 8] Finally, pursuit eye movements involve the perception of a moving stimulus, and consist of smooth, slow eye rotations matching the velocity of the object they are tracking, with a 100 to 150 millisecond latency.[4]

Investigating Visual Perception

Past research on oculomotor control has investigated the mechanics of eye movements during simple tasks such as reading, higher cognitive functions such as decision making, and motion perception in relation to oculomotor control.[9-11] Such studies are typically accomplished by using an eye tracking device which can measure subjects' eye movements either using a screen display or a wearable in the form of glasses or goggles. Popular types of eye tracking devices that have been extensively used in research include the EyeLink 1000 and the Tobii Pro, which can vary slightly in data produced but provide very similar results in terms of accuracy.[3, 7] A relatively recent development in research is the use of eye tracking technology to measure oculomotor control and dysfunction in neurological disorders and injuries including, but not limited to, Parkinson's, dementia, traumatic brain injury, and stroke.[2, 12-14] This emerging field has the potential to address gaps in diagnosis and treatment of various neurological injuries and

examine the role of oculomotor function in neurological impairment that may have been currently overlooked.

Oculomotor Dysfunction in Structural Neurological Disease

Most of the current research on eye tracking focuses on investigations into concussion and traumatic brain injury (TBI). For example, the study by Samadani et al. (2015)[15] explores binocular gaze disconjugacy, or the eyes not moving together, in traumatic brain injury and concussion with a novel algorithm. They found that eye movements predicted symptom severity in head trauma patients, regardless of positive or negative head CT for TBI, indicating eye tracking could be a useful diagnostic tool as opposed to CT.[15] This result has been supported by other studies and reviews, which have found eye movements to be useful as ocular biomarkers for concussion assessments and outcome measures for brain injury.[16, 17] Studies have not only focused on eye conjugacy, but also more common oculomotor mechanics such as saccades, pursuits, and fixations, as well as vergence, or the ability of both eyes to focus together on a point.[13, 16-19]

These studies are relevant because eye tracking is capable of detecting subtle deficits in oculomotor function which are commonly classified as negative on a CT or other screening measures.[13, 15] Deficits may also persist beyond the acute phase of injury, and have been found three to five months after injury, when patients are cleared as safe from head trauma and no longer consistently monitored.[16, 19, 20] However, they may still be at risk of deficits in visual perception, and oculomotor deficits may be present in up to 90% of patients with concussion, or blast injury.[15]

Oculomotor deficits are also seen in stroke, as both a symptom following stroke and a preliminary indicator of possible stroke.[14] Visual symptoms include monocular or binocular vision loss, cortical vision loss, with pupillary response, impaired conjugate gaze, saccadic intrusions to one side, and impaired smooth pursuits.[14] In some patient cases, visual saccadic abnormalities following stroke lagged behind motor recovery, which indicates eye tracking could be used to track nonmotor or cognitive recovery in stroke patients.[2]

Individuals with Parkinson's disease have shown similar saccadic tendencies, convergence insufficiency, and instability in fixations, which may serve as a physiological biomarker for the disease.[2, 12, 21] Specifically, saccadic readings were found to be 20% slower than controls.[22] One study found that 82% of Parkinson's patients reported visual symptoms, including oculomotor dysfunction.[23] Patients were also more likely than controls to report that these visual symptoms interfered with every day activities, such as causing driving difficulties and falls.[23] Biomarkers are especially important in Parkinson's disease to aid early detection and indication of future symptoms because of the late onset of motor symptoms, so visual dysfunction tracking could be a novel approach to apply for early identification.[12]

Visual Perception in Functional Neurological Disease

More cognitive and otherwise functional forms of neurological impairment have been shown to affect visual perception and processing, but less research has been published on specific oculomotor deficits than with structural neurological diseases. For example, one neurological disease that is not structurally linked is Functional Cognitive Disorder (FCD), categorized by persistent, distressing cognitive symptoms with no link to neurodegenerative or psychiatric causes.[24] Patients who suffer from FCD show a lack of metacognition or knowledge

of their symptoms and score low on visual perceptual tasks which require self-analysis of a task or object.[24] Other functional neurological diseases including dementia and Alzheimer's disease have been found to present with saccadic latencies, which could help to distinguish between types of dementia.[25] These diseases though involve both structural and functional changes in the brain. However, it is important to note that functional neurological disease does profoundly impact the visual system and oculomotor dysfunction is not limited to primarily structural diseases.

Another functional neurological disease is persistent postural-perceptual dizziness (PPPD), a form of chronic dizziness with much currently unknown about it. It is named for the patients' experience of persistent dizziness exacerbated by postural challenges, or movements, and perceptual sensitivity to space-motion stimuli.[26] The symptoms of PPPD are severe for patients in environments with complex, moving visual stimuli, which includes simple everyday activities such as looking at traffic.[27] Visual dysfunction in PPPD is important to investigate because, as with other forms of dizziness, patients tend to compensate for dizziness sensations with increased reliance on visual cues.[27] When these cues fail them, patients are unable to cope with persistent dizziness and have far poorer quality of life.[27] Currently, the underlying cause for of PPPD is still unknown, and a possibility for continued research.[28] This could be done with eye tracking studies to evaluate gaze stability and other visual perceptual symptoms of PPPD.[28]

While research on PPPD is newly emerging, its diagnostic criteria have been in the works for the last three decades and have just recently been adopted.[26] This opens the door for more specific research such as eye tracking studies with patients with PPPD with an objective to investigate visual perception. About half of PPPD patients do better with anti-anxiety medications, however the remainder struggle with quality of life without any relief from

dizziness.[27, 29] Visual studies could reveal much about eye movements relevant to motion-tracking sensitivities, such as oculomotor dysfunction in pursuits, and illuminate new information about visual tracking in dizziness. This could also translate to new treatment methods for dizziness to help patients cope with severe and chronic symptoms.

CHAPTER THREE

Methods

Experimental Design

The goal of this study was to create an experimental protocol to test visual perception using the Tobii Pro Spectrum eye tracker.[3] The stimuli used four simple, easily identifiable symbols located in four locations around the screen, and on four different backgrounds to be organized into four slide stimulus sets. The backgrounds were a gradient from pure white (100% opacity) to dark grey (25% opacity black) with all black symbols to test the foreground-background discrimination with increasing similarity in color. The stimulus symbols included a star, plus, circle, and diamond, all chosen as basic and easily identifiable shapes to randomize the appearance of the stimuli over the trial. To aid in randomization, the symbols were also located in four different quadrants of the screen over the course of the trial. The final variable included was animation of the stimuli, with two static and two dynamic, flashing white every 0.5 seconds in each stimulus set to test the impact of static versus dynamic stimuli on visual perception.

The stimulus sets were randomized so that each set had one of each shape, background, and location and two of each animation (Figure 1). All of the conditions for each symbol were made into a slideshow and a random number generator was used to select one slide of each shape, the later slides being limited to the remaining background colors, locations, and animations which had not been used yet in the set. This was repeated to create four unique stimulus sets to limit the effects of running multiple trials with a small sample size.

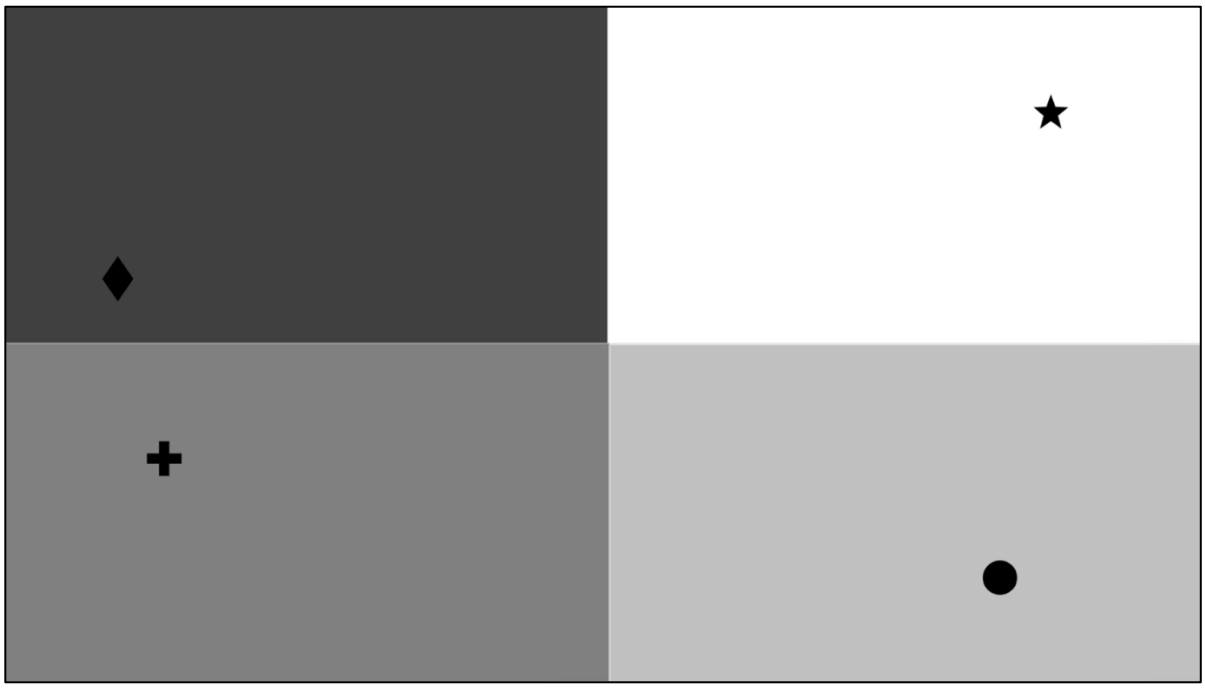

Figure 1. Stimulus Set 1 slides with different shapes, background colors, and positions.

The stimuli were designed in Microsoft PowerPoint to standardize the measures and animate the dynamic stimuli.[30] To upload each stimulus set to the Tobii Pro Lab software, the set of four stimuli was compiled into a PowerPoint with animations for each slide to last 5 seconds to allow sufficient time for multiple fixations and stimulus processing.[31] The set was then recorded through the Powerpoint "record" function and saved as an mp4 file to import to Tobii Pro Lab (Figure 2).[30, 31] Once in the Tobii Pro Lab software, the "design" function was used to create a protocol for each stimulus set.[31] A text slide was added before the stimulus set mp4 to state instructions for the participant and was designed to stay on the screen for 10 seconds before progressing to the stimulus set video, to allow sufficient time to read the text for all participants (Figure 3).

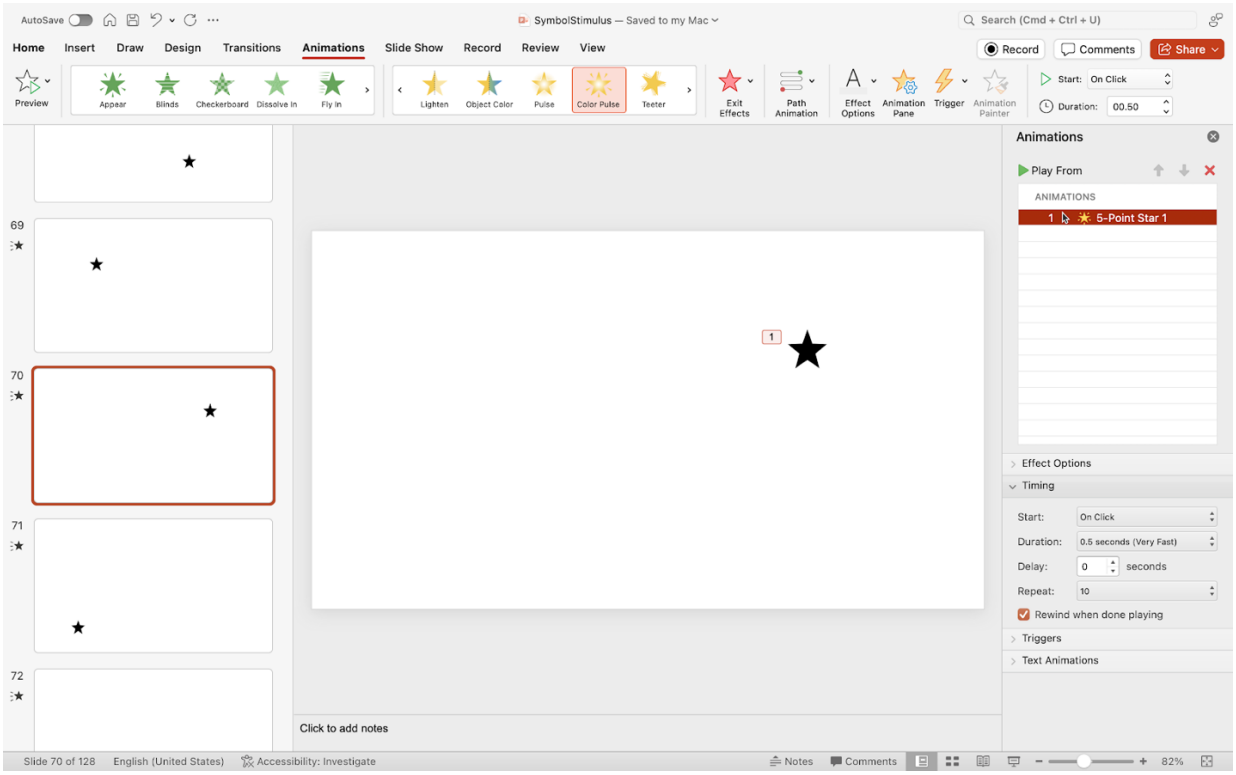

Figure 2. PowerPoint animation function to add dynamic flashing to stimuli for each stimulus set.

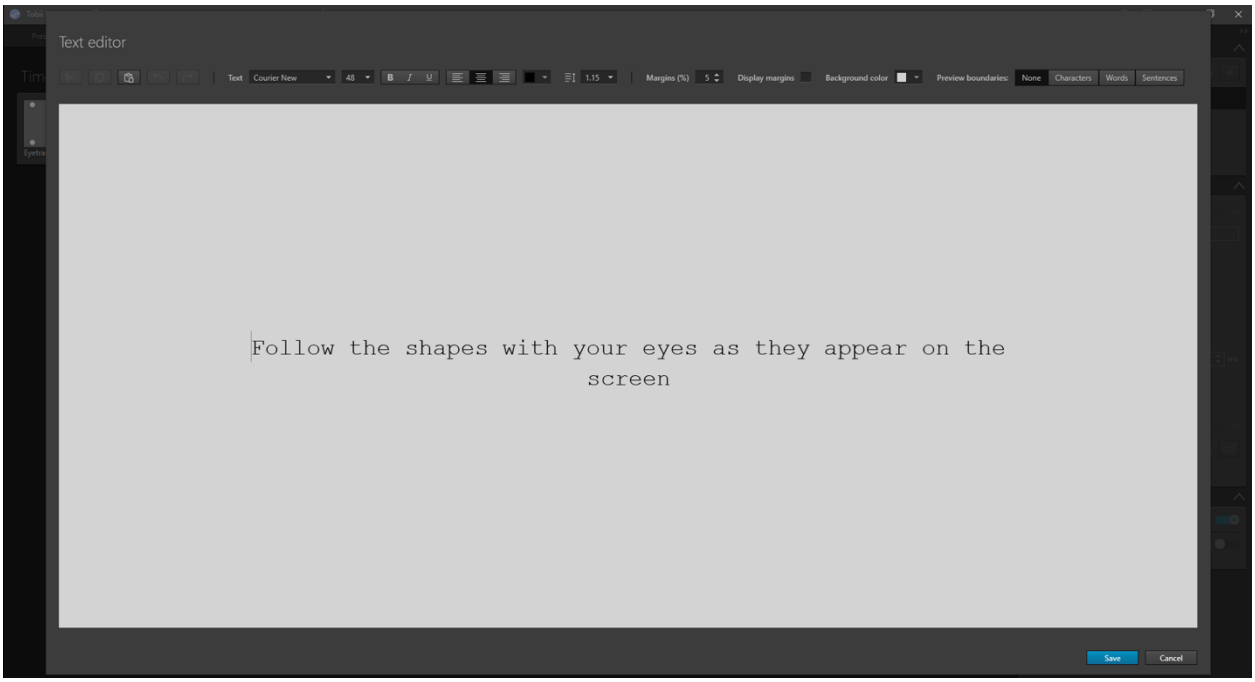

Figure 3. Tobii Pro Lab text slide preceding each stimulus set.

Measures

The independent variables were the stimulus variations in shape, background color, position, and animation. The shapes included star, circle, diamond, and plus. The backgrounds were on a gradient from white to black, with white being 100% opacity, then light grey at 75%, medium grey at 50%, and dark grey at 25% opacity. Four positions were included, one in each corner quadrant of a rectangular slide. Animations were either static (no animation) or dynamic, flashing every 0.5 seconds. The dependent variables measured were components of participants' gaze patterns. These were reported as fixation duration and number of fixations on each stimulus and sorted based on background color, shape, position, and animation.

The fixation locations were determined using the area of interest (AOI) tool in Tobii Pro Lab under the "analyze" tab. Each shape was highlighted with the vertex tool by selecting each corner of the shape, except for the circle which used the circle tool by clicking and dragging to the correct size. The shapes were then adjusted with the select vertex tool to align as closely as possible with the stimuli. Each AOI was set as active for the 5 seconds the shape was presented and set as inactive for the remainder of the stimulus set. The background was also selected as an AOI for each stimulus duration, with the rectangle select tool. This allowed the fixations on the stimulus and the total fixations on the slide during the stimulus presentation to be recorded. The AOIs were also tagged with each variable including background (dark, light, medium, white), shape (circle, diamond, plus, star), location (upper right, lower right, upper left, lower left), and stimulus type (static or dynamic) for ease of analysis.

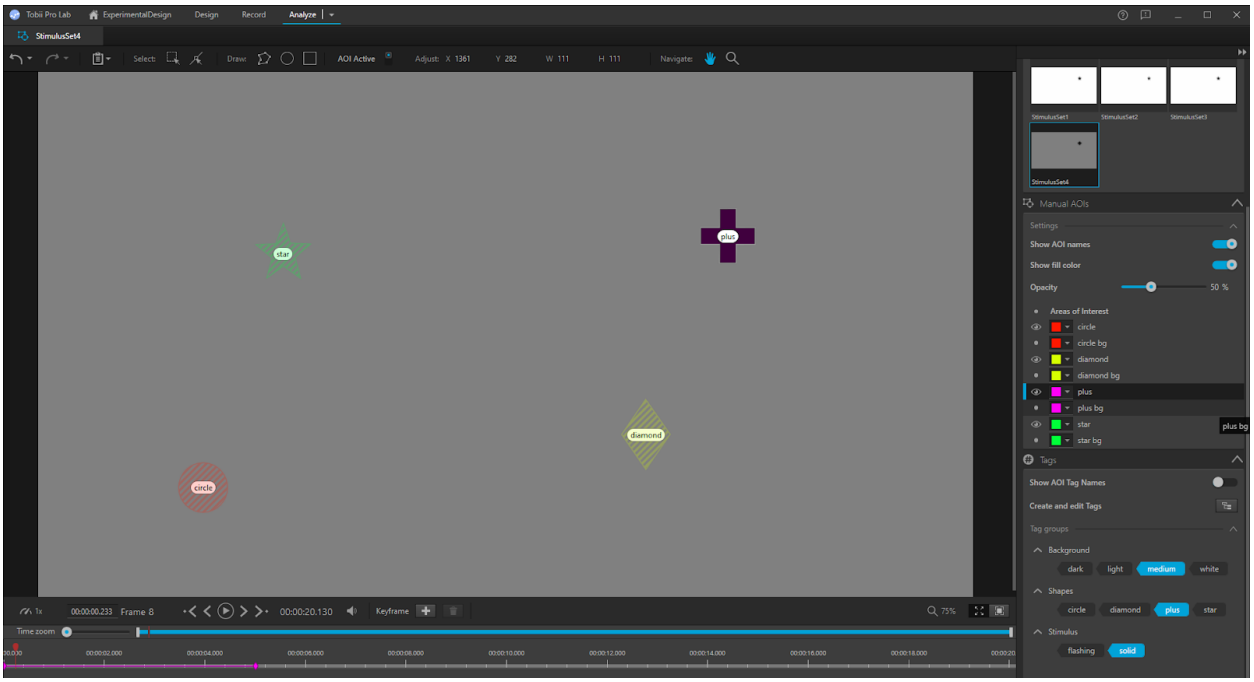

Figure 4. Tobii Pro Lab Area of Interest (AOI) tool used to highlight each shape, set as active (solid) or inactive (striped), and add tags for analysis.

Procedure

Four healthy control participants were recruited for this preliminary methodological study to assess the feasibility of the proposed methods. Participants were seated in front of the Tobii Pro Spectrum eye tracker and were positioned in range, 55 to 75 cm from the monitor, with the aid of the Tobii Pro Eye Tracker Manager software's alignment tool.[3, 32] The moderator then started the selected protocol, based on the designated stimulus set, and the participant began with calibration, following the dots with their eyes as they moved across the screen to adjust the sensitivity of the eye tracker for the participant's gaze. The moderator then clicked "use calibration" to begin the stimulus set protocol. The prompt slide first instructed participants to look at the shapes as they appeared on screen and was presented for 5 seconds. Next, the stimulus set recording began, presenting four different stimuli, each appearing for 5 seconds in a

randomized order. Once the trial was complete, the participants went through a second randomized stimulus set with the same format. When beginning the second protocol, the moderator selected “skip calibration” to reuse the calibration from the previous trial. The complete assessment took approximately 3 minutes for each participant.

Data Analysis

The Tobii Pro Lab software recorded the total gaze percentage for each trial, and any trials under 90% were removed from the analysis.[31] The data from the remaining trials was exported through the “Metrics Export” function as an Excel spreadsheet with the selected data points: all recordings, all AOIs, total duration of fixation in AOI (including zeroes), and number of fixations in AOI (including zeroes).

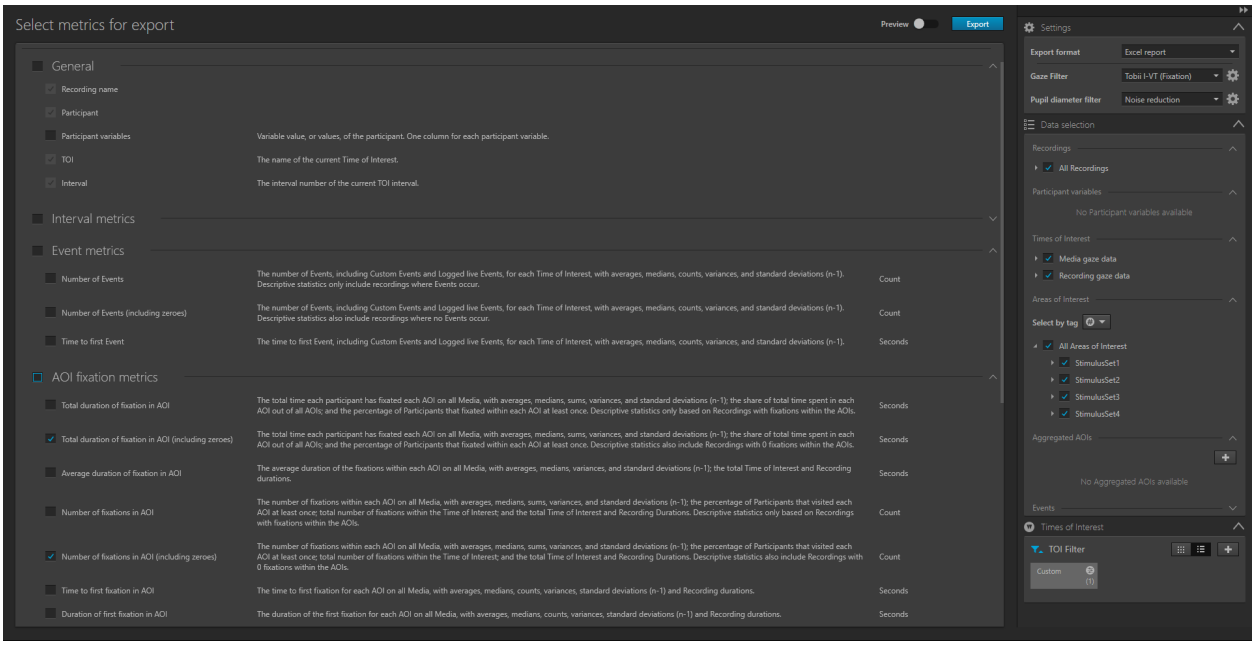

Figure 5. Tobii Pro Lab Export Metrics tool used to create Microsoft Excel Sheet for data processing.

To process the data in Microsoft Excel, averages for each shape AOI were organized into tables by stimulus set with each shape, total fixation duration in milliseconds, and number of

fixations.[33] More tables were then created for each variable type, background, shape, location, and animation, with the data from all stimulus sets and trials. The data were then averaged for each condition over all trials in each table to create figures. Bar charts were created with the averages of each condition, for both fixation duration and number of fixations, with all conditions for each variable (Figures 4a-7b).

For analysis, the data was evaluated with the goal of refining the methodology of this experiment. This study was a preliminary pilot study to inform the design and planning of larger, more comprehensive studies. Therefore, detailed statistical analysis was not warranted, and the small sample size would not allow for accurate analysis. The focus was instead on assessing the practical aspects of data collection and refining study procedures.

CHAPTER FOUR

Results

Figures 6a and b show the differences in fixation duration and number of fixations on the target based the shape of the stimulus, averaged over all trials and stimulus sets. The total fixation durations in milliseconds for the circle, diamond, plus, and star, averaged over all trials were 319, 316, 258, and 257 respectively, as seen in Figure 6a. The average number of fixations on each shape over all trials was 2.25 for the circle, 2.3 for the diamond, 2.06 for the plus, and 1.26 for the star, as seen in Figure 6b. The trends in Figure 6a show the fixation durations were slightly decreased for the plus and star as compared to the circle and diamond, and in Figure 6b the number of fixations was still slightly decreased for the plus, but greatly decreased for the star.

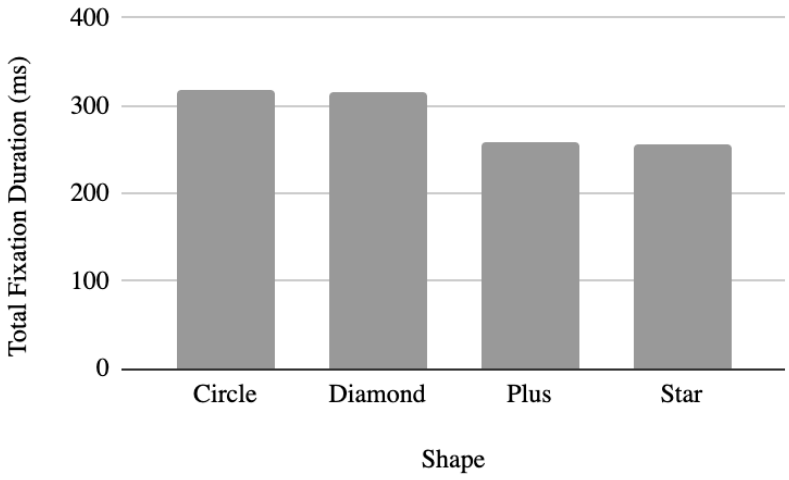

Figure 6a. Total fixation duration in milliseconds on each shape AOI, averaged over all trials.

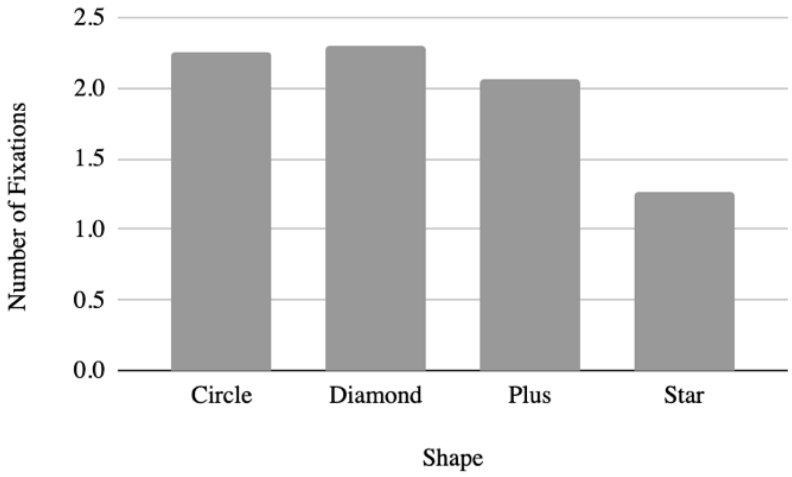

Figure 6b. Average number of fixations on each shape AOI, over all trials.

Figures 7a and b show the total fixation duration and number fixations based on the positioning of the target in each quadrant of the slide, averaged over all trials and irrespective of all other conditions. The average total fixation duration in milliseconds for the top right, bottom right, top left, and bottom left was 258, 315, 256, and 320, respectively, as seen in Figure 7a. The average number of fixations on the target in each quadrant was 1.51 in the top right, 2.24 in the bottom right, 1.81 in the top left, and 2.31 in the bottom left, as seen in Figure 7b. The trends in Figures 7a and b show the total fixation duration and number of fixations were slightly decreased for the top two quadrants as compared to the bottom two quadrants.

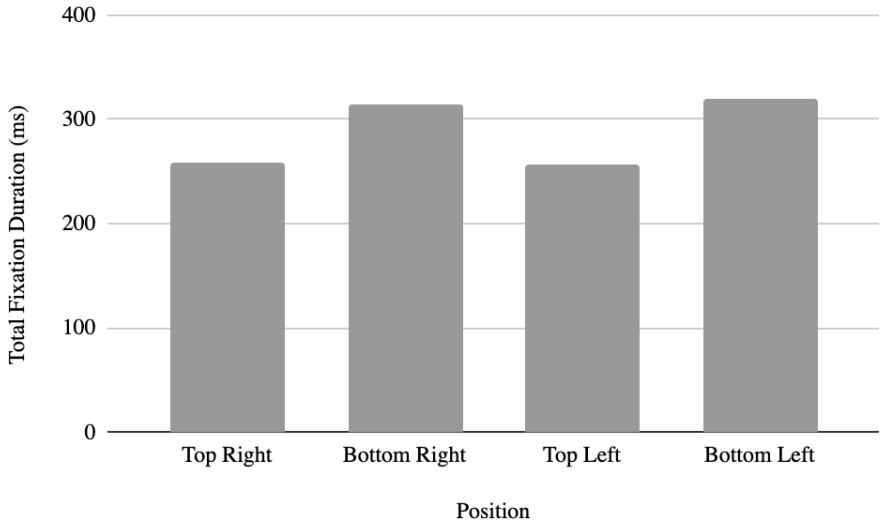

Figure 7a. Total fixation duration in milliseconds on targets in each quadrant position, averaged over all trials.

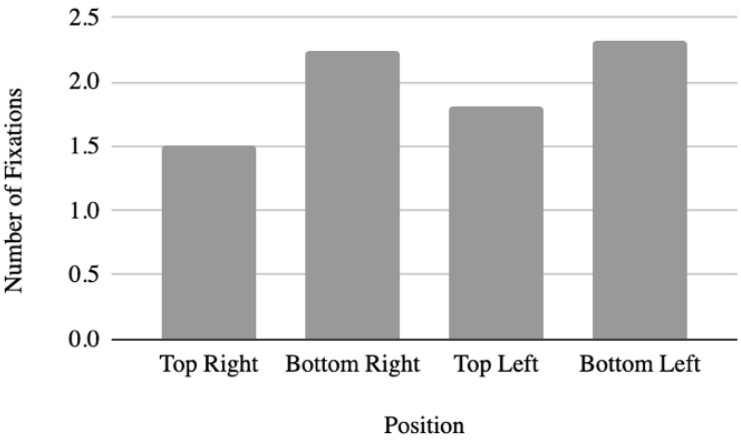

Figure 7b. Average number of fixations on targets in each quadrant position, over all trials.

Figures 8a and b show the average fixations on the target for the dynamic and static stimuli, averaged over all trials and irrespective of all other conditions. The average total fixation duration in milliseconds was 284 for dynamic shapes and 291 for static shapes, as seen in Figure 8a. The average number of fixations over all trials was 1.6 for dynamic shapes, and 2.34 for static shapes, as seen in Figure 8b. Figure 8a shows no clear difference in fixation duration based

on the animation, however, Figure 8b illustrates a large decrease in fixations for the dynamic stimuli, as compared to the static targets.

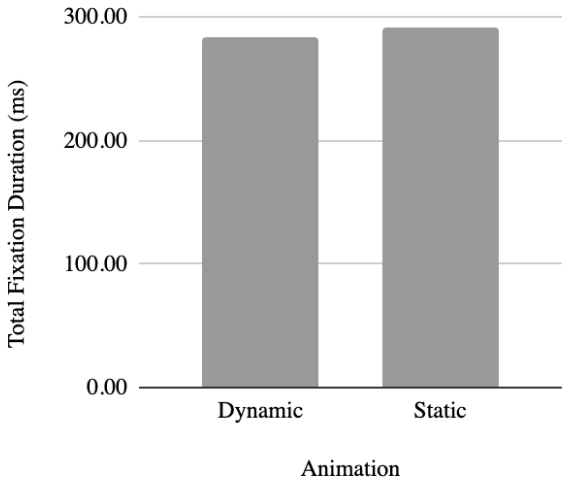

Figure 8a. Total fixation duration in milliseconds on targets in each animation condition, averaged over all trials.

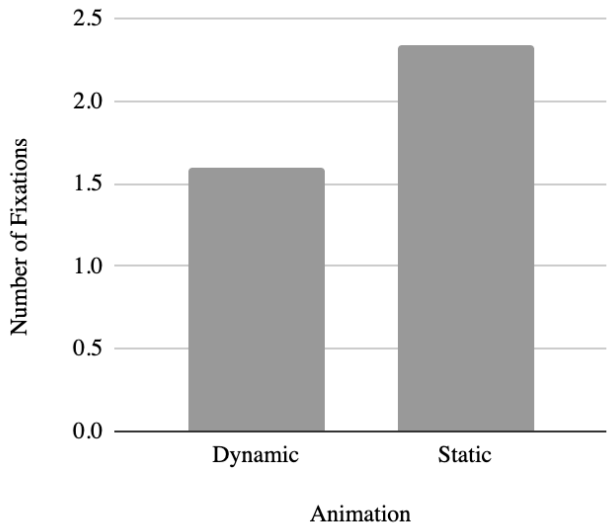

Figure 8b. Average number of fixations on targets in each animation condition, over all trials.

Figures 9a and b show the breakdown in fixation duration and number of fixations on the target based on by the background color of the slide, averaged over all trials and irrespective of all other conditions. The total fixation duration in milliseconds for white, light, medium, and

dark averaged over all trials being 257, 311, 271, and 311, respectively, as seen in Figure 9a. The average number of fixations on the target for each background color was 1.26 for white, 1.94 for light grey, 2.24 for medium grey, and 2.44 for dark grey, as seen in Figure 9b. The trends in Figure 9a show slight decreases in fixation duration for white and medium grey backgrounds, as compared to light and dark grey backgrounds. Figure 9b, however, shows a clear increase in number of fixations as the background gets darker in color, with white at the lowest and dark grey at the highest number of fixations.

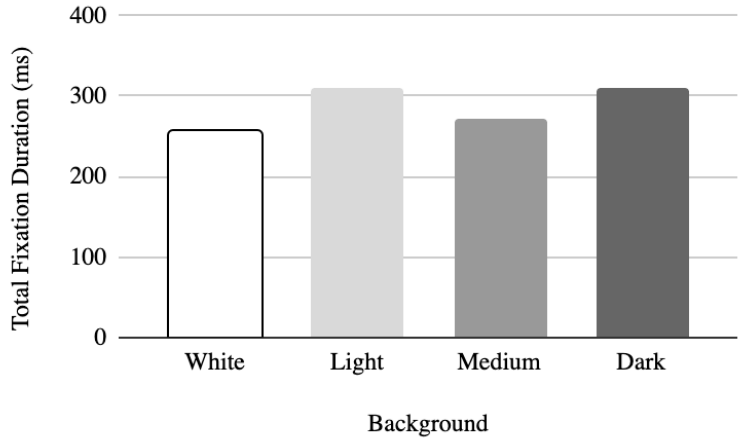

Figure 9a. Total fixation duration in milliseconds on the target for each background color, averaged over all trials.

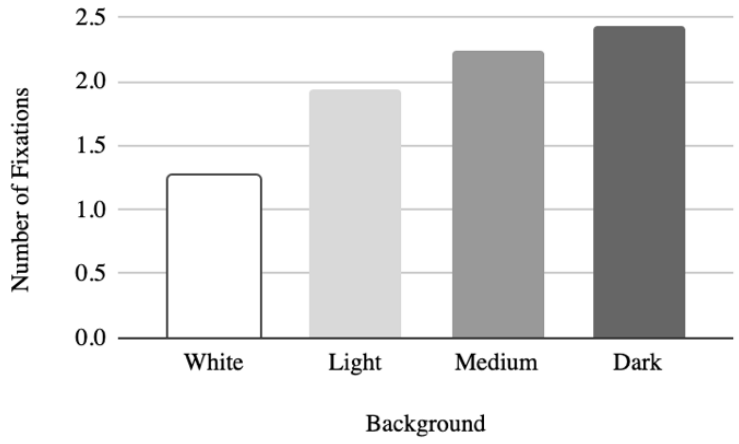

Figure 9b. Average number of fixations on the target for each background color, over all trials.

CHAPTER FIVE

Discussion and Conclusions

Discussion

The overall results supported some of our hypotheses, but some resulted in unexpected interactions. Hypothesis 1, was supported by results, suggesting that the lightest background color would have the least and shortest durations (Figures 9a-b). Our results partly support hypothesis 2, with a decrease in number of fixations for the dynamic as compared to the static stimuli, but no obvious difference in fixation duration between static and dynamic stimuli (Figures 8a-b). Furthermore, our results did not support hypothesis 3, that the shape and location would have no effect on the numbers of fixations or the total duration of the fixations. Instead, the data showed a decrease in fixations and duration for the plus and star, when compared to the circle and diamond shapes (Figures 6a-b), The location showed similar trends, with a decrease in fixations and duration for the bottom two quadrants, as compared to the top two (Figures 7a-b).

The differences in fixations by stimulus shape may indicate a need to use one consistent shape for all trials, to reduce unwanted interactions. Figure 6a shows a slight decrease in fixation duration for the plus and star, about 60ms lower than the circle and diamond. However, figure 6b shows a further decrease in the number of fixations for the star as compared to the three other shapes, about 0.7-0.9 below the others. This may be due to the shape itself, or because of issues with the randomization of the stimulus sets, as the star symbol was dynamic in all four of the stimulus sets. The flashing could have lowered the number of fixations on the shape due to dynamic stimuli being easier to perceive. This would show why the star decreased so much more than the plus, since the plus was presented as both dynamic and static over the four stimulus sets. Since the plus and the star both had decreases in fixation duration, though, it is possible that

those shapes were easier to perceive on the backgrounds. This may have been because the star and plus were more unique shapes than the circle and diamond, as previous studies have shown that unique shapes are quicker to draw fixational attention.[34]

The data for target location showed decreases for the top two quadrants in comparison to the bottom two quadrants. For fixation duration, the top quadrants showed about a 60ms decrease as compared to the bottom quadrants, as seen in Figure 7a. The number of fixations in Figure 7b showed similar differences, with a decrease of about 0.5-0.8 fixations for the top quadrants. These decreases in fixations indicate that the top quadrants were easier to locate and process, which may be due to the fact that the top quadrants were at the eye level of the participants when seated in front of the screen, whereas the bottom quadrants would have required greater movement to track downward. This has been studied previously when multiple stimuli are presented at once, wherein the first fixation falls toward a "center of gravity" or center of the visual field.[34]

The animation data showed no obvious difference in the fixation duration between dynamic and static stimuli, as seen in Figure 8a. The number of fixations, however, showed about a 0.75 decrease in fixations for dynamic stimuli, as seen in Figure 8b. This indicates that the dynamic stimuli may have been easier to identify on the screen, resulting in faster processing time and a decrease in fixations. This is supported by previous research, which shows dynamic stimuli are easier to process because many neurons are preferentially sensitive specifically to movement, and help to identify and bring attention to the dynamic stimuli.[35, 36] This processing occurs in a preattentive stage, which detects color, size, orientation, and motion of stimuli.[34]

The background color data showed decreased average fixation duration for both white and medium grey, as seen in Figure 9a, by 40-50ms. The medium grey was a did not follow the

trend in fixation duration, as it was decreased slightly compared to the light and dark grey background colors (Figure 9a). The number of fixations, however, showed a strong trend with an increase in fixations with darker background colors, as seen in Figure 9b. For the number of fixations, dark grey was the highest, at 2.44, and white as the lowest, at 1.26, with the largest increase in fixations as 0.7 from white to light grey, with the other colors only about 0.2-0.3 apart (Figure 7b). These results indicate that the shapes are easier to perceive and visualize on the lighter backgrounds, with shorter and less fixations due to faster processing time, and a clear positive trend for number of fixations with darker backgrounds. This is consistent with previous research, that darker backgrounds require longer processing times, especially with minimal target-background color differences.[37]

Overall, our results show relatively smaller differences between each condition, which was to be expected with a healthy participant population in this preliminary methodological study. The hypotheses were partially supported by the study data and are expected to show a larger impact in a patient population, or even a healthy population with a larger sample size. In a patient population, the differences would be expected to be significant, identifying the underlying deficits in patients' visual perception. For example, in a PPPD study, the patients would likely have more difficulty distinguishing stimuli on dark backgrounds and have more ease identifying dynamic stimuli. This might manifest statistically in longer fixation times for dark backgrounds and static targets, due to increased processing time to take in more complex stimuli. These theories remain to be investigated in future studies involving patients with PPPD.

Limitations

As anticipated, there were several limitations in this preliminary methodological study. A primary limitation of the study was the small sample size, involving only healthy participants. Thus, results from the study cannot be generalized to the patient population. However, being a methodological study, the utilization of four healthy participants helped us problem solve multiple issues that arose with study design and software/hardware integration during data collection. Additionally, the equipment was newly acquired by the laboratory. Thus, the focus of this study was to learn the basics of operation of the eye tracker and software and discover all of the relevant functionality for future visual perception studies.

The eye tracker device itself also has limitations that impacted the scope of the study. The Tobii Pro Spectrum is the desktop model of the eye tracker, and although more accurate in tracking oculomotor movements, it has less flexibility than a wearable eye tracker like the Tobii Pro Glasses which can be better in translating to real-world applications. However, the wearable versions are not perfect analogs for everyday interactions with stimuli either, as they are relatively new and need further refinement to function well with 3D stimuli.[1] The Tobii Pro Lab software was also limited in terms of design, as videos had to be premade and uploaded to the portal as jpg, png, gif, or mp4 files, and could only be organized into protocols through the software.[31] The main function of the software was the AOI tool, however, to compare eye gaze on particular stimuli in the protocols. This tool was easy to use with stationary stimuli, but was more difficult in tracking moving stimuli, as it was only able to follow a smooth trajectory in experimental designs.

Within the scope of the study, these limitations were not too drastic, but moving into larger studies with clinical participants, there is still more that needs to be accomplished in

testing the device on additional healthy control participants as well as patients with various visual perceptual concerns. In conclusion, eye tracking holds great value to understand visual perceptual changes in injury and disease, and it is likely the data collection hardware and software will improve in development over the next decade.

Implications

This study has important implications for future research, in both the short and long term. In the short term, the experimental design can be modified to resolve predicted errors in the findings of this study. This study's results can also be used to create similar studies with more complex stimuli, as the lab now understands how to best use the equipment and software. The goal of this study was simply to learn more about eye tracking and how it can be applied to relevant research on visual perception or related disorders.

In the long term, this software could provide a novel diagnostic tool for visual perception disorders and oculomotor dysfunction, which would provide a better understanding of necessary treatments for patients with visual perception impairments. It could also provide a safe method to track eye movements in relation to real world situations that may be difficult to track in real-time. With subsequent research in this area, eye tracking can prove an invaluable tool for robust diagnosis and potential intervention strategies in vulnerable populations, such as PPPD patients.

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